1000 PHYSICS

MCQ with HELPS

Frequently Examined Questions

CE

A LEVEL

REDSPOT

GCE 'A' Level

1000 Physics MCQ with Helps

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TOPIC 1

TOPIC 1

Measurement

Key content that you will be examined on:

1. SI Units
2. Errors and uncertainties
3. Scalars and vectors

Topic 1 Measurement

1. Which of the following is a unit of pressure?

A $kg\,m\,s^{-1}$ B $kg\,m^{-1}\,s^{-2}$

C $kg\,m^2\,s^{-2}$ D $kg\,m^{-2}\,s^{-1}$

Helping concepts

Unit of pressure = $N\,m^{-2} = (kg\,m\,s^{-2})m^{-2} = kg\,m^{-1}\,s^{-2}$

2. The energy of a photon of light of frequency *f* is given by *hf*, where *h* is the Planck constant.

What are the base units of *h*?

A $kg\,m\,s^{-1}$ B $kg\,m^2\,s^{-1}$

C $kg\,m^2\,s^{-2}$ D $kg\,m^2\,s^{-3}$

Helping concepts

Energy of a photon = *hf*

Base units of energy = $kg\,m^2\,s^{-2}$

Base units of frequency = s^{-1}

∴ Base units of Planck constant = $kg\,m^2\,s^{-1}$

3. Which of the following pairs of units are both SI base units?

A ampere, degree celsius

B ampere, kelvin

C coulomb, degree celsius

D coulomb, kelvin

Helping concepts

7 SI base units are ampere, kelvin, mole, metre, second, kilogram and candela.

4. Which of the following could be measured in the same units as force?

A energy/distance

B energy × distance

C energy/time

D momentum × distance

Helping concepts

Work done = force × distance

$$\text{Force} = \frac{\text{work done}}{\text{distance}} = \frac{\text{energy}}{\text{distance}}$$

5. The following physical quantities can be either positive or negative.

s: displacement of a particle along a straight line
θ: temperature on the Celsius scale
q: electric charge
V: readings on a digital voltmeter

Which of these quantities are vectors?

A *s*, θ, *q*, *V* B *s*, *q*, *V*

C θ, *V* D *s* only

Helping concepts

Only displacement is a vector, while the rest of physical quantities are scalars.

6. For which quantity is the magnitude a resonable estimate?

A	frequency of a radio wave	500 pHz
B	mass of an atom	500 μg
C	the Young modulus of a metal	500 kPa
D	wavelength of green light	500 nm

Helping concepts

By definition, wavelength of light is estimated to be between 400 nm to 700 nm.

7. Which pair contains one vector and one scalar quantity?

   A displacement : acceleration
   B force : kinetic energy
   C momentum : velocity
   D power : speed

Helping concepts

Vectors have directions while scalars do not.

A: both quantities are vectors

B: force is a vector while energy is a scalar

C: both quantities are vectors

D: both quantities are scalars

8. What is the ratio $\frac{1\,\mu m}{1\,Gm}$?

   A 10^{-3} B 10^{-9}
   C 10^{-12} D 10^{-15}

Helping concepts

$$\frac{1\,\mu m}{1\,Gm} = \frac{1 \times 10^{-6}\ m}{1 \times 10^{9}\ m} = 10^{-15}$$

9. Which experimental technique reduces the systematic error of the quantity being investigated?

   A adjusting an ammeter to remove its zero error before measuring a current
   B measuring several internodal distance on a standing wave to find the mean internodal distance
   C measuring the diameter of a wire repeatedly and calculating the average
   D timing a large number of oscillations to find a period

Helping concepts

A zero error is a systematic error.

10. Which quantity has different units from the other three?

   A density × volume × velocity
   B rate of change of momentum
   C the Young modulus × area
   D weight

Helping concepts

$$\text{Units in A} = \frac{kg}{m^3} \times m^3 \times ms^{-1} = kg\,ms^{-1}$$

$$\text{Units in B} = \frac{kg\,ms^{-1}}{s} = kg\,ms^{-2}$$

$$\text{Units in C} = \frac{kg\,ms^{-2}}{m^2} \times m^2 = kg\,ms^{-2}$$

$$\text{Units in D} = kg\,ms^{-2}$$

11. The unit of work, the joule, may be defined as the work done when the point of application of a force 1 newton is moved a distance of 1 metre in the direction of the force.

   Express the joule in terms of the base units of mass, length and time, the kg, m and s.

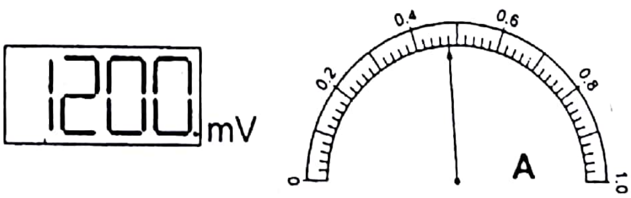
   A kg m^{-1} s^2 B kg m^2 s^{-2}
   C kg m^2 s^{-1} D kg s^{-2}

Helping concepts

$W = F \times d \Rightarrow [W] = [F][d]$

$\Rightarrow J = [ma][d] = kg\ m s^{-2} m = kg\ m^2\ s^{-2}$

12. The resistance of an electrical component is measured. The following meter readings are obtained.



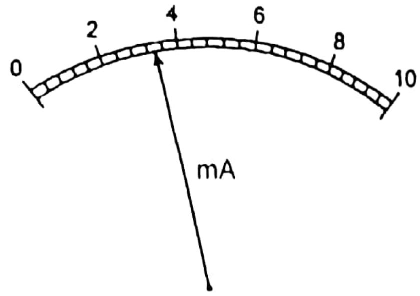
What is the resistance?

   A 2.5 Ω B 2.7 Ω
   C 2500 Ω D 2700 Ω

Helping concepts

$$R = \frac{V}{I} = \frac{200\ mV}{0.48\ A} = 2.5\ \Omega$$

13. What is the reading shown on this milliammeter?



A 2.35 mA
B 2.7 mA
C 3.4 mA
D 3.7 mA

Helping concepts

Each interval is $\frac{4-2}{5} = 0.4$ mA.

For 3.5 interval, its value is $3.5 \times 0.4 = 1.4$ mA.

Measured reading is $2 + 1.4 = 3.4$ mA.

---

14. Errors in measurement may be either systematic or random.

Which of the following involves random error?

A not allowing for zero error on a moving-coil voltmeter
B not subtracting background count rate when determining the count rate from a radioactive source
C stopping a stopwatch at the end of a race
D using the value of g as 10 N kg^{-1} when calculating weight from mass

Helping concepts

Random error arises when measured value is higher or lower than its true value.

---

15. A micrometer, reading to ±0.01 mm, gives the following results when used to measure the diameter d of a uniform wire:

1.02 mm 1.02 mm 1.01 mm 1.02 mm 1.02 mm

When the wire is removed and the jaws are closed, a reading of –0.02 mm is obtained.

Which of the following gives the value of d with a precision appropriate to the micrometer?

A 1.0 mm
B 1.00 mm
C 1.038 mm
D 1.04 mm

Helping concepts

Mean measurement $= \frac{1.02 \times 4 + 1.01}{5} = 1.02$ mm

Value of $d = 1.02 - (-0.02) = 1.04$ mm

---

16. A student makes measurements from which she calculates the speed of sound as 327.66 ms^{-1}. She estimates that her result is accurate to ±3%.

Which of the following gives her result expressed to the appropriate number of significant figures?

A 327.7 ms^{-1}
B 328 ms^{-1}
C 330 ms^{-1}
D 300 ms^{-1}

Helping concepts

Value of error $= 327.66 \times 3\%$

$= 9.83\ ms^{-1}$

$\approx 10\ ms^{-1}$ (1 sig. fig.)

Speed of sound $= 330\ ms^{-1}$ (rounded to the same tens place as the error)

---

17. A metal sphere of radius r is dropped into a tank of water. As it sinks at speed v, it experiences a drag force F given by $F = krv$, where k is a constant.

What are the SI units of k?

A $kg\,m^2 s^{-1}$
B $kg\,m^{-2} s^{-2}$
C $kg\,m^{-1} s^{-1}$
D $kg\,ms^{-2}$

Helping concepts

$F = krv \Rightarrow k = \frac{F}{rv}$

$\Rightarrow [k] = \frac{[F]}{[r][v]} = \frac{kg\,ms^{-2}}{m \cdot ms^{-1}} = kg\,m^{-1}s^{-1}$

---

18. An Olympic athlete of mass 80 kg competes in a 100 m race.

What is the best estimate of his mean kinetic energy during the race?

A 4×10^2 J B 4×10^3 J

C 4×10^4 J D 4×10^5 J

Helping concepts

Estimate time to complete 100 m = 10 s

Average speed $= \frac{100 \text{ m}}{10 \text{ s}} = 10 \text{ ms}^{-1}$

Average K.E. $= \frac{1}{2}mv^2 = \frac{1}{2}(80)(10)^2 = 4 \times 10^3$ J

---

19. In a simple electrical circuit, the current in a resistor is measured as (2.50 ± 0.05) mA. The resistor is marked as having a value of $4.7\,\Omega \pm 2\%$.

If these values were used to calculate the power dissipated in the resistor, what would be the percentage uncertainty in the value obtained?

A 2% B 4%

C 6% D 8%

Helping concepts

Power P is related to current I in the resistor of resistance R by

$$P = I^2R$$

Given $I = 2.50 \pm 0.05$ mA $\Rightarrow \frac{\Delta I}{I} = \frac{0.05}{2.50} = 2\%$

$R = 4.7\,\Omega \pm 2\% \Rightarrow \frac{\Delta R}{R} = 2\%$

∴ Percentage uncertainty in power P is thus

$$\frac{\Delta P}{P} = 2\frac{\Delta I}{I} + \frac{\Delta R}{R} = 2(2\%) + 2\% = 6\%$$

---

20. When comparing systematic and random errors, the following pairs of properties of errors in an experimental measurement may be contrasted:

P_1: error can possibly be eliminated
P_2: error cannot possibly be eliminated
Q_1: error is of constant sign and magnitude
Q_2: error is of varying sign and magnitude
R_1: error will be reduced by averaging repeated measurements
R_2: error will not be reduced by averaging repeated measurements

Which properties apply to **random** errors?

A P_1, Q_1, R_2 B P_1, Q_2, R_2

C P_2, Q_2, R_1 D P_2, Q_1, R_1

Helping concepts

systematic error	random error
P_1	P_2
Q_1	Q_2
R_2	R_1

---

21. Argon and neon are monatomic gases. One mole of argon has mass 40 g and one mole of neon has mass 20 g.

What is the ratio $\frac{\text{no. of atoms in 1 mole of argon}}{\text{no. of atoms in 1 mole of neon}}$?

A always 1

B always 2

C 1, only if both gases are at the same temperature and pressure

D 2, only if both gases are at the same temperature and pressure

Helping concepts

The number of atoms in one mole of any monatomic gas is always the Avogadro number (6.02×10^{23}).

---

22. An instrument gives a numerical reading of 0.00160 ± 0.00005.

Which statement is correct?

A The actual uncertainty is 5.

B The fractional uncertainty is 5×10^{-5}.

C The fractional uncertainty is $\frac{5}{16}$.

D The percentage uncertainty is 3%.

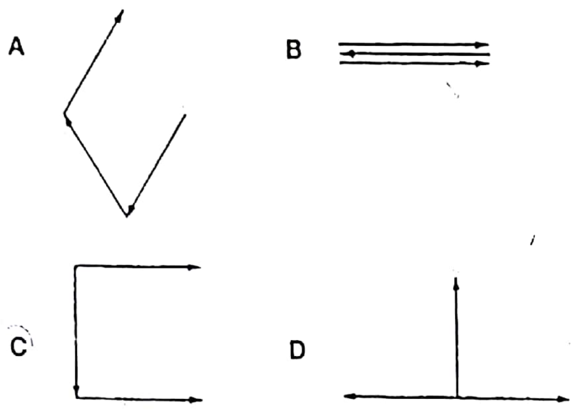
Helping concepts

Fractional uncertainty $= \frac{0.00005}{0.00160} = \frac{5}{160} = 0.03125$

Percentage uncertainty = fractional uncertainty × 100%
= 3.125%
≈ 3%

23. Each diagram shows three vectors of equal magnitude.

In which diagram is the magnitude of the resultant vector different from the other three?



Helping concepts

The resultant magnitude of the other 3 choices is 1 vector arrow.

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24. A steel rule can be read to the nearest millimetre. It is used to measure the length of a bar whose true length is 895 mm. Repeated measurements give the following readings.

length / mm	892, 891, 892, 891, 891, 892

Are the readings accurate and precise to within 1 mm?

	results are accurate to within 1 mm	results are precise to within 1 mm
A	no	no
B	no	yes
C	yes	no
D	yes	yes

Helping concepts

Precise readings are close to one another when measured. Accurate readings are close to the true values.

---

25. In an experiment, a radio-controlled car takes 2.50 ± 0.05 s to travel 40.0 ± 0.1 m.

What is the car's average speed and the uncertainty in this value?

A $16 \pm 1\ \text{ms}^{-1}$

B $16.0 \pm 0.2\ \text{ms}^{-1}$

C $16.0 \pm 0.4\ \text{ms}^{-1}$

D $16.00 \pm 0.36\ \text{ms}^{-1}$

Helping concepts

Average speed, $v = \dfrac{\text{distance}}{\text{time}} = \dfrac{40.0}{2.50} = 16.00$

$$\frac{\Delta v}{v} = \frac{\Delta d}{d} + \frac{\Delta t}{t} = \frac{0.1}{40} + \frac{0.05}{2.5} = 0.0225$$

$\Rightarrow \Delta v = (16.00)(0.0225) = 0.36 \approx 0.4$ (1 sig. fig.)

$\therefore\ v = 16.0 \pm 0.4\ \text{ms}^{-1}$

---

26. The power loss P in a resistor is calculated using the formula

$$P = \frac{V^2}{R}.$$

The uncertainty in the potential difference V is 3% and the uncertainty in the resistance R is 2%.

What is the uncertainty in P?

A 4%

B 7%

C 8%

D 11%

Helping concepts

$$P = \frac{V^2}{R}$$

$$\frac{\Delta P}{P} \times 100\% = 2\frac{\Delta V}{V} \times 100\% + \frac{\Delta R}{R} \times 100\%$$
$$= 2(3\%) + 2\%$$
$$= 8\%$$

---

27. Decimal sub-multiples and multiples of units are indicated using a prefix to the unit. For example, the prefix milli (m) represents 10^{-3}.

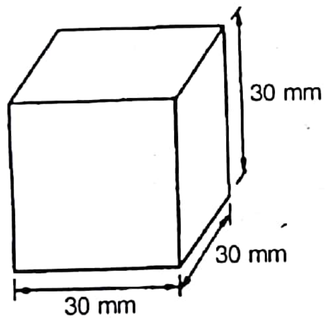
Which of the following gives the sub-multiples or multiples represented by pico (p) and giga (G)?

	pico (p)	giga (G)
A	10^{-9}	10^{9}
B	10^{-9}	10^{12}
C	10^{-12}	10^{9}
D	10^{-12}	10^{12}

Helping concepts

giga	10^9
mega	10^6
kilo	10^3
milli	10^{-3}
micro	10^{-6}
nano	10^{-9}
pico	10^{-12}

28. The dimensions of a cube are measured with vernier callipers.



The measured length of each side is 30 mm. If the vernier callipers can be read with an uncertainty of ± 0.1 mm, what does this give for the approximate uncertainty in the value of its volume?

A $\frac{1}{27}\%$ B $\frac{3}{10}\%$

C $\frac{1}{3}\%$ D 1%

Helping concepts

Since volume $V = l^3$, the fractional uncertainty in the value of volume is given by

$$\frac{\Delta V}{V} = 3\left(\frac{\Delta l}{l}\right) = \pm 3\left(\frac{0.1}{30}\right) = \pm 0.01 = \pm 1\%$$

29. The relation between the energy E of a photon and its wavelength λ is

$$E = \frac{K}{\lambda}$$

where K is a constant.

When E is measured in electronvolts and λ in nanometres, what is the numerical value of K?

A 3.18×10^{-53} B 3.18×10^{-35}

C 1.24×10^{-15} D 1.24×10^{3}

Helping concepts

$$E(eV) = \frac{hc}{\lambda(nm)}$$

$$E(1.6 \times 10^{-19}\ J) = \frac{hc}{[1 \times 10^{-9}(m)]\lambda}$$

$$E = \frac{1.24 \times 10^3}{\lambda}$$

30. A radio aerial of length L, when the current is I, emits a signal of wavelength λ and power P. These quantities are related by

$$P = kI^2\left(\frac{L}{\lambda}\right)^2$$

where k is a constant.

What unit, if any, should be used for the constant k?

A volt B ohm

C watt D no unit

Helping concepts

$$P = kI^2\left(\frac{L}{\lambda}\right)^2 \Rightarrow k = \frac{P}{I^2}\left(\frac{\lambda}{L}\right)^2$$

$$\Rightarrow [k] = \frac{[P]}{[I]^2}\left[\frac{\lambda}{L}\right]^2 = \frac{[I^2R]}{[I^2]}(1) = [R] = \Omega$$

31. Which expression could be correct for the velocity v of ocean waves in terms of ρ the density of seawater, g the acceleration of free fall, h the depth of the ocean and λ the wavelength?

A $\sqrt{g\lambda}$ B $\sqrt{\frac{g}{h}}$

C $\sqrt{\rho g h}$ D $\sqrt{\frac{g}{\rho}}$

Topic 1 Measurement

Helping concepts

The units for each of the quantities are given below.

quantity	units
$\sqrt{g\lambda}$	$\sqrt{(ms^{-2})m} = ms^{-1}$
$\sqrt{\frac{g}{h}}$	$\sqrt{\frac{ms^{-2}}{m}} = s^{-1}$
$\sqrt{\rho gh}$	$\sqrt{kgm^{-3}ms^{-2}m} = kg^{\frac{1}{2}}m^{-\frac{1}{2}}s^{-1}$
$\sqrt{\frac{g}{\rho}}$	$\sqrt{\frac{ms^{-2}}{kgm^{-3}}} = kg^{-\frac{1}{2}}m^{2}s^{-1}$

Hence, only quantity $\sqrt{g\lambda}$ has the same units as that of velocity v.

---

32. The manufacturers of a digital voltmeter give, as its specification,

'accuracy $\pm 1\%$ with an additional uncertainty of ± 10 mV'.

The meter reads 4.072 V.

How should this reading be recorded, together with its uncertainty?

A (4.07 ± 0.01) V B (4.07 ± 0.04) V

C (4.072 ± 0.052) V D (4.07 ± 0.05) V

Helping concepts

Uncertainty, $\Delta V = (4.072 \times 1\% + 10 \text{ mV})$

$= 0.0572$

≈ 0.05 V (1 S.F.)

$\therefore V \pm \Delta V = (4.07 \pm 0.05)$ V

where decimal places of V and ΔV are the same, in the hundredth decimal place in this case.

---

33. A mass of a liquid of density ρ is thoroughly mixed with an equal mass of another liquid of density 2ρ. No change of the total volume occurs.

What is the density of the liquid mixture?

A $\frac{4}{3}\rho$ B $\frac{3}{2}\rho$

C $\frac{5}{3}\rho$ D 3ρ

Helping concepts

Total volume, $V = V_1 + V_2 = \frac{m}{\rho} + \frac{m}{2\rho}$

Total mass, $M = m_1 + m_2 = 2m$

Final density, $\rho = \frac{M}{V} = \frac{2m}{V_1 + V_2} = \frac{2m}{\frac{m}{\rho} + \frac{m}{2\rho}} = \frac{4}{3}\rho$

---

34. A student uses an analogue voltmeter to measure the potential difference across a lamp. The voltmeter is marked every 0.02 V but has a zero error of 0.08 V. The student is not aware of this zero error and writes down a reading of 2.16 V.

Is the reading accurate and is it precise?

	accurate	precise
A	no	no
B	no	yes
C	yes	no
D	yes	yes

Helping concepts

% systematic error is $\frac{0.08}{2.16} \times 100\% = 3.7\%$.

It is accurate as the systematic error is small (i.e. close to the true value).

It is precise as the random error is small (i.e. 0.02 V).

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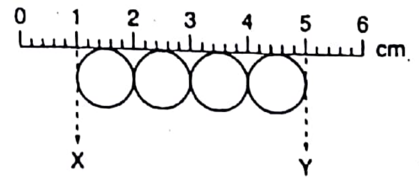
35. A student attempts to measure the diameter of a steel ball by using a metre rule to measure four similar balls in a row.



The student estimates the positions on the scale to be as follows.

X (1.0 ± 0.2) cm
Y (5.0 ± 0.2) cm

What is the diameter of a steel ball together with its associated uncertainty?

A (1.0 ± 0.05) cm B (1.0 ± 0.1) cm

C (1.0 ± 0.2) cm D (1.0 ± 0.24) cm

Helping concepts

The diameter of a steel ball ×4 = (5.0 ± 0.2) − (1.0 ± 0.2)
= (4.0 ± 0.4) cm

$\therefore$ Diameter of a steel ball $= \dfrac{4.0 \pm 0.4}{4} = (1.0 \pm 0.1)$ cm

---

36. The e.m.f. induced in a coil by a changing magnetic flux is equal to the rate of change of flux with time.

Which is a unit for magnetic flux?

A $\text{kg m}^2\text{s}^{-2}\text{A}^{-1}$ B $\text{kg m}^2\text{s}^{-2}\text{A}$

C $\text{kg ms}^2\text{A}^{-1}$ D $\text{ms}^{-2}\text{A}^{-1}$

Helping concepts

Magnetic flux, $\phi = BA$

where B is the magnetic flux density and A is the cross-sectional area.

$$\therefore [\phi] = [B][A] = \left[\frac{F}{IL}\right][A] = \frac{[F]}{[I][L]}[A] = \frac{[m][a]}{[I][L]}[A]$$

$$= \frac{\text{kg ms}^{-2}}{\text{A}\cdot\text{m}}\text{m}^2 = \text{kg m}^2\text{s}^{-2}\text{A}^{-1}$$

---

37. Which estimate is realistic?

A The kinetic energy of a bus travelling on an expressway is 30 000 J.

B The power of a domestic light is 300 W.

C The temperature of a hot oven is 300 K.

D The volume of air in a car tyre is 0.03 m³.

Helping concepts

Option A: KE of bus $= \frac{1}{2}mv^2$

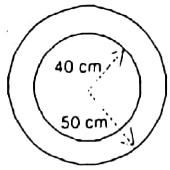
$= \frac{1}{2}(10^4)(20)^2$

$= 2.0 \times 10^6$ J

Option B: Power of light bulb ≈ 20 W

Option C: 300 K = 27 °C = room temperature

Option D: Estimate thickness of tire
= 0.20 m



Volume of tire $= \left[\pi(0.50)^2 - \pi(0.40)^2\right] \times (0.20)$

$= 0.057 \text{ m}^3$

---

38. Two solid substances P and Q have atoms of mass M_P and M_Q respectively. They have N_P and N_Q atoms per unit volume.

It is found by experiment that the density of P is greater than that of Q.

Which of the following deductions from this experiment must be correct?

A $M_P > M_Q$ B $N_P > N_Q$

C $M_PN_P > M_QN_Q$ D $\dfrac{M_P}{N_P} > \dfrac{M_Q}{N_Q}$

Helping concepts

Density of P $= M_PN_P$

Density of Q $= M_QN_Q$

Since density P > density Q,

$$M_PN_P > M_QN_Q$$

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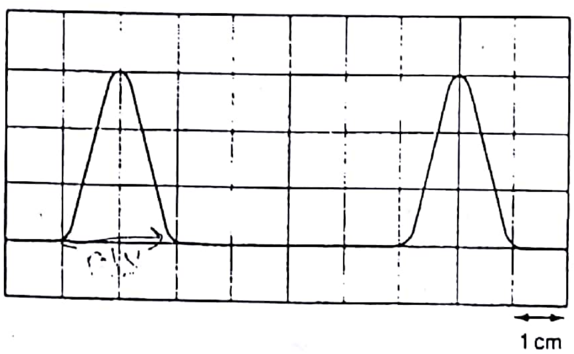
39. The diagram shows two pulses on the screen of a cathode-ray oscilloscope. A grid of 1 cm squares covers the screen. The time base setting is $1\ \mu\text{s cm}^{-1}$.



How long does each pulse last?

A 2 μs B 3 μs
C 4 μs D 6 μs

Helping concepts

Duration of pulse is equal to 2 squares,

i.e. $2\text{ cm} \times 1\,\mu s\text{ cm}^{-1} = 2\,\mu s$.

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40. A boat changes its velocity from 8 ms^{-1} due north to 6 ms^{-1} due east.

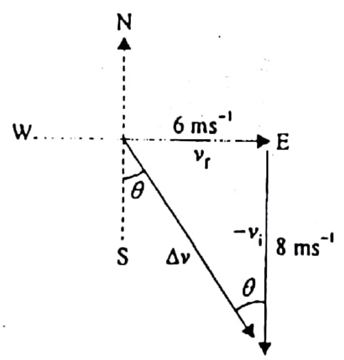
What is its change in velocity?

A 2 ms^{-1} at a direction of 37° east of north
B 2 ms^{-1} at a direction of 53° east of north
C 10 ms^{-1} at a direction of 37° east of south
D 10 ms^{-1} at a direction of 53° west of south

Helping concepts

Change in velocity,

$$\Delta v = v_f - v_i$$
$$= v_f + (-v_i)$$



$$|\Delta v| = \sqrt{6^2 + 8^2} = 10\text{ ms}^{-1}$$

$$\tan\theta = \frac{6}{8} \Rightarrow \theta = 37°$$

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41. The equation connecting object distance u, image distance v and focal length f for a lens is

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}.$$

A student measures values of u and v, with their associated uncertainties. These are

$u = 50\text{ mm} \pm 3\text{ mm}$,
$v = 200\text{ mm} \pm 5\text{ mm}$.

He calculates the value of f as 40 mm.

What is the uncertainty in this value?

A ±2.1 mm B ±3.4 mm
C ±4.5 mm D ±6.8 mm

Helping concepts

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$
$$\frac{\Delta f}{f} = \frac{\Delta u}{u} + \frac{\Delta v}{v}$$
$$\frac{\Delta f}{40} = \frac{3}{50} + \frac{5}{200}$$
$$\Delta f = 3.4\text{ mm}$$

Uncertainty Δf is usually left to 1 significant figure, i.e. 3 mm.

---

42. Four students each made a series of measurements of the acceleration of free fall g. The table shows the results obtained.

Which student obtained a set of results that could be described as precise but not accurate?

student	results, g/ms^{-2}			
A	9.81	9.79	9.84	9.83
B	9.81	10.12	9.89	8.94
C	9.45	9.21	8.99	8.76
D	8.45	8.46	8.50	8.41

Helping concepts

A small spread of the measurements in an experiment is said to be precise. On the other hand, the set of results is not accurate if the measured mean value deviates too far from the true value, for example, if the systematic error associated with the experiment is too large.

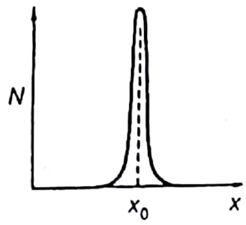
Acceleration of free fall, $g = 9.81\text{ ms}^{-2}$

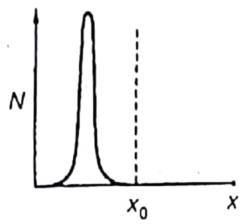
student	max. deviation = max. value − min. value	mean of the set of value
A	9.84 − 9.79 = 0.05	9.82
B	10.12 − 8.94 = 1.18	9.69
C	9.45 − 8.76 = 0.69	9.10
D	8.50 − 8.41 = 0.09	8.46

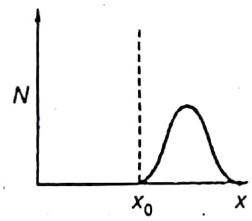
Hence, set of values measured by student D can say to be precise but not accurate.

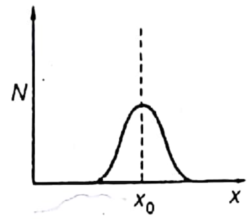
43. A quantity x is measured many times and the number N of measurements giving a value x is plotted against x. The true value of the quantity is x_0.

Which graph best represents precise measurements with poor accuracy?

A


B


C


D


Helping *concepts*

A small spread of the measurements is said to be precise. However, the results are not accurate if the measured mean value deviates too far from the true value.

44. An object of mass 1.000 kg is placed on four different balances. For each balance, the reading is taken five times.

The table shows the values obtained together with the means.

Which balance has the smallest systematic error but is not very precise.

balance	1	2	3	4	5	mean / kg
A	1.000	1.000	1.002	1.001	1.002	1.001
B	1.011	0.999	1.001	0.989	0.995	0.999
C	1.012	1.013	1.012	1.014	1.014	1.013
D	0.993	0.987	1.002	1.000	0.983	0.993

Helping *concepts*

A small systematic error occurs when all readings are consistently higher or lower than true value.

Not precise readings means there are a spread of readings about true value. The spread for banlance B is more than balance A.

45. The density of the material of a rectangular block was determined by measuring the mass and linear dimensions of the block. The table shows the results obtained, together with their uncertainties.

mass = (25.0 ± 0.1) g
length = (5.00 ± 0.01) cm
breadth = (2.00 ± 0.01) cm
height = (1.00 ± 0.01) cm

The density was calculated to be 2.50 g cm^{-3}.

What was the uncertainty in this result?

A ± 0.01 g cm^{-3} B ± 0.02 g cm^{-3}
C ± 0.05 g cm^{-3} D ± 0.13 g cm^{-3}

Helping *concepts*

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{\text{mass}}{\text{length} \times \text{breadth} \times \text{height}}$$

$$\frac{\Delta D}{D} = \pm\left(\frac{0.1}{25.0} + \frac{0.01}{5.00} + \frac{0.01}{2.00} + \frac{0.01}{1.00}\right) = \pm 0.021$$

$\therefore$ Uncertainty, $\Delta D = \pm 0.021 \times 2.50 = \pm 0.0525$

46. The resistance R of an unknown resistor is found by measuring the potential difference V across the resistor and the current I through it and using the equation $R = \frac{V}{I}$. The voltmeter reacting has a 3% uncertainty and the ammeter reading has a 2% uncertainty.

What is the uncertainty in the calculated resistance?

A 1.5% B 3%
C 5% D 6%

Helping *concepts*

$$R = \frac{V}{I}$$

Given $\frac{\Delta V}{V} \times 100\% = 3\%$

$\frac{\Delta A}{A} \times 100\% = 2\%$

$$\frac{\Delta R}{R} = \frac{\Delta V}{V} + \frac{\Delta I}{I}$$

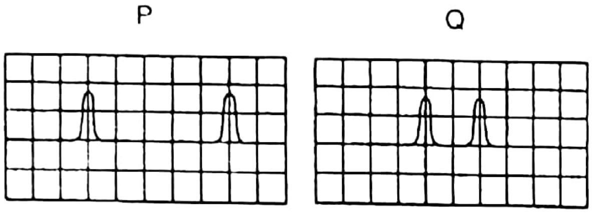
$$\Rightarrow \frac{\Delta R}{R} \times 100\% = \frac{\Delta V}{V} \times 100\% + \frac{\Delta I}{I} \times 100\%$$

$$= 3\% + 2\%$$

$$= 5\%$$

47. Two pulses are displayed on the screen of a cathode-ray oscilloscope. The grid markings indicate intervals of 1 cm on the screen.

When the time base is set at $0.50\ \text{ms cm}^{-1}$, the screen display is as shown in P.



What time base setting is needed to make these pulses produce the display shown in Q?

A $0.20\ \text{ms cm}^{-1}$ **B** $1.00\ \text{ms cm}^{-1}$

C $1.25\ \text{ms cm}^{-1}$ **D** $2.50\ \text{ms cm}^{-1}$

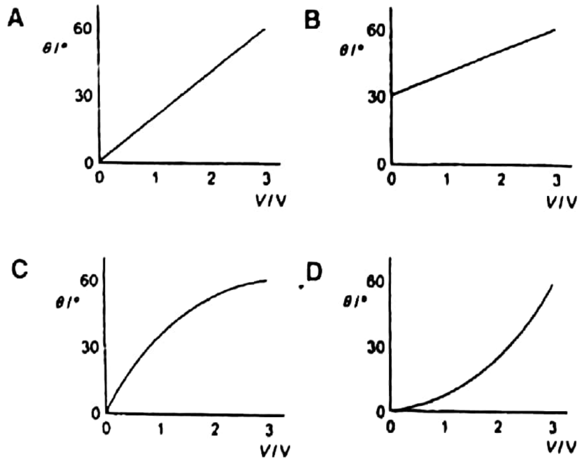
Helping *concepts*

Period of pulse in $P = 0.50 \times 5 = 2.50\ \text{ms}$

Time setting $= \dfrac{2.5}{2} = 1.25\ \text{ms cm}^{-1}$

48. Calibration curves showing the variation with potential difference V of the deflection θ of the pointer of four different voltmeters are given below.

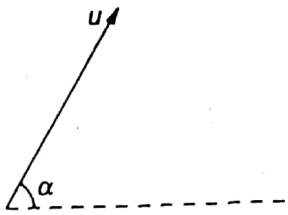
Which meter gives the largest angular change per unit potential difference at 2.5 V?



Helping *concepts*

The gradient at 2.5 V of graph D is the greatest.

49. A projectile is fired at an angle α to the horizontal at a speed u, as shown.



What will be the vertical and horizontal components of its velocity after a time t? Assume that air resistance is negligible. The acceleration of free fall is g.

	vertical component	horizontal component
A	$u\sin\alpha$	$u\cos\alpha$
B	$u\sin\alpha - gt$	$u\cos\alpha - gt$
C	$u\sin\alpha - gt$	$u\cos\alpha$
D	$u\cos\alpha$	$u\sin\alpha - gt$

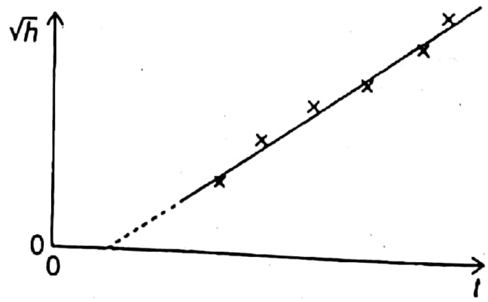
Helping *concepts*

Horizontal component of velocity remains unchanged after time t, $u\cos\alpha$.

Vertical component of u after time t is

$$v = u + at \uparrow$$
$$= u\sin\alpha + (-g)(t)$$

50. A student measures the time t for a ball to fall from rest through a vertical distance h. Knowing that the equation $h = \frac{1}{2}gt^2$ applies, the student plots the graph shown.



Which of the following is an explanation for the intercept on the t axis?

A Air resistance has not been taken into account for larger values of h.

B There is a constant delay between starting the timer and releasing the ball.

C There is an error in the timer that consistently makes it run fast.

D The student should have plotted h against t^2.

Helping concepts

The student starts timing before the ball is dropped.

---

51. In an experiment to determine the acceleration of free fall g, the period of oscillation T and length l of a simple pendulum were measured. The uncertainty in the measurement of l was estimated to be 4% and that of T, 1%.

The value of g was determined using the formula

$$g = \frac{4\pi^2 l}{T^2}.$$

What is the uncertainty in the calculated value for g?

A 2% **B** 3%

C 5% **D** 6%

Helping concepts

$$g \propto \frac{l}{T^2}$$

$\Rightarrow$ uncertainty in calculated value for g

= uncertainty in measurement of l + (2 × uncertainty in measurement of T)

= 4% + 2(1%)

= 6%

---

52. In an experiment to measure the viscosity η of a liquid, the following equation was used.

$$\eta = \frac{kr^2}{v}$$

where $r = (0.83 \pm 0.01)$ mm,
$v = (0.065 \pm 0.002)$ ms^{-1},
k is a constant of value 93.7 Nm^{-3}.

How should the value of η be expressed?

A $(9.93 \pm 0.54) \times 10^{-4}$ Nsm^{-2}

B $(9.9 \pm 0.6) \times 10^{-4}$ Nsm^{-2}

C $(9.93 \pm 0.42) \times 10^{-4}$ Nsm^{-2}

D $(9.9 \pm 0.4) \times 10^{-4}$ Nsm^{-2}

Helping concepts

$$\eta = \frac{(93.7)(0.83 \times 10^{-3})^2}{0.065} = 9.9308 \times 10^{-3} \text{ Nsm}^{-2}$$

$$\frac{\Delta\eta}{\eta} = 2\frac{\Delta r}{r} + \frac{\Delta v}{v}$$

$$\frac{\Delta\eta}{(9.9308 \times 10^{-4})} = 2\frac{(0.01)}{(0.83)} + \frac{(0.002)}{(0.065)}$$

$$\Delta\eta = 0.54 \times 10^{-4} \text{ Nsm}^{-2}$$

$$\approx 0.6 \times 10^{-4} \text{ Nsm}^{-2} \text{ (1 s.f.)}$$

Looking at the choices, the best answer is (B).

---

53. Potential differences may be compared by using a potentiometer, with a galvanometer as an indicator. The potential differences are adjusted until the galvanometer reads zero. This is an example of a null method.

Which statement about null methods is *incorrect*?

A Null methods are most suitable for the measurement of rapidly varying quantities.

B Null methods can give only relative, and not absolute values.

C The indicator in a null method need not be calibrated.

D The indicator in a null method need not have a linear response.

Helping concepts

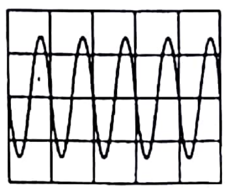
Null methods can be used to make measurements based on comparisons with a known, reference value. For this reason, null methods are not the most suitable for the measurement of rapidly varying quantities as the adjustment of the potential differences may not be made rapidly enough for the comparisons to be made.

---

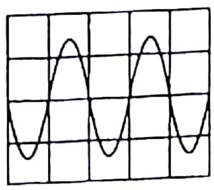
54. The Y-input terminals of an oscilloscope are connected to a supply of peak value 5.0 V and of frequency 50 Hz. The time-base is set at 10 ms per division and the Y-gain at 5 V per division.

Which trace could be obtained?

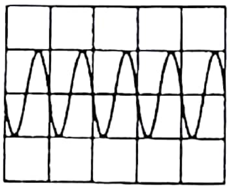
A



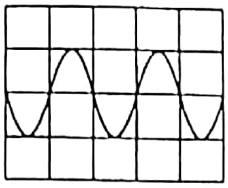
B



C



D



Helping concepts

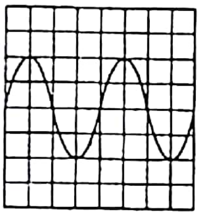
$$\text{Period} = \frac{1}{\text{frequency}} = \frac{1}{50} = 0.02 \text{ s} = 20 \text{ ms}$$

⇒ one complete cycle of the trace should occupy 2 divisions since the time-base is 10 ms per division.

The amplitude of the trace should occupy 1 division since the peak value is 5.0 V and the Y-gain is 5 V per division.

---

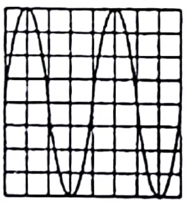
55. The following trace is seen on the screen of a cathode-ray oscilloscope.



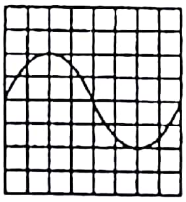
The setting of the time base is then changed from 10 ms cm^{-1} to 20 ms cm^{-1} and the Y-sensitivity is unaltered.

Which trace is now seen on the screen?

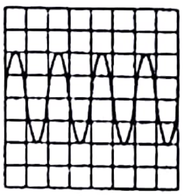
A



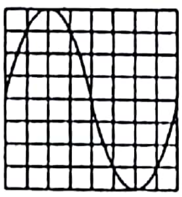
B



C



D



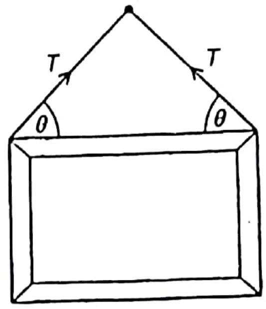
Helping concepts

For time base of 10 ms cm^{-1}, the period is $4 \times 10 = 40$ ms.

This period of 40 ms under a time base of 20 ms cm^{-1} will occupy 2 squares for each wavelength.

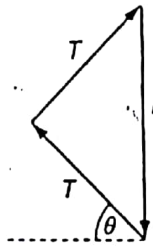
---

56. A picture frame is hung by a cord from a nail.

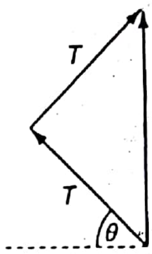


Which vector triangle represents the resultant R of the two tension forces T in the cord?

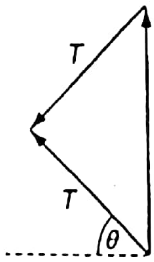
A



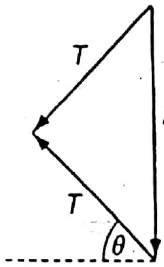
B



C



D



Helping concepts

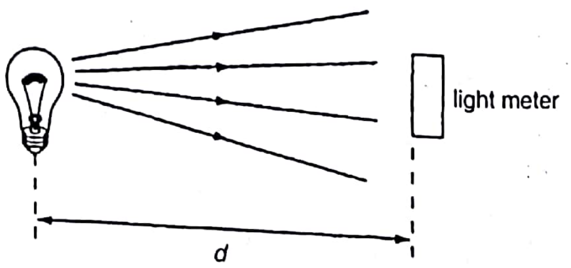
This is the sum of vectors where the end of the second vector follows the arrow head of the first vector.

The magnitude and direction of the individual vectors do not change during the addition process.

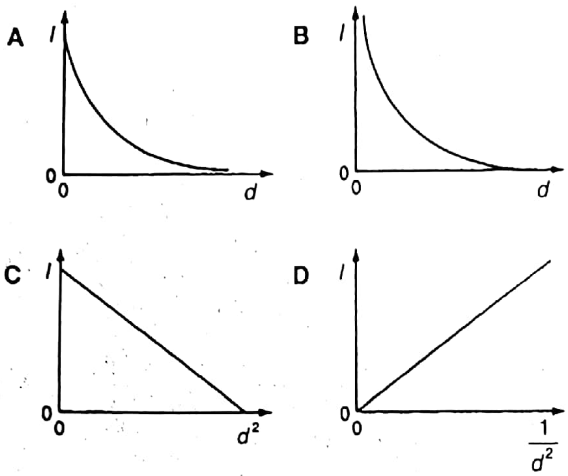
The resultant vector is the end of first arrow to the arrow head of the second vector.

---

57. A light meter measures the intensity I of the light falling on it. Theory suggests that this varies as the inverse square of the distance d.



Which graph of the results supports this theory?



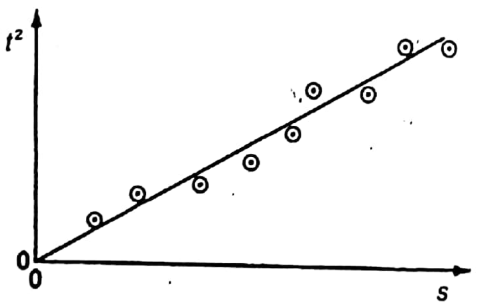
Helping concepts

Inverse square of distance $d \Rightarrow \frac{1}{d^2}$

$\therefore$ Intensity, $I \propto \frac{1}{d^2} \Rightarrow I = k(\frac{1}{d^2})$ which is of the form $y = mx + c$ where y-intercept $c = 0$, when a graph of I and $\frac{1}{d^2}$ is plotted.

---

58. An object falls freely from rest and travels a distance s in time t. A graph of t^2 against s is plotted and used to determine the acceleration of free fall g.



The gradient of the graph is found to be 0.204 $s^2\ m^{-1}$.

Which statement about the value obtained for g is correct?

A It is accurate but not precise.
B It is both precise and accurate.
C It is neither precise nor accurate.
D It is precise but not accurate.

Helping concepts

$$s = ut + \frac{1}{2}at^2$$

As $u = 0$ (falls freely from rest),

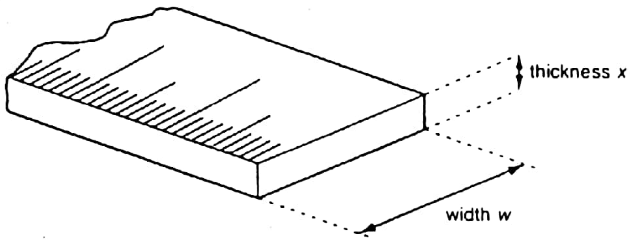
$$s = \frac{1}{2}gt^2 \Rightarrow t^2 = (\frac{2}{g})s$$

$\therefore \frac{2}{g} = 0.204 \Rightarrow$ gradient, $g = 9.80\ ms^{-2}$, which is close to true value of 9.81 ms^{-2}. The value of calculated g is accurate.

As the plotted points are distributed about best fit line, it is not precise.

---

59. In an experiment, the width w and the thickness x of a metre rule are to be measured as precisely as possible using normal laboratory apparatus.



Which combination of instruments is most appropriate for these measurement?

	measurement of w	measurement of x
A	half - metre rule	half - metre rule
B	half - metre rule	vernier calipers
C	vernier calipers	half - metre rule
D	vernier calipers	micrometer screw gauge

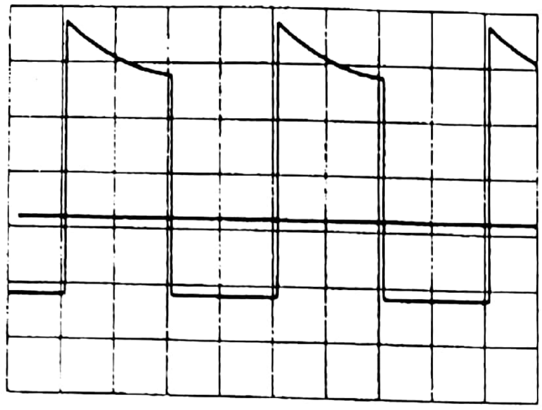
Helping concepts

As the width w is of a few centimetres, a vernier calipers is suitable. The thickness x is of a few millimetres, a micrometer screw gauge is appropriate.

---

60. An oscilloscope display consists of two separate traces, a waveform and a long horizontal line. The horizontal line may be taken as the zero level.

The grid on the screen is calibrated in cm squares, the timebase setting is 2.5 ms cm^{-1}, and the Y-sensitivity is 5 mV cm^{-1}.



What are the period and the peak positive voltage of the waveform in the diagram?

	period / ms	peak positive voltage / mV
A	5	17
B	5	25
C	10	17
D	10	25

Helping *concepts*

Period = 4 cm × 2.5 ms cm^{-1} = 10 ms

Peak voltage as measured from the zero horizontal line upwards ≈ 3.4 cm × 5 mV cm^{-1}

= 17 mV

61. A wire of uniform circular cross-section has diameter d and length L. A potential difference V between the ends of the wire gives rise to current I in the wire.

The resistivity ρ of the material of the wire is given by the expression

$$\rho = \frac{\pi d^2 V}{4LI}.$$

In one particular experiment, the following measurements are made.

$d = 1.20 \pm 0.01$ cm

$I = 1.50 \pm 0.05$ A

$L = 100 \pm 1$ cm

$V = 5.0 \pm 0.1$ V

Which measurement gives rise to the **least** uncertainty in the value for the resistivity?

A d **B** I

C L **D** V

Helping *concepts*

% uncertainty of each measurement,

$$\frac{\Delta d}{d} \times 100\% = 0.83\%$$

$$\frac{\Delta I}{I} \times 100\% = 3.3\%$$

$$\frac{\Delta L}{L} \times 100\% = 1.0\%$$

$$\frac{\Delta V}{V} \times 100\% = 2.0\%$$

However, $\frac{\Delta \rho}{\rho} = 2\frac{\Delta d}{d} + \frac{\Delta V}{V} + \frac{\Delta L}{L} + \frac{\Delta I}{I}$.

Uncertainty due to $2\frac{\Delta d}{d} \times 100\% = 1.66\%$ is greater than $\frac{\Delta L}{L} \times 100\% = 1\%$.

∴ Uncertainty of $\frac{\Delta L}{L} \times 100\%$ in equation is the least.

TOPIC 2

Kinematics

Key content that you will be examined on:

1. Rectilinear motion
2. Non-linear motion

Topic 2 Kinematics

1. Which feature of a graph allows acceleration to be determined?

   A the area under a displacement-time graph
   B the area under a velocity-time graph
   C the slope of a displacement-time graph
   D the slope of a velocity-time graph

Helping concepts

Fact. The gradient (or slope) at a point of a velocity-time graph equals to the acceleration at that point.

---

2. A car is travelling with uniform acceleration along a straight road. The road has marker posts every 100 m. When the car passes one post, it has a speed of 10 ms^{-1} and, when it passes the next one, its speed is 20 ms^{-1}.

   What is the car's acceleration?

   A 0.67 ms^{-2} B 1.5 ms^{-2}
   C 2.5 ms^{-2} D 6.0 ms^{-2}

Helping concepts

$v^2 = u^2 + 2as$

$$a = \frac{v^2 - u^2}{2s} = \frac{20^2 - 10^2}{2 \times 100} = 1.5\ ms^{-2}$$

---

3. A motorist travelling at 10 ms^{-1} can bring his car to rest in a distance of 10 m.

   If he had been travelling at 30 ms^{-1}, in what distance could he bring the car to rest using the same braking force?

   A 17 m B 30 m
   C 52 m D 90 m

Helping concepts

$$v^2 = u^2 + 2as$$

$$0 = 10^2 + 2(a)(10) \Rightarrow a = \frac{10^2}{20} = -5\ ms^{-2} \text{----}(1)$$

$$0 = 30^2 + 2(a)(s) \text{----}(2)$$

Subst. (1) into (2):

$$0 = 30^2 + 2(-5)(s) \Rightarrow s = 90\ m$$

---

4. A tracing car accelerates uniformly through three gear changes with the following average speeds:

   20 ms^{-1} for 2.0 s
   40 ms^{-1} for 2.0 s
   60 ms^{-1} for 6.0 s

   What is the overall average speed of the car?

   A 12 ms^{-1} B 13.3 ms^{-1}
   C 40 ms^{-1} D 48 ms^{-1}

Helping concepts

Overall average speed of the car is

$$\frac{\text{total distance travelled}}{\text{total time taken}} = \frac{(20)(2.0) + (40)(2.0) + (60)(6.0)}{2.0 + 2.0 + 6.0} = 48\ ms^{-1}$$

---

5. An experiment is done to measure the acceleration of free fall of a body from rest.

   Which measurement are needed?

   A the height of fall and the time of fall
   B the height of fall and the weight of the body
   C the mass of the body and the height of fall
   D the mass of the body and the time of fall

Helping concepts

$$s = ut + \frac{1}{2}at^2$$

Since the body is dropped from rest, $u = 0$.
To find a,

$$s = \frac{1}{2}at^2 \Rightarrow a = \frac{2s}{t^2}$$

Hence, displacement s and time t are required.

---

6. A motorist travelling at 10 ms^{-1} can bring his car to rest in a braking distance of 10 m.

   In what distance could he bring the car to rest from a speed of 30 ms^{-1} using the same braking force?

   A 17 m B 30 m
   C 52 m D 90 m

Helping concepts

Given $u = 10$ ms^{-1}, $s = 10$ m and $v = 0$ ms^{-1}.

$$v^2 = u^2 + 2as$$

$\therefore 0 = 10^2 + 2(a)(10) \Rightarrow a = -5 \text{ ms}^{-2}$

New scenario: $u = 30 \text{ ms}^{-1}$
$v = 0 \text{ ms}^{-1}$
$a = -5 \text{ ms}^{-2}$

$\therefore 0 = 30^2 + 2(-5)s \Rightarrow s = 90$ m

---

7. A stone is dropped from the top of a tower of height 40 m. The stone falls from rest and air resistance is negligible.

   What time is taken for the stone to fall the last 10 m to the ground?

   A 0.38 s B 1.4 s
   C 2.5 s D 2.9 s

Helping concepts

$$s = ut + \frac{1}{2}at^2$$

For $u = 0$, $s = 40$ m, $a = 9.81$ ms^{-2},

$$40 = 0 + \frac{1}{2}(9.81)t_1^2 \Rightarrow t_1 = 2.86 \text{ s}$$

For $u = 0$, $s = 30$ m, $a = 9.81$ ms^{-2},

$$30 = 0 + \frac{1}{2}(9.81)t_2^2 \Rightarrow t_2 = 2.47 \text{ s}$$

Time difference $(t_1 - t_2) = 2.86 - 2.47$
≈ 0.38 s

---

8. A racing car of mass 500 kg, including driver but not fuel, decelerates from a speed of 50 ms^{-1} to 30 ms^{-1} when approaching a bend.

   The brakes exert a fixed retarding force of 7000 N. The time for the car to decelerate when it is almost out of fuel is t_1. The time for it to decelerate when it has a full load of 130 kg of fuel is t_2.

   What is the difference $(t_2 - t_1)$ in the times?

   A 0.37 s B 0.56 s
   C 0.93 s D 1.43 s

Helping concepts

Using $a = \dfrac{F}{m}$ and $a = \dfrac{v-u}{t}$,

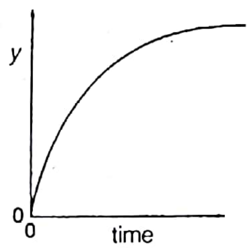
$$\frac{F}{m} = \frac{v-u}{t_1} \Rightarrow \frac{7000}{500} = \frac{50-30}{t_1} \Rightarrow t_1 = 1.43 \text{ s}$$

$$\frac{F}{m} = \frac{v-u}{t_2} \Rightarrow \frac{7000}{500+130} = \frac{50-30}{t_2} \Rightarrow t_2 = 1.80 \text{ s}$$

$\therefore$ Difference $(t_2 - t_1) = 0.37$ s

---

9. The graph relates to the motion of a falling body.



   What could y represent on the vertical axis?

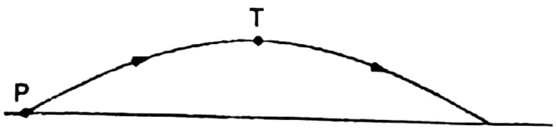
   A distance when air resistance is negligible
   B distance when air resistance is not negligible
   C speed when air resistance is negligible
   D speed when air resistance is not negligible

Helping concepts

As a body undergoes free fall, its speed increases linearly with time if there is no air resistance. If air resistance is not negligible, its speed increases with decreasing gradient until terminal velocity is reached.

---

10. In the absence of air resistances, a stone is thrown from P and follows a parabolic path in which the highest point reached is T.



The vertical component of acceleration of the stone is

A zero at T.
B greatest at T.
C greatest at P.
D the same at P as at T.

Helping concepts

For such a projectory path described by a stone thrown into the air, the vertical component of the acceleration is always the acceleration of free fall, *g*, taken as 9.8 ms^{-2}, towards centre of Earth.

Thus, vertical component of acceleration at point **P** is the same as that at point **T** and is equal to *g*.

---

11. A boy throws a ball vertically upwards. It rises to a maximum height, where it is momentarily at rest, and falls back to his hands.

Which of the following gives the acceleration of the ball at various stages in its motion? Take vertically upwards as positive. Neglect air resistance.

	rising	at max. height	falling
A	$-9.81\ ms^{-2}$	0	$+9.81\ ms^{-2}$
B	$-9.81\ ms^{-2}$	$-9.81\ ms^{-2}$	$-9.81\ ms^{-2}$
C	$+9.81\ ms^{-2}$	$+9.81\ ms^{-2}$	$+9.81\ ms^{-2}$
D	$+9.81\ ms^{-2}$	0	$-9.81\ ms^{-2}$

Helping concepts

Acceleration is constant at value of 9.81 ms^{-2} for free fall without air resistance, in downwards direction only.

---

12. A ball falls vertically and bounces on the ground.

The following statements are about the forces acting while the ball is in contact with the ground.

Which statement is correct?

A The force that the ball exerts on the ground is always equal to the weight of the ball.

B The force that the ball exerts on the ground is always equal in magnitude and opposite in direction to the force the ground exerts on the ball.

C The force that the ball exerts on the ground is always greater than the weight of the ball.

D The weight of the ball is always equal and opposite to the force that the ground exerts on the ball.

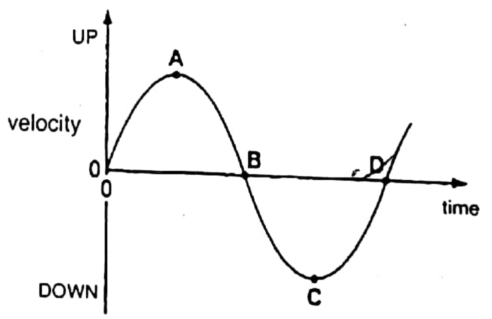
Helping concepts

Newton's third law of motion states that if body A exerts a force *F* on body B, then body B exerts a force *F* on body A of the same magnitude, but in the opposite direction.

---

13. The diagram shows a velocity-time graph for a mass moving up and down on the end of a spring.

Which point represents the velocity of the mass when at the lowest point of its motion?

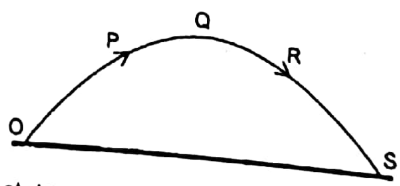


Helping concepts

At the lowest point of simple harmonic motion of a spring, velocity = 0. It is on the verge of moving up.

---

14. A projectile is launched at point O and follows the path OPQRS, as shown. Air resistance may be neglected.



Which statement is true for the projectile when it is at the highest point Q of its path?

A The horizontal component of the projectile's acceleration is zero.

B The horizontal component of the projectile's velocity is zero.

C The kinetic energy of the projectile is zero.

D The momentum of the projectile is zero.

Helping concepts

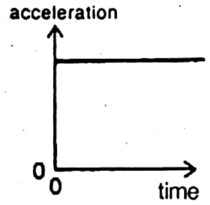
At the highest point Q, the vertical component of speed is zero. The horizontal component of speed is non-zero. This means kinetic energy and momentum at Q is non-zero.

There is no horizontal acceleration in projectile motion.

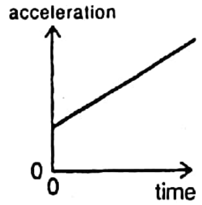
---

15. Which graph represents the motion of a car that is travelling along a straight road with a uniformly increasing speed?

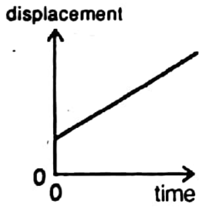
A



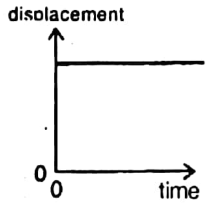
B



C



D



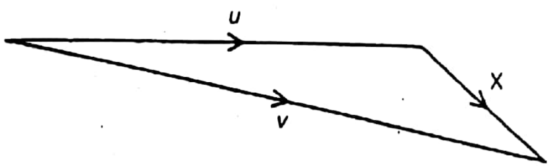
Helping concepts

A uniformly increasing speed means the air is accelerating at a constant value ($v = u + at$).

---

16. An object has an initial velocity u. It is subjected to a constant force F for t seconds, causing a constant acceleration a. The force is **not** in the same direction as the initial velocity.

A vector diagram is drawn to find the final velocity v.



What is the length of side X of the vector diagram?

A F **B** Ft

C at **D** $u + at$

Helping concepts

From the vector diagram,

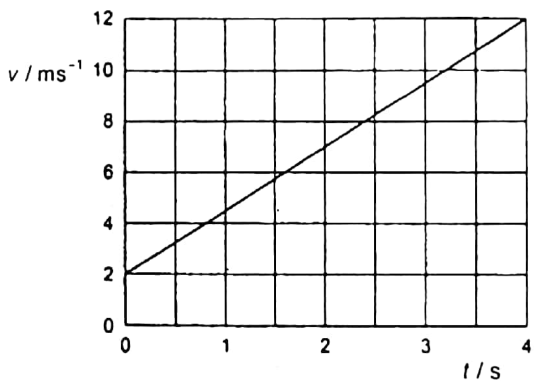
$$X = v - u$$

For constant acceleration,

$$v = u + at$$
$$v - u = at$$
$$X = at$$

---

17. The diagram shows a velocity-time graph for a car.



What is the distance travelled between time $t = 0$ and $t = 4$ s?

A 2.5 m **B** 3.0 m

C 20 m **D** 28 m

Helping concepts

Distance travelled = area under the graph

$$= \tfrac{1}{2}(2 + 12)(4)$$
$$= 28 \text{ m}$$

---

18. A man stands on the edge of a cliff. He throws a stone upwards with a velocity of 19.6 ms^{-1} at time $t = 0$. The stone reaches the top of its trajectory after 2.00 s and then falls towards the botton of the cliff. Air resistance is negligible.

Which row shows the correct velocity v and acceleration a of the stone at different times?

	t / s	v / ms^{-1}	a / ms^{-2}
A	1.00	9.81	9.81
B	2.00	0	0
C	3.00	9.81	−9.81
D	5.00	−29.4	−9.81

Helping concepts

Upward velocity of +19.6 ms^{-1} means the convention is upwards direction is taken to be positive.

Acceleration due to gravity will be −9.81 ms^{-2}, at all times.

At $t = 3.00$ s,

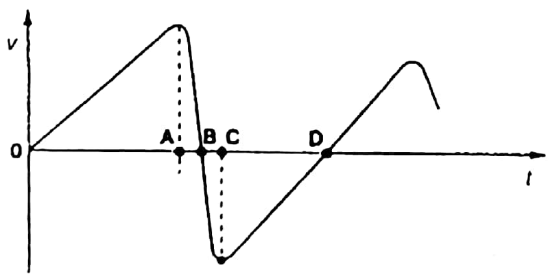
$$v = u + at$$
$$= 19.6 + (-9.81)(3)$$
$$= -9.81\ \text{ms}^{-1}$$

At $t = 5.00$ s,

$$v = u + at$$
$$= 19.6 + (-9.81)(5)$$
$$= -29.4\ \text{ms}^{-1}$$

19. The graph shows the variation with time t of the velocity v of a bouncing ball, released from rest. Downward velocities are taken as positive.

At which time does the ball reach its maximum height after bouncing?

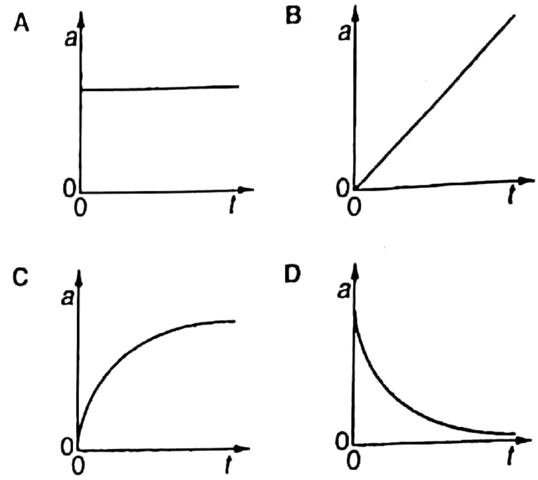


Helping concepts

At maximum height, the velocity of the ball is zero.

20. A tennis ball is released from rest at the top of a tall building.

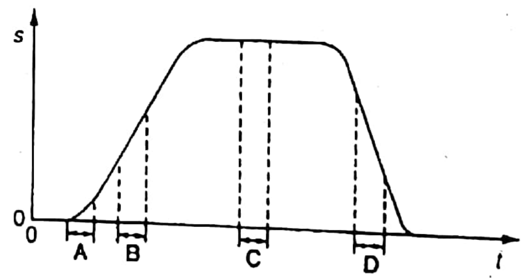
Which graph best represents the variation with time t of the acceleration a of the ball as it falls, assuming that the effects of air resistance are appreciable?



Helping concepts

The ball will eventually reach terminal velocity from a tall building. This means there will be no net force and hence no net acceleration, as time is large.

21. The graph shows the variation with time t of the displacement s of a vehicle moving along a straight line.



During which time interval does the acceleration of the vehicle have its greatest numerical value?

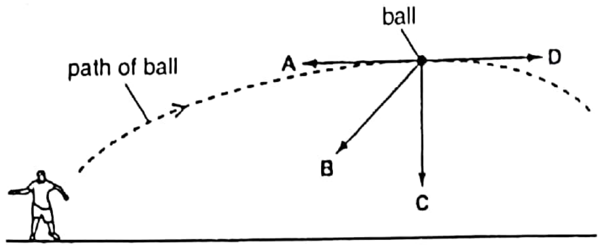
Helping concepts

$$a = \frac{dV}{dt} = \frac{d}{dt}\left(\frac{ds}{dt}\right)$$

The gradients for **B**, **C** and **D** are constant, i.e. $\frac{ds}{dt}$ is constant. Hence $a = 0$ for all except **A**.

22. The diagram shows a ball which has been thrown and is being acted on by air resistance.

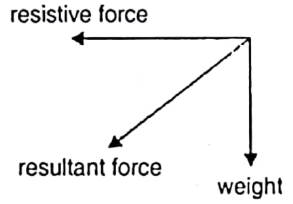
Which labelled arrow shows the direction of the resultant force on the ball when it is at the position shown?



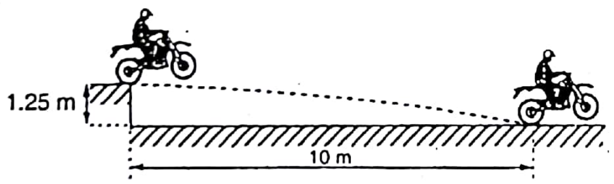
Helping concepts

At the highest point of projectile, there is a resistive force acting opposite to the motion of ball. The force is to the left.

There is also a gravitational force, i.e. the weight of ball.



23. A motorcycle stunt-rider moving horizontally takes off from a point 1.25 m above the ground, landing 10 m away as shown.



What was the speed at take-off?

A $5\ ms^{-1}$ B $10\ ms^{-1}$

C $15\ ms^{-1}$ D $20\ ms^{-1}$

Helping concepts

Take off speed consists only of horizontal component of speed.

$$u = \frac{s}{t} = \frac{10}{t} \text{------}(1)$$

To find time taken t,

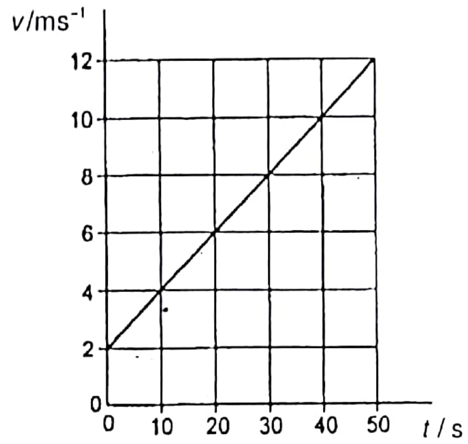
$$s = ut + \tfrac{1}{2}at^2$$

$$-1.25 = 0 + \tfrac{1}{2}(-9.81)t^2$$

$$t = 0.50\ s$$

Subst. t into (1): $u = \dfrac{10}{0.5} = 20\ ms^{-1}$

24. A train travelling at $2.0\ ms^{-1}$ passes through a station. The variation with time t of the speed v of the train after leaving the station is shown below.



What is the speed of the train when it is 150 m from the station?

A $6.0\ ms^{-1}$ B $8.0\ ms^{-1}$

C $10\ ms^{-1}$ D $12\ ms^{-1}$

Helping concepts

Acceleration of train = gradient of graph

$$= \frac{4-2}{10-0}$$

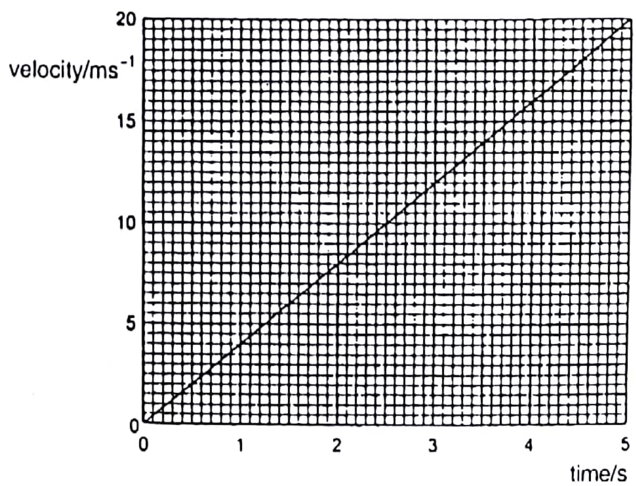
$$= 0.2\ ms^{-2}$$

Using $v^2 = u^2 + 2as$,

$$v^2 = 2^2 + 2(0.2)(150)$$

$$v = 8.0\ ms^{-1}$$

25. The velocity of an object during the first five seconds of its motion is shown on the graph.



What is the distance travelled by the object in this time?

A 4 m B 20 m

C 50 m D 100 m

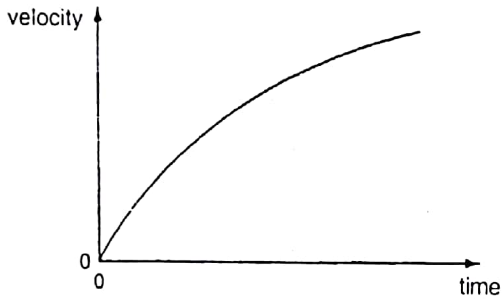
Helping concepts

Distance travelled = area under the graph

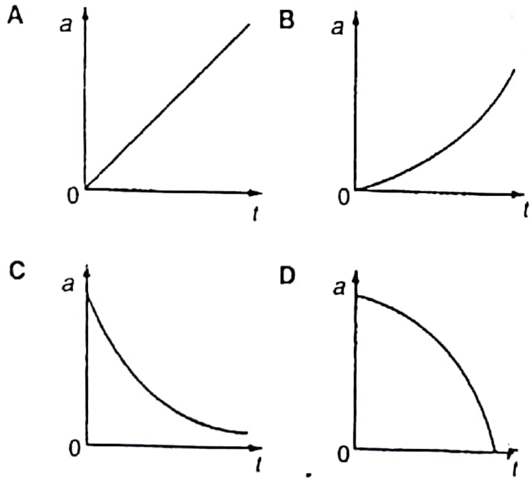
$= \frac{1}{2}(5)(20)$

$= 50$ m

26. A table-tennis ball is released in air and falls vertically. The graph shows how its velocity varies with time.



Which graph best illustrates the variation with time t of its acceleration a?

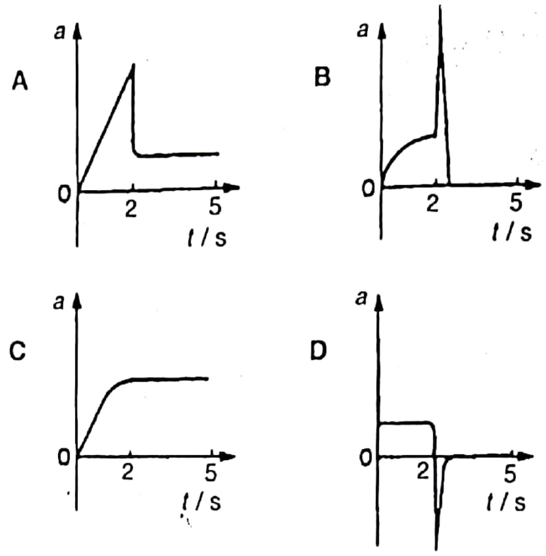


Helping concepts

The acceleration (gradient of velocity-time graph) is decreasing but not zero, at the end of the graph.

27. A parachutist steps from an aircraft, falls without air resistance for 2 s and then opens his parachute.

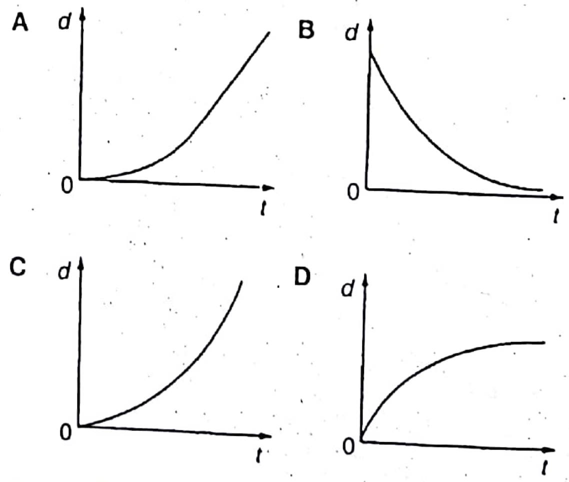
Which graph best represents how a, his vertical acceleration varies with time t during the first 5 s of his descent?



Helping concepts

The parachutist undergoes free fall motion for an initial 2 seconds, then experiences a sudden great retardation when he opens his parachute, follows by descending with constant terminal velocity.

28. Which graph shows how the distance d fallen varies with time t for a body falling from rest through air?



Helping concepts

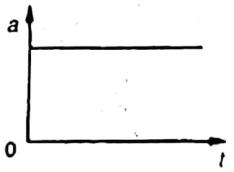
From $s = ut + \frac{1}{2}at^2$,

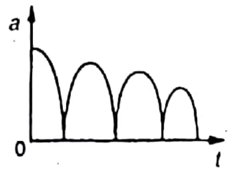
$d = \frac{1}{2}at^2$ as $u = 0$.

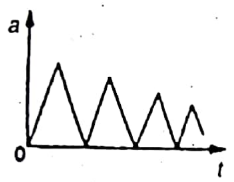
$\therefore\ d \propto t^2$ - a quadratic curve

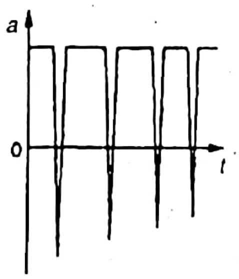
29. A steel ball is held above a horizontal table and released so that it falls onto the table and rebounds several times.

If the collision are inelastic, which graph best represents the variation of acceleration a of the ball with time t?

A


B


C


D


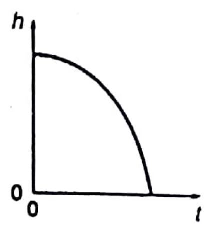
Helping *concepts*

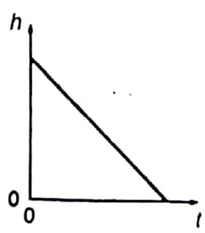
If collisions are inelastic, the time of flight decreases successively after each collision. However, the acceleration of free fall remains the same during the ascending and descending motions. But the steel ball suffers tremendous deceleration and acceleration during impact onto the table since energy is lost during the collision.

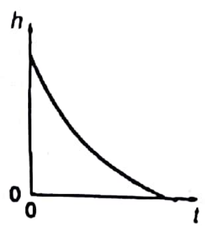
---

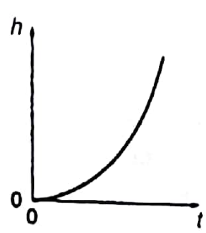
30. A small steel ball falls freely under gravity after being released from rest.

Which graph best represents the variation of the height h of the ball with time t?

A


B


C


D


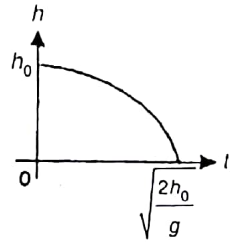
Helping *concepts*

If h_0 is the initial height of the ball above ground and g is the acceleration of free fall under gravity, variation of height of the ball with time is then given by

$$h_0 - h = ut + \frac{1}{2}gt^2 = \frac{1}{2}gt^2$$

since the ball is released from rest and $u = 0$.

i.e. $h = h_0 - \frac{1}{2}gt^2$ which is best described by graph A.



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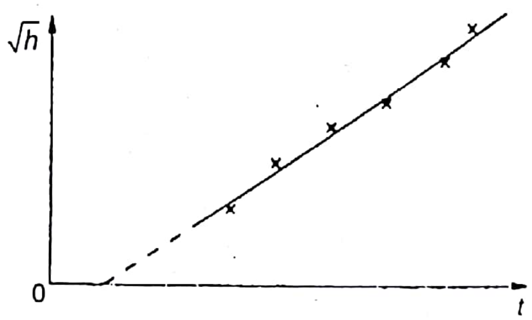
31. A student measures the time t for a ball to fall from rest through a vertical distance h. Knowing that the equation $h = \frac{1}{2}at^2$ applies, the student plots the graph shown.



Which of the following is an explanation for the intercept?

A Air resistance has not been taken into account for larger values of h.

B There is a constant delay between starting the time and releasing the ball.

C There is an error in the timer that consistently makes it run fast.

D The student should have plotted h against t^2.

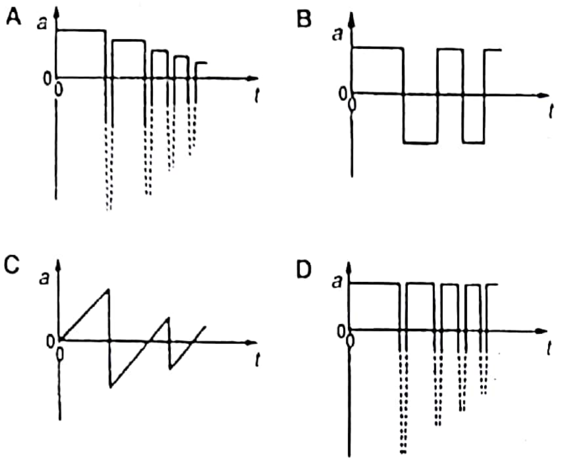
Helping *concepts*

By $h = \frac{1}{2}at^2$, $\sqrt{h}$ is directly proportional to t. A plot should give a straight line graph passing through the origin. The actual graph does not pass through the origin shows that there is a delay between releasing the ball and starting the timer.

---

32. A steel ball is released from rest a distance above a rigid horizontal surface and is allowed to bounce.

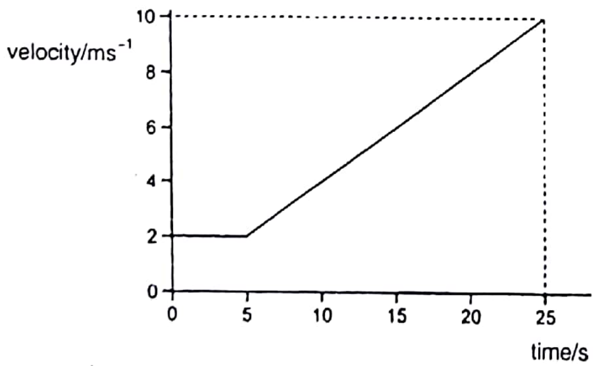
Which graph best represents the variation with time t of acceleration a?



Helping concepts

Whenever the ball is not in contact with the surface, its acceleration equals the gravitational acceleration. When it is in contact with the surface, its acceleration depends on the force exerted by the surface on the ball.

33. The diagram shows a velocity-time graph for a particle moving along a straight line.



What is the displacement of the particle between 0 s and 25 s?

A 90 m B 120 m

C 130 m D 150 m

Helping concepts

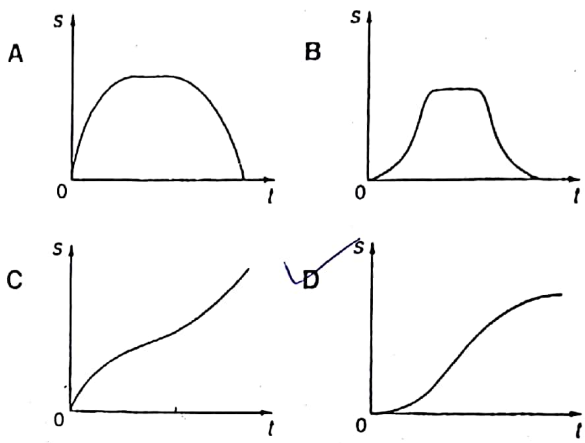
Displacement = area under graph

$= (2 \times 5) + \frac{1}{2}(25 - 5)(2 + 10)$

$= 130$ m

34. A cyclist accelerates down a hill and then travels at constant speed before decelerating as he climbs back up another hill.

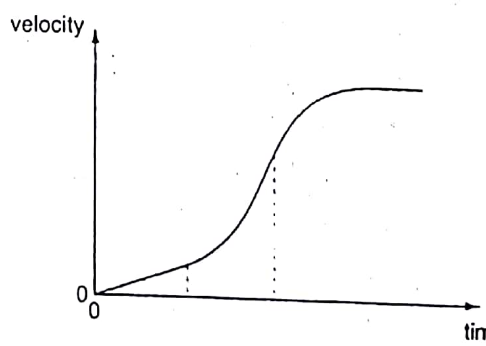
Which graph shows the variation with time t of the distance s moved by the cyclist?



Helping concepts

When the cyclist accelerates down the hill, his speed is increasing. This means that the gradient of distance-time graph (i.e. speed) is increasing as time increases. When the cyclist travels at constant speed, the gradient of distance-time graph is constant and non-zero. When the cyclist decelerates, his speed is decreasing. This means the gradient of distance-time graph is decreasing as time increases.

35. The graph shows the velocity of a racing car changes with time.



Which statement describes the acceleration?

A A constant positive accleration is followed by an acceleration increase and then a negative acceleration.

B The acceleration increases positively in the first two sections and then decreases to zero.

C The acceleration is positive at the start, increases, then decreases to zero.

D The acceleration starts from zero, increases, then decreases to zero.

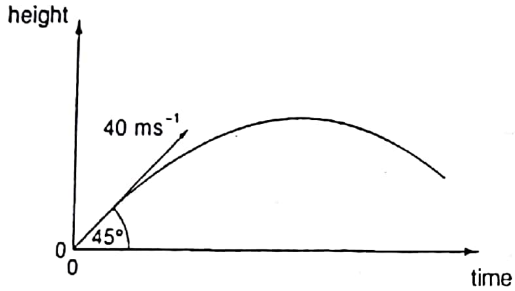
Helping concepts

The gradient of the velocity-time graph is the acceleration.

The acceleration is positive from the start to the end, before it goes to zero.

The gradient, i.e. the acceleration is the steepest at the middle of the time of graph.

36. An object is projected with velocity 40 ms^{-1} at an angle of 45° to the horizontal. Air resistance is negligible.



What is the speed of the object after 5.0 s?

A 21 ms^{-1} B 28 ms^{-1}

C 35 ms^{-1} D 49 ms^{-1}

Helping concepts

	x	y
a	0	−9.81
s	s_x	s_y
t	5.0	5.0
u	$40\cos 45°$	$40\sin 45°$
v	$40\cos 45°$	v_y

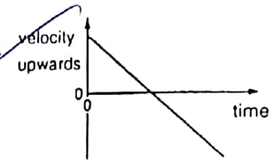
To find v_y

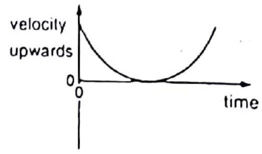
$$v_y = u_y + at$$
$$= 40\sin 45° + (-9.81)(5)$$
$$= -20.8\ ms^{-1}$$

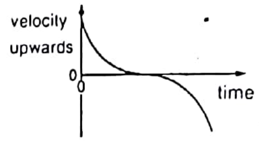
$$\text{Resultant speed} = \sqrt{(40\cos 45°)^2 + (-20.8)^2}$$
$$= 35\ ms^{-1}$$

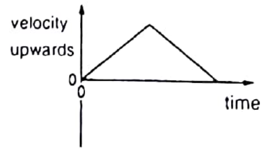
37. A ball is thrown vertically upwards and returns along the same path. The graph shows how its height varies with time.

Which velocity-time graph describes this motion?

A


B


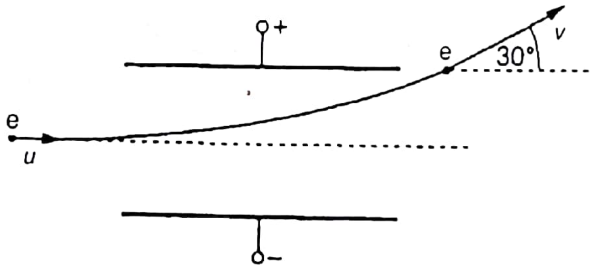
C


D


Helping concepts

For the ball in free fall, there is a constant acceleration, i.e. 9.81 ms^{-2}. Hence, the gradient of the velocity-time graph must be constant and the graph must therefore be a straight non-horizontal line (a vertical line has an infinite gradient value).

38. A electron enters the space between two parallel charged plates with an initial velocity u.



While in the electric field its direction changes by 30° and it emerges with a velocity v. What is the relation between v and u?

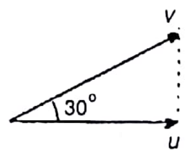
A $v = \dfrac{u}{\cos 30°}$ B $v = u\cos 30°$

C $v = \dfrac{u}{\sin 30°}$ D $v = u\sin 30°$

Helping concepts

The initial velocity in the x-direction remains unchanged.

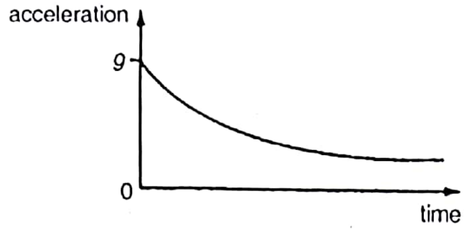
$$v\cos 30° = u$$



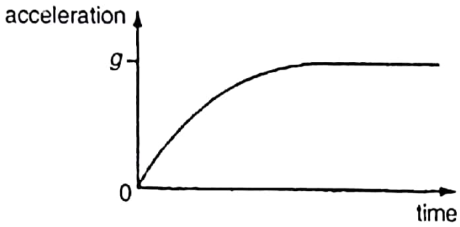
39. An object is dropped from a great height so that air resistance becomes significant.

Which graph shows how its acceleration varies with time?

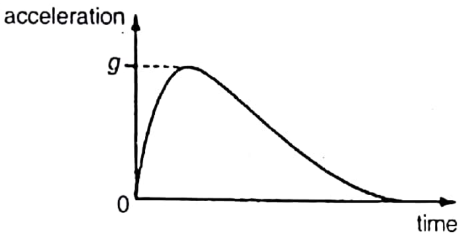
A



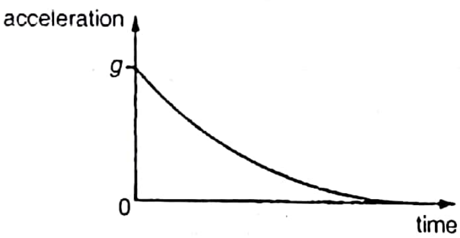
B



C



D

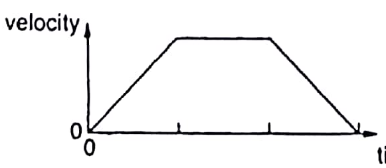


Helping *concepts*

When object is first dropped, its net force is due to its weight only. At $t = 0$, acceleration equals to g.

At terminal constant velocity, there is no resultant force. This means acceleration will eventually decrease to zero.

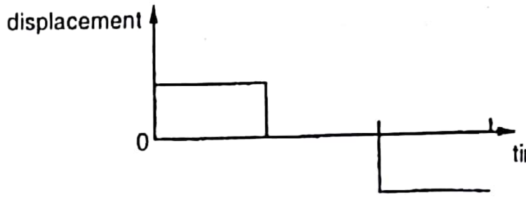
40. The graph of velocity against time for an object moving in a straight line is shown.



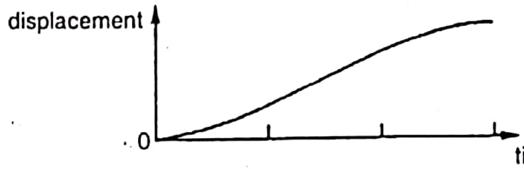
Which of the following is the corresponding graph of displacement against time?

A

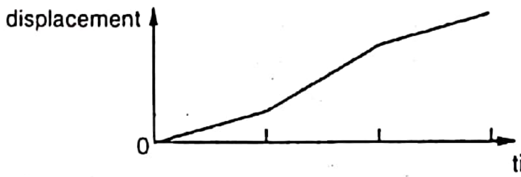
B



C



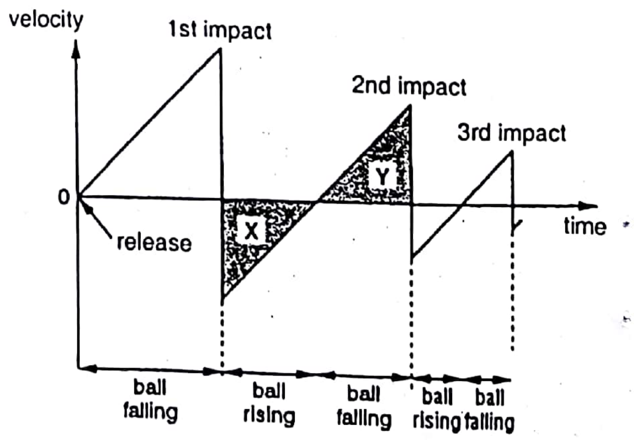
D



Helping *concepts*

The displacement-time graph will give the velocity of the object. When velocity is increasing, the gradient of displacement-time graph (i.e. velocity) is increasing. When velocity is constant, the gradient of displacement-time graph is constant. When velocity is decreasing, the gradient of displacement-time graph is decreasing.

41. A ball is released from rest above a horizontal surface. The graph shows the variation with time of its velocity.



Area X and Y are equal.

This is because

A the ball's acceleration is the same during its upward and downward motion.

B the speed at which the ball leaves the surface after an impact is equal to the speed at which it returns to the surface for the next impact.

C for one impact, the speed at which the ball hits the surface equals the speed at which it leaves the surface.

D the ball rises and falls through the same distance between impacts.

Helping *concepts*

Area **X** is the distance covered till the higher point after bounce.

Area **Y** is the distance covered from highest point to the second impact.

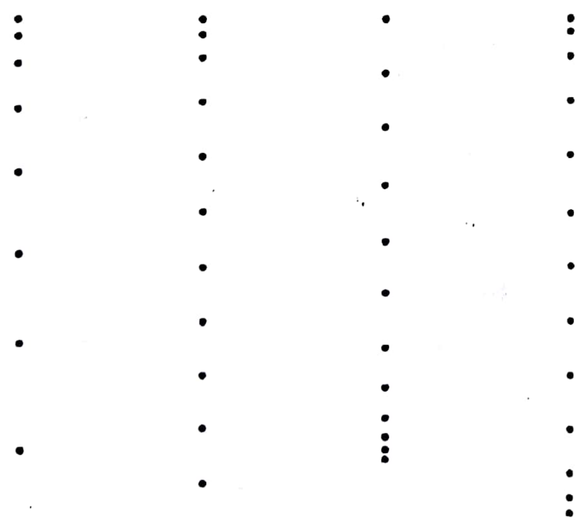
---

42. A steel sphere is released from rest at the surface of a deep tank of viscous oil. A multiple exposure photograph is taken of the sphere as it falls.

The time interval between exposures is always the same.

Which of the following could represent this photograph?

A **B** **C** **D**

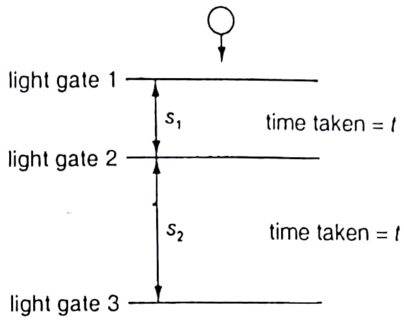


Helping *concepts*

The sphere will reach terminal velocity and hence, the distance between exposure will be constant.

---

43. An object falls freely with constant acceleration a from above three light gates. It is found that it takes a time t to fall between the first two light gates a distance of s_1 apart. It then takes an additional time, also t, to fall between the second and third light gates a distance s_2 apart.



What is the acceleration in terms of s_1, s_2 and t?

A $\dfrac{(s_2 - s_1)}{t^2}$ **B** $\dfrac{(s_2 - s_1)}{2t^2}$

C $\dfrac{2(s_2 - s_1)}{3t^2}$ **D** $\dfrac{2(s_2 - s_1)}{t^2}$

Helping *concepts*

Let u be the speed of object when it is at light gate 1.

$$s = ut + \frac{1}{2}at^2$$

Between light gate 1 and 2,

$$s_1 = ut + \frac{1}{2}gt^2 \text{ -----(1)}$$

Between light gate 1 and 3,

$$s_1 + s_2 = u(2t) + \frac{1}{2}g(2t)^2 \text{ -----(2)}$$

To get rid of unknown u,

$(2) - 2 \times (1)$: $s_2 - s_1 = gt^2$

$$g = \frac{s_2 - s_1}{t^2}$$

---

44. A metal ball is dropped from rest over a bed of sand. It hits the sand bed one second later and makes an impression of maximum depth 8.0 mm in the sand.

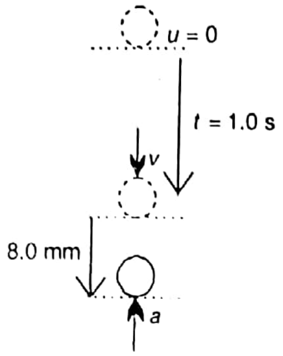
Air resistance is negligible.

On hitting the sand, what is the average deceleration of the ball?

A 6.0×10^2 ms^{-2} **B** 1.2×10^3 ms^{-2}

C 6.0×10^3 ms^{-2} **D** 1.2×10^4 ms^{-2}

Helping concepts



Just before the metal ball hits the sand,

$$v = u + at$$
$$= 0 + (9.81)(1)$$
$$= 9.81 \text{ ms}^{-1}$$

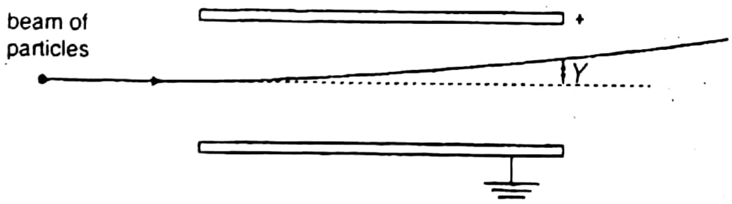
Using $v^2 = u^2 + 2as$,

$$0 = (9.81)^2 + 2(a)(8.0 \times 10^{-3})$$
$$a = -6.0 \times 10^3 \text{ ms}^{-2}$$

Acceleration is negative as it is acting upwards. In this case, downwards direction is taken to be positive.

---

45. Two horizontal metal plates are situated in a vacuum. A potential difference is maintained between the plates as shown.



A beam of negatively-charged particles is horizontal when it enters the region between the plates. It is deflected as shown in the diagram.

The potential difference is then increased.

How does this affect the time T that a particle in the beam spends between the plates and the vertical deflection Y as shown on the diagram?

	effect on T	effect on Y
A	decreases	decreases
B	no change	increases
C	no change	decreases
D	increases	increases

Helping concepts

Time taken to travel horizontally between the plates,

$$T = \frac{\text{horizontal distance}}{\text{horizontal constant speed}}.$$

Using kinematics, $s = ut + \frac{1}{2}at^2$,

$$Y = \frac{1}{2}\left(\frac{F}{m}\right)t^2 = \frac{1}{2}\left(\frac{qE}{m}\right)t^2 = \frac{1}{2}\left(\frac{q}{m}\right)\left(\frac{V}{d}\right)t^2$$

where V is potential difference and d is the distance between parallel plates.

As the p.d. is increased,

1. time taken remains unchanged as the factors are independent of p.d. V.
2. the value of Y is proportional to p.d., Y will increase as p.d. is increased.

---

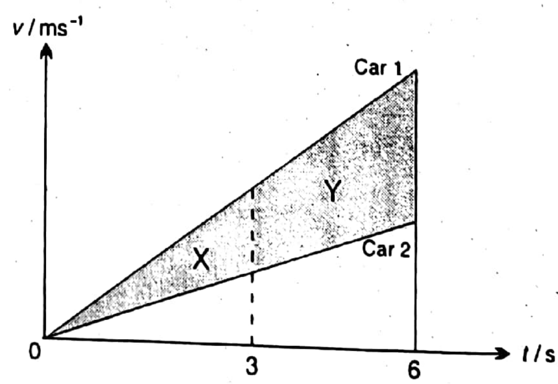
46. Two cars, initially next to each other and at rest, accelerate in the same straight line at different uniform rates. After 3 s, they are 12 m apart.

If they continue to accelerate at the same rate, how far apart will they be 6 s after they started?

A 18 m **B** 24 m
C 36 m **D** 48 m

Helping concepts

It is easier to solve using a velocity time graph.



Let Car 1 be faster than Car 2.

$$s = ut + \frac{1}{2}at^2$$

At any time t,

$$\begin{cases} s_1 = 0 + \frac{1}{2}a_1t^2 \\ s_2 = 0 + \frac{1}{2}a_2t^2 \end{cases}$$

For $t = 3$ s,

$$\text{distance } X = s_1 - s_2$$

$$12 = \left[\tfrac{1}{2}a_1(3)^2\right] - \left[\tfrac{1}{2}a_2(3)^2\right]$$

$$12 = \frac{9}{2}(a_1 - a_2) \text{-----} (1)$$

For $t = 6$ s,

$$\text{distance } Y = s_1 - s_2$$

$$Y = \left[\tfrac{1}{2}a_1(6)^2\right] - \left[\tfrac{1}{2}a_2(6)^2\right]$$

$$Y = 18(a_1 - a_2) \text{-----} (2)$$

Subst. (2) into (1):

$$12 = \frac{9}{2}\left(\frac{Y}{18}\right)$$

$$Y = 48 \text{ m}$$

TOPIC 3

Dynamics

Key content that you will be examined on:

1. Newtons's laws of motion
2. Linear momentum and its conservation

Topic 3 Dynamics

1. What is the meant by the weight of an object?

   A the gravitational field acting on the object
   B the gravitational force acting on the object
   C the mass of the object multiplied by gravity
   D the object's mass multiplied by its acceleration

Helping concepts

The weight of an object is equilibrium to the gravitational force acting on the object.

2. Which is **not** one of Newton's laws of motion?

   A The total momentum of a system of interacting bodies remains constant, providing no external force acts.
   B The rate of change of momentum of a body is directly proportional to the external force acting on the body and takes place in the direction of the force.
   C If body A exerts a force on body B, then body B exerts an equal and oppositely-directed force on body A.
   D A body continues in a state of rest or of uniform motion in a straight line unless acted upon by some external force.

Helping concepts

By Newton's laws, only (A) is incorrect.

3. When a force of 4 N acts on a mass of 2 kg for a time of 2 s, what is the rate of change of momentum?

   A 2 kg ms^{-2} B 4 kg ms^{-2}
   C 8 kg ms^{-2} D 16 kg ms^{-2}

Helping concepts

By Newton's 2nd law, we have

$$F = ma = m(\frac{v-u}{t})$$

$$\Rightarrow \text{Rate of change of momentum} = \frac{mv - mu}{t}$$
$$= F$$
$$= 4 \text{ N or } 4 \text{ kg ms}^{-2}$$

4. An object of mass m is travelling with velocity v.

   Which equation gives the momentum p of the object in terms of either m or v and its kinetic energy E_k?

   A $p = \frac{2E_k}{m}$ B $p = 2E_k v$

   C $p = \sqrt{\frac{2E_k}{v}}$ D $p = \sqrt{2E_k m}$

Helping concepts

Kinetic energy, $E_k = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

Rearranging,

$$p = \sqrt{2E_k m}$$

5. Newton's third law concerns the forces of interaction between two bodies.

   Which of the following statements relating to the third law is **not** correct?

   A The two forces must be of the same type.
   B The two forces must act on different bodies.
   C The two forces are always opposite in direction.
   D The two forces are equal and opposite so the bodies are in equilibrium.

Helping concepts

Newton's third law generally applies to two bodies which may be in motion. The bodies concerned thus need not be in equilibrium.

6. Two satellites in space collide inelastically.

What happens to the kinetic energy and momentum?

	kinetic energy	momentum
A	conserved	conserved
B	conserved	reduced
C	reduced	conserved
D	reduced	reduced

Helping concepts

Linear momentum is always conserved when no external force is applied during collision, and the kinetic energy is conserved only if the collision is elastic. Hence, for inelastic collision of two satellites, linear momentum is conserved but the total kinetic energy is reduced since some initial kinetic energy is lost in the forms of sound and heat energies.

7. A force $2F$ acting on a particle of mass 10 kg produces an acceleration of 60 ms^{-2}.

A force $5F$ acting on a particle of mass M produces an acceleration of 50 ms^{-2}.

What is the mass M?

A 3.3 kg　　B 4.8 kg

C 21 kg　　D 30 kg

Helping concepts

Using Newton's 2nd law, $F_{net} = ma$, we have

$$2F = (10)(60) \text{------}(1)$$
$$5F = (M)(50) \text{------}(2)$$

$$\frac{(2)}{(1)}: \frac{5}{2} = \frac{50M}{600} \Rightarrow M = 30 \text{ kg}$$

8. A cyclist is riding at a steady speed on a level road.

According to Newton's third law of motion, what is equal and opposite to the backward push of the back wheel on the road?

A the force exerted by the cyclist on the pedals

B the forward push of the road on the back wheel

C the tension in the cycle chain

D the total air resistance and friction force

Helping concepts

By definition of Newton's third law,

backward push of **back wheel on road**
= forward push of **road on back wheel**

9. The diagram shows the masses and velocities of two trolleys about to collide.

After the impact they move off together.

What is the total kinetic energy of the trolleys after the collision?

A 1.3 J　　B 12 J

C 18 J　　D 19 J

Helping concepts

Final momentum, p = sum of initial momentum
$= 2(4) + 4(1)$
$= 12$ J

10. The rate of change of momentum of a body falling freely under gravity is equal to its

A impulse.　　B kinetic energy.

C power.　　D weight.

Helping concepts

By Newton's 2nd law,

$$F = ma = m(\frac{v-u}{\Delta t}) = \frac{mv - mu}{\Delta t} = \frac{\Delta p}{\Delta t}$$

where Δp = change in momentum $= mv - mu$,

Δt = time period over which Δp occurs.

Hence, rate of change of momentum is equal to the force acting on the body by the gravity under free fall, which is its weight.

11. A constant mass undergoes uniform acceleration.

Which of the following is a correct statement about the resultant force acting on the mass?

A It increases uniformly with respect to time.

B It is constant but not zero.

C It is proportional to the displacement from a fixed point.

D It is proportional to the velocity.

Helping concepts

Statement A is incorrect as the resultant force acting on the mass is constant since the acceleration is constant (uniform).

Statement C is incorrect as it would imply that the resultant force changes with the displacement from the fixed point, as in the case of S.H.M.

Statement D is incorrect as it would imply that the resultant force changes with time.

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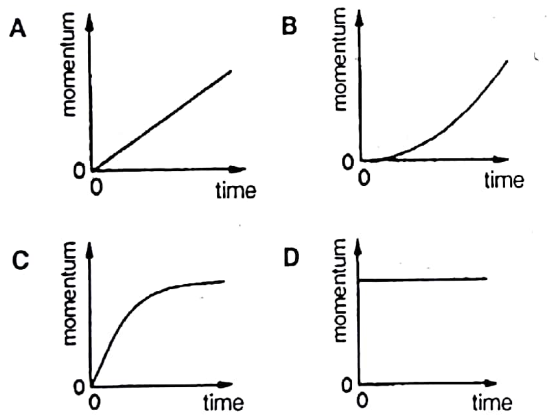
12. Which graph best shows the variation with time of the momentum of a body accelerated by a constant force?



Helping concepts

A body accelerated by a constant force has constant acceleration. Its velocity increases linearly with time. Hence, its momentum also increases linearly with time.

---

13. In perfectly elastic collisions between two atoms, it is always true to say that

A the initial speed of one atom will be the same as the final speed of the other atom.

B the relative speed of approach between the two atoms equals their relative speed of separation.

C the total momentum must be conserved, but a small amount of the total kinetic energy may be lost in the collision.

D whatever their initial states of motion, neither atom can be stationary after the collision.

Helping concepts

By definition, for an elastic collision, the relative speed of approach between two atoms equals their relative speed of separation. Also total kinetic energy of the two atoms is conserved.

---

14. Two similar spheres, each of mass m and travelling with speed v, are moving towards each other.

The spheres have a head-on elastic collision.

Which statement is correct?

A The spheres stick together on impact.

B The total kinetic energy after impact is mv^2.

C The total kinetic energy before impact is zero.

D The total momentum before impact is $2mv$.

Helping concepts

Kinetic energy is conserved for elastic collision.

$$\frac{1}{2}mv^2 + \frac{1}{2}mv^2 = mv^2$$

---

15. The diagram shows two trolleys, X and Y, about to collide and gives the momentum of each trolley before the collision.

After the collision, the directions of motion of both trolleys are reversed and the magnitude of the momentum of X is then 2 Ns.

What is the magnitude of the corresponding momentum of Y?

A 6 Ns B 8 Ns

C 10 Ns D 30 Ns

Helping concepts

Since linear momentum is conserved,

$$20 - 12 = -2 + \text{momentum of Y}$$

$$\text{momentum of Y} = 10 \text{ Ns}$$

Helping concepts

$$\text{Change in momentum} = \int F\,dt$$
$$= \text{area under the curve}$$
$$= (2)(2) + \tfrac{1}{2}(2+6)(4)$$
$$= 20 \text{ kg ms}^{-1}$$

16. Two railway trucks of masses m and $3m$ move towards each other in opposite directions with speeds $2v$ and v respectively. These trucks collide and stick together.

What is the speed of the trucks after the collision?

A $\frac{v}{4}$ B $\frac{v}{2}$

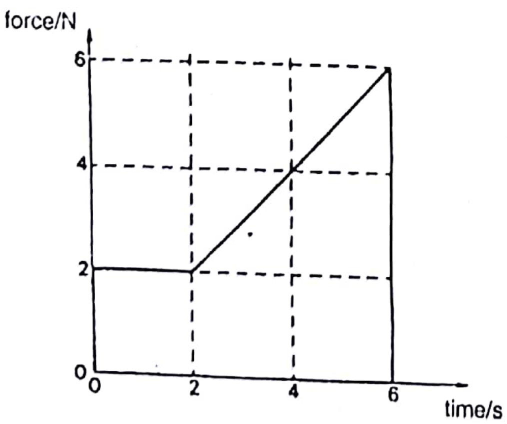
C v D $\frac{5v}{4}$

Helping concepts

This is a perfectly inelastic collision.

$$m(2v) + 3m(-v) = (m + 3m)v_1$$
$$-mv = 4mv_1$$
$$v_1 = -\frac{1}{4}v$$

17. The graph shows how the force acting on a body varies with time.

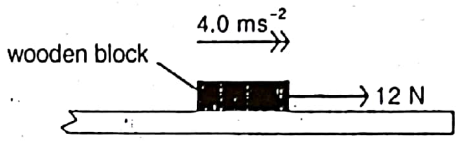


Assuming that the body is moving in a straight line, by how much does its momentum change?

A 40 kg ms^{-1} B 36 kg ms^{-1}

C 20 kg ms^{-1} D 16 kg ms^{-1}

18. A wooden block of mass 0.60 kg is on a rough horizontal surface. A force of 12 N is applied to the block and it accelerates at 4.0 ms^{-2}.



What is the magnitude of the frictional force acting on the block?

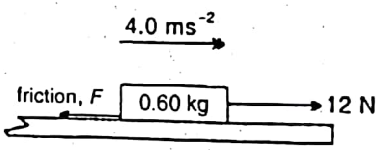
A 2.4 N B 9.6 N

C 14 N D 16 N

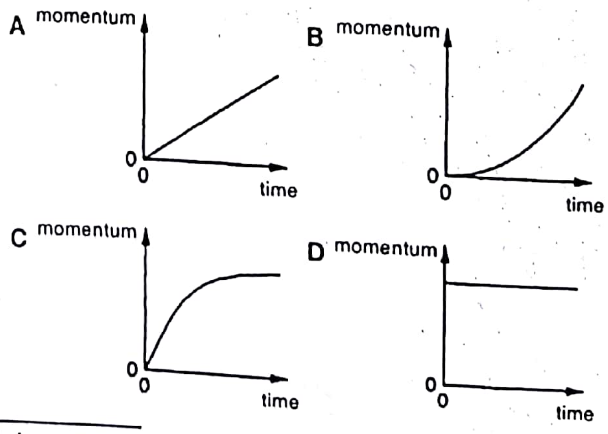
Helping concepts

Net force = ma

$$12 - F = (0.60)(4)$$
$$F = 9.6 \text{ N}$$



19. Which graph best shows the variation with time of the momentum of a body accelerated by a constant force?



Helping concepts

Net force is the rate of change of momentum, which is the gradient of momentum vs time graph.

Since net force is constant, gradient is also constant and not equal to zero.

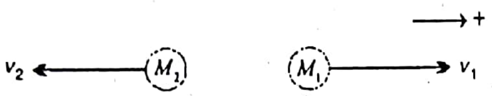
20. A body, initially at rest, explodes into two masses M_1 and M_2 that move apart with speeds v_1 and v_2 respectively.

What is the ratio $\frac{v_1}{v_2}$?

A $\frac{M_1}{M_2}$ B $\frac{M_2}{M_1}$

C $\left(\frac{M_1}{M_2}\right)^{\frac{1}{2}}$ D $\left(\frac{M_2}{M_1}\right)^{\frac{1}{2}}$

Helping concepts



By conservation of momentum,

$$0 = M_1v_1 + M_2(-v_2)$$
$$\frac{v_1}{v_2} = \frac{M_2}{M_1}$$

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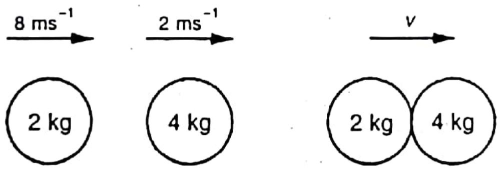
21. A ball of mass 2 kg travelling at 8 ms^{-1} strikes a ball of mass 4 kg travelling at 2 ms^{-1}. Both balls are moving along the same straight line as shown.



After collision, both balls move at the same velocity v.

What is the magnitude of the velocity v?

A 4 ms^{-1} B 5 ms^{-1}

C 6 ms^{-1} D 8 ms^{-1}

Helping concepts

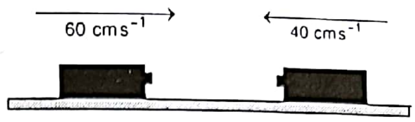
For inelastic collision, momentum is still conserved.

momentum before collision = momentum after collision

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$
$$(2)(8) + (4)(2) = (2 + 4)v$$
$$v = 4 \text{ ms}^{-1}$$

---

22. Two equal masses travel towards each other on a frictionless air track at speeds of 60 cm s^{-1} and 40 cm s^{-1}. They stick together on impact.



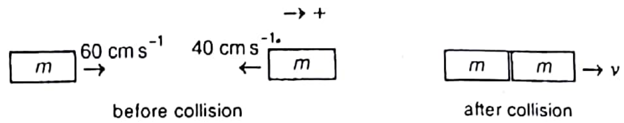
What is the speed of the masses after impact?

A 10 cm s^{-1} B 20 cm s^{-1}

C 40 cm s^{-1} D 50 cm s^{-1}

Helping concepts

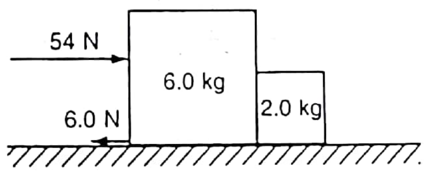
Let the mass be m.



$$m(60) + m(-40) = (m + m)v$$
$$20m = 2mv$$
$$v = 10 \text{ cm s}^{-1}$$

---

23. A force of 54 N pushes two touching blocks of mass 6.0 kg and 2.0 kg along a flat surface. The frictional force between the blocks and the surface is 6.0 N.



What is the magnitude of the resultant force on the 6.0 kg mass?

A 12 N B 36 N

C 45 N D 48 N

Helping concepts

Net force on (6.0 + 2.0) kg = 54 N − 6.0 N = 48 N

Net acceleration, $a = \frac{F}{m}$

$= \frac{48}{8}$

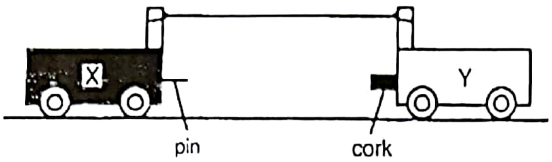
$= 6.0 \text{ ms}^{-2}$

Resultant force on 6.0 kg mass,

$$F = ma = (6)(6) = 36 \text{ N}$$

---

24. The diagram shows two trolleys X and Y held stationary and connected by an extended elastic cord. The mass of X is twice that of Y.



The trolleys are released at the same instant. They move towards each other and stick together on impact. Just before the collision, the speed of X is 20 cm s^{-1}.

What is the speed of Y after the collision?

A zero B 5 cm s^{-1}
C 7 cm s^{-1} D 10 cm s^{-1}

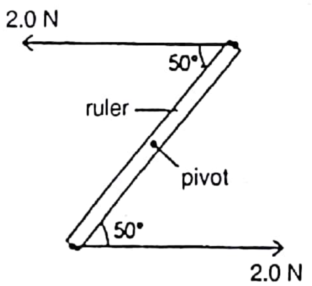
Helping concepts

By conservation of momentum,

initial momentum before release = momentum after collision

$$0 = (m_X + m_Y)v$$
$$v = 0$$

25.



A ruler of length 0.30 m is pivoted at its centre. Equal and opposite forces of magnitude 2.0 N are applied to the ends of the ruler, creating a couple as shown.

What is the magnitude of the torque of the couple on the ruler when it is in the position shown?

A 0.23 Nm B 0.39 Nm
C 0.46 Nm D 0.60 Nm

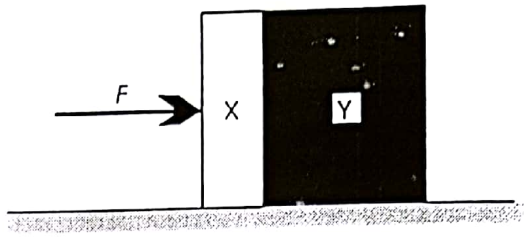
Helping concepts

Couple = foece × perpendicular distance between 2 equal forces

$= 2.0 \times (0.3 \sin 50°)$

$= 0.46$ Nm

26. Two blocks X and Y, of masses m and $3m$ respectively, are accelerated along a smooth horizontal surface by a force F applied to block X are shown.



What is the magnitude of the force exerted by block X on block Y during this acceleration?

A $\frac{F}{4}$ B $\frac{F}{3}$
C $\frac{F}{2}$ D $\frac{3F}{4}$

Helping concepts

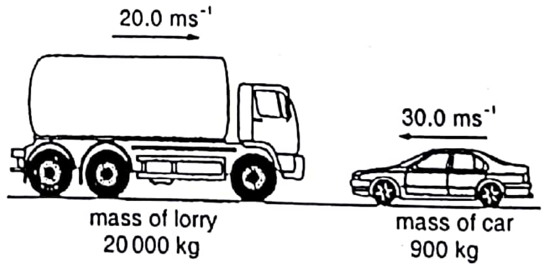
Using $F = ma$,

$$\text{acceleration, } a = \frac{F}{4m}$$

Considering block Y,

$$F_{XY} = 3m\left(\frac{F}{4m}\right) = \frac{3F}{4}$$

27. The diagram shows a situation just before a head-on collision. A lorry of mass 20000 kg is travelling at 20.0 ms^{-1} towards a car of mass 900 kg travelling at 30.0 ms^{-1} towards the lorry.



What is the magnitude of the total momentum?

A 373 kNs B 427 kNs
C 3600 kNs D 4410 kNs

Helping concepts

Momentum is a vector and is given by mass × velocity.

Momentum of lorry $= (2 \times 10^4)(20)$

$= 4 \times 10^5$ Ns

Momentum of car = (900)(30)

$= 2.7 \times 10^4$ Ns

Since they are in opposite direction,

net momentum $= (4 \times 10^5) - (2.7 \times 10^4)$

$= 3.73 \times 10^5$ Ns

---

28. A ball of mass 80 g collides with a vertical wall. The ball has a velocity of 23 ms^{-1} in a horizontal direction. After hitting the wall the ball moves with a velocity of 18 ms^{-1} in the opposite direction.

What is the impulse provided by the wall?

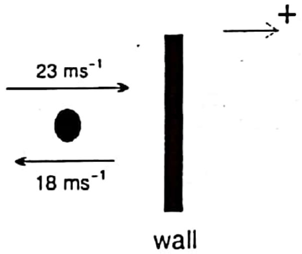
A 0.40 Ns in a direction away from the wall

B 3.3 Ns in a direction away from the wall

C 33 Ns in a direction towards the wall

D 3300 Ns in a direction towards the wall

Helping *concepts*



impulse of wall = –impulse of ball

$= -(mv - mu)$

$= m(u - v)$

$= (80 \times 10^{-3})(-18 - 23)$

$= -3.3$ Ns

= 3.3 Ns (to the left, away from the wall)

---

29. A neutron is in head-on elastic collision with a stationary nitrogen nucleus. The mass of a nitrogen nucleus is 14 times that of a neutron.

The neutron's velocity after the collision is

A less in magnitude than its initial velocity.

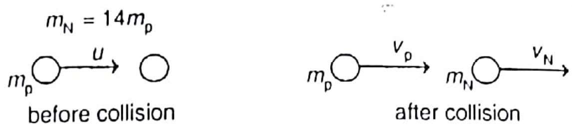
B less in magnitude than the final velocity of the nitrogen atom.

C equal in magnitude to its initial velocity but in the opposite direction.

D greater in magnitude than its initial velocity.

Helping *concepts*

Assume mass of a neutron is m_p and its initial velocity is u.



By conservation of momentum,

$$m_p u = m_p v_p + m_N v_N \Rightarrow u = v_p + 14 v_N \text{ -----(1)}$$

By conservation of energy,

$$\frac{1}{2} m_p u^2 = \frac{1}{2} m_p v_p^2 + \frac{1}{2} m_N v_N^2 \Rightarrow u^2 = v_p^2 + 14 v_N^2 \text{-----(2)}$$

Solving (1) & (2),

$$v_p = -\frac{13}{15} u$$

$$v_N = \frac{2}{15} u$$

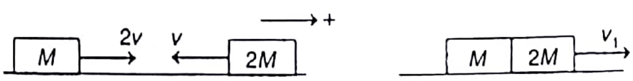
---

30. An object of mass M travelling to the right with velocity $2v$ collides with another object of mass $2M$ travelling to the left with velocity v. After the collision, the objects stick together.

Which line in the table shows the total momentum and the total kinetic energy of the two objects after the collision?

	momentum	kinetic energy
A	0	0
B	$4Mv$	0
C	0	$3Mv^2$
D	$4Mv$	$3Mv^2$

Helping *concepts*



Final momentum = initial total momentum

$= M(2v) + 2M(-v)$

$= 0$

$$\therefore \text{Kinetic energy} = \frac{(\text{momentum})^2}{2 \times \text{mass}} = 0$$

31. A stationary thoron nucleus ($A = 200$, $Z = 90$) emits an alpha particle with kinetic energy E_α. What is the kinetic energy of the recoiling nucleus?

A $\frac{E_\alpha}{108}$ B $\frac{E_\alpha}{110}$

C $\frac{E_\alpha}{54}$ D $\frac{E_\alpha}{55}$

Helping concepts

The α-particle emitting radioactive gas, Thoron-220, decays to Radium-216 and emits an α-particle, Helium-4 nucleus. The reaction can be represented by

$$^{220}_{90}Th \longrightarrow {}^{4}_{2}He + {}^{216}_{88}Ra$$

By conservation of momentum, we have

momentum of α-particle = momentum of recoiling nucleus Ra

$$m_\alpha v_\alpha = m_R v_R$$

$$\frac{v_R}{v_\alpha} = \frac{m_\alpha}{m_R}$$

$$= \frac{4}{216} = \frac{1}{54}$$

The kinetic energy of Ra, E_R is related to the kinetic energy of alpha particle E_α by the equation below.

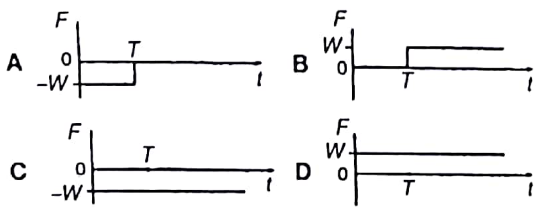
$$\frac{E_R}{E_\alpha} = \frac{\frac{1}{2}m_R v_R^2}{\frac{1}{2}m_\alpha v_\alpha^2} = \left(\frac{m_R}{m_\alpha}\right)\left(\frac{v_R}{v_\alpha}\right)^2 = \left(\frac{m_R}{m_\alpha}\right)\left(\frac{m_\alpha}{m_R}\right)^2 = \frac{m_\alpha}{m_R} = \frac{1}{54}$$

$$\therefore E_R = \frac{E_\alpha}{54}$$

---

32. A ball of weight W slides along a smooth horizontal surface until it falls off the edge at time T.

Which graph represents how the resultant vertical force F, acting on the ball, varies with time t as the ball moves from position **X** to position **Y**?



Helping concepts

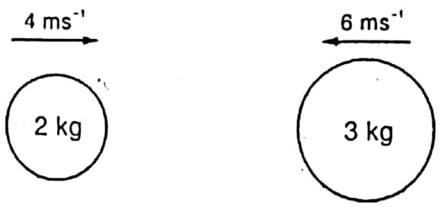
During the horizontal motion, the resultant vertical force, F, on the ball is zero.

As the ball falls,

F = weight of ball, W.

---

33. The diagram shows two spheres of masses 2 kg and 3 kg moving at constant speed along a straight line towards one another.



The speeds of the spheres are 4 ms^{-1} and 6 ms^{-1} respectively.

The spheres collide elastically.

Which statement explains why the spheres **cannot** come to rest at the same time?

A The impulses during the collision are not equal and opposite.

B The masses of the two spheres are not equal.

C The momenta of the spheres are not equal and opposite.

D The speeds of the spheres are not equal.

Helping concepts

Taking right-hand side to be positive,

By conservation of momentum, the total momenta before collision is

$$2(4) + 3(-6) = -10 \text{ kgms}^{-1}$$

This means that momenta of the system of 2 kg and 3 kg is always at 10 kgms^{-1} at all times.

The reason that both spheres cannot come to a rest at the same time is because the momenta of spheres are not equal and opposite.

---

34. A stationary ^{238}U nucleus decays by α emission generating a total kinetic energy T.

$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha$$

What is the kinetic energy of the α-particle?

A slightly less than $T/2$

B $T/2$

C slightly less than T

D slightly greater than T

Helping concepts

Let the kinetic energy of the α-particle be E_α and that of the thorium (Th) be E_{th}.

The ratio of kinetic energies is

$$\frac{E_\alpha}{E_{th}} = \frac{\frac{1}{2}m_\alpha v_\alpha^2}{\frac{1}{2}m_{th}v_{th}^2} = \left(\frac{m_\alpha}{m_{th}}\right)\left(\frac{v_\alpha}{v_{th}}\right)^2 \text{-----(1)}$$

By conservation of momentum, the momentum of the α-particle and that of the recoiling thorium (Th) must equal. Thus

$$m_\alpha v_\alpha = m_{th}v_{th} \text{ or } \frac{v_\alpha}{v_{th}} = \frac{m_{th}}{m_\alpha} \text{-----(2)}$$

Subst. (2) into (1), we have

$$\frac{E_\alpha}{E_{th}} = \left(\frac{m_\alpha}{m_{th}}\right)\left(\frac{m_{th}}{m_\alpha}\right)^2 = \frac{m_{th}}{m_\alpha} = \frac{234}{4} = 58.5$$

Hence, the kinetic energy of the α-particle, expressed as the fraction of the total kinetic energy T is given by

$$E_\alpha = \frac{58.5}{1+58.5}T = \frac{58.5}{59.5}T = 0.98T$$

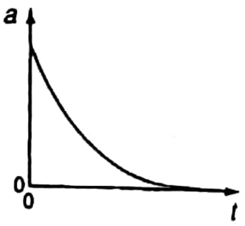
which is slightly less than T.

---

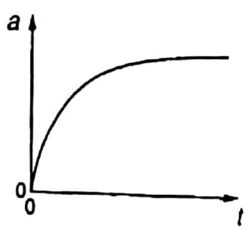
35. **A car is accelerated from rest by a constant force. It also experiences a drag force proportional to its speed.**

Which graph best represents the variation of the acceleration a of the car with time t?

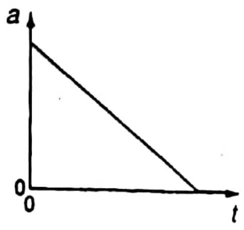
A



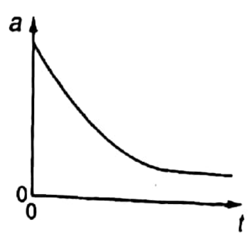
B



C



D



Helping concepts

Eventually, the car will come to a constant speed. This means that the final acceleration will be zero.

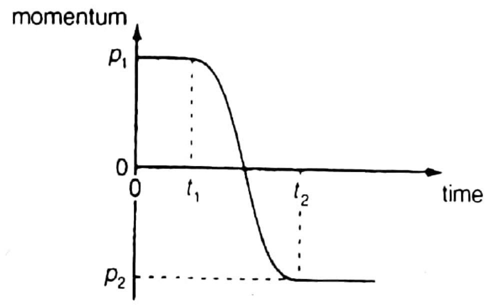
By Newton's second law,

$$F_{net} = F - kv$$
$$ma = F - kv$$

The force due to car F is constant and as speed v increases, the net force (F_{net}) and hence acceleration a will decrease exponentially.

---

36. The graph shows the variation with time of the momentum of a ball as it is kicked in a straight line.



Initially, the momentum is p_1 at time t_1. At time t_2 the momentum is p_2.

What is the magnitude of the average force acting on the ball between times t_1 and t_2?

A $\frac{p_1 - p_2}{t_2}$

B $\frac{p_1 - p_2}{t_2 - t_1}$

C $\frac{p_1 + p_2}{t_2}$

D $\frac{p_1 + p_2}{t_2 - t_1}$

Helping concepts

Average force of ball from graph

$$= \frac{\text{change in momentum}}{\text{time taken}}$$

$$= \frac{p_2 - p_1}{t_2 - t_1}$$

Average force acting on ball = −(average force of ball)

$$= -\left(\frac{p_2 - p_1}{t_2 - t_1}\right)$$

$$= \frac{p_1 - p_2}{t_2 - t_1}$$

---

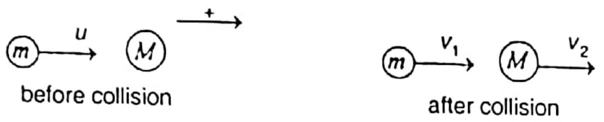
37. A particle of mass m travelling with velocity u collides elastically and head-on with a stationary particle of mass M.

Which expression gives the velocity of the particle of mass M after the collision?

A u B $\frac{mu}{M}$

C $\frac{2mu}{M+m}$ D $\frac{(M-m)u}{M+m}$

Helping concepts



Total linear momentum before collision
= total linear momentum after collision

$\Rightarrow mu = mv_1 + Mv_2$

$\Rightarrow v_2 = \frac{m}{M}(u - v_1)$-----(1)

For elastic collision,

speed of approach = speed of separation

$u - 0 = -(v_1 - v_2)$

$v_1 = v_2 - u$-----(2)

Subst. (2) into (1):

$v_2 = \frac{m}{M}[u - (v_2 - u)] = \frac{m}{M}(2u - v_2)$

$\Rightarrow v_2(M + m) = 2mu$

$\Rightarrow v_2 = \frac{2mu}{M+m}$

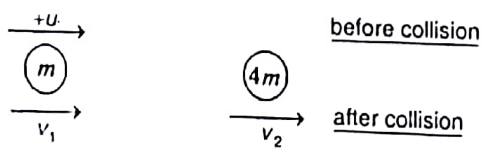
38. A molecule of mass m travels with velocity $+u$ directly towards a stationary molecule of mass $4m$ and collides elastically with it.

What is the velocity of the molecule of mass m after the collision?

A $+\frac{u}{5}$ B $-\frac{3}{5}u$

C $-\frac{4}{5}u$ D $-u$

Helping concepts



Taking rightwards to be positive and by conservation of momentum,

$mu = mv_1 + 4mv_2$

$u = v_1 + 4v_2$-----(1)

Speed of approach = speed of separation

$u_1 - u_2 = -(v_1 - v_2)$

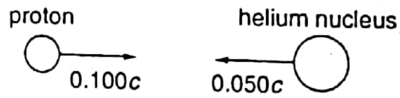
$u = -(v_1 - v_2)$

$u = v_2 - v_1$-----(2)

(1) − 4 × (2): $-3u = 5v_1$

$v_1 = -\frac{3}{5}u$

39. A proton (mass 1u) travelling with velocity +0.100c collides elastically head-on with a helium nucleus (mass 4u) travelling with velocity −0.050c.



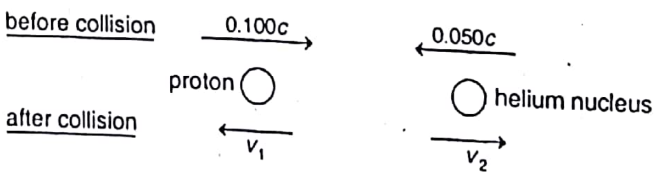
What are the velocities of each particle after the collision?

	proton	helium nucleus
A	−0.140c	+0.010c
B	+0.140c	+0.010c
C	+0.233c	−0.083c
D	−0.233c	+0.083c

Helping concepts

In elastic collision,

relative speed of approach = relative speed of separation



Taking right-wards to be positive,

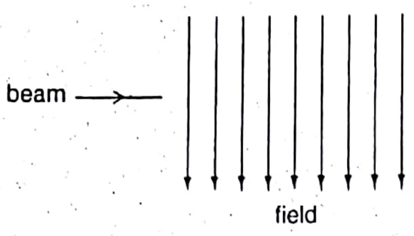
$u_1 - u_2 = -(v_1 - v_2)$

$0.100c - (-0.05c) = v_2 - v_1$

$0.15c = v_2 - v_1$

From the options available, only (A) is correct.

40. A beam of particles or radiation is directed horizontally into vertical gravitational, electric and magnetic fields in turn.



The table shows features of the force on the beam and the shape of the beam in each case.

	gravitational field	electric field	magnetic field
force	negligible	upwards	out of the page
shape of beam	a horizontal line	a curve	a circle

Which particles or radiation are used in the beam?

A alpha particles B beta particles
C gamma rays D protons

Helping concepts

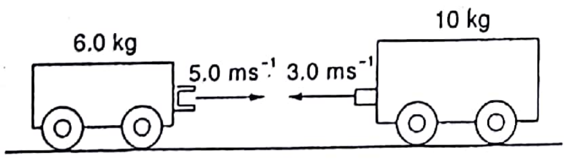
Negligible force due to gravitational field means the particles is light or not heavy.

The upwards force (opposite to the direction of electric field) means the particles are negatively charged.

Using Fleming's left hand rule, it is confirmed that the particles are negatively charged.

---

41. A trolley of mass 6.0 kg travelling at a speed of 5.0 ms^{-1} collides head-on and locks together with another trolley of mass 10 kg which is travelling in the opposite direction at a speed of 3.0 ms^{-1}. The collision lasts for 0.20 s.



What is the total momentum of the two trolleys before the collision and the average force acting on each trolley during this collision?

	total momentum before collision / kg ms^{-1}	average force on each trolley / N
A	0	300
B	60	150
C	0	150
D	60	300

Helping concepts

Taking right-wards to be positive,

total momentum of the 2 trolleys before collision $(\rightarrow +)$

$= 6.0 \times (5.0) + 10 \times (-3.0)$

$= 0 \text{ kg ms}^{-1}$

Final momentum of 2 trolleys after momentum is also 0 kgms^{-1} by conservation of momentum. This means that both the 6.0 kg and 10 kg come to a rest after collision.

By Newton's second law,

$$\text{average force on 6.0 kg mass} = \frac{\Delta(mv)}{\Delta t} = \frac{0 - 6.0(5.0)}{0.20} = -150 \text{ N}$$

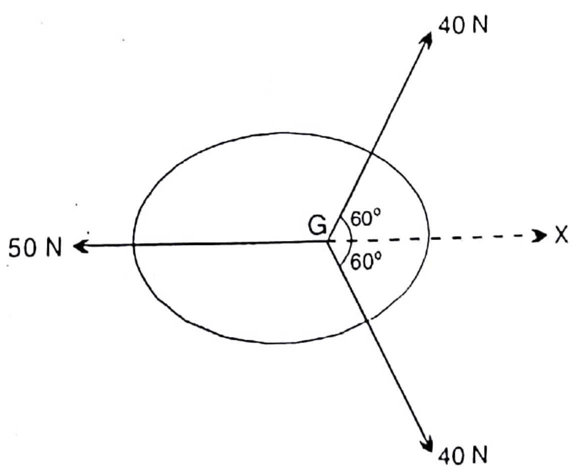
The negative sign means the average force is acting towards the left (in order to stop the trolley).

By Newton's third law,

force on 6.0 kg mass by 10.0 kg mass
= force on 10.0 kg mass by 6.0 kg mass
= 150 N

---

42. The diagram shows three forces acting on the centre of gravity G of a body which was initially at rest.



Later, a 10 N force is applied to G in the direction GX.

What is the final motion of the body?

A It accelerates in the direction GX.
B It accelerates in the direction XG.

Topic 3 Dynamics

C It moves at constant speed in the direction GX.

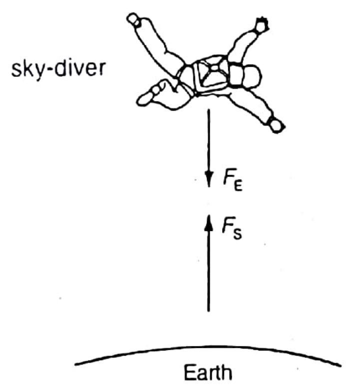
D It moves at constant speed in the direction XG.

Helping concepts

By Newton's second law, the body will accelerate in the same direction as the net force of 10 N, i.e. GX.

---

43. A sky-diver jumps from an aircraft. The Earth exerts a downward force F_E on the sky-diver who also exerts an upward force F_S on the Earth.



(diagram not to scale)

Which statement is correct?

A the magnitude of F_E > the magnitude of F_S

B the magnitude of F_E < the magnitude of F_S

C the magnitude of F_E = the magnitude of F_S and they cancel each other out

D the magnitude of F_E = the magnitude of F_S and they do not cancel each other out

Helping concepts

By Newton's third law, F_E equals to F_S in magnitude and are opposite in direction. F_E and F_S also act on different bodies. Hence, they do not cancel each other.

TOPIC 4

Forces

Key content that you will be examined on:

1. Types of force
2. Equilibrium of forces
3. Centre of gravity
4. Turning effects of forces

Topic 4 Forces

1. What is the centre of gravity of an object?

   A the geometrical centre of the object
   B the point about which the total torque is zero
   C the point at which the weight of the object may be considered to act
   D the point through which gravity acts

Helping *concepts*

Fact. It is also a convenient point to represent the weight of an object.

---

2. What is **not** true of two forces that give rise to a couple?

   A They act in opposite directions.
   B They both act at the same point.
   C They both act on the same body.
   D They both have the same magnitude.

Helping *concepts*

Magnitude of couple = force × distance between them

For 2 forces acting on the same point, there is zero distance between them.

---

3. A submarine descends vertically at constant velocity. The three forces acting on the submarine are viscous drag, upthrust and weight.

   Which relationship between their magnitudes is correct?

   A weight < drag   B weight = drag
   C weight < upthrust   D weight > upthrust

Helping *concepts*

At constant velocity, there is no net force.

weight = upthrust + drag

⇒ weight > upthrust

---

4. An object in a space capsule orbiting the Earth seems to be floating.

   Which statement describes the forces acting on the object?

   A There are no forces on the object.
   B The centrifugal force on the object is equal and opposite to its weight.
   C The centripetal force on the object is equal and opposite to its weight.
   D The weight of the object is the only force acting on it.

Helping *concepts*

In orbit, or circular motion, around the Earth. There is a net force acting on the object.

In this case, it is the weight or the gravitational force on object by Earth which results in the circular motion.

---

5. An object, immersed in a liquid in a tank, experiences an upthrust.

   What is the physical reason for this upthrust?

   A The density of the body differs from that of the liquid.
   B The density of the liquid increases with depth.
   C The pressure in the liquid increases with depth.
   D The value of g in the liquid increases with depth.

Helping *concepts*

Pressure within a liquid is given by

$$p = h\rho g$$

where h is the depth.

---

6. An object, immersed in a liquid in a tank, experiences an upthrust.

   What is the physical reason for this upthrust?

A The density of the body differs from that of the liquid.

B The density of the liquid increases with depth.

C The pressure in the liquid increases with depth.

D The value of g in the liquid increases with depth.

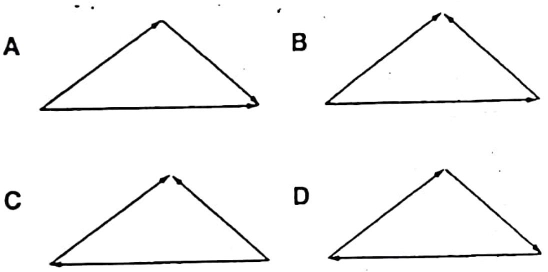
Helping concepts

Since the pressure in the liquid increases with depth, the upward force exerted on the bottom of a body immersed in liquid would be greater than the downward force exerted on the top of the body, giving rise to a net upward force, the upthrust.

---

7. The diagrams show three forces acting on a body.

In which diagram is the body in equilibrium?



Helping concepts Angles

In equilibrium, the vector forces must

1. form a **closed** triangle, i.e. by following the direction of arrows, it can go back to its starting point.
2. all vector forces passed through the same point.

---

8. In describing the behaviour of a spring, the spring constant is used.

Different loads are used to extend the spring by different amounts.

To find the spring constant, which quantities are required?

A the elastic limit and the loads

B the elastic limit, extensions and the length of the spring

C the loads and the extensions of the spring

D the loads and the length of the spring

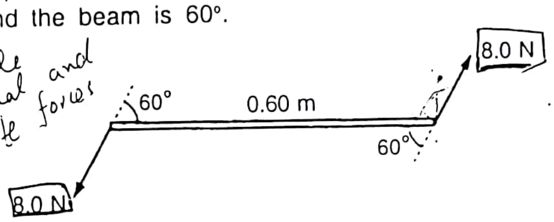
Helping concepts

$$\text{Spring constant, } k = \frac{\text{force, } F}{\text{extension, } x}$$

From the above formula, to find k, F and x have to be known.

---

9. Two 8.0 N forces act at each end of a beam of length 0.60 m. The forces are parallel and act in opposite directions. The angle between the forces and the beam is 60°.



What is the torque of the couple exerted on the beam?

A 2.4 Nm **B** 4.2 Nm

C 4.8 Nm **D** 9.6 Nm

Helping concepts

Couple = force × perpendicular distance

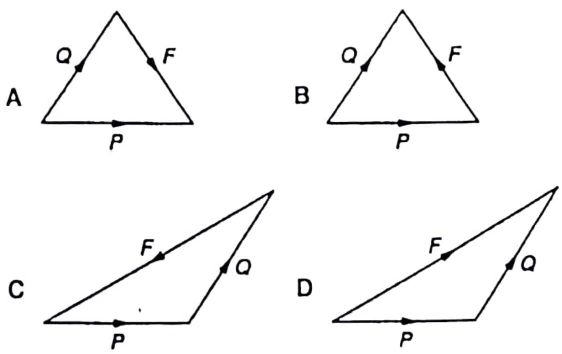
$= (8.0)(0.60 \sin 60°)$

$= 4.2$ Nm

Two equal forces in opposite direction cause couple. (It is torque) From S.L Note Book

10. An object is acted on by two forces P and Q. A frictional force F holds the object in equilibrium.

Which vector triangle could represent the relationship between these forces?

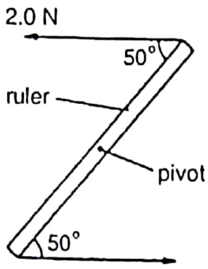


Helping concepts

At equilibrium, the arrows in a vector triangle flow in one direction, clockwise or anti-clockwise.

---

11. A ruler of length 0.30 m is pivoted at its centre. Equal and opposite forces of magnitude 2.0 N are applied to the ends of the ruler, creating a couple as shown.



What is the magnitude of the torque of the couple on the ruler when it is in the position shown?

A 0.46 Nm B 0.64 Nm

C 0.72 Nm D 0.79 Nm

Helping concepts

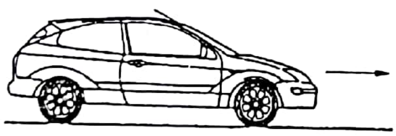
The torque produced by a couple

= force × perpendicular distance between forces

$= 2.0 \times 0.30 \sin 50°$

= 0.46 Nm

12. A car with front-wheel drive accelerates in the direction shown.

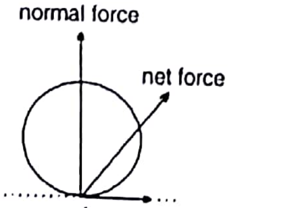


Which diagram best shows the direction of the total force exerted by the road on the front wheels?

A  B 

C  D 

Helping concepts



13. A cylindrical block of wood has a cross-sectional area A and weight W. It is totally immersed in water with its axis vertical.

The block experiences pressures p_t and p_b at its top and bottom surfaces respectively.

Which of the following expressions is equal to the upthrust on the block?

A $(p_b - p_t)A + W$ B $(p_b - p_t)$

C $(p_b - p_t)A$ D $(p_b - p_t)A - W$

Helping concepts

Upthrust is a force, and acts upwards.

$$\text{Pressure, } p = \frac{F}{A} \Rightarrow \text{force, } F = p \times A$$

$\therefore$ Upthrust $= (p_b - p_t)A$

In couple, the pivot will be at centre while in when different forces act than it may not be at centre or may be. In these diagram will clarify (e.g. in Q 16)

14. A surface is bombarded by particles, each of mass m, which have velocity v normal to the surface. On average, n particles strike unit area of the surface each second and rebound elastically.

What is the pressure on the surface?

A nmv B $2nmv$

C $\frac{1}{3}nmv^2$ D $\frac{1}{2}nmv^2$

Helping concepts

Momentum of a particle due to v is mv. After impact, the momentum is $-mv$.

$\therefore$ Change in momentum of a particle on impact

$= mv - (-mv) = 2mv$

Force per unit area

= (momentum change per second per unit area)

= (number of particles strike the surface per second per unit area)(2mv)

= 2nmv

Hence, pressure on the surface = 2nmv.

15. A child drinks a liquid of density ρ through a vertical straw.

Atmospheric pressure is p_0 and the child is capable of lowering the pressure at the top of the straw by 10%. The acceleration of free fall is g.

What is the maximum length of straw that would enable the child to drink the liquid?

A $\frac{p_0}{10\rho g}$ B $\frac{9p_0}{10\rho g}$

C $\frac{p_0}{\rho g}$ D $\frac{10p_0}{\rho g}$

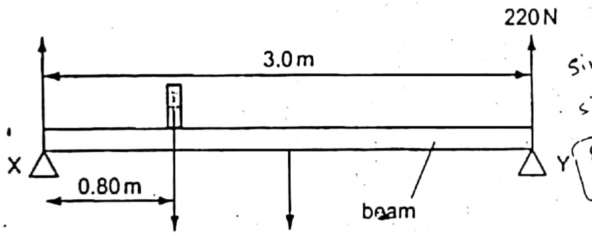
Helping concepts

Difference in pressure = $h\rho f$

where h is the maximum length of the straw.

$\therefore (0.1)p_0 = h\rho g \Rightarrow h = \frac{p_0}{10\rho g}$

16. A uniform beam in a roof structure has a weight of 180 N. It is supported in two places X and Y, a distance 3.0 m apart. A load is placed on the beam a distance of 0.80 m from X. The support provided by Y is 220 N.



What is the value of the load?

A 270 N B 490 N

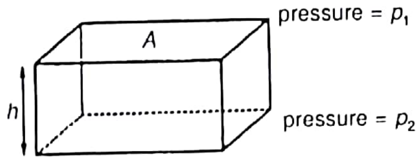
C 520 N D 830 N

Helping concepts

Taking moments about point X and let L be the weight of load.

$$L(0.80) + 180 \times 1.5 = 220 \times 3$$
$$L = 488 \text{ N}$$
$$\approx 490 \text{ N}$$

17. A solid block of material of density ρ, height h and horizontal surface area A is immersed in a liquid. The pressures of the liquid at the liquid at the upper and lower surfaces are p_1 and p_2 respectively.



Which of the following is an expression for the upthrust on the block?

A $Ah\rho g$ B $Ah\rho g + p_1A$

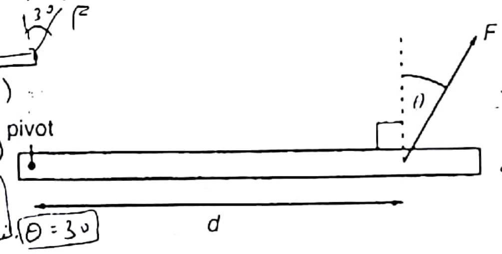
C p_2A D $p_2A - p_1A$

Helping concepts

Upthrust (U) is a force.

U = pressure difference × area
$= (p_2 - p_1) \times A$

18. A force F is applied to a beam at a distance d from a povot. The force acts at an angle θ to a line perpendicular to the beam.



Which combination will cause the largest turning effect about the pivot?

	F	d	θ
A	large	large	large
B	large	large	small
C	small	small	large
D	small	large	small

Helping concepts

Turning effect of F is $F\cos\theta(d)$.

For moment to be large, F and d must be large. In order for $\cos\theta$ to be large, θ must be small.

19. The hydrostatic pressure p at a depth h in a liquid of density ρ is given by the formula $p = h\rho g$.

Which equation, or principle of physics, is used in the derivation of this formula?

A density = mass ÷ volume

B potential energy = mgh

C atmospheric pressure decreases with height

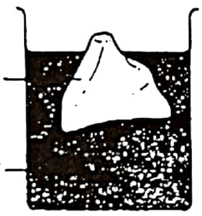
D density increases with depth

Helping concepts

By definition,

$$\text{pressure} = \frac{\text{force}}{\text{area}} = \frac{\text{weight}}{\text{area}} = \frac{mg}{A} \text{ (density = mass ÷ volume used)} = \frac{\rho Vg}{A} = \frac{\rho Ahg}{A} = \rho hg$$

20. A lump of ice floats in water as shown.



Which statement is correct?

A The lump of ice floats because the area of its lower surface is larger than the area of its upper surface.

B The pressure difference between the lower and the upper surfaces of the lump of ice give rise to an upthrust equal to its weight.

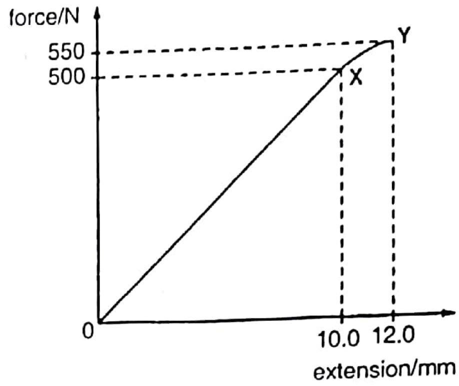
C The ice has a greater density than the water.

D The mass of water displaced by the ice is equal to the upthrust.

Helping concepts

The upthrust acting on a floating object is the pressure difference between the lower and upper surface.

21. The graph shows the behaviour of a sample of a metal when it is stretched until it starts to undergo plastic deformation.



What is the total work done in stretching the sample from zero extension to 12.0 mm?

Simplify the calculation by treating the region XY as a straight line.

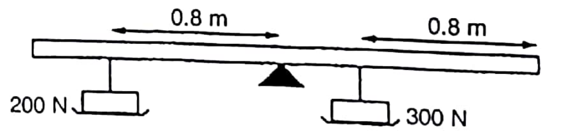
A 3.30 J B 3.55 J

C 3.60 J D 6.60 J

Helping concepts

$$\text{Work done} = \frac{1}{2}F \cdot x$$
$$= \text{area under the graph}$$
$$= \frac{1}{2}(500)(10 \times 10^{-3}) + \frac{1}{2}(500 + 550)(2 \times 10^{-3})$$
$$= 3.55 \text{ J}$$

22. A rigid uniform bar of length 2.4 m is pivoted horizontally at its mid-point.



Weights are hung from two points of the bar as shown in the diagram. To maintain horizontal equilibrium, a couple is applied to the bar.

What is the torque and direction of this couple?

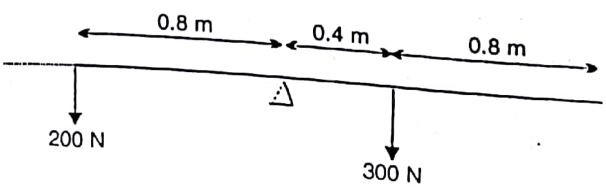
A 40 Nm clockwise

B 40 Nm anticlockwise

C 80 Nm clockwise

D 80 Nm anticlockwise

Helping concepts



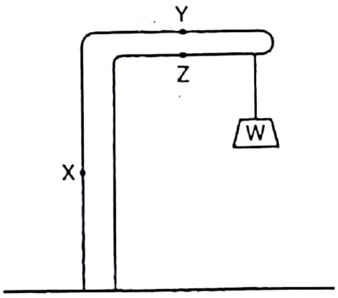
clockwise moment = 300 × 0.4 = 120 Nm

anticlockwise moment = 200 × 0.8 = 160 Nm

Hence, an additional 40 Nm of clockwise moment will balance the bar.

---

23. A simple crane consists of a rigid vertical pillar supporting a horizontal beam.



A weight W is lifted by a rope at the end of the beam.

What are the forces at points X, Y and Z due to the weight W?

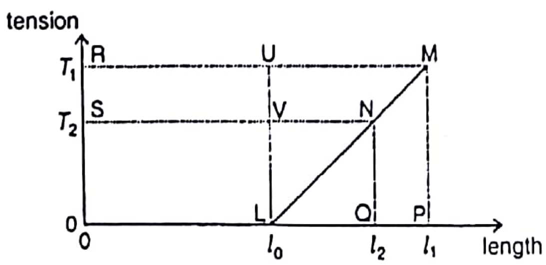
	force at X	force at Y	force at Z
A	tension	compression	tension
B	tension	tension	compression
C	compression	tension	compression
D	compression	compression	compression

Helping concepts

As the weight of beam is downwards, X and Y will be stretched (tension arises) while Z will be compressed (compression).

---

24. The tension in a spring of natural length l_0 is first increased from zero to T_1, causing the length to increase to l_1. The tension is then reduced to T_2, causing the length to decrease to l_2 (as shown).



Which area of the graph represents the work done by the spring during this reduction in length?

A MLP B MNQP

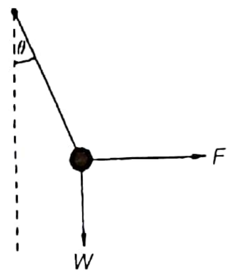
C MNSR D MPLU

Helping concepts

As length is contracted from l_2 to l_1, work done by the spring is the area under MN, i.e. MNQP.

---

25. A small ball of weight W is suspended by a light thread. When a strong wind blows horizontally exerting a constant force F on the ball, the thread makes an angle θ to the vertical as shown in the diagram.

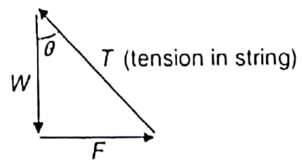


Which of the following equations correctly relates θ, F and W?

A $\cos\theta = F/W$ B $\cos\theta = W/F$

C $\sin\theta = F/W$ D $\tan\theta = F/W$

Helping concepts



From the diagram, we have $\tan\theta = F/W$.

---

26. A diver watches an air bubble as it rises to the surface in water. The weight of the air in the bubble is negligible. The volume and speed of ascent of the bubble increase as it rises. Two forces, up-thrust and viscous drag, act on the bubble.

Which changes occur in these forces as the bubble rises?

	upthrust	viscous drag
A	decreases	decreases
B	increases	no change
C	increases	increases
D	no change	decreases

Helping concepts

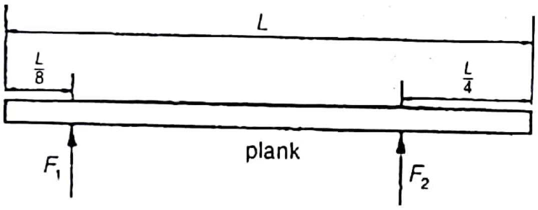
As the bubble rises, its volume will expand at constant temperature as the pressure decreases, i.e. pV = constant.

As the volume of the bubble increases, the upthrust will increase as weight of fluid displaced increases.

As upthrust increases, the speed of bubble will increase. This will also increase the drag force.

---

27. A heavy uniform plank of length L is supported by two forces F_1 and F_2 at points distant $\frac{L}{8}$ and $\frac{L}{4}$ from its ends as shown.



What is the value of $\frac{F_1}{F_2}$?

A $\frac{2}{5}$ B $\frac{3}{5}$

C $\frac{2}{3}$ D $\frac{3}{2}$

Helping concepts

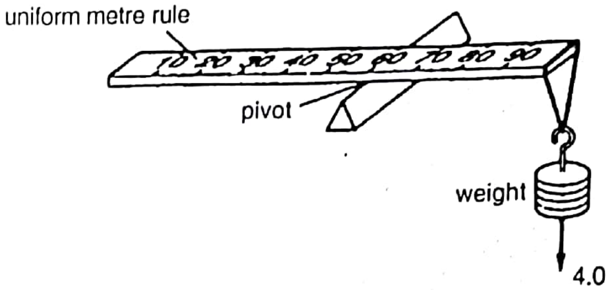
Taking moments about the centre of gravity of the plank,

$$F_1\left(\frac{3L}{8}\right) = F_2\left(\frac{L}{4}\right)$$

$$\frac{F_1}{F_2} = \frac{2}{3}$$

---

28. A uniform metre rule of weight 2.0 N is pivoted at the 60 cm mark. A 4.0 N weight is suspended from one end, causing the rule to rotate about the pivot.

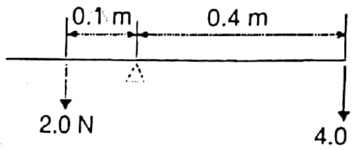


At the instant when the rule is horizontal, what is the value of the resultant turning moment about the pivot?

A zero B 1.4 Nm

C 1.6 Nm D 1.8 Nm

Helping concepts

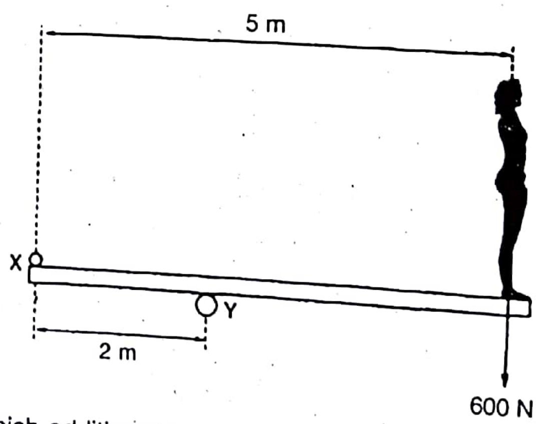


From the diagram, turning moment in clockwise direction about the pivot is

$$(0.4)(4) - (0.1)(2.0) = 1.4 \text{ Nm}$$

---

29. The diagram shows a diving-board held in position by two rods X and Y.



Which additional forces do these rods exert on the board when a diver of weight 600 N stands on the right-hand end?

	at X (downwards)	at Y (upwards)
A	400 N	1000 N
B	600 N	1200 N
C	900 N	600 N
D	900 N	1500 N

Helping concepts

Taking moment about X,

$$2Y = 5(600)$$
$$Y = 1500 \text{ N (upwards)}$$

At equilibrium,

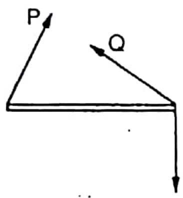
$$X + 600 = 1500$$
$$X = 900 \text{ N (downwards)}$$

---

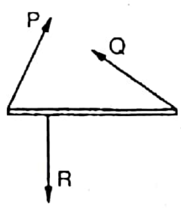
30. A light rod is acted upon by three forces P, Q and R.

Which diagram could show the position and direction of each of the forces when the rod is in equilibrium?

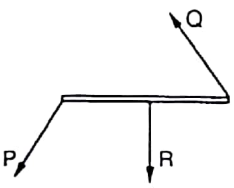
A



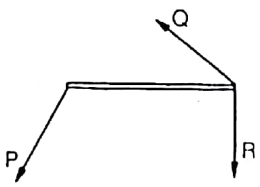
B



C



D



Helping concepts

The rod is in equilibrium when the three forces are directed such that they do not produce a net torque and the resultant force is zero.

---

31. A small air bubble in some water is rising to the surface with constant velocity.

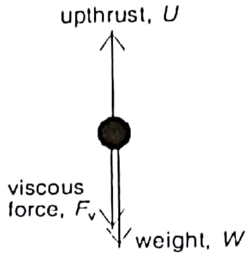
The volume of the bubble is 2.370×10^{-8} m³.
The density of water is 1000 kg m⁻³.
The density of air is 1.290 kg m⁻³.

What is the magnitude of the viscous force on the bubble?

A 2.367×10^{-5} N **B** 2.373×10^{-5} N

C 2.322×10^{-4} N **D** 2.328×10^{-4} N

Helping concepts



By Newton's second law, there is no net force due to constant velocity, i.e. total upward forces equal to total downward forces.

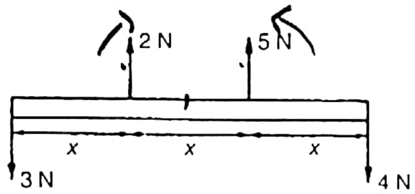
$$U = F_v + W$$
$$F_v = U - W$$
$$= \rho_{water} V_1 g - \rho_{air} V_0 g$$
$$= V_1 g(\rho_{water} - \rho_{air}) \quad (\because V_1 = V_0)$$
$$= (2.37 \times 10^{-8})(9.81)(1000 - 1.29)$$
$$= 2.322 \times 10^{-4} \text{ N}$$

---

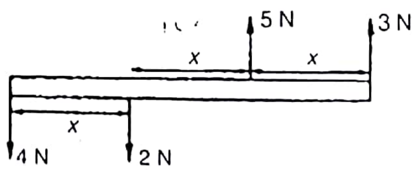
32. The force diagrams show all the forces acting on a beam of length 3x.

Which force system causes only rotational motion of the beam without any linear movement?

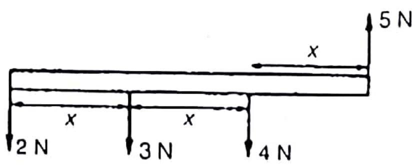
A



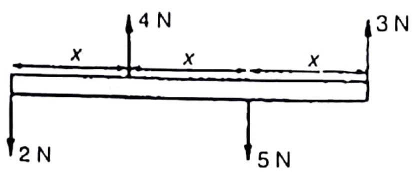
B



C



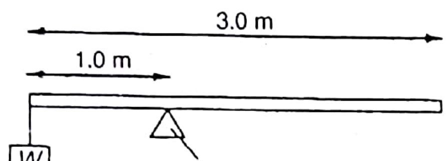
D



Helping concepts

Equal and opposite forces act on a beam to produce no linear movement. Force diagram A shows no rotational motion whereas force diagram D shows a net rotational moment of $3x$.

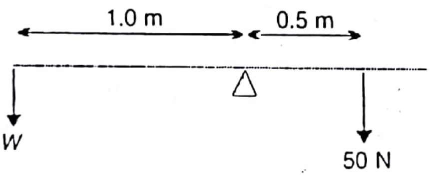
33. A uniform beam of weight 50 N is 3.0 m long and is supported on a pivot situated 1.0 m from one end. When a load of weight W is hung from the end, the beam is in equilibrium, as shown in the diagram.



What is the value of W?

A 25 N
B 50 N
C 75 N
D 100 N

Helping concepts

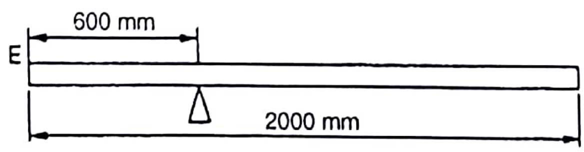


Taking moments about pivot,

$$W \times 1.0 = 50 \times 0.5$$
$$W = 25 \text{ N}$$

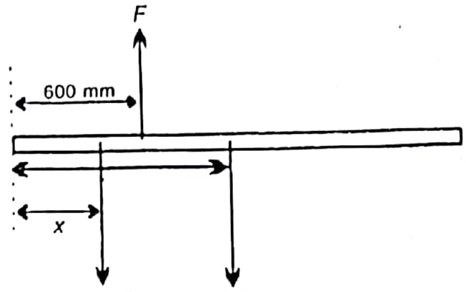
34. A uniform plank of weight 60 N is 2000 mm long and rests on a support that is 600 mm from end E.

At what distance from E must a 160 N weight be placed in order to balance the plank?



A 150 mm
B 225 mm
C 375 mm
D 450 mm

Helping concepts



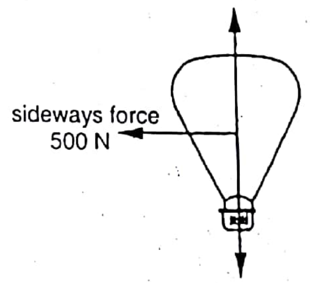
The 160 N weight should be placed to the left of the fulcrum in order to balance the plank. Let x be the distance from E that the 160 N should be placed.

For the plank to be balanced,

total clockwise moments = total anticlockwise moments

$$60(1000-600) = 160(600-x)$$
$$x = 450 \text{ mm}$$

35. A balloon is acted upon by three forces, weight, upthrust and sideways force due to the wind, as shown in the diagram.



What is the vertical component of the resultant force on the balloon?

A 500 N
B 1000 N
C 10000 N
D 10500 N

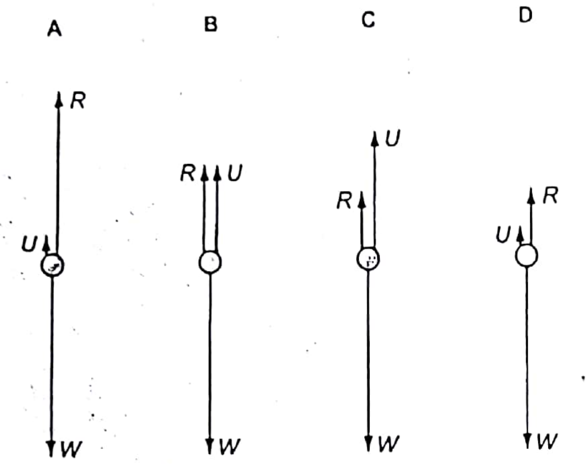
Helping concepts

Sideways force of 500 N can be ignored here as it does not contribute to vertical component of resultant force.

Net force in the upwards direction $= 10000 - 9000$
$= 1000$ N

36. A water droplet in a cloud is falling through air and is in equilibrium. Three forces act on it, its weight W, upthrust U and air resistance R.

Which diagram, showing these three forces to scale, is correct?



Helping concepts

In equilibrium,

total upwards forces = total downwards forces

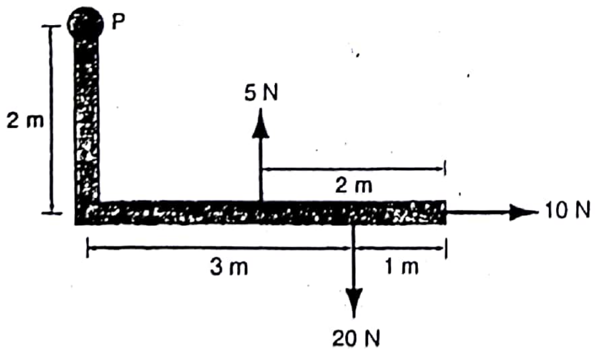
$\Rightarrow$ total length of upwards arrows
= total length of downwards arrows

Upthrust of water droplet will be small due to the low density of air ($U = \rho_{air} V_{droplet} g$).

Hence, the arrow of U will be <u>short</u>.

---

37. An L-shaped rigid lever arm is pivoted at point P.



Three forces act on the lever arm, as shown in the diagram.

What is the magnitude of the resultant moment of these forces about point P?

A 30 Nm B 35 Nm
C 50 Nm D 90 Nm

Helping concepts

About P,

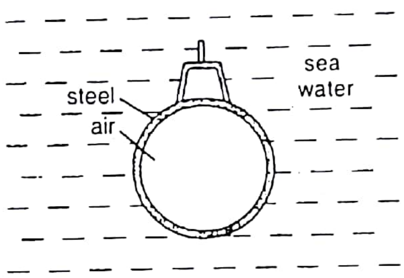
anticlockwise moment = (5 N × 2 m) + (10 N × 2 m)
= 30 Nm

clockwise moment = 20 N × 3 m
= 60 Nm

resultant moment = 60 Nm − 30 Nm
= 30 Nm

---

38. A submarine is in equilibrium in a fully submerged position.



What causes the upthrust on the submarine?

A The air exerts a greater upward force on the submarine than the weight of the steel.

B The air in the submarine is less dense than sea water.

C There is a difference in water pressure acting on the top and bottom of the submarine.

D The submarine displaces its own volume of sea water.

Helping concepts

The pressure in a liquid is given by

$$p = h\rho g$$

where h is the depth.

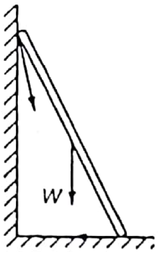
The deeper it is, the higher the pressure.

---

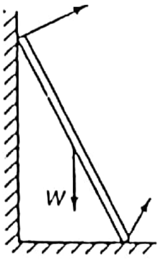
39. A ladder of weight W rests against a vertical wall. Friction between the ladder and the ground and also between the ladder and the wall prevents the ladder from slipping.

Which diagram shows the directions of the forces on the ladder?

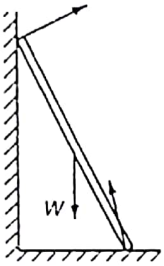
A



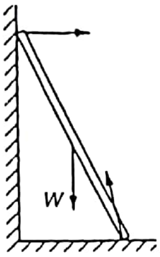
B



C



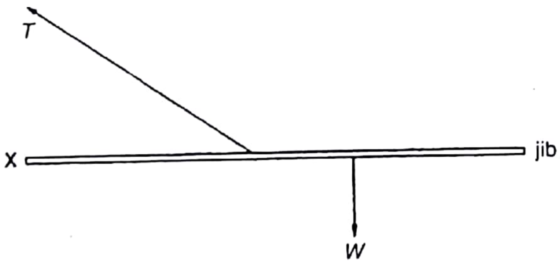
D



Helping concepts

As there is friction between the wall and the ladder, the force on the top of ladder will be at an angle upwards from the horizontal (   ) instead of a horizontal normal force (⟶) [seen in diagram D].

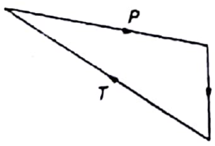
40. The diagram shows the jib of a tower crane. Only three forces act on the jib: the tension T provided by a supporting cable; the weight W of the jib; and a force P (not shown) acting at point X.



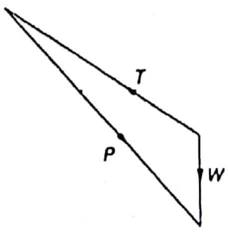
The jib is in equilibrium.

Which triangle of forces is correct?

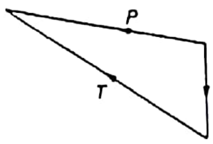
A



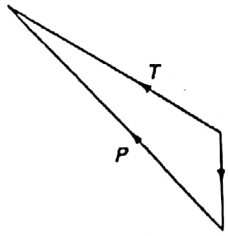
B



C



D

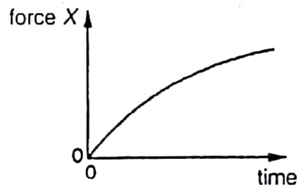


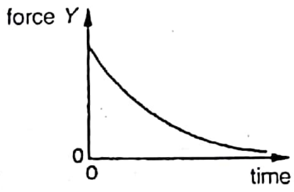
Helping concepts

The forces on an object in equilibrium from a closed triangle. The directions of the vectors should be such that you can trace out a complete triangle by following the arrows, as in the case for diagram A.

41. A ball falls from rest through air and eventually reaches a constant velocity.

For this fall, forces X and Y vary with time as shown.





What are forces X and Y?

	force X	force Y
A	air resistance	resultant force
B	air resistance	weight
C	upthrust	resultant force
D	upthrust	weight

Helping concepts

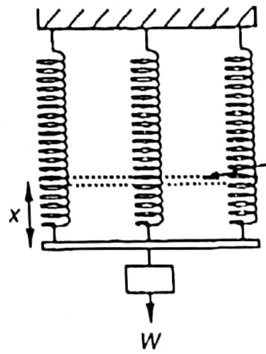
Air resistance is present, and will increase as the ball becomes faster.

Force equation on ball:

$$\text{net force} = \text{weight} - \text{air resistance}$$

As air resistance increases, net force will decrease.

42. A beam, the weight of which may be neglected, is supported by three identical springs. When a weight W is hung from the middle of the beam, the extension of each spring is x.



The middle spring and the weight are removed.

What is the extension when a weight of $2W$ is hung from the middle of the beam?

A $\frac{3x}{2}$ B $\frac{4x}{3}$

C $2x$ D $3x$

Helping concepts

Each spring share the weight equally and so, each of them will bear $\frac{W}{3}$ N.

By Hooke's law,

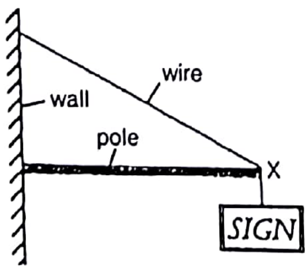
$$k = \frac{F}{x} = \frac{W}{3x} \text{ where } k \text{ is the spring constant.}$$

2 springs share $2W$ of weight and so, 1 spring bears W N.

By Hooke's law,

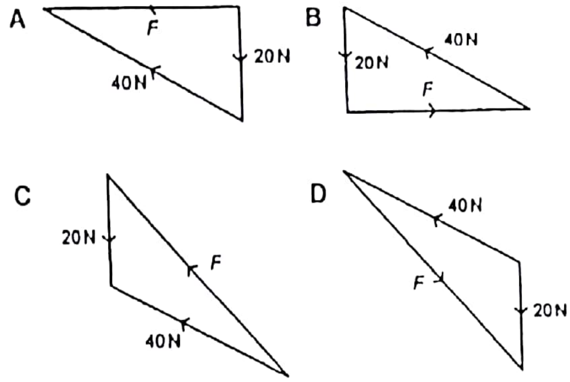
$$x = \frac{F}{x} = \frac{W}{\left(\frac{W}{3x}\right)} = 3x$$

43. The diagram shows a sign of weight 20 N suspended from a pole, attached to a wall. The pole is kept in equilibrium by a wire attached at point X of the pole.



The force exerted by the pole at point X is F, and the tension in the wire is 40 N.

Which diagram represents the three forces acting at point X?



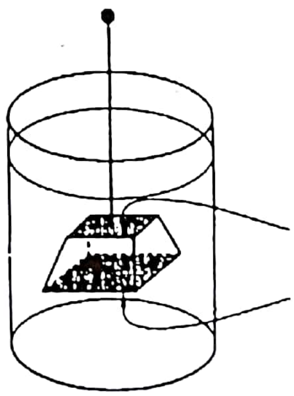
Helping concepts

In equilibrium, the three forces formed a closed triangle. A closed triangle is one where all the added vectors are in clockwise or anticlockwise direction.

44. The diagram shows a block of copper suspended in water.

The block experiences an upthrust from the water.

Which statement is the basis of an explanation for this upthrust.



A Copper is more dense than water.

B The area of face R is greater than the area of face S.

C The density of water increases with depth.

D The pressure of water increases with depth.

Helping concepts

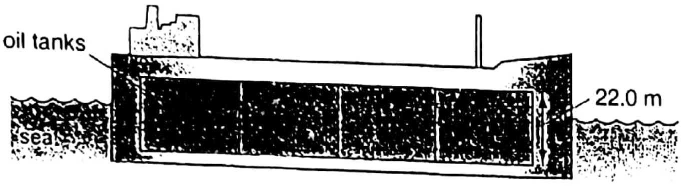
Total pressure at depth h below water surface,

$$p = p_0 + h\rho g$$

where p_0 is the atmospheric pressure.

The higher pressure at R (deeper than S) will cause the upthrust.

45. An oil tanker, with vertical sides, has an external cross-sectional area of 36500 m² in the plane of the sea.



The tanker carries oil of density 930 kg m⁻³ in its tanks, which have a constant cross-sectional area of 34 000 m² and depth 22.0 m. Sea water has density 1030 kg m⁻³.

By how much does the tanker rise in the water when it unloads its oil?

A 26.2 m **B** 22.7 m

C 21.3 m **D** 18.5 m

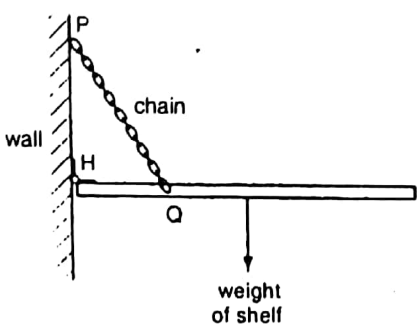
Helping concepts

How much the tanker rises is the same as asking how much will the same amount of oil displaces the sea water.

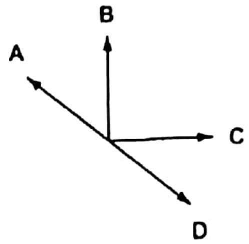
Since the tanker floats,

$$\text{weight of oil} = \text{weight of sea water displaced}$$
$$m_{oil}g = m_{sea\ water}g$$
$$V_{oil}\rho_{oil} = V_{sea\ water}\rho_{sea\ water}$$
$$A_{oil}h_{oil}\rho_{oil} = A_{sea\ water}h_{sea\ water}\rho_{sea\ water}$$
$$(34000)(22)(930) = (36500)(h)(1030)$$
$$h = 18.5 \text{ m}$$

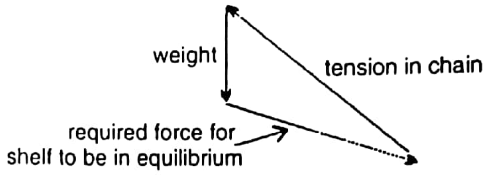
46. A hinged shelf is held horizontally against a wall by a chain PQ. The forces acting on the shelf are its weight, the force exerted by the chain and the force exerted by the hinge H.



Which arrow could represent the direction of the force the hinge exerts on the shelf?

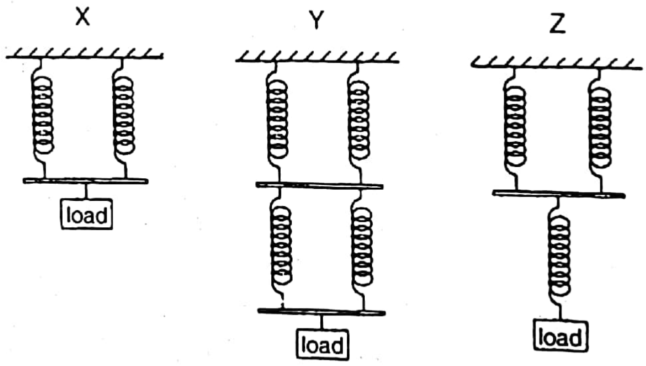


Helping concepts



In equilibrium, all forces formed a closed polygon.

47. A number of similar springs, each having the same spring constant, are joined in three arrangements X, Y and Z. The same load is applied to each.



What is the order of increasing extension for these arrangements?

	smallest	→	largest
A	X	Y	Z
B	Z	X	Y
C	Z	Y	X
D	Y	X	Z

Helping concepts

Let the weight of load be mg.

The extension of spring is proportional to weight applied in each system.

For X, each spring supports $\frac{mg}{2}$.

For Y, each spring supports $\frac{mg}{2}$.

Extension is **doubled** as 2 pairs of strings are in series, when compared to X.

For Z, upper pair of string supports $\frac{mg}{2}$. The bottom string supports mg, which means the extension will be doubled of X.

The total extension for Z is 3 times of X.

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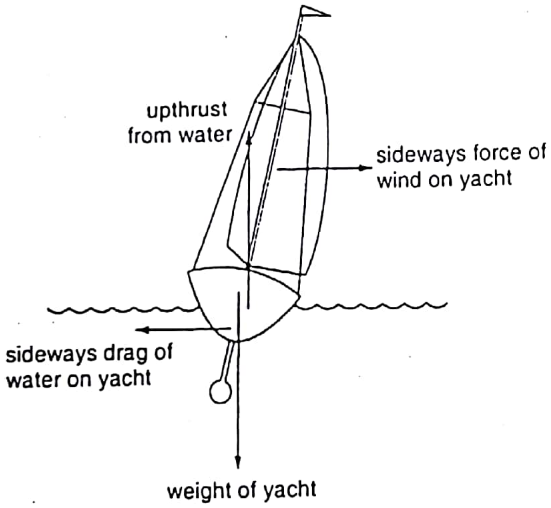
48. A yacht that is in equilibrium has two vertical and two horizontal forces acting on it.



Which statement about the forces is **not** correct?

A The sideways drag from the water on the yacht is equal and opposite to the sideways force of the wind on the yacht.

B The resultant of all four forces is zero.

C The torque provided by the vertical forces is the same as the torque provided by the horizontal forces.

D The upthrust from the water is equal and opposite to the weight of the yacht.

Helping *concepts*

Torque due to vertical forces is in the anticlockwise direction.

Torque due to horizontal forces is in the clockwise direction.

As torque is a vector quantity, torque due to vertical forces is not equal to torque due to horizontal forces.

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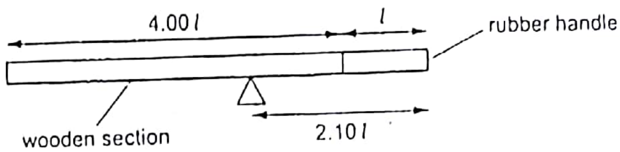
49. A uniform rod has a wooden section and a solid rubber handle, as shown.



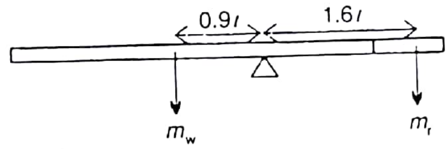
The length of the handle is l and the length of the wooden section is 4.00 l. The rod balances a distance of 2.10 l from the rubber end.

What is the ratio $\frac{\text{density of rubber}}{\text{density of wood}}$?

A 1.71 **B** 2.25

C 2.50 **D** 3.27

Helping *concepts*



where m_w = mass of wooden section,
m_r = mass of rubber section.

As the rod is uniform, the centre of gravity of wooden section is at the 2.00l from the left end of the rod.

The centre of gravity of the rubber section is at 0.50l from the right-end of the rod.

By principle of moments,

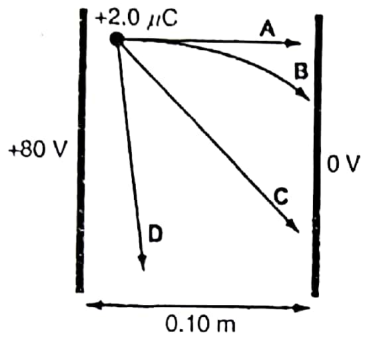
$$\text{clockwise} = \text{anticlockwise}$$
$$(m_r)(g)(1.6l) = (m_w)(g)(0.9l)$$
$$(\rho_r)(V_r)(1.6) = (\rho_w)(V_w)(0.9)$$
$$(\rho_r)(1.0l \times A)(1.6) = (\rho_w)(4.0l \times A)(0.9)$$
$$\frac{\rho_r}{\rho_w} = 2.25$$

where V_r = Volume of rubber section,
V_w = Volume of wooden section,
A = uniform-cross-section of rod,
ρ_r = density of rubber,
ρ_w = density of wood.

---

50. A sphere of weight 1.6×10^{-3} N has an electric charge of $+2.0\ \mu C$. It is released from rest, in vacuum, between two parallel, vertical metal plates. The separation of the plates is 0.10 m and the potential difference between them is 80 V. The point of release of the sphere is within the region of uniform electric field between the plates. The arrangement is shown in the diagram.

Which path does the sphere follow after release?



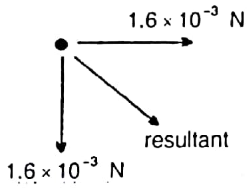
Helping concepts

Electric force = qE

$= q\dfrac{V}{d}$

$= (2 \times 10^{-6})(\dfrac{80-0}{0.10})$

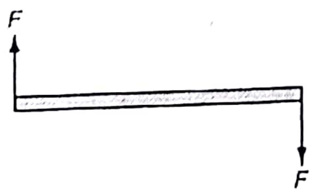
$= 1.6 \times 10^{-3}$ N

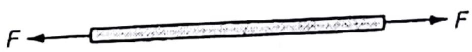


51. In which situation could the pair of forces applied to the rigid object produce a couple?

A


B


C


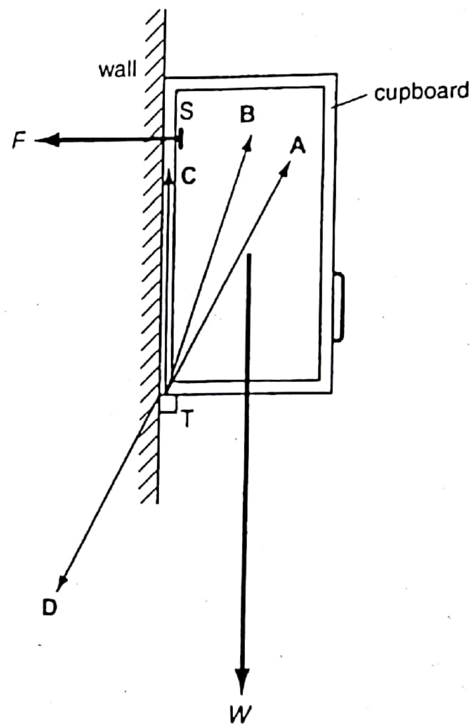
D


Helping concepts

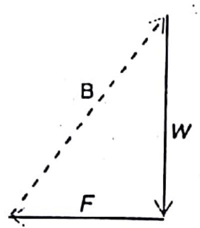
A couple is the product of a force and the perpendicular distance between two forces of the same magnitude. The two forces must not act along the same straight line. The two forces must also be in the opposite direction.

52. A cupboard is secured to a wall by a screw at S. It rests on a support at T. Arrows show the directions of the weight W of the cupboard and the horizontal force F of the screw at S on the cupboard.

Which arrow best represents the direction of the force on the cupboard from the support T?



Helping concepts



In equilibrium, all forces must pass through a common point. The intercept of F and W must also be the point where the support force must pass through.

The forces must also form a closed triangle.

TOPIC 7

Gravitational Field

Key content that you will be examined on:

1. Gravitational field
2. Force between point masses
3. Field of a point mass
4. Field near to the surface of the Earth
5. Gravitational potential

Topic 7 Gravitational Field

1. A model of a black hole is a point mass of 6×10^{24} kg.

What is the force on a point mass of 1 kg at a distance of 2 cm from this black hole?

A 1×10^{14} N B 2×10^{14} N

C 2×10^{16} N D 1×10^{18} N

Helping concepts

Force, $F = \dfrac{GMm}{r^2}$

$= \dfrac{(6.67 \times 10^{-11})(6 \times 10^{24})(1)}{(2 \times 10^{-2})^2}$

$= 1.0 \times 10^{18}$ N

2. Satellite are in circular orbit around the Earth.

What is the relationship between the radii r of their orbits and their speeds v?

A $v \propto r^2$ B $v \propto r$

C $v^2 \propto \dfrac{1}{r}$ D $v \propto \dfrac{1}{r^2}$

Helping concepts

Gravitational force provides the necessary centripetal force for the circular motion performed by the satellites.

$$\frac{GMm}{r^2} = \frac{mv^2}{r} \Rightarrow v^2 \propto \frac{1}{r}$$

3. An artificial satellite travels in a circular orbit about the Earth. Its rocket engine is then fired and produces a force on the satellite exactly equal and opposite to that exerted by the Earth's gravitational field.

The satellite would then start to move

A along a spiral path towards the Earth's surface.

B along the line joining it to the centre of the Earth (i.e. radially).

C along a tangent to the orbit.

D in a circular orbit with a longer period.

Helping concepts

Since the net force on the satellite along the radial direction is zero after the rocket engine is fired, no net motion will occur in the radial direction. Hence, the satellite starts to move along a tangent to the orbit.

4. An experimental satellite is found to have a weight W when assembled before launching from a rocket site. It is placed in a circular orbit at a height $h = 6R$ above the surface of the Earth (of radius R).

What is the gravitational force acting on the satellite whilst in orbit?

A $\dfrac{W}{6}$ B $\dfrac{W}{7}$

C $\dfrac{W}{36}$ D $\dfrac{W}{49}$

Helping concepts

On the Earth's surface, $W = \dfrac{GMm}{R^2}$ whilst in orbit,

$F = \dfrac{GMm}{(7R)^2} = \dfrac{W}{49}$.

5. If a body of mass m were released in a vacuum just above the surface of a planet of mass M and radius R, what would be its gravitational acceleration?

A $\dfrac{GmM}{R}$ B $\dfrac{GmM}{R^2}$

C $\dfrac{Gm}{R}$ D $\dfrac{GM}{R^2}$

Helping concepts

The gravitational force between the body and the planet is

$$F = G\frac{Mm}{R^2}$$

By Newton's second law, the gravitational acceleration of the body of mass m is

$$a = \frac{F}{m} = \frac{GM}{R^2}$$

6. The radius of the Earth's orbit about the Sun is 1.50×10^{11} m. The Earth takes 365 days to orbit the Sun.

   What is the mass of the Sun?

   A 6.40×10^{29} kg B 2.01×10^{30} kg

   C 1.16×10^{33} kg D 3.31×10^{33} kg

Helping concepts

$$\frac{GM_S m_E}{r^2} = m_E r\omega^2$$

$$\Rightarrow M_S = \frac{r^3\omega^2}{G} = \frac{r^3(\frac{2\pi}{T})^2}{G} = \frac{4\pi^2 r^3}{GT^2}$$

$$= \frac{4\pi^2(1.50 \times 10^{11})^3}{(6.67 \times 10^{-11})(365 \times 24 \times 60 \times 60)^2} = 2.01 \times 10^{30} \text{ kg}$$

7. The Earth may be considered to be a uniform sphere of mass M and radius R. Which one of the following equations correctly relates the universal gravitational constant G to the acceleration of free fall g at the surface of the Earth?

   A $G = \frac{gM}{R^2}$ B $G = \frac{R^2}{gM}$

   C $G = \frac{gR^2}{M}$ D $G = \frac{M}{gR^2}$

Helping concepts

The gravitational force on a body of mass m on the Earth's surface is given by

$$F = mg = G\frac{Mm}{R^2} \Rightarrow g = \frac{GM}{R^2} \Rightarrow G = \frac{gR^2}{M}$$

8. Star X of mass $2M$ and star Y of mass M perform circular motion about their common centre of mass under their gravitational attraction.

   Ignoring the effects of any other bodies, what is the ratio $\frac{\text{force acting on X}}{\text{force acting on Y}}$?

   A 1 B 2

   C 4 D 1/2

Helping concepts

The force acting on X is the ***same*** as the force acting on Y.

i.e. $\frac{\text{force acting on X}}{\text{force acting on Y}} = 1.$

It is given by $F = G\frac{(2M)(M)}{d^2} = \frac{2GM^2}{d^2}$ where d is the distance between the stars.

9. A satellite of mass m is in a circular orbit of radius r about the Earth, mass M and remains at a vertical height h above the Earth's surface. Taking the zero of the gravitational potential to be at an infinite distance from the Earth, what is the gravitational potential energy of the satellite?

   A mgh B $-mgh$

   C $\frac{-GMm}{r}$ D $\frac{-GMm}{2r}$

Helping concepts

The gravitational potential energy of the satellite at distance r from the centre of Earth is given by

$$U = \int_\infty^r F\,dr = \int_\infty^r G\frac{Mm}{r^2}\,dr$$

$$= \left[-G\frac{Mm}{r}\right]_\infty^r = -G\frac{Mm}{r}$$

10. A meteorite falls freely towards the centre of an isolated spherical planet of radius R. When it reaches the surface of the planet, its acceleration is g_s.

    What is its acceleration when at a height $2R$ above the surface?

A $\frac{1}{9}g_s$

B $\frac{1}{4}g_s$

C $\frac{1}{3}g_s$

D $\frac{1}{2}g_s$

Helping concepts

Using the formula for gravitational field strength, $g = \frac{GM}{r^2}$, we have

$$g_s = \frac{GM}{R^2} \text{-----(1)}$$
$$g_{2R} = \frac{GM}{(2R)^2} \text{-----(2)}$$

$\frac{(2)}{(1)}$: $\frac{g_{2R}}{g_s} = (\frac{R}{2R})^2$

$g_{2R} = \frac{1}{4}g_s$

11. The acceleration of free fall on the surface of the Earth is 6 times its value on the surface of the Moon. The mean density of the Earth is 5/3 times the mean density of the Moon.

If r_E is the radius of the Earth and r_M the radius of the Moon, what is the value of $\frac{r_E}{r_M}$?

A 1.9

B 3.6

C 6.0

D 10

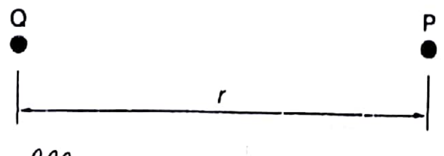
Helping concepts

Acceleration of free fall, $g = G\frac{M}{r^2} = \frac{4\pi}{3}G\rho r$

where M = mass of planet,
ρ = density of planet,
r = radius of planet (assuming spherical shape).

$$\therefore \frac{g_E}{g_M} = \frac{\rho_E r_E}{\rho_M r_M} \Rightarrow \frac{r_E}{r_M} = \frac{g_E/g_M}{\rho_E/\rho_M} = \frac{6}{5/3} = \frac{18}{5} = 3.6$$

12. A mass m is at fixed point Q. It produces a gravitational potential at point P, distant r from Q.



This gravitational potential is equal to the external work done on unit mass in moving it.

A from P to Q.

B from Q to P.

C from P to infinity.

D from infinity to P.

Helping concepts

Gravitational potential at a point is defined by work done in bringing a unit mass from infinity to the point.

13. On the ground, the gravitational force on a satellite is W. What is the gravitational force on the satellite when at a height $R/50$, where R is the radius of the Earth?

A $1.02W$

B $1.00W$

C $0.98W$

D $0.96W$

Helping concepts

The gravitational force F on a satellite is given by

$$F = G\frac{Mm}{r^2}$$

where G is the gravitational constant,
M is the mass of Earth,
m is the mass of satellite,
r is the distance from centre of Earth to satellite.

$\therefore F \propto \frac{1}{r^2}$

Now, $F = W$ when $r = R$.

To find F where $r = R + \frac{R}{50} = \frac{51}{50}R$, we have

$$\frac{F}{W} = \left(\frac{R}{\frac{51}{50}R}\right)^2 \Rightarrow F = (\frac{50}{51})^2 W = 0.96W$$

14. The gravitational field strength at a point P on the Earth's surface is numerically equal to

A the acceleration of free fall at P.

B the change in potential energy per unit distance from P.

C the force acting on any body placed at P.

D the work done in bringing unit mass from infinity to P.

Helping concepts

By definition, gravitational force,

$$F = G\frac{Mm}{r^2} = mg$$

where m is the mass of object on the Earth's surface.

Or, gravitational field strength,

$$g = \frac{F}{m}$$

= gravitational force per unit mass

= acceleration of free fall

15. Two instruments are used on the Earth to measure the mass of an object. A spring balance reads 600 g and a lever balance requires six 100 g discs to balance.

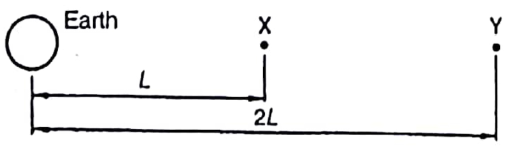
If these measurement were to be repeated on the Moon, where the gravitational field is 1/6 of its value on Earth, which results would be expected?

	reading on spring balance	number of 100 g discs required for balance on lever balance
A	600 g	6
B	600 g	1
C	100 g	6
D	100 g	1

Helping concepts

A spring balance measures the weight of an object while a lever balance compares masses of objects. On the Moon, the weight of an object is 1/6 that on Earth, but the mass is not affected.

16. The diagram shows two points X and Y at distance L and $2L$ from the centre of the Earth. The gravitational potential at X is –8 kJ kg^{-1}.



What is the gain in potential energy of a 1 kg mass when it is moved from X to Y?

A –4 kJ B –2 kJ

C +2 kJ D +4 kJ

Helping concepts

The gravitational potential at X is –8 kJ kg^{-1}. The gravitational potential at Y is inversely proportional to its distance from the centre of the Earth. Hence, its values is half of that at X, or –4 kJ kg^{-1}. Gain in potential energy of a 1 kg mass when it is moved fron X to Y is

$$-4\text{ kJ kg}^{-1} - (-8\text{ kJ kg}^{-1}) = +4\text{ kJ kg}^{-1}$$

17. In this question, you can consider all the mass of the Earth to be concentrated at its centre.

Work to five significant figures using the following data:

Mass of Earth = 5.9768×10^{24} kg

Distance of San Francisco from centre to Earth = 6.3782×10^{6} m

Gravitational constant $G = 6.6730 \times 10^{-11}$ Nm^{2}kg^{-2}

What is the value of g, the gravitational field strength of the Earth, in San Francisco?

A 9.8038 N kg^{-1} B 9.8067 N kg^{-1}

C 9.8100 N kg^{-1} D 9.8879 N kg^{-1}

Helping concepts

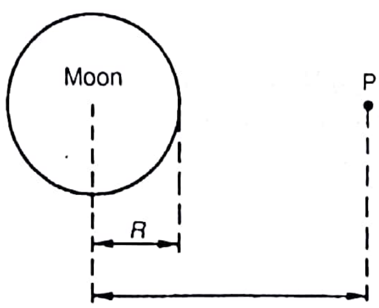
$$g = \frac{GM}{r^2}$$

$$= \frac{(6.6730 \times 10^{-11})(5.9768 \times 10^{24})}{(6.3782 \times 10^{6})^2}$$

$$= 9.8038\text{ N kg}^{-1}$$

Note that all the values are given in five significant figures, so the final answer for gravitational field strength is also in five significant figures.

18. A stationary object is released from a point P, a distance $3R$ from the centre of the Moon which has radius R and mass M.



Which one of the following expressions gives the speed of the object on hitting the Moon?

A $\left(\frac{2GM}{3R}\right)^{\frac{1}{2}}$ B $\left(\frac{4GM}{3R}\right)^{\frac{1}{2}}$

C $\left(\frac{2GM}{R}\right)^{\frac{1}{2}}$ D $\left(\frac{4GM}{R}\right)^{\frac{1}{2}}$

Helping concepts

Gain in kinetic energy by the object = Loss in gravitational potential energy by the object (of mass m)

$$\therefore \frac{1}{2}mv^2 = (-\frac{GMm}{3R}) - (-\frac{GMm}{R}) \Rightarrow \frac{1}{2}v^2 = \frac{2GM}{3R}$$

$\therefore$ Speed of the object, $v = \sqrt{\frac{4GM}{3R}}$

---

19. A satellite of mass m is placed in an equatorial orbit so that it remains vertically above a fixed point on the Earth's surface.

If ω is the Earth's angular velocity of rotation and M is the Earth's mass, what is the radius of the satellite's orbit?

A $\left[\frac{GM}{\omega^2}\right]^{\frac{1}{3}}$ B $\left[\frac{Gm}{\omega^2}\right]^{\frac{1}{3}}$

C $\left[\frac{GmM}{\omega^3}\right]^{\frac{1}{3}}$ D $\left[\frac{GM}{\omega^3}\right]^{\frac{1}{2}}$

Helping concepts

If r is the radius of the satellite's orbit, we have

gravitational force, $F = G\frac{Mm}{r^2} = mr\omega^2$

$$\Rightarrow \frac{GM}{\omega^2} = r^3$$

$$\Rightarrow r = \left[\frac{GM}{\omega^2}\right]^{\frac{1}{3}}$$

---

20. A satellite of mass 810 kg is to be raised from the Earth to a height of 92.0 km above the surface of the Earth.

What is the necessary increase in the potential energy of the satellite?

The mass of the Earth is 5.98×10^{24} kg.
The radius of the Earth is 6370 km.

A 7.22×10^5 J B 7.31×10^5 J

C 7.22×10^8 J D 7.31×10^8 J

Helping concepts

Note that the formula, GPE = mgh cannot be used here as g is not constant,

i.e. $mgh = (810)(9.81)(92 \times 10^3) = 7.31 \times 10^8$ J.

Correct answer should be:

$$\Delta GPE = (-\frac{GMm}{r_2}) - (-\frac{GMm}{r_1})$$

$$= GMm(\frac{1}{r_1} - \frac{1}{r_2})$$

$$= (6.67 \times 10^{-11})(5.98 \times 10^{24})(810) \times (\frac{1}{6370 \times 10^3} - \frac{1}{(6370 + 92) \times 10^3})$$

$$= 7.22 \times 10^8 \text{ J}$$

---

21. Outside a uniform sphere of mass M, the gravitational field strength is the same as that of a point mass M at the centre of the sphere.

The Earth may be taken to be a uniform sphere of radius r. The gravitational field strength at its surface is g.

What is the gravitational field strength at a height h above the ground?

A $\frac{gr^2}{(r+h)^2}$ B $\frac{gr}{r+h}$

C $\frac{g(r-h)}{r}$ D $\frac{g(r-h)^2}{r^2}$

Helping concepts

On the surface,

$$g = \frac{GM}{r^2} \Rightarrow GM = gr^2$$

At a height h above the ground,

$$\text{gravitational field strength} = \frac{GM}{(r+h)^2} = \frac{gr^2}{(r+h)^2}$$

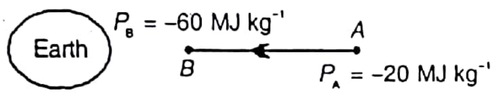
---

22. A satellite of mass 50 kg moves from a point where the gravitational potential due to the Earth is -20 MJ kg^{-1} to another point where the gravitational potential is -60 MJ kg^{-1}.

During this change of position, it has moved

- **A** closer to the Earth and lost 2000 MJ of potential energy.
- **B** closer to the Earth and lost 40 MJ of potential energy.
- **C** further from the Earth and gained 2000 MJ of potential energy.
- **D** further from the Earth and gained 40 MJ of potential energy.

Helping concepts



The gravitational potential at infinity is taken as zero. Thus, the nearer the gravitational potential to zero, the further the satellite is away from Earth.

Hence, the satellite has come closer to Earth and lost its potential energy moving from A at -20 MJ kg^{-1} to B at -60 MJ kg^{-1}.

$\therefore$ Potential energy lost $= (60 - 20)50 = 2000$ MJ

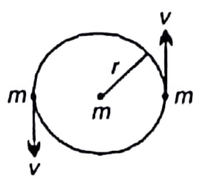
---

23. A satellite moves at constant speed in a circular orbit about the Earth.

Which statement about the momentum and kinetic energy of the satellite is correct?

	momentum	kinetic energy
A	constant	changing
B	constant	constant
C	changing	changing
D	changing	constant

Helping concepts



Linear momentum (mv) of the satellite is a vector quantity, whereas its kinetic energy ($\frac{1}{2}mv^2$) is a scalar quantity.

---

24. A satellite orbits a planet at a distance r from its centre. Its gravitational potential energy is -3.2 MJ.

Another identical satellite orbits the planet at a distance $2r$ from its centre.

What is the sum of the kinetic energy and the gravitational potential energy of this second satellite?

A	-0.40 MJ	**B**	-0.80 MJ
C	-1.6 MJ	**D**	-6.4 MJ

Helping concepts

$$\text{GPE} = -\frac{GMm}{r}$$

$$-3.2\text{ MJ} = -\frac{GMm}{r} \quad \text{-----(1)}$$

Total energy of satellite, $\text{GPE} + \text{KE} = -\frac{GMm}{2r}$

As $2r$ distance away from the planet centre,

$$\text{total energy, } E = -\frac{GMm}{2(2r)} = -\frac{GMm}{4r} = \frac{1}{4}(-3.2\text{ MJ}) = -0.8\text{ MJ}$$

---

25. A communications satellite which takes 24 hours to orbit the Earth is replaced by a new satellite which has twice the mass of the first.

If the new satellite also has an orbit time of 24 hours, then the ratio $\frac{\text{radius of orbit of new satellite}}{\text{radius of orbit of old satellite}}$ is

A	$\frac{1}{2}$.	**B**	$\frac{1}{1}$.
C	$\frac{\sqrt{2}}{1}$.	**D**	$\frac{2}{1}$.

Helping concepts

If m is the mass of the satellite orbiting the Earth of mass M at a distance R from centre of Earth, then

$$mR\left(\frac{2\pi}{T}\right)^2 = \frac{GMm}{R^2}$$

where G is the gravitational constant and T the period of the satellite in its orbit.

$\therefore T = 2\pi\sqrt{\frac{R^3}{GM}} \propto R^{\frac{3}{2}}$ independent of the mass of the satellite.

Hence, for same period of orbit,

$$\frac{R_1}{R_2} = \left(\frac{T_1}{T_2}\right)^{\frac{2}{3}} = \frac{1}{1}$$

---

26. For points outside a uniform sphere of mass M, the gravitational field is the same as that of a point mass M at the centre of the sphere. The Earth may be taken to be a uniform sphere of radius r and density ρ.

How is the gravitational field strength g at its surface related to these quantities to the gravitational constant G?

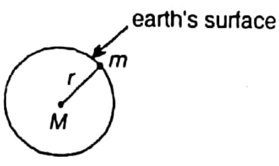
A $g = \frac{G\rho}{r^2}$ B $g = \frac{3G}{4\pi r\rho}$

C $g = \frac{4\pi r\rho G}{3}$ D $g = \frac{4\pi r^2\rho G}{3}$

Helping concepts

Consider a point mass m on the Earth's surface, the gravitational force F is given by

$$F = \frac{GMm}{r^2} = mg$$

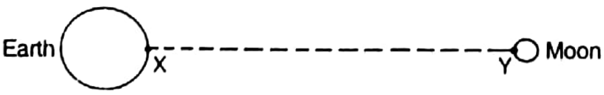


Hence, gravitational field strength, g, is given by

$$g = \frac{GM}{r^2} = \frac{G}{r^2}(\rho\frac{4}{3}\pi r^3) = \frac{4\pi r\rho G}{3}$$

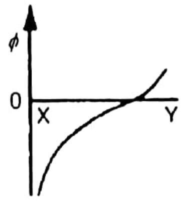
---

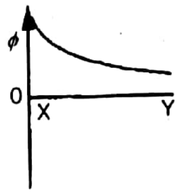
27. The diagram (not to scale) represents the relative positions of the Earth and the Moon.

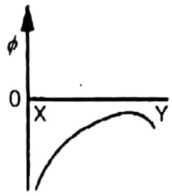


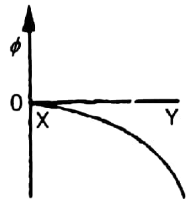
The line XY joins the surface of the Earth to the surface of the Moon.

Which graph represents the variation of gravitational potential ϕ along the line XY?

A


B


C


D


Helping concepts

Gravitational potential along XY
= potential due to Earth + potential due to Moon

ϕ will be negative with a turning point between X and Y where the net gravitational force equals zero.

---

28. Which statement about geostationary orbits is **false**?

A A geostationary orbit must be directly above the equator.

B All satellites in a geostationary orbit must have the same mass.

C The period of a geostationary orbit must be 24 hours.

D There is only one possible radius for a geostationary orbit.

Helping concepts

For a geostationary satellite,

$$\frac{GMm}{R^2} = \frac{mv^2}{R}$$

where M : mass of Earth,
m : mass of satellite,
R : distance between centres of Earth and satellite, i.e. the satellite is above equator.

$$\therefore v^2 = \frac{GM}{R} \Rightarrow \left(\frac{2\pi R}{T}\right)^2 = \frac{GM}{R} \Rightarrow T = \sqrt{\frac{4\pi^2R^3}{GM}}$$

For geostationary orbits, $T = 24$ hours.

It can be seen that there is only one possible radius for a geostationary orbit.

T does not depend on m, the mass of the satellite.

29. The neutral point in the gravitational field between the Sun, the Earth and the Moon is the point at which the resultant gravitational field due to the three bodies is zero. The mass of the Earth is about 80 times the mass of the Moon.

At what position is it possible for the neutral point to be? (The diagram is not drawn to scale.)

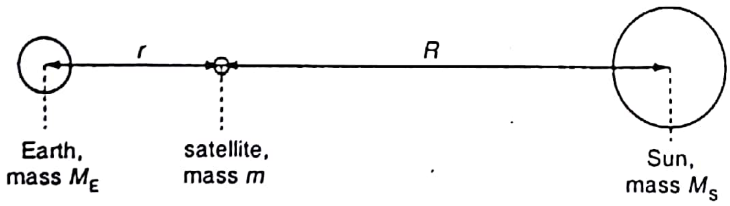
Helping concepts

Neutral point of Earth and Moon only is **A**.

Neutral point of Earth and Sun only is **D**.

The neutral distance is nearer to the Moon as its mass is smaller than Earth. Hence, the neutral point of the combined three masses must be nearer to the Moon and is towards the direction of the Sun.

30. The diagram shows a solar satellite, mass m, positioned directly between the Earth, mass M_E, and the Sun, mass M_S. The satellite is a distance r from the Earth and a distance R from the Sun.



The satellite rotates in a circle around the Sun once a year and therefore moves around the Sun with the Earth, both having the same angular velocity ω.

Which *force* = *mass* × *acceleration* equation applies for the satellite?

A $\dfrac{GM_Sm}{R^2} = m \times (R\omega^2)$

B $\dfrac{GM_Em}{R^2} = m \times (r\omega^2)$

C $\left(\dfrac{GM_Em}{r^2} - \dfrac{GM_Sm}{R^2}\right) = m \times (R\omega^2)$

D $\left(\dfrac{GM_Sm}{R^2} - \dfrac{GM_Em}{r^2}\right) = m \times (R\omega^2)$

Helping concepts

By Newton's second law,

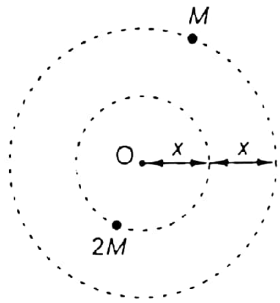
$$F_{net} = ma$$

As satellite moves round the Sun in circular motion, there is a net force towards the Sun.

$$F_{sun} - F_{earth} = mR\omega^2$$

$$\frac{GM_Sm}{R^2} - \frac{GM_Em}{r^2} = mR\omega^2$$

31. Two stars of mass M and $2M$, a distance $3x$ apart, rotate in circles about their common centre of mass O.



The gravitational force acting on the stars can be written as $\dfrac{kGM^2}{x^2}$.

What is the value of k?

A 0.22 **B** 0.50

C 0.67 **D** 2.0

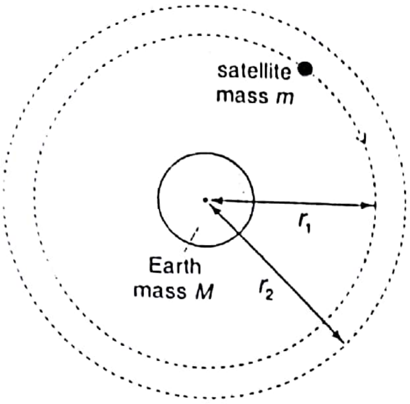
Helping concepts

$$F = \frac{GMm}{r^2} = \frac{G(2M)(M)}{(x+2x)^2}$$

$$= \left(\frac{2}{9}\right)\left(\frac{GM^2}{x^2}\right) = (0.22)\left(\frac{GM^2}{x^2}\right)$$

$\therefore\ k = 0.22$

32. A satellite of mass m is moved from a circular orbit of radius r_1 around the Earth to a new circular orbit of radius r_2, as shown.



The mass of the Earth is M and the gravitational constant is G.

What is the increase in the potential energy of the satellite?

A $GM(\frac{1}{r_2}-\frac{1}{r_1})$ B $GM(\frac{1}{r_1}-\frac{1}{r_2})$

C $GMm(\frac{1}{r_2}-\frac{1}{r_1})$ D $GMm(\frac{1}{r_1}-\frac{1}{r_2})$

Helping concepts

Potential energy at $r_1 = -\frac{GMm}{r_1}$

Potential energy at $r_2 = -\frac{GMm}{r_2}$

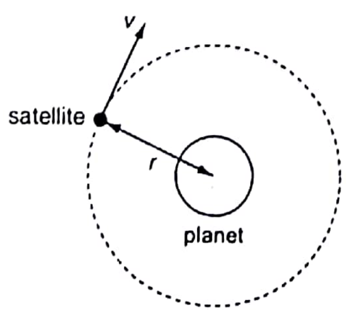
Increase in potential energy from r_1 to r_2

$$= -\frac{GMm}{r_2} - (-\frac{GMm}{r_1})$$

$$= GMm(\frac{1}{r_1}-\frac{1}{r_2})$$

---

33. A satellite of mass m moves in a circular orbit at speed v and distance r from the centre of a planet of mass M.



What expression gives the total energy of the satellite?

A $m\left(\frac{v^2}{r}-\frac{GM}{r}\right)$ B $m\left(\frac{v^2}{2}-\frac{GM}{r}\right)$

C $m\left(\frac{v^2}{r}+\frac{GM}{r}\right)$ D $m\left(\frac{v^2}{2}+\frac{GM}{r}\right)$

Helping concepts

Total energy, $E = KE + GPE$

$$= \frac{1}{2}mv^2 + (-\frac{GMm}{r})$$

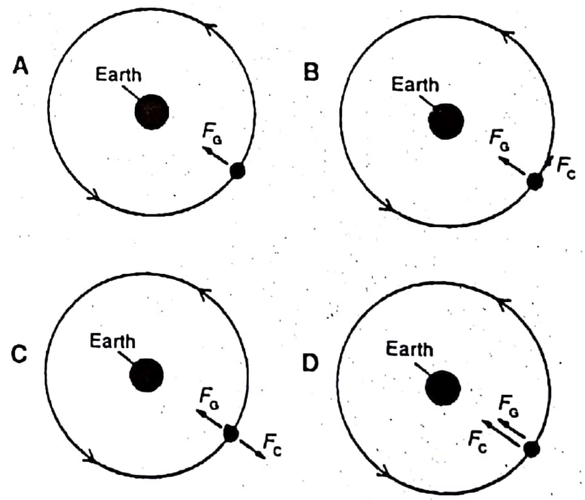
$$= m\left(\frac{v^2}{2}-\frac{GM}{r}\right)$$

---

34. A satellite is orbiting the Earth.

The gravitational force on the satellite is F_G. The centripetal force required to maintain the satellite in orbit is F_C.

Which diagram shows the force, acting on the orbiting satellite?

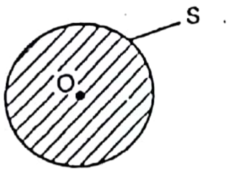


Helping concepts

The gravitational force is the centripetal force. They act in the same direction.

---

35. An astronomical gas cloud has mass M and radius R. The gravitational potential on its surface S is $-\frac{GM}{R}$ and at its centre O is $-\frac{3GM}{2R}$.



A unit mass is moved slowly by means of an external force from the surface S to the centre O.

What is the work done on the mass by the external force?

A $-\frac{5GM}{2R}$ B $-\frac{GM}{2R}$

C $\frac{GM}{2R}$ D $\frac{5GM}{2R}$

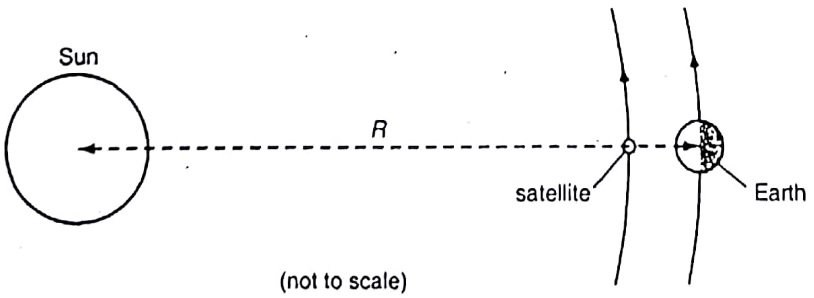
Helping concepts

Work done = change in potential energy

$$= \Delta(m\phi)$$
$$= m\Delta\phi$$
$$= m\left[-\frac{3GM}{2R} - (-\frac{GM}{R})\right]$$
$$= -\frac{GM}{2R} \quad (\because m = 1)$$

where ϕ is the gravitational potential.

36. An unpowered artificial satellite called SOHO has been placed in a stable orbit around the Sun at a distance of 0.99R from the Sun, where R is the orbital radius of the Earth. The satellite is always on the radial line from the Sun to the Earth so that it has a period of 1.0 year, the same as the Earth.



(not to scale)

Which statement relating to the satellite helps to explain how it is possible for its period to be 1.0 year?

A The gravitational field of the Sun at the satellite is reduced by the presence of the Earth.

B The gravitational force of the Earth on the satellite balances the gravitational force of the Sun on the satellite.

C The mass of the satellite is much less than the mass of the Earth.

D The resultant gravitational force on the satellite is less than the gravitational force the Sun exerts on it.

Helping concepts

By using Newton's second law,

$$\sum F = ma = mr(\frac{2\pi}{T})^2$$

Net force on satellite doing circular motion around the sun.

$$F_{sun} - F_{earth} = mr(\frac{2\pi}{T})^2$$

Net force will affect the period of revolution inversely.

Note that option A is also a true statement, but is an inferior answer compared to answer D.

TOPIC 8

Oscillations

Key content that you will be examined on:

1. Simple harmonic motion
2. Energy in simple harmonic motion
3. Damped and forced oscillations: resonance

Topic 8 Oscillations

1. A body moves with simple harmonic motion and makes n complete oscillations in one second.

What is its angular frequency?

A n rad s^{-1}

B $\frac{1}{n}$ rad s^{-1}

C $2\pi n$ rad s^{-1}

D $\frac{2\pi}{n}$ rad s^{-1}

Helping concepts

Frequency, $f = n$ Hz

Angular frequency, $\omega = 2\pi f = 2\pi n$ rad s^{-1}

---

2. In some circumstances, resonance is useful and in others it is a nuisance.

What is a useful example of resonance?

A The air column in a clarinet resonates when air is blown over the reed.

B The rear-view mirror of a car resonates at a particular engine speed.

C A suspension bridge resonances in a gusting wind.

D An ornament placed on a loudspeaker cabinet resonates when a particular note sounds.

Helping concepts

All except option A are examples of resonance as nuisance.

---

3. A body performing simple harmonic motion has a displacement x given by the equation $x = 30\sin 50t$, where t is the time in seconds. What is the frequency of oscillation?

A 0.020 Hz

B 0.13 Hz

C 8.0 Hz

D 30 Hz

Helping concepts

Given the displacement of a S.H.M.,

$$x = 30\sin 50t$$

The angular frequency of the motion is thus

$$\omega = 2\pi f = 50 \text{ rad s}^{-1}$$

The frequency of oscillation is hence calculated to be

$$f = \frac{50}{2\pi} = 8.0 \text{ Hz}$$

---

4. A simple harmonic oscillator has a time period of 10 seconds.

Which equation relates its acceleration a and displacement x?

A $a = -10x$

B $a = -(20\pi)x$

C $a = -(20\pi)^2 x$

D $a = -(2\pi/10)^2 x$

Helping concepts

$$a = -\omega^2 x \text{ and } \omega = \frac{2\pi}{T}$$

where T is the period.

$$\therefore\ a = -(\frac{2\pi}{10})^2 x$$

---

5. A particle performs simple harmonic motion of amplitude 0.020 m and frequency 2.5 Hz. What is its maximum speed?

A 0.008 ms^{-1}

B 0.050 ms^{-1}

C 0.125 ms^{-1}

D 0.314 ms^{-1}

Helping concepts

Maximum speed is given by

$$v = r\omega$$

where r is the amplitude of oscillation = 0.020 m,

ω is the angular frequency which is related to frequency f.

$$\omega = 2\pi f = 2\pi(2.5) = 15.71 \text{ rad s}^{-1}$$

$$\therefore\ v_{max} = (0.020)(15.71) = 0.314 \text{ ms}^{-1}$$

---

6. Simple harmonic motion is **defined** as the motion of a particle such that

A its displacement x is always given by the expression $x = x_0 \sin \omega t$.

B its displacement x is related to its velocity v by the expression $v = \omega x$.

C its acceleration is always $\omega^2 x_0$ and is directed at right angles to its motion.

D its acceleration is proportional to, and in the opposite direction to, the displacement.

Helping concepts

Simple harmonic motion is described by the equation $\ddot{x} = -\omega^2 x$ which states that the acceleration of a particle is always proportional to, and in the opposite direction to, the displacement.

7. A body performs simple harmonic motion with a period of 0.063 s. The maximum speed of the body is 3.0 ms^{-1}.

What are the values of the amplitude x_0 and the angular frequency ω?

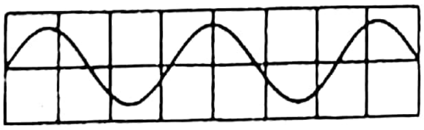
	x_0 / m	ω / rad s^{-1}
A	0.030	100
B	0.19	16
C	5.3	16
D	33	100

Helping concepts

Angular frequency, $\omega = \frac{2\pi}{T} = \frac{2\pi}{0.063} = 100 \text{ rad s}^{-1}$

$v_{max} = \omega x_0 \Rightarrow 3 = 100(x_0) \Rightarrow x_0 = 0.030 \text{ m}$

8. The diagram below shows the trace on an oscilloscope screen when a sinusoidal signal was applied to the Y plates.



Given that the linear time base was set to 2.00 ms per division, what was the frequency of the signal?

A 62.5 Hz B 156 Hz

C 312 Hz D 625 Hz

Helping concepts

The number of complete revolution shown on the screen is 2.5.

$\therefore 2.5T = (2.00 \times 10^{-3})(8) \Rightarrow T = 6.4 \times 10^{-3} \text{ s}$

Frequency of the signal is given by

$$f = \frac{1}{T} = \frac{1}{6.4 \times 10^{-3}} = 156 \text{ Hz}$$

9. The ionosphere contains free electrons. What is the amplitude of oscillation of these electrons when subject to a 200 kHz electronmagnetic wave in which the oscillations of electric field have amplitude 5×10^{-3} Vm^{-1}?

A 3.2×10^{-15} m B 4.0×10^{-9} m

C 2.5×10^{-8} m D 5.6×10^{-4} m

Helping concepts

The force acting on an electron by the electric field is

$$F = eE$$

where $e = 1.6 \times 10^{-19}$ C for electron,
$E = 5 \times 10^{-3}$ Vm^{-1}.

If x is the amplitude of the oscillator of the electron, we have

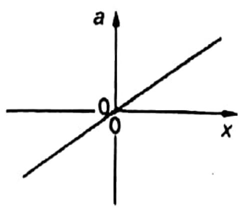
$$F = m\ddot{x} = m\omega^2 x$$

where $m = 9.1 \times 10^{-31}$ kg for electron,
$\omega = 2\pi f = 2\pi(200 \times 10^3) \text{ rads}^{-1}$.

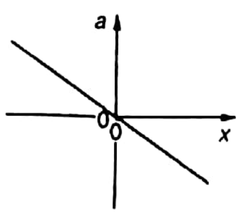
$$\therefore x = \frac{eE}{m\omega^2} = \left(\frac{1.6 \times 10^{-19}}{9.1 \times 10^{-31}}\right)\left(\frac{5 \times 10^{-3}}{4\pi^2(200 \times 10^3)^2}\right)$$
$$= 5.6 \times 10^{-4} \text{ m}$$

10. Which graph correctly represents the variation of acceleration a with displacement x for a body moving in simple harmonic motion?

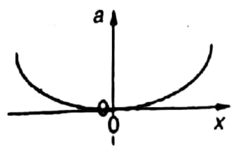
A



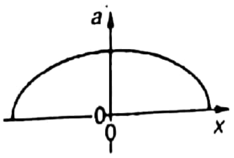
B



C



D



Helping concepts

For S.H.M,

$$a = -\omega^2 x$$

where ω is constant.

---

11. A mass of 8.0 g oscillates in simple harmonic motion with an amplitude of 5.0 mm at a frequency of 40 Hz.

What is the total energy of this simple harmonic oscillator?

A 0.16 mJ B 6.3 mJ

C 13 mJ D 640 mJ

Helping concepts

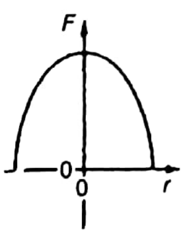
$$\begin{aligned}\text{Total energy} &= \text{KE} + \text{elastic PE} \\ &= \text{maximum KE} \\ &= \tfrac{1}{2}mv_{max}^2 \\ &= \tfrac{1}{2}m(\omega x_{max})^2 \\ &= \tfrac{1}{2}m\omega^2 x_{max}^2 \\ &= \tfrac{1}{2}m(2\pi f)^2 x_{max}^2 \\ &= \tfrac{1}{2}(8.0\times10^{-3})(2\pi\times40)^2(5.0\times10^{-3})^2 \\ &= 6.3 \text{ mJ}\end{aligned}$$

---

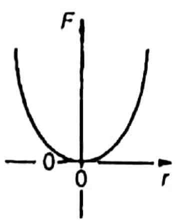
12. A resultant force F acts on a particle moving with simple harmonic motion.

Which graph shows the variation with displacement r of force F?

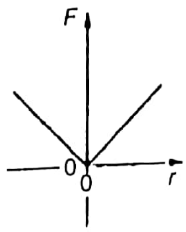
A



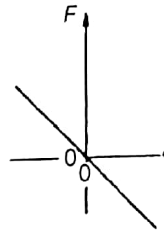
B



C



D



Helping concepts

In simple harmonic motion, $a = -\omega^2 r$.

Since $F = ma$,

$$F = -m\omega^2 r$$

$\therefore$ F is directly proportional to $-r$.

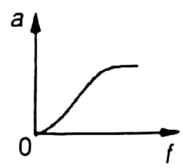
---

13. A pendulum is driven by a sinusoidal driving force of frequency f.

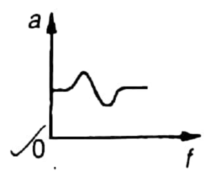
Which graph best shows how the amplitude a of the motion of the pendulum varies with f ?

A

B



C



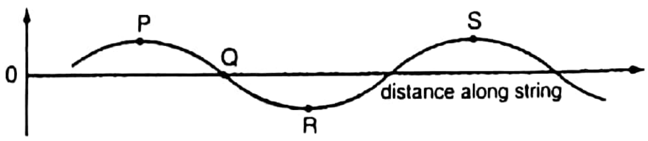
D

Helping concepts

Graph A shows the phenomenon of resonance, i.e. the amplitude a is high when driving force frequency equals the natural frequency of the pendulum.

---

14. The graph shows the shape at a particular instant of part of a transverse wave travelling along a string.



Which statement about the motion of points in the string is correct?

A The speed at point P is a maximum.
B The displacement at point Q is always zero.
C The energy at point R is entirely kinetic.
D The acceleration at point S is a maximum.

Helping concepts

Each point is a particle doing simple harmonic motion.

	P	Q	R	S
displacement	max.	zero	max.	max.
velocity	zero	max.	zero	zero
acceleration	max.	zero	max.	max.

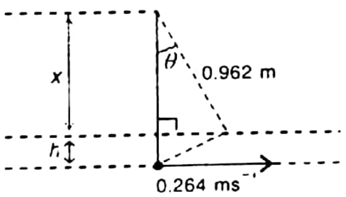
---

15. A pendulum bob has a speed of 0.264 ms^{-1} at the mid-point of its travel. It is oscillating along the arc of a circle of radius 0.962 m.

What is the **total** angle through which it is oscillating?

A 4.9° B 7.0°
C 9.8° D 14°

Helping concepts



Using conservation of energy,

$$mgh = \frac{1}{2}mv^2$$

$$\Rightarrow h = \frac{v^2}{2g} = \frac{(0.264)^2}{2(9.81)} = 3.55 \times 10^{-3} \text{ m}$$

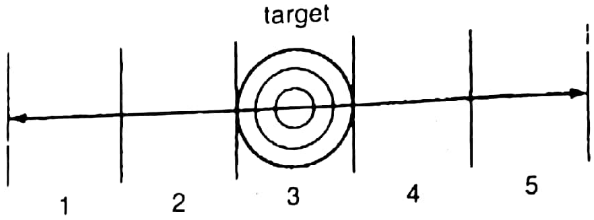
$$\therefore x = 0.962 - (3.55 \times 10^{-3}) = 0.958 \text{ m}$$

$$\therefore \cos\theta = \frac{0.958}{0.962} \Rightarrow \theta = 4.9^\circ$$

Total angle, $2\theta = 2(4.9^\circ) = 9.8^\circ$

---

16. In a fairground shooting game, a gun fires at a moving target. The gun fires by itself at random times. The player has to point the gun in a fixed direction, and the target moves from side to side with simple harmonic motion.



At which region should the player take a fixed aim in order to score the greatest number of hits?

A 3 B either 1 or 5
C either 2 or 4 D any of 1, 2, 3, 4 and 5

Helping concepts

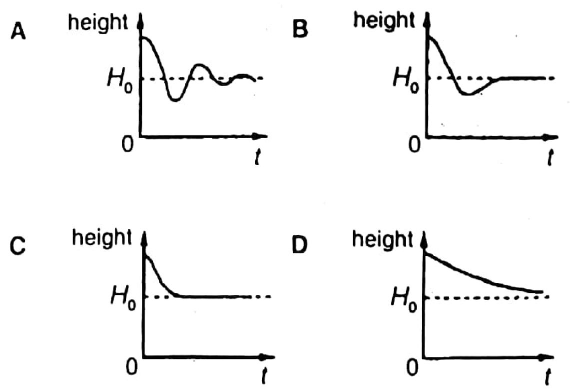
The target has its velocity at zero when at the two extreme ends. The average velocity of the target in region 1 or 5 is thus the slowest and hence time exposure of the target in either region 1 or 5 will be the longest. Hence, the aim should be taken at either region 1 or 5 to score the greatest possible number of hits.

---

17. It is important that a car suspension system should be critically damped.

The equilibrium height above the ground of the bodywork of such a car is H_0. The body of the car is raised slightly to a greater height and released at time $t = 0$. Assume that the car tyres remain in contact with the ground throughout and there is critical damping.

Which graph shows how the height of the car body above the ground varies with time?



Helping concepts

A critically damped spring returns to its equilibrium position in the shortest possible time.

---

18. The value of g, the acceleration of free fall, is found by determining the period T of a simple pendulum and using the relationship $T = 2\pi\sqrt{(l/g)}$, where l is the length of the pendulum. The experiment is repeated for different values of the amplitude, keeping l constant, and the resulting value of g is found to vary systematically. How should the best value for g be determined?

- **A** Plot values of g against amplitude and extrapolate to zero amplitude.
- **B** Plot values of g against amplitude and take the point where the slope is a maximum.
- **C** Take the mean of all values of g.
- **D** Take the root-mean-square value of all values of g.

Helping *concepts*

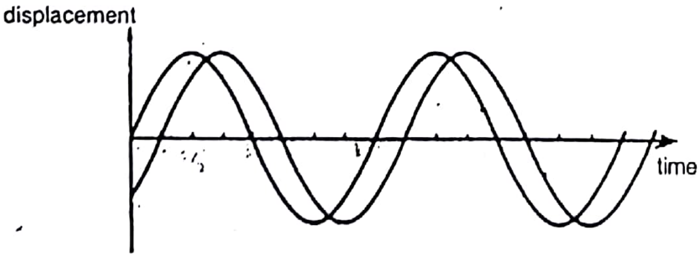
Given $T = 2\pi\sqrt{\frac{l}{g}}$.

$$\therefore \frac{T^2}{4\pi^2} = \frac{l}{g} \text{ or } g = \frac{4\pi^2 l}{T^2}$$

At large amplitude, the pendulum swings faster to keep the same period T for the given length l. But faster swings increases the centripetal force and stretches the pendulum in l. Hence, the period T would increase a bit with a stretched length l'. If we can measure the variation of l, we can calculate g accurately. But it is easier to assume no change of l by plotting g against amplitude and extrapolate to zero amplitude.

---

19. The diagram shows two oscillations.



What is the phase difference between the oscillations?

- **A** $\frac{\pi}{4}$ rad
- **B** $\frac{\pi}{2}$ rad
- **C** $\frac{3}{4}\pi$ rad
- **D** π rad

Helping *concepts*

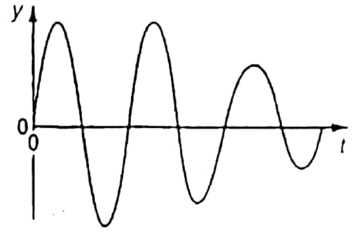
The wavelength (2π rad) of the oscillations corresponds to 8 divisions on the time scale. The phase difference between the oscillations corresponds to 1 division of the time scale. Hence, the phase difference is given by

$$\Delta\theta = \frac{2\pi}{8}(1) = \frac{\pi}{4} \text{ rad}$$

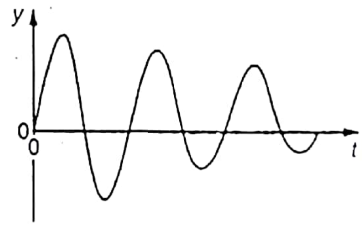
---

20. Which diagram shows the variation with time t of the displacement y of an object that is undergoing lightly-damped oscillations?

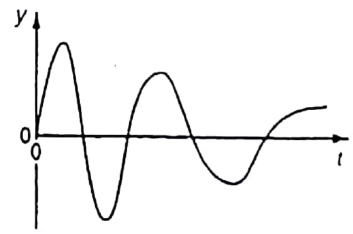
A



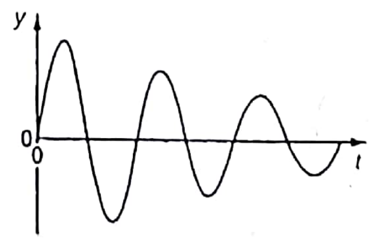
B



C



D

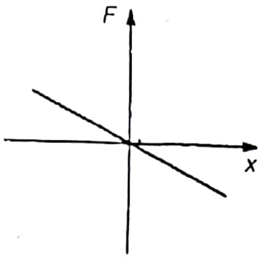


Helping *concepts*

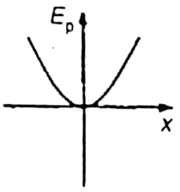
The succeeding amplitudes will be of smaller value as time increases.

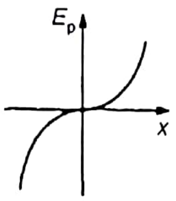
---

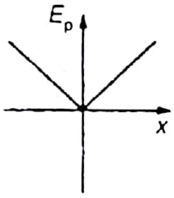
21. The resultant force F on a body moving in a straight line varies with displacement x from a fixed point as shown in the graph.

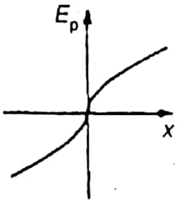


Which graph represents the variation with x of the potential energy E_p of the body?

A


B


C


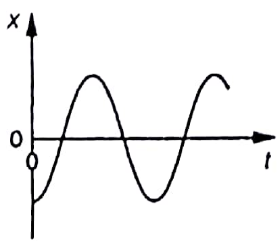
D


Helping concepts

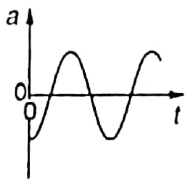
From the graph, $F = -kx$, the motion of the body is thus simple harmonic motion.

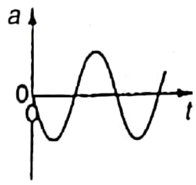
$$\therefore\ u = -\int F\,dx$$
$$= \int kx\,dx$$
$$= \tfrac{1}{2}kx^2$$
= potential energy of the body
$= E_p$

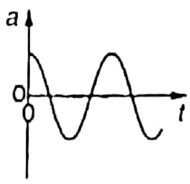
22. A body moves with simple harmonic motion about a point P. The graph shows the variation with time t of its displacement x from P.

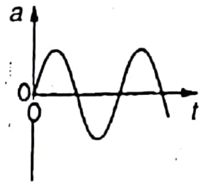


Which graph shows the variation with time t of its acceleration a?

A


B


C


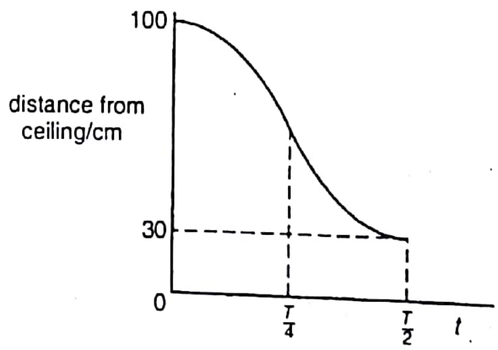
D


Helping concepts

For S.H.M, $a = -\omega^2 x$.

The graph of acceleration is reflected about x-axis compared to that of its displacement.

23. A mass hanging from a spring suspended from the ceiling is pulled down and released. The mass then oscillates vertically with simple harmonic motion of period T. The graph shows how its distance from the ceiling varies with time t.



What can be deduced from this graph?

A The amplitude of the oscillation is 70 cm.

B The kinetic energy is a maximum at $t = \dfrac{T}{2}$.

C The restoring force on the mass increases between $t = 0$ and $t = \dfrac{T}{4}$.

D The speed is a maximum at $t = \dfrac{T}{4}$.

Helping concepts

Amplitude of oscillation $= \tfrac{1}{2}(100 - 30) = 35$ cm

$\therefore$ (A) is incorrect.

At $t = \frac{T}{2}$, the velocity of the mass is zero as it is at the turning point. The kinetic energy is minimum here.

∴ (B) is incorrect.

The mass is at the equilibrium point at $t = \frac{T}{4}$. Hence, the restoring force on the mass decreases between $t = 0$ and $t = \frac{T}{4}$ and increases between $t = \frac{T}{4}$ and $t = \frac{T}{2}$.

∴ (C) is also incorrect.

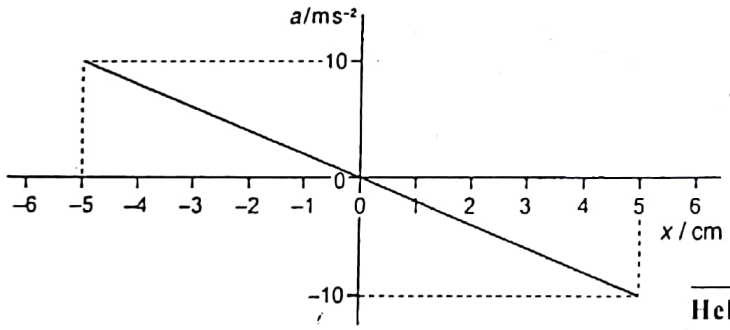
---

24. The defining equation for a particle moving in simple harmonic motion is

$$a = -\omega^2 x$$

where a is the acceleration of the particle, x is the displacement and ω is the angular frequency.

The graph shows how a varies with x for a particle moving in simple harmonic motion.



What is the amplitude and period of the motion?

	amplitude/cm	period/s
A	5.0	0.44
B	5.0	14
C	10	0.44
D	10	14

Helping *concepts*

Amplitude is maximum distance from equilibrium equals 5.0 cm.

Using the coordinate point (–5, 10),

$$10 = -\omega^2(-5 \times 10^{-2})$$

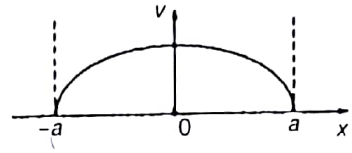
$$200 = \left(\frac{2\pi}{T}\right)^2$$

$$T = \underline{0.44\ s}$$

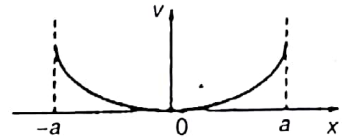
---

25. Which graph best shows how the velocity v of an object performing simple harmonic motion of amplitude a varies with displacement x for one complete oscillation?

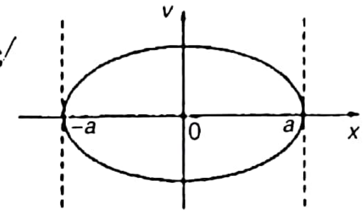
A



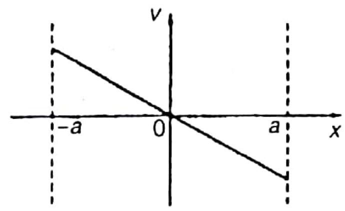
B



C



D

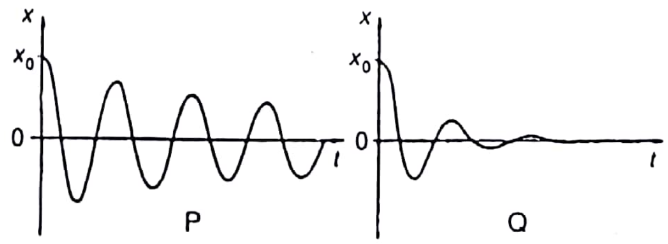


Helping *concepts*

Recall the formula: $v = \pm\omega\sqrt{a^2 - x^2}$

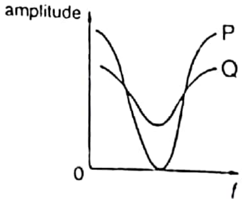
---

26. Two bodies P and Q are given an initial displacement x_0 and then released. The graphs below show how their displacement vary with time.

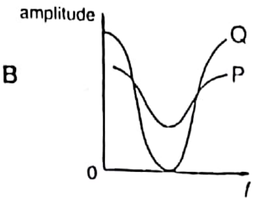


P and Q are then subjected to a driving force of constant amplitude and of variable frequency f. Which graph best represents the way in which the amplitudes of P and Q vary with f ?

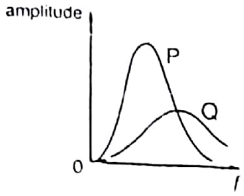
A



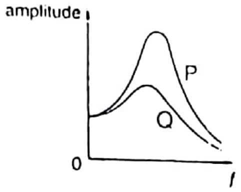
B



C



D

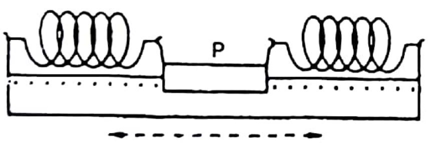


Helping concepts

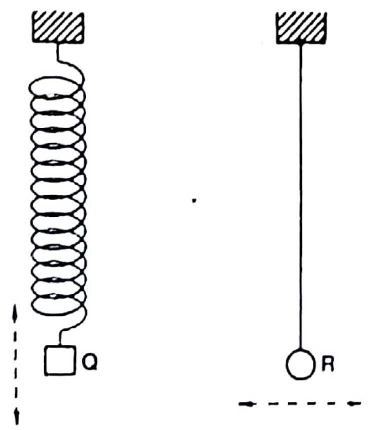
From the given graphs in the question, we observe that both P and Q have the same frequency of oscillation (same wavelength). However, Q is heavily damped as compared to P. When both bodies P and Q are subjected to forced oscillation of variable frequency f, the peak of P and Q will occur at the same frequency. P will demonstrate a higher amplitude than Q since it is lightly damped as compared to Q.

---

27. The three bodies, represented as **P**, **Q** and **R** in the diagrams below each show simple harmonic motion.



frictionless slider and springs



mass of springs *simple pendulum*

In which of these systems will the period increase if the mass of the body increases?

A P only
B Q only
C P and Q only
D Q and R only

Helping concepts

The period for each of the three systems is S.H.M. for **P** is given by

$$T = 2\pi\sqrt{\frac{m_P}{k_P}}$$

where m_p is the mass of body **P**,
k_p is the system's string constant.

The period for each of the three systems in S.H.M for **Q** is given by

$$T = 2\pi\sqrt{\frac{m_Q}{k_Q}}$$

where m_Q is the mass of body **Q**;
k_Q is the system's string constant.

The period for each of the three systems in S.H.M. for **R** is given by

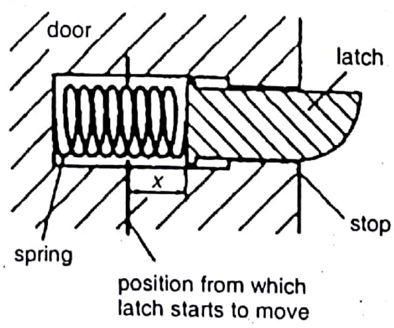
$$T = 2\pi\sqrt{\frac{l}{g}}$$

where l is the length of wire,
g is the acceleration of free fall.

If mass of the body increases, the period for both systems **P** and **Q** will increase.

---

28. A door is fitted with a spring-operated latch as shown.



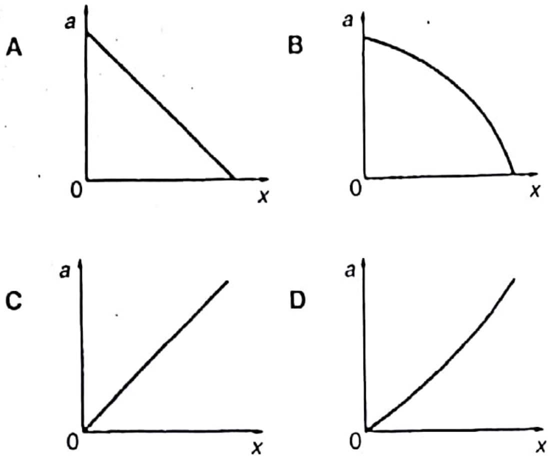
The latch is well-oiled so friction is negligible.

When the latch is pushed in, the spring becomes compressed but remains within its elastic limit.

The latch is then suddenly released.

Which graph best shows how the acceleration a of the latch varies with the distance x it moves before it is stopped?

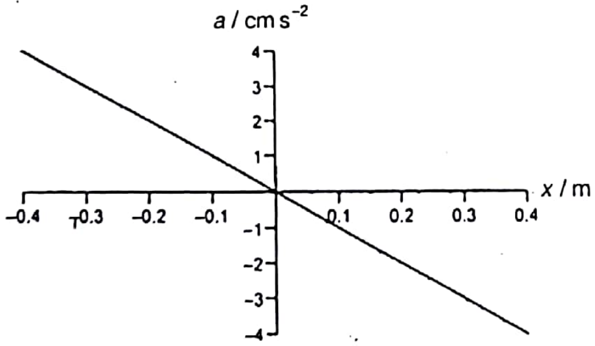
 Frequently Examined Questions



Helping concepts

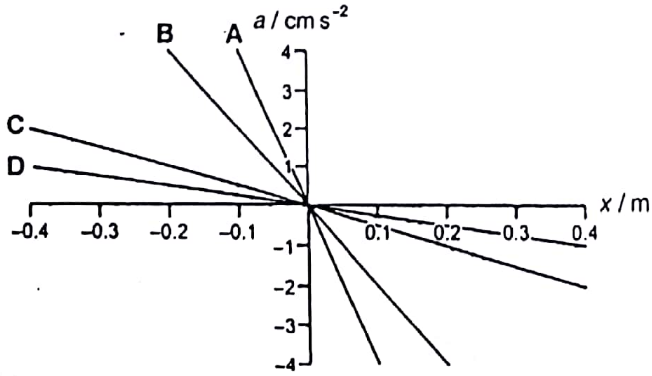
The latch performs simple harmonic motion after it is released. The acceleration is directly proportional and in opposite direction to the displacement from the equilibrium point. (Note that x is not measured from equilibrium point.)

29. The graph shows the variation of acceleration a with displacement x for an object undergoing simple harmonic motion.



The simple harmonic motion system is altered so that it has a period of oscillation twice that of before.

Which line could be produced?



Helping concepts

For simple harmonic motion, gradient of (a vs x) graph is ω^2.

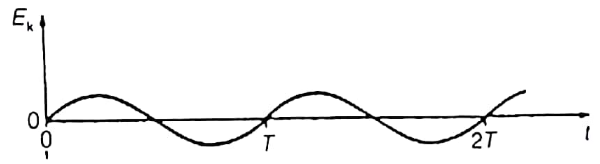
$$\text{gradient} = \omega^2 = \left(\frac{2\pi}{T}\right)^2 = \frac{4\pi^2}{T^2}$$

As period T doubles, gradient $= \dfrac{4\pi^2}{(2T)^2} = \dfrac{4\pi^2}{T^2}\left(\dfrac{1}{4}\right)$.

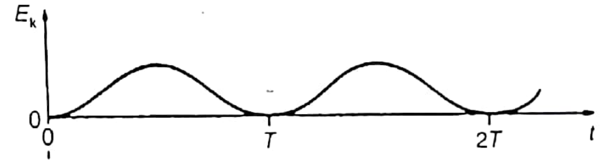
This means that the new gradient is ¼ that of the original gradient.

30. Which graph correctly shows the variation with time t of kinetic energy E_k of an object undergoing simple harmonic motion of period T?

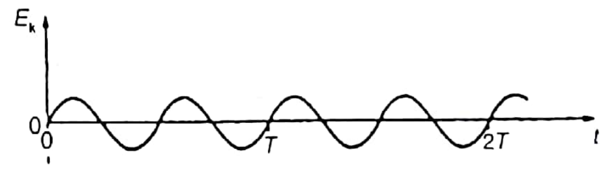
A



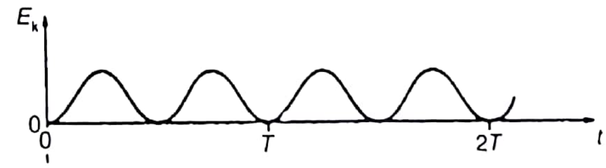
B



C



D



Helping concepts

The kinetic energy E_k of an object undergoing S.H.M. of period T is given by

$$E_k = \frac{1}{2}mv^2$$

where $\dfrac{d^2x}{dt^2} = -\omega^2 x$,

$x = a\cos(\omega t + \theta)$,

$v = \pm\omega\sqrt{a^2 - x^2}$ = velocity of the object,

$\omega = \dfrac{2\pi}{T}$ = angular frequency of the S.H.M.,

T = period of S.H.M.,

x = displacement from equilibrium position,

a = maximum displacement.

$$\Rightarrow E_k = \frac{1}{2}m\omega^2(a^2 - x^2)$$

$$= \frac{1}{2}m\omega^2 a^2\left[1-\cos^2(\omega t+\theta)\right]$$

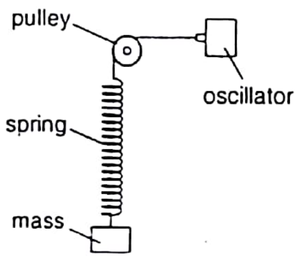
$$= \frac{1}{2}m\omega^2 a^2 \sin^2(\omega t+\theta)$$

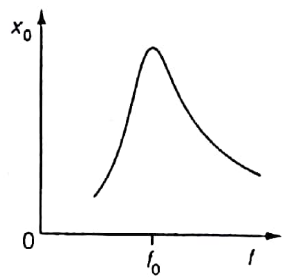
i.e. $E_k = \frac{1}{4}m\omega^2 a^2\left[1+\cos(2\omega t+2\theta)\right]$

Hence, E_k is sinusoidal with period $T/2$ and is non-negative, which is best described by graph D.

31. A mass, suspended from a helical spring, is made to oscillate.

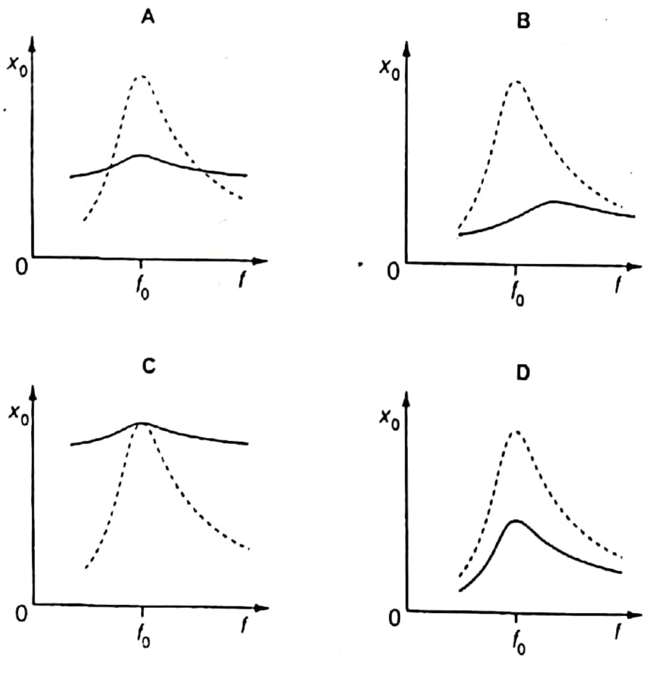
The graph shows the variation with frequency f of the amplitude x_0 of vibration of the mass.





A sheet of cardboard of negligible mass is now fixed to the mass on the spring to cause light damping of the oscillations.

Which graph shows how x_0 will vary with f over the same frequency range?



Helping concepts

The cardboard increases damping effect and amplitude will decrease. This means that the new graph will below the original graph.

TOPIC 9

Thermal Physics

Key content that you will be examined on:

1. Internal energy
2. Temperature scales
3. Specific heat capacity
4. Specific latent heat
5. First law of thermodynamics
6. The ideal gas equation
7. Kinetic energy of a molecule

Topic 9 Thermal Physics

1. For a given liquid at atmospheric pressure, which process can occur at any temperature?

A boiling B evaporation
C melting D solidification

Helping concepts

For a liquid, evaporation can take place at any temperature.

---

2. Which quantity **must** be the same for two bodies if they are to be in thermal equilibrium?

A internal energy B potential energy
C temperature D mass

Helping concepts

When two bodies are in thermal equilibrium, no energy transfer takes place between them and they are both at the same temperature.

---

3. Two bodies are in thermal equilibrium.

Which condition **must** apply?

A Their heat capacities are equal.
B Their internal energies are equal.
C They are at the same temperature.
D They emit and absorb electromagnetic radiation at the same rate.

Helping concepts

Temperature difference between bodies indicate **net** heat transfer. Hence in thermal equilibrium, the temperature must be the same for two bodies.

---

4. How is the Avogadro constant defined?

A the constant n in the equation $pV = nRT$
B the constant N in the equation $pV = NkT$
C the number of atoms in 0.012 kg of carbon-12
D the number of particles in 0.001 kg of hydrogen-1

Helping concepts

By definition, Avogadro constant is the number of atoms in 0.012 kg of carbon-12.

---

5. 20 g of oxygen at a temperature of 100 °C occupy a cubic container of side 20 cm.

The mass of a mole of oxygen is 32 g.

What is the pressure of the oxygen in the container?

A 12 kPa B 65 kPa
C 240 kPa D 7800 kPa

Helping concepts

$pV = nRT$

$$p = \frac{nRT}{V} = \frac{(\frac{20}{32})(8.31)(100+273)}{(20\times10^{-2})^3} = 242 \text{ kPa}$$

---

6. What is 273.00 K on the Celsius scale of temperature?

A −0.15 °C B 0.00 °C
C 0.15 °C D 273.15 °C

Helping concepts

The Celsius temperature, symbol θ, is defined by $\theta = T - 273.15$ where T is the thermodynamic temperature.

$\therefore$ T = 273.00 K is equivalent to $\theta = 273.00 - 273.15$
$= -0.15$ °C

---

7. What thermodynamic temperature is equivalent to 501.85 °C?

A 775.01 K B 775.00 K

C 774.85 K D 228.85 K

Helping concepts

The Celsius temperature, symbol θ, is defined by $\theta = T - 273.15$ where T is the thermodynamic temperature.

$\therefore \theta = 501.85$ °C is equivalent to $T = \theta + 273.15$
$= 501.85 + 273.15$
$= 775.00$ K

8. The temperature of a body at 100 °C is increased by $\Delta\theta$ as measured on the Celsius scale.

How is this temperature change expressed on the Kelvin scale?

A $\Delta\theta + 373$ B $\Delta\theta + 273$

C $\Delta\theta + 100$ D $\Delta\theta$

Helping concepts

Although the temperature in Kelvin is (273 + temperature in Celsius), the temperature change on either scale is the same.

9. A system absorbs 80 J through heating while doing 100 J of external work.

What is the change in the internal energy of the system?

A −100 J B −20 J

C +80 J D +180 J

Helping concepts

$\Delta U = Q + W$
$= (+80) + (-100)$
$= -20$ J

10. An ideal gas has a volume of 8.70 m³ and contains 1.44×10^{26} molecules.

Its pressure is 9.80×10^4 Pa.

What is its temperature?

A 156 K B 429 K

C 4290 K D 29 600 K

Helping concepts

$$pV = NkT$$

$$\therefore T = \frac{pV}{Nk} = \frac{(9.8 \times 10^4)(8.7)}{(1.44 \times 10^{28})(1.38 \times 10^{-23})} = 429 \text{ K}$$

11. The temperature of 1 kg of hydrogen gas is the same as that of 1 kg of helium gas if

A the gases have the same internal energy.

B the gases radiate energy at the same rate.

C the gas molecules have the same root mean square speed.

D the gas molecules have same mean translational kinetic energy.

Helping concepts

At temperature T, the average translational kinetic energy of gas is given by

$$\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$$

which is directly proportional to T.

For the same mass, the temperature of hydrogen will be the same as that of helium if both gas molecules have the same mean translational kinetic energy.

12. A temperature may be measured by using a constant-volume gas thermometer and measuring the pressure of the gas both at the triple point of water and at the unknown temperature. Which one of the following procedures is necessary if two gas thermometers, using different real gases, are to agree?

A Use gases of the same density in both thermometers.

B Use gases of the same specific heat capacity in both thermometers.

C Take readings at very low pressures in both thermometers.

D Use the same mass of gas in both thermometers.

Helping concepts

At very low pressures, all real gases behave as ideal gas and they give same temperature readings. Hence, readings should be taken at very low pressures in both thermometers.

13. Which statement concerning the evaporation and boiling of a liquid is true?

A Boiling always occurs at a higher temperature than evaporation.

B Evaporation and boiling are unaffected by changes in the surface area of the liquid.

C Evaporation occurs at any temperature whereas the boiling point depends on the external pressure.

D Evaporation results in the loss of the most energetic molecules from a liquid whereas in boiling, all molecules have the same energy.

Helping concepts

Evaporation of a liquid occurs from the surface of a liquid at all temperatures whereas boiling takes place at a temperature determined by the external pressure and consists in the formation of bubbles of vapour throughout the liquid. The pressure inside is the saturation vapour pressure (s.v.p.) at the temperature of the boiling point, that outside may be taken as practically equal to atmospheric pressure for the liquid in an open vessel. Hence, a liquid would boil when its s.v.p. equals the external pressure.

14. An electric kettle contains 500 g of water at 15 °C. The heating element of the kettle is rated at 2.2 kW and the specific heat capacity of water is 4.2×10^3 J kg^{-1} K^{-1}.

What is the minimum time it takes to raise the temperature of the water to 100 °C?

A 22 s

B 81 s

C 95 s

D 8.1×10^4 s

Helping concepts

$Q = mc\Delta\theta$

$Pt = mc\Delta\theta$

$$t = \frac{mc\Delta\theta}{P} = \frac{(500 \times 10^{-3})(4.2 \times 10^3)(100-15)}{2.2 \times 10^3} = 81\text{ s}$$

15. The thermodynamic temperature of an ideal gas is raised from T to $2T$.

Which quantity must be doubled?

A the root-mean-square speed of the molecules

B the square of the mean speed of the molecules

C the mean speed of the molecules

D the mean-square speed of the molecules

Helping concepts

Temperature of ideal gas is proportional to its kinetic energy, $\frac{1}{2}mv^2$.

When temperature is doubled, the square of mean speed should be doubled.

16. Which statement about the first law of thermodynamics is correct?

A The heating of a system equals the increase of its internal energy plus the work done on the system.

B The increase in the internal energy of a system equals the heating of the system plus the work done by the system.

C The increase in the internal energy of a system equals the heating of the system plus the work done on the system.

D The work done on a system equals the increase of its thermal energy plus the heating of the system.

Helping concepts

By defintion,

$$\Delta U = Q + W$$

where ΔU = change in internal energy of system,
Q = heat supplied to system,
W = work done on system.

17. What is the number of hydrogen atoms, in terms of the Avogadro constant N_A, in one mole of water (H_2O)?

A $\frac{1}{3}N_A$

B $\frac{2}{3}N_A$

C N_A

D $2N_A$

Helping concepts

$$1H_2O \rightarrow 2H + 1O$$

The ratio of water to hydrogen atom is 1 : 2.

Hence for one mole of water, two moles of hydrogen atoms are needed. Since one mole equals to one N_A number of molecules, $2N_A$ hydrogen atoms are needed.

---

18. Air is injected from a cylinder of compressed air into a ballon of volume V, causing its diameter to double. What is the work done against the pressure p of the atmosphere?

A pV B $3pV$

C $4pV$ D $7pV$

Helping concepts

The new volume of the ballon is now

$$V_2 = \frac{4}{3}\pi(2r)^3 = \frac{4}{3}\pi(8r^3) = 8(\frac{4}{3}\pi r^3) = 8V$$

where V_1 = initial volume of the ballon $= \frac{4}{3}\pi r^3 = V$.

Hence, the work done in expanding the ballon against the atmospheric pressure p is given by

$$\Delta W = p\Delta V = p(V_2 - V_1) = p(8V - V) = 7pV$$

---

19. The molecules of an ideal gas at thermodynamic (absolute) temperature T have a root-mean-square speed $c_{r.m.s}$.

The gas is heated to temperature $2T$.

What is the new root-mean-square speed of the molecules?

A $\sqrt{2}c_{r.m.s}$ B $2c_{r.m.s}$

C $2\sqrt{2}c_{r.m.s}$ D $4c_{r.m.s}$

Helping concepts

The root-mean-square speed is proportional to $\sqrt{T}$.

$$\therefore\ c'_{r.m.s} = \left(\sqrt{\frac{2T}{T}}\right)c_{r.m.s} = \sqrt{2}c_{r.m.s}$$

---

20. In the expressions below, R is the molar gas constant, p is the pressure, T is the thermodynamic temperature, N_A is the Avogadro constant, n is the amount of substance, k is the Boltzmann constant, and m is the mass of gas. Which one of the expressions is correct for the molar volume V_m of an ideal gas?

A $\frac{RT}{p}$ B $\frac{N_A RT}{p}$

C $\frac{nRT}{p}$ D $\frac{nkT}{p}$

Helping concepts

The ideal gas equation is given by

$$pV_m = RT$$

where p is the pressure in Pa,
V_m is the molar volume of gas in m³,
T is the absolute temperature in kelvin,
R is the molar gas constant.

$$\therefore\ V_m = \frac{RT}{p}$$

---

21. What is the approximate number of atoms in a cubic metre of an ideal gas at a temperature of 27 °C and a pressure of 1×10^5 Pa.

A 1×10^{21} B 1×10^{22}

C 6×10^{23} D 2×10^{25}

Helping concepts

Apply the ideal gas equation, we have

$$pV = nRT = \frac{N}{N_A}RT$$

where p = pressure of gas in Pa = 1×10^5 Pa;
V = volume of gas in m³ = 1 m³;
R = molar gas constant = 8.31 $JK^{-1}\ mol^{-1}$,
T = temperature in K = 27 + 273 = 300 K,
n = number of moles of gas,
N_A = Avogadro constant = $6.02 \times 10^{23}\ mol^{-1}$.

$$\therefore \text{No. of gas atoms} = \frac{pV}{RT}N_A = \frac{10^5(6.02\times10^{23})}{(8.31)(300)} \approx 2\times10^{25}$$

---

22. The root-mean-square of the molecules of an ideal gas in a sealed container is v. The gas is heated until the pressure in the container is trebled. Assuming that the volume of the container remains unchanged, the value of the r.m.s. speed is now

A $9v$. B $3v$.

C $\sqrt{3}v$. D v.

Helping concepts

The speed of molecules at temperature T is given by

$$pV = \frac{1}{3}m\bar{c}^2 = RT$$

Hence, at constant volume, r.m.s. speed of molecules is directly proportional to its pressure p. Therefore, if the pressure is trebled, the new r.m.s. speed is given by

$$\frac{\sqrt{\bar{c}^2}}{v} = \sqrt{\frac{3}{1}} \Rightarrow \sqrt{\bar{c}^2} = \sqrt{3}v$$

---

23. The values of the pressure and volume of a fixed mass of gas in a gas thermometer at the triple point of water are

$$p_{tr} = 1.00 \times 10^5 \text{ Pa}; \ V_{tr} = 1.00 \times 10^{-3} \text{ m}^3.$$

When the pressure of the gas is 1.10×10^5 Pa and its volume is 1.20×10^{-3} m^3, what is the temperature of the gas?

A 207 K B 250 K

C 273 K D 361 K

Helping concepts

Applying the ideal gas equation, we have

$$\frac{pV}{T} = \frac{(pV)_{tr}}{T_{tr}}$$

$$\frac{(1.10 \times 10^5)(1.20 \times 10^{-3})}{T} = \frac{(1.00 \times 10^5)(1.00 \times 10^{-3})}{273.16}$$

$\therefore$ Temperature of the gas, $T = \left(\frac{1.10}{1.00}\right)\left(\frac{1.20}{1.00}\right)273.16$

$= 361 \text{ K}$

---

24. An ideal gas undergoes an expansion in volume from 1.3×10^{-4} m^3 to 3.6×10^{-4} m^3 at a constant pressure of 1.3×10^5 Pa. During this expansion, 24 J of heat is supplied to the gas.

What is the overall change in the internal energy of the gas?

A decrease of 54 J B decrease of 6 J

C increase of 6 J D increase of 54J

Helping concepts

Work done on gas $= p\Delta V$

$= -(1.3 \times 10^5)(3.6 \times 10^{-4} - 1.3 \times 10^{-4})$

$= -29.9 \text{ J}$

$U = Q + W$

$= (+24) + (-29.9)$

$= -6 \text{ J}$

---

25. In a mixture of two monatomic gases X and Y in thermal equilibrium, the molecules of Y has twice the mass of those of X. The mean translational kinetic energy of the molecules of Y is 6.0×10^{-21} J.

What is the mean translational kinetic energy of the molecules of X?

A 3.0×10^{-21} J B 4.2×10^{-21} J

C 6.0×10^{-21} J D 8.5×10^{-21} J

Helping concepts

The mean translational kinetic energy of the gas molecules is given by

$$\frac{1}{2}m\bar{c}^2 = \frac{3}{2}kT$$

which is directly proportional to temperature T.

Since the two gases are in thermal equilibrium, the temperature T is the same. Therefore, both gases have the same mean translational kinetic energy and the mean translational kinetic energy of the molecules of X is 6.0×10^{-21} J.

---

26. After the pressure of the car in a bicycle tyre has been increased slightly by pumping air into it, the number of moles of air in the tyre is found to have increased by 2%, the thermodynamic temperature by 1% and the internal volume of the tyre by 0.2%.

By what percentage has the pressure of the air in the tyre increased?

A 0.4% B 1.2%

C 2.8% D 3.2%

Helping concepts

By the ideal gas equation $pV = nRT$ in its usual notation, we have

$$p = \frac{nRT}{V}$$

$$\frac{\Delta p}{p} = \left(\frac{\Delta n}{n} + \frac{\Delta T}{T} - \frac{\Delta V}{V}\right) = (2 + 1 - 0.2)\% = 2.8\%$$

---

27. The molecules in a gas have a mean spacing of 10x, where x is the mean spacing between the centres of the molecules in the liquid phase. The molecules may be assumed to be spherical.

What is the ratio $\dfrac{\text{density of liquid}}{\text{density of gas}}$?

A $\sqrt[3]{10}$ **B** $\sqrt{10}$

C 10 **D** 10^3

Helping concepts

Density of a material is inversely proportional to its volume.

∴ For some mass of the material,

$$\frac{\text{density of liquid}}{\text{density of gas}} = \frac{\text{volume of gas}}{\text{volume of liquid}}$$

$$= \left(\frac{\text{diameter of gas molecule}}{\text{diameter of liquid molecule}}\right)^3$$

$$= \left(\frac{10x}{x}\right)^3$$

$$= 10^3$$

---

28. Below are four short paragraphs describing the molecules in a beaker of water at 50 °C.

Which paragraph correctly describes the molecules?

A The molecules all travel at the same speed. This speed is not large enough for any of the molecules to leave the surface of the water. There are attractive forces between the molecules.

B The molecules have a range of speeds. Some molecules travel sufficiently fast to leave the surface of the water. There are no forces between the molecules.

C The molecules have a range of speeds. Some molecules travel sufficiently fast to leave the surface of the water. There are attractive forces between the molecules.

D The molecules have a range of speeds. The faster molecules are unable to leave the surface of the water. There are attractive forces between the molecules.

Helping concepts

Even at the same temperature of 50 °C, water molecules will have a range of speed. Evaporation occurs all the time and thus, water molecules will escape the surface of water if they move fast enough. There are attractive forces between molecules in solid and liquid state.

---

29. An ideal gas is compressed at constant temperature.

Which line of the table is correct?

	work done	heating of gas
A	work is done **by** gas	heat energy goes **into** gas
B	work is done **by** gas	heat energy goes **out of** gas
C	work is done **on** gas	heat energy goes **into** gas
D	work is done **on** gas	heat energy goes **out of** gas

Helping concepts

By first law of thermodynamics,

$$\Delta U = Q + W$$

For constant temperature, $\Delta U = 0$.

As gas is compressed, work is done <u>on</u> gas, and value of W is positive.

∴ $Q = -W$ (as $\Delta U = 0$)

Hence, heat energy goes **out of** gas.

---

30. The densities of water and steam are 1.0×10^3 kg m^{-3} and 6.1×10^{-1} kg m^{-3} respectively.

What is the ratio

$$\frac{\text{average separation of steam molecules}}{\text{average separation of water molecules}}?$$

A 12 **B** 40

C 250 **D** 1600

Helping concepts

For the same mass m of water and steam, the average separation of steam and water molecules are given by d_s and d_w respectively.

$$d_s = \sqrt[3]{\frac{m}{\rho_s}}$$

where ρ_s = density of steam = 6.1×10^{-1} kg m^{-3}.

$$d_w = \sqrt[3]{\frac{m}{\rho_w}}$$

where ρ_w = density of water = 1.0×10^3 kg m^{-3}.

$$\therefore \frac{d_s}{d_w} = \sqrt[3]{\frac{\rho_w}{\rho_s}} = \sqrt[3]{\frac{1.0\times10^3}{6.1\times10^{-1}}} = \sqrt[3]{1639} \approx 12$$

---

31. The density of liquid air is 700 times the density of gaseous air at standard temperature and pressure.

Using these data, what is the approximate value of

$$\frac{\text{mean separation of liquid air molecules}}{\text{mean separation of gaseous air molecules}}?$$

A $\frac{700}{1}$ B $\frac{700^{\frac{1}{3}}}{1}$

C $\frac{1}{700^{\frac{1}{3}}}$ D $\frac{1}{700^3}$

Helping concepts

The mean separation between two molecules is equal to its size. If d is the separation, then the volume of the molecule (assuming spherical) is given by

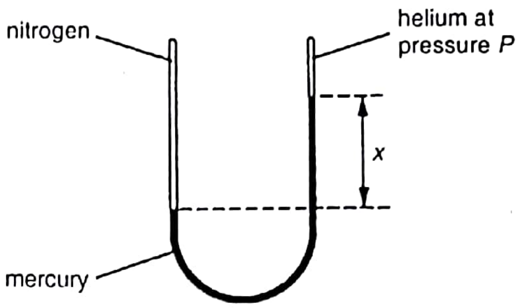
$$V = \frac{4}{3}\pi\left(\frac{d}{2}\right)^3 \propto d^3$$

i.e. density of molecule, $\rho \propto \frac{1}{V} \propto \frac{1}{d^3}$, is then inversely proportional to the mean separation d raised to the power of three.

$$\therefore \text{Ratio required} = \frac{d_{liquid}}{d_{gaseous}} = \left(\frac{\rho_{gaseous}}{\rho_{liquid}}\right)^{\frac{1}{3}} = \left(\frac{1}{700}\right)^{\frac{1}{3}} = \frac{1}{700^{\frac{1}{3}}}$$

---

32. A sealed U-tube contains nitrogen in one side and helium at pressure P in the other, as shown in the diagram. The gases are separated by mercury of density ρ. The acceleration of free fall is g.



What is the pressure of the nitrogen?

A P B $x\rho g$

C $P - x\rho g$ D $P + x\rho g$

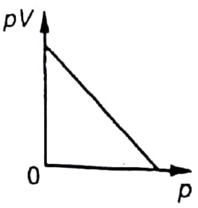
Helping concepts

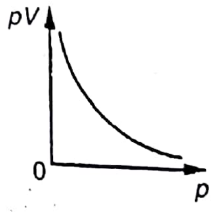
Pressure of nitrogen = pressure of helium + pressure due to height of mercury $= P + x\rho g$

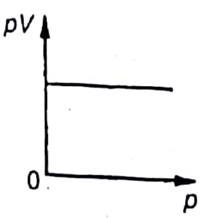
---

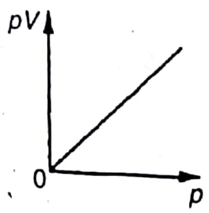
33. In an experiment to investigate the relationship between the volume V of a fixed mass of an ideal gas and its pressure p, a graph of pV against p is plotted.

Which graph shows the correct relationship at constant temperature?

A


B


C


D


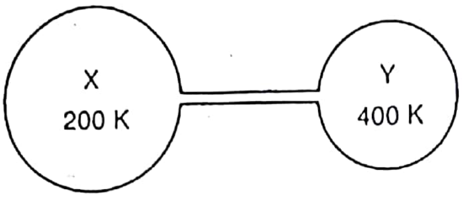
Helping concepts

Ideal gas equation: $pV = nRT$

For constant temperature, pV = a constant.

---

34. In the diagram, the volume of bulb X is twice that of bulb Y. The system is filled with an ideal gas and a steady state is established with the bulbs held at 200 K and 400 K.



There are x moles of gas in X.

How many moles of gas are in Y?

A $\frac{x}{4}$ B $\frac{x}{2}$

C x D $2x$

Helping concepts

At steady state,

$$p_X = p_Y$$
$$\frac{n_X R T_X}{V_X} = \frac{n_Y R T_Y}{V_Y}$$
$$\frac{x(200)}{2V_Y} = \frac{n_Y(400)}{V_Y} \quad (\because V_X = 2V_Y)$$
$$100x = 400n_Y$$
$$n_Y = \frac{x}{4}$$

35. A cylinder, closed by a moveable piston, contains an ideal gas at 50 °C and atmospheric pressure 1.0×10^5 Pa. The piston is moved out until the volume of the gas doubles and the temperature falls to 25 °C.

What is the new pressure of the gas in the cylinder?

A 1.6×10^4 Pa B 2.5×10^4 Pa

C 4.6×10^4 Pa D 1.9×10^5 Pa

Helping concepts

For the same amount of ideal gas, i.e. moles of gas, are constant.

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$
$$\frac{(1.0 \times 10^5)V}{50+273} = \frac{p_2(2V)}{25+273}$$
$$p_2 = 4.6 \times 10^4 \text{ Pa}$$

36. A metal ball-bearing of specific heat capacity c, moving with speed v, is brought to rest. All its kinetic energy is converted into thermal energy which it absorbs, causing a temperature rise $\Delta\theta$.

What was the value of v?

A $\frac{1}{2}c\Delta\theta$ B $2c\Delta\theta$

C $\sqrt{c\Delta\theta}$ D $\sqrt{2c\Delta\theta}$

Helping concepts

Loss in kinetic energy $= \frac{1}{2}mv^2$

Gain in thermal energy $= mc(\Delta\theta)$

By conservation of energy,

$$mc(\Delta\theta) = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{2c(\Delta\theta)}$$

37. A small quantity, mass m, of water at a temperature θ (in °C) is poured onto a large mass M of ice which is at its melting point.

If c is the specific heat capacity of water and L the specific latent heat of fusion of ice, then the mass of ice melted is given by

A $\frac{ML}{mc\theta}$ B $\frac{mc\theta}{ML}$

C $\frac{Mc\theta}{L}$ D $\frac{mc\theta}{L}$

Helping concepts

By the principle of mixture,

heat given out by water
= heat absorbed by the melted ice

$$\therefore mc(\theta - 0) = ML \Rightarrow M = \frac{mc\theta}{L}$$

38. A car tyre, initially at 25 °C, has been inflated to a pressure of 200 kPa as indicated by the pressure gauge. This means that the pressure in the tyre is 200 kPa above atmospheric pressure of 100 kPa.

After driving on hot roads, the temperature of the air in the tyre is 50 °C.

What is the percentage increase in the pressure gauge reading?

A 8.4%   B 12.5%
C 100%   D 150%

Helping concepts

At constant volume,

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$\frac{200+100}{273+25} = \frac{p_2}{273+50}$$

$$p_2 = 325 \text{ kPa}$$

Indicator will be $325 - 100 = 225$ kPa.

$$\text{Percentage increase} = \frac{225-200}{200} \times 100\% = 12.5\%$$

---

39. The air in an aircraft when travelling has

8 MJ of kinetic energy as a result of the motion of the aircraft;

30 MJ of kinetic energy as a result of the random movement of the air molecules;

75 MJ of potential energy as a result of the altitude of the aircraft;

−3 MJ of potential energy as a result of intermolecular attraction between the air molecules.

What is the internal energy of the air in the aircraft?

A 27 MJ   B 33 MJ
C 35 MJ   D 110 MJ

Helping concepts

Internal energy of molecules

= random KE of molecules + intermolecular PE of molecules

= (30) + (−3)

= 27 MJ

---

40. An electric kettle contains 1.5 kg of water at 100 °C and is powered by a 2.0 kW electric element.

If the thermostat of the kettle fails to operate, approximately how long will the kettle take to boil dry?

[Take the specific latent heat of vaporisation of water as 2000 kJ kg^{-1}.]

A 500 s   B 1000 s
C 1500 s   D 3000 s

Helping concepts

If t is the time taken to boil the water dry, then

$$Pt = Q = mL$$

where P = electric power supplied = 2.0 kW,
Q = heat energy absorbed by water,
m = mass of water = 1.5 kg,
L = specific latent heat of vaporisation of water = 2000 kJ kg^{-1}.

$$\therefore\ (2.0 \times 10^3)t = (1.5)(2000 \times 10^3) \Rightarrow t = 1500 \text{ s}$$

---

41. The internal energy of a fixed mass of an ideal gas depends on

A pressure, but not volume or temperature.
B temperature, but not pressure or volume.
C volume, but not pressure or temperature.
D pressure and temperature, but not volume.

Helping concepts

The change in internal energy ΔU of a fixed mass of an ideal gas is given by

$$\Delta U = c_v \cdot \Delta T$$

where c_v is the molar heat capacity of gas at constant volume,
ΔT is the change in temperature.

Hence, internal energy of the ideal gas is dependent only on its temperature, not the volume nor its pressure.

---

42. A fixed mass of an ideal gas absorbs 1000 J of heat and expands under a constant pressure of 20 kPa from a volume of 25×10^{-3} m^3 to a volume of 50×10^{-3} m^3.

What is the change in internal energy of the gas?

A −1000 J   B −500 J
C zero   D +500 J

Helping concepts

From the first law of thermodynamics,

$$\Delta Q = \Delta U + p\Delta V$$

$p\Delta V = 20 \times 10^3(50 \times 10^{-3} - 25 \times 10^{-3}) = 500$ J

Given $\Delta Q = 1000$ J.

$\therefore$ Change in internal energy, $\Delta U = \Delta Q - p\Delta V$
$= 1000 - 500$
$= 500$ J

Helping concepts

The specific heat capacity, $c = \dfrac{Q}{m\Delta\theta}$

$= \dfrac{\text{power} \times \text{time}}{\text{mass} \times \Delta\theta}$

$= \dfrac{(1.0 \times 10^3)(180)}{(1.5)(357 - 300)}$

$= 2100 \text{ J kg}^{-1} \text{ K}^{-1}$

43. Which statement about internal energy is **correct**?

- **A** The internal energy of a system can be increased without transfer of energy by heating.
- **B** The internal energy of a system depends only on its temperature.
- **C** When the internal energy of a system is increased, its temperature always rises.
- **D** When two system have the same internal energy, they must be at the same temperature.

Helping concepts

$$\Delta U = \Delta Q + p\Delta V$$

Statement A is *correct* because the internal energy of a system can be increased by doing work ($p\Delta V$) on the system. Statements B, C and D are incorrect as the underlying assumption for all of them is that internal energy depends only on the temperature of the system. However, this holds only when the system is an ideal gas.

44. In an experiment to determine the specific heat capacity of a liquid by an electrical method, a student obtained the following results.

mass of liquid heated	1.5 kg
initial liquid temperature	300 K
final liquid temperature	357 K
electrical power of heater	1.0 kW
time of heating	180 s

What is the specific heat capacity of the liquid?

- **A** 2.1 J kg^{-1} K^{-1}
- **B** 18 J kg^{-1} K^{-1}
- **C** 1800 J kg^{-1} K^{-1}
- **D** 2100 J kg^{-1} K^{-1}

45. Which statement describes the internal energy of a system?

- **A** The maximum amount of work that can be extracted from the system.
- **B** The sum of the kinetic and potential energies of the particles in the system.
- **C** The total amount of work which has been done on the system.
- **D** The thermal energy needed to raise the temperature of the system by one kelvin.

Helping concepts

The definition of the internal energy of a system is the sum of the kinetic and potential energies of the molecules of the system.

Note that an ideal gas is assumed to have no intermolecular forces of attraction, i.e. zero potential energy. Hence, the internal energy of an ideal gas is the kinetic energy of all the molecules of the gas.

46. The temperature of a hot liquid in a container of negligible heat capacity falls at a rate of 2 K per minute just before it begins to solidify. The temperature then remains steady for 20 minutes by which time the liquid has all solidified.

What is the value of the ratio

$$\frac{\text{specific heat capacity of liquid}}{\text{specific latent heat of fusion}}?$$

- **A** $\frac{1}{40}$ K^{-1}
- **B** $\frac{1}{10}$ K^{-1}
- **C** 10 K^{-1}
- **D** 40 K^{-1}

Helping concepts

Assuming that the rate at which heat is removed remains constant,

$$mc\frac{\Delta\theta}{\Delta t} = \frac{mL}{T}$$

$$\frac{c}{L} = \frac{1}{\frac{\Delta\theta}{\Delta t}} \times \frac{1}{T} = \frac{1}{2\text{ K min}^{-1}} \times \frac{1}{20\text{ min}} = \frac{1}{40}\text{ K}^{-1}$$

47. An airgun pellet, mass m and specific heat capacity c, hits a steel plate at speed v. During the impact, 50% of the pellet's kinetic energy is converted to thermal energy in the pellet.

What is the rise in temperature of the pellet?

A $\frac{v^2}{2c}$ B $\frac{v^2}{4c}$

C $\frac{mv^2}{2c}$ D $\frac{mv^2}{4c}$

Helping concepts

Thermal energy in the pellet is

$$\theta = \frac{1}{2}(\text{kinetic energy of the pellet})$$
$$= \frac{1}{2}(\frac{1}{2}mv^2)$$
$$= \frac{1}{4}mv^2$$

The rise in temperature of the pellet, θ, is given by

$$mc\theta = Q \Rightarrow mc\theta = \frac{1}{4}mv^2 \Rightarrow \theta = \frac{v^2}{4c}$$

48. The contents of a refrigerator are at a constant temperature, and the surroundings of the refrigerator are at a higher temperature. Because of this, thermal energy flows into the refrigerator from outside, and is removed at the same rate by the cooling mechanism.

The first law of thermodynamics may be applied to the contents of the refrigerator. This law is represented by $\Delta U = Q + W$, where ΔU is the increase of internal energy of the contents of the refrigerator, Q is the net heating of the contents, and W is the mechanical work done on the contents. For the refrigerator contents, which of the quantities ΔU, Q and W is/are zero?

A ΔU only B Q only

C W only D each of ΔU, Q and W

Helping concepts

There is thermal energy flows into the refrigerator from its surrounding and this implies that $Q \neq 0$. This same thermal energy supply is being removed at the same rate, i.e. $W \neq 0$. Since the temperature of the contents is kept constant, this means that $\Delta U = 0$.

49. In a heating experiment, it was noted that the temperature of liquid in a beaker rose at 4.0 K per minute just before it began to boil, and that 40 minutes later all the liquid had boiled away.

For this liquid, what is the numerical ratio

$$\frac{\text{specific heat capacity}}{\text{specific latent heat of vaporisation}}?$$

A $\frac{1}{10}$ B $\frac{1}{40}$

C $\frac{1}{160}$ D $\frac{1}{640}$

Helping concepts

The rate of heat supply P remains constant throughout the experiment.

If m is the mass of the liquid, c is its specific heat capacity and L is its specific latent heat of vaporisation. Hence, just before the liquid starts to boil.

$$P = \frac{Q}{t} = mc\frac{\Delta\theta}{\Delta t} = 4mc$$

where Q is the heat absorbed, $\frac{\Delta\theta}{\Delta t} = 4\text{ K min}^{-1}$.

During the next 40 minutes,

$$P = \frac{Q}{t} = mL(\frac{1}{40}) = \frac{mL}{40}$$

$$\therefore\ 4mc = \frac{mL}{40} \Rightarrow \frac{c}{L} = \frac{1}{4(40)} = \frac{1}{160}$$

50. The first law of thermodynamics may be expressed as shown.

$$\Delta U = Q + W$$

where ΔU is the change in internal energy,
Q is the heating of the system,
W is the work done on the system.

A fixed mass of ideal gas at high pressure is contained in a balloon. The balloon suddenly bursts, causing the gas to expand and cool.

In this situation, which row describes the values of ΔU, Q and W?

	ΔU	Q	W
A	negative	negative	positive
B	negative	zero	negative
C	positive	zero	negative
D	positive	negative	positive

Helping *concepts*

As the gas expands, W is negative.

Also, ΔU decreases as gas expands.

There is no heat supplied to the system. The cooling occurs because of expansion.

---

51. Cooling water enters the heat exchanger in the turbine hall of a nuclear power station at 6 °C and leaves at 14 °C. The specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

If the rate of heat removal by the water is 6.72×10^9 J per minute, what is the rate of water flow?

A $\dfrac{6.72 \times 10^9}{4200 \times 8}$ kg s^{-1} B $\dfrac{6.72 \times 10^9 \times 60}{4200 \times 8}$ kg s^{-1}

C $\dfrac{6.72 \times 10^9}{4200 \times 8 \times 60}$ kg s^{-1} D $\dfrac{4200 \times 8}{6.72 \times 10^9 \times 60}$ kg s^{-1}

Helping *concepts*

The rate of heat absorption by the water is

$$\frac{Q}{t} = \frac{mc(\theta_o - \theta_i)}{t} = (\frac{m}{t})c(\theta_o - \theta_i)$$

where $\frac{Q}{t}$ = heat removal per second = $\frac{6.7 \times 10^9}{60}$ J s^{-1},

c = specific heat capacitor of water = 4200 J kg^{-1} K^{-1},

θ_i = temperature of water entering the heat exchanger = 6 °C,

θ_o = temperature of water leaving the heat exchanger = 14 °C,

$\frac{m}{t}$ = rate of water flow in kg s^{-1}.

$$\therefore \frac{m}{t} = (\frac{Q}{t})(\frac{1}{c(\theta_o - \theta_i)})$$

$$= \frac{6.72 \times 10^9}{60 \times 4200 \times (14 - 6)}$$

$$= \frac{6.72 \times 10^9}{4200 \times 8 \times 60} \text{ kg s}^{-1}$$

---

52. A 20 W filament lamp has been operating normally for an hour so that its temperature is constant.

When the first law of thermodynamics is used to quantitatively describe the filament of the lamp after this time, which row correctly describes the application of the first law?

	rate of increase of internal energy / W	rate of heating the filament / W	rate of doing work on filament / W
A	+20	+20	0
B	+20	0	+20
C	0	+20	−20
D	0	−20	+20

Helping *concepts*

As temperature is constant, change in internal energy, $\Delta U = 0$ J.

As power is continuously supplied, rate of heating, $(\frac{Q}{t})$ is $+20$ W.

To use a modified first law of thermodynamics,

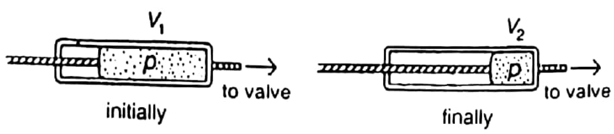
$$\frac{\Delta U}{t} = \frac{Q}{t} + \frac{W}{t}$$

$$0 = (+20) + \frac{W}{t}$$

$$\frac{W}{t} = -20 \text{ W}$$

---

53. Air in a bicycle pump is forced through a valve at a constant pressure p. In one stroke of the pump, the volume of air in the pump chamber is reduced from V_1 to V_2.



What is the work done on this air in one stroke of the pump?

A $\frac{p(V_1 + V_2)}{2}$ B $p(V_1 + V_2)$

C $p(V_1 - V_2)$ D pV_1

Helping concepts

Magnitude of work done, $W = |p\Delta V|$

$= |p(V_2 - V_1)|$

$= p(V_1 - V_2)$ (as $V_1 > V_2$)

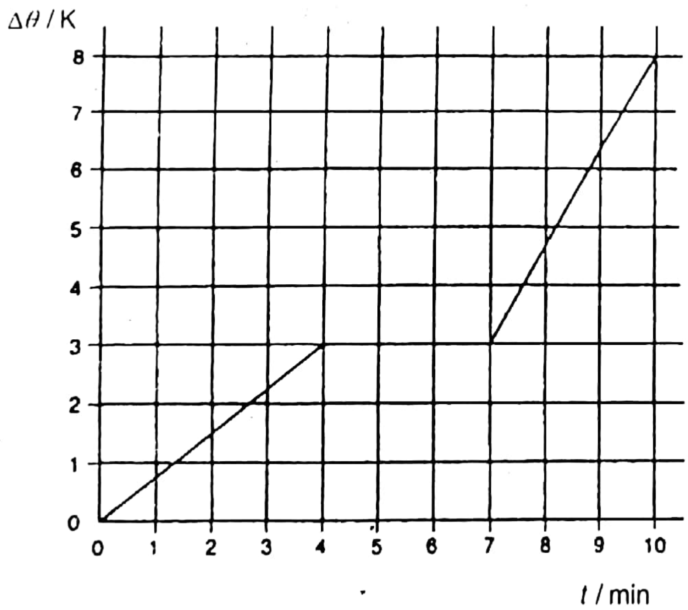
As the volume of gas compresses, there is positive value of work done on gas.

$\therefore$ Work done $= p(V_1 - V_2)$

---

54. The graph shows the variation of temperature change $\Delta\theta$ with time t for 1 kg of a substance, initially solid at room temperature.

The substance is heated at a uniform rate of 2000 J min^{-1}.



What can be deduced from this graph?

A After 4 min of heating, the substance is all liquid.

B After 10 min of heating, the substance is all gaseous.

C The specific heat capacity of the substance is greater when liquid than when solid.

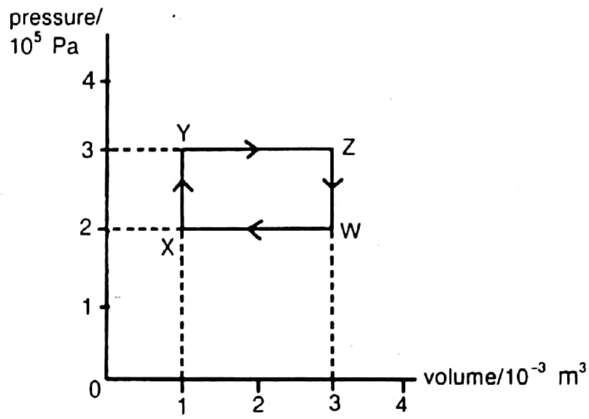
D The specific latent heat of fusion of the substance is 6000 J kg^{-1}.

Helping concepts

From time $t = 4$ to $t = 7$, there is no temperature change even though heat is continuously being applied. During this time, the substance undergoes the melting process. The amount of heat required to melt 1 kg of a substance is called the *specific latent heat of fusion.* In this case, as the substance takes 3 minutes to melt completely, the amount of heat required = 2000 × 3 = 6000 J, i.e. its specific latent heat of fusion is 6000 J.

---

55. A gas undergoes the cycle of pressure and volume changes W → X → Y → Z → W shown in the diagram.



What is the net work done by the gas?

A −600 J B −200 J

C 0 J D 200 J

Helping concepts

The net work done by the gas is positive and is given by the enclosed area defined by WXYZ.

Hence, the net work done is

$$\Delta W = (3 \times 10^5 - 2 \times 10^5)(3 \times 10^{-3} - 1 \times 10^{-3})$$
$$= (1 \times 10^5)(2 \times 10^{-3})$$
$$= 2 \times 10^2$$
$$= 200 \text{ J}$$

---

56. The first law of thermodynamics states that ΔU, the change of internal energy of a system, is related to ΔQ, the heat supplied to it and ΔW, the work done on it by the equation

$$\Delta U = \Delta Q + \Delta W.$$

What are ΔQ, ΔU and ΔW for a constant mass of ideal gas which is cooled at constant pressure?

	ΔU	ΔQ	ΔW
A	negative	negative	positive
B	negative	negative	zero
C	zero	negative	positive
D	negative	zero	negative

Helping *concepts*

When the gas is cooled at constant pressure, it is compressed and hence positive work is done on the gas, i.e. ΔW = positive. At the same time, heat is drawn away from it when it is cooled and therefore, ΔQ is negative.

Now, the equation of state of the gas gives $pV = RT$ for a mole of gas.

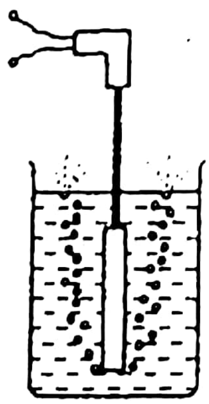
Since p is constant and V is reduced, the thermodynamic temperature of the gas T also decreases.

Internal energy of the gas depends only on its temperature, the internal energy is thus reduced or ΔU is negative.

In summary, when the gas is cooled at constant pressure, by first law of thermodynamics,

ΔU = negative; ΔQ = negative; ΔW = positive.

57. In an experiment to find its specific latent heat of vaporisation, water is vaporised using an immersion heater as shown.



Two sources of error in this experiment are:

error 1 water splashing out of the container;

error 2 vapour condensing on the handle of the heater and dripping back into the container.

What is the effect of these two experimental errors on the calculated value for the specific latent heat?

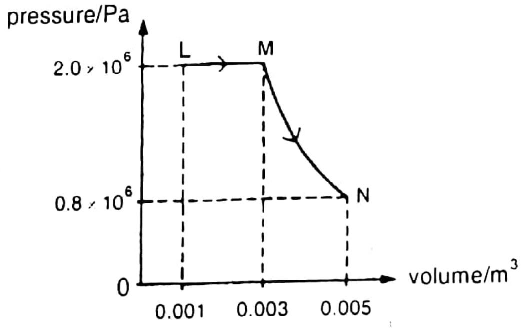
	error 1	error 2
A	decrease	decrease
B	decrease	increase
C	increase	decrease
D	increase	increase

Helping *concepts*

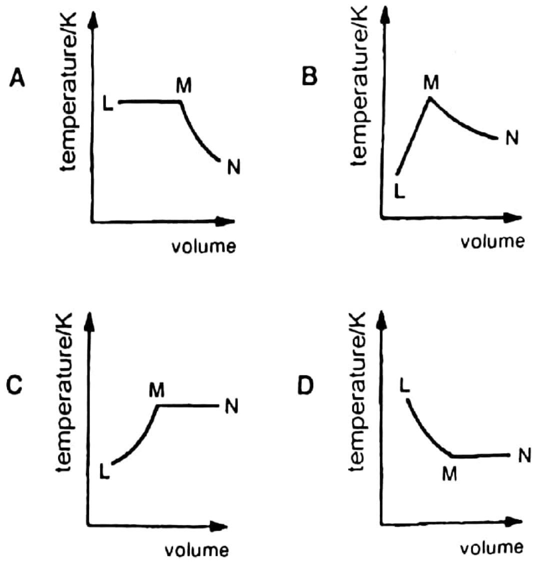
When water splashes out of the container, the mass of water in the container falls below the measured mass.

Since specific latent heat is given by $\frac{\text{heat required}}{\text{mass}}$, the calculated value of specific latent heat as a result of this error will increase. Conversely, when vapour condenses and drips back into the container, the mass of water in the container increases, resulting in a decrease in the calculated value of specific latent heat.

58. A fixed mass of ideal gas undergoes changes of pressure and volume starting at **L**, as shown.



Which graph shows how temperature (measured in kelvin) changes with volume?



Helping concepts

Applying the equation of state,

$$\frac{pV}{T} = \text{constant}$$

$$\frac{2.0 \times 10^6 \times 0.003}{T_M} = \frac{2.0 \times 10^6 \times 0.001}{T_L}$$

$$T_M = 3T_L$$

Again, $$\frac{0.8 \times 10^6 \times 0.005}{T_N} = \frac{2.0 \times 10^6 \times 0.003}{T_M}$$

$$T_N = 0.67T_M$$

$$T_M = 1.5T_N$$

T_M is greater than T_L or T_N.

Comparatively, $3T_L = 1.5T_N = T_M$

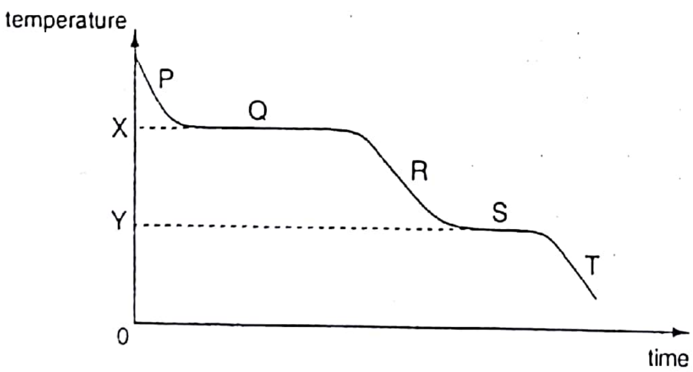
$$2T_L = T_N$$

Hence, T_N is greater than T_L.

In summary, $T_M > T_N > T_L$.

59. A vapour in a container is at a high temperature and loses heat to its surroundings.

The graph shows how its temperature changes over the next few minutes.



Which feature of the graph indicates that the specific latent heat of vaporisation of the substance is greater than its specific latent heat of fusion?

A The gradient of the graph at P is greater than the gradient at R.

B The gradient of the graph at T is greater than the gradient at R.

C The length of the line Q is greater than the length of the line S.

D The value of X is greater than the value of Y.

Helping concepts

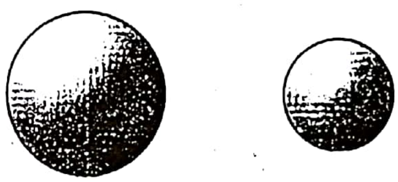
$$\text{Latent heat} = \frac{\text{energy loss}}{\text{mass}}$$

$$= \frac{(\text{rate of heat loss}) \times \text{time}}{\text{mass of substance}}$$

Assuming rate of heat loss is constant, value of latent heat is proportional to time taken.

Therefore, the longer length of Q compared to S means the specific heat of vaporisation is larger than its fusion.

60. Two spheres P and Q are both made of steel. Sphere P has a radius that is larger than that of sphere Q.



sphere P temperature T_P sphere Q temperature T_Q

Initially, sphere P is at temperature T_P and sphere Q is at temperature T_Q, where $T_P > T_Q$.

The spheres are brought into contact and their final temperature is T. No thermal energy is transferred from the spheres to the surroundings.

Which expression gives the relation between T_P, T_Q and T?

A $(T_P - T) = (T - T_Q)$

B $(T_P - T) > (T - T_Q)$

C $(T_P - T) < (T - T_Q)$

D $(T_P - T) = (T + T_Q)$

Helping concepts

$$\text{heat loss by P} = \text{heat gained by Q}$$

$$m_P c(T_P - T) = m_Q c(T - T_Q)$$

where c is the heat capacity of steel for both P and Q.

$$m_P(T_P - T) = m_Q(T - T_Q)$$

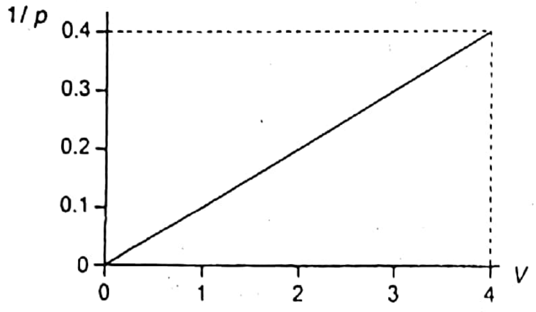
Since volume of sphere P > sphere Q,

$$m_P > m_Q$$

$$(T_P - T) < (T - T_Q)$$

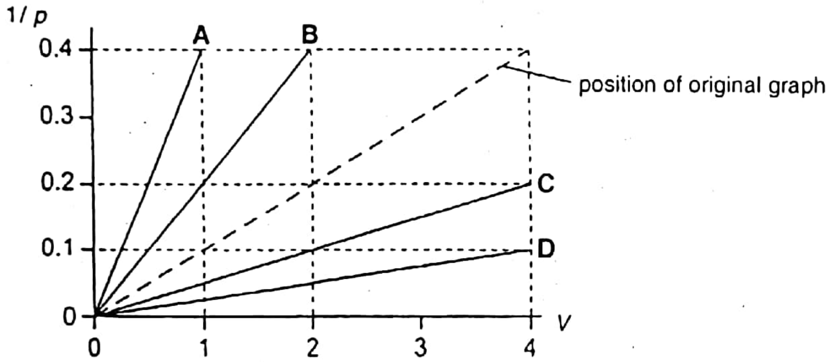
61. A fixed amount of an ideal gas has pressure p and volume V.

The graph shows the variation of $1/p$ with V at a constant temperature.



The amount of gas and the thermodynamic temperature are both doubled.

Which line will be produced?



Helping *concepts*

Ideal gas equation: $pV = nRT$

$$\therefore \frac{1}{p} = \left(\frac{1}{nRT}\right)V$$

As amount of gas n is doubled, thermodynamic temperature T is doubled.

$$\therefore \frac{1}{p} = \frac{1}{(2n)R(2T)}V = \frac{1}{4}\left(\frac{1}{nRT}\right)V$$

Hence, the new graph should be of 1/4 of the original gradient.

TOPIC

10

Wave Motion

Key content that you will be examined on:

1. Progressive waves
2. Transverse and longitudinal waves
3. Polarisation
4. Determination of frequency and wavelength

Topic 10 Wave Motion

1. What do **not** travel at the speed of light in a vacuum?

   A electrons B microwaves
   C radio waves D X-rays

Helping concepts

By definition, electromagnetic waves (microwaves, radio waves and X-rays) travel at speed of light in vacuum.

2. Which of the following types of wave can be polarised?

   A a longitudinal progressive wave
   B a longitudinal stationary wave
   C a transverse stationary wave
   D a transverse sound wave

Helping concepts

Only a transverse wave can be polarised. A sound wave is longitudinal, not transverse.

3. Which one of the following could be the frequency of ultra-violet radiation?

   A 1.0×10^6 Hz
   B 1.0×10^9 Hz
   C 1.0×10^{12} Hz
   D 1.0×10^{15} Hz

Helping concepts

Ultra-violet radiation has its wavelength, λ, at the order of 10^{-7} m. Hence, its frequency is of the order given by

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8}{10^{-7}} \approx 3 \times 10^{15} \text{ Hz}$$

i.e. at the order of 10^{15} Hz.

4. The number of wavelengths of visible light in one metre is of the order of

   A 10^4. B 10^6.
   C 10^8. D 10^{10}.

Helping concepts

Average wavelength of light $= 5.0 \times 10^{-7}$ m

In 1 m, there are $\frac{1}{5.0 \times 10^{-7}} = 2.0 \times 10^6$ wavelengths of light.

5. If a wave can be polarised, it **must** be

   A an electromagnetic wave.
   B a longitudinal wave.
   C a progressive wave.
   D a transverse wave.

Helping concepts

Transverse waves can be polarised. These include all electromagnetic waves such as light, radio waves and X-rays. On the other hand, longitudinal waves such as sound cannot be polarised.

6. Which of the following gives three regions of the electromagnetic spectrum in order of increasing wavelength?

   A gamma rays, microwaves, visible radiation
   B radio waves, ultra-violet, X-rays
   C ultra-violet, infra-red, microwaves
   D visible radiation, gamma rays, radio waves

Helping concepts

Increasing order (from shortest to longest) of wave lengths for electromagnetic spectrum is gamma rays, X-rays, ultra-violet, visible light, infra-red, microwaves, radio waves.

7. The wavelength of a radio wave and that of an X-ray are in the ratio $10^m : 1$.

Which of the following is a possible value for m?

A +24 B +12

C −12 D −24

Helping concepts

The wavelength of an X-ray ranges from 10^{-12} to 10^{-8} m, and the wavelength of a radio wave ranges from 10^{-1} to 10^4 m.

8. Which line of the table gives correct wavelengths for infra-red radiation and for X-rays?

	infra-red radiation	X-rays
A	3×10^{-7} m	3×10^{-12} m
B	3×10^{-7} m	3×10^{-10} m
C	3×10^{-6} m	3×10^{-12} m
D	3×10^{-6} m	3×10^{-10} m

Helping concepts

The approximate wavelengths for infra-red radiation and X-rays are 10^{-6} and 10^{-10} m respectively.

9. A health inspector is measuring the intensity of a sound. Near a loudspeaker his meter records an intensity I. This corresponds to an amplitude A of the sound wave. At another position, the meter gives an intensity reading of $2I$.

What is the corresponding sound wave amplitude?

A $\frac{A}{\sqrt{2}}$ B $\sqrt{2}A$

C $2A$ D $4A$

Helping concepts

Using intensity $\propto$ (amplitude)^2,

$$I \propto A^2 \text{ ------(1)}$$
$$2I \propto A_1^2 \text{ ------(2)}$$

$$\frac{(2)}{(1)}: 2 = \left(\frac{A_1}{A}\right)^2 \Rightarrow A_1 = \sqrt{2}A$$

10. The metre was defined in terms of the wavelength λ of the orange spectral line emitted by excited atoms of Krypton-86. Thus 1 metre $= n\lambda$, where n is the number of wavelengths in 1 metre of vacuum.

What is the best value for n?

A 1.43×10^4 B 1.65×10^6

C 2.00×10^8 D 3.33×10^{12}

Helping concepts

The best value for the wavelength of orange spectral line is $\lambda = 610$ nm.

$$\therefore n = \frac{1}{\lambda} = \frac{1}{610 \times 10^{-9}} \approx 1.65 \times 10^6$$

11. A progressive sound wave is a means of transferring energy.

A progressive sound wave of constant frequency is generated in air. The intensity of energy transfer is directly proportional to another of the wave parameters.

Which of the following is correct?

A intensity $\propto$ (amplitude)^2

B intensity $\propto$ (periodic time)^2

C intensity $\propto$ (speed)^2

D intensity $\propto$ (wavelength)^2

Helping concepts

By definition, intensity of wave is proportional to the squared of the amplitude of the wave.

12. Data transmitted along glass-fibre cables is in the form of pulses of monochromatic red light each of duration 2.5 ns. Which of the following is the best estimate of the number of wavelength in each pulse?

A 10^3 B 10^6

C 10^9 D 10^{12}

Helping concepts

The wavelength of the red light is 7.5×10^{-7} m. Its frequency is thus given by

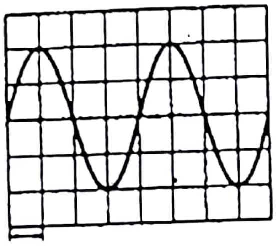
$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^8}{7.5 \times 10^{-7}} = 4.0 \times 10^{14} \text{ Hz}$$

Hence, the number of wavelength, n, in each pulse of duration 2.5 ns is calculated to be

$$n = ft = (4.0\times10^4)(2.5\times10^{-9}) = 10^6$$

---

13. The trace shown appeared on an oscilloscope screen with the time-base set to 2.0 ms cm^{-1}.



What was the frequency of the signal?

A 40 Hz
B 125 Hz
C 250 Hz
D 500 Hz

Helping concepts

Oscilloscope's time-base setting = 2.0 ms cm^{-1}

Period of the signal from the screen = 4 cm

$$\therefore \text{Frequency of the signal} = \frac{1}{T} = \frac{1}{(2.0\times10^3)\times4} = 125\text{ Hz}$$

---

14. Ultra-violet rays differ from X-rays in that ultra-violet rays

A cannot be diffracted.
B cannot be polarised.
C do not affect a photographic plate.
D have a lower frequency.

Helping concepts

Both ultra-violet rays and X-rays are electromagnetic waves that possess the same wave properties.

Wavelength of ultra-violet rays is 10^{-7} to 10^{-8} m; whereas wavelength of X-rays is of the order of 10^{-10} m.

Wavelength is inversely proportional to wave frequency and hence uv rays have a lower frequency than that of X-rays.

---

15. Sound wave X has intensity 10^{12} times greater than that of sound wave Y.

By how much is the amplitude of X greater than the amplitude of Y?

A 10^6 times
B 3.16×10^6 times
C 5×10^{11} times
D 10^{12} times

Helping concepts

Intensity, $I \propto Amp^2$------(1)

$10^{12} I \propto A^2$------(2)

$\frac{(2)}{(1)}$: $10^{12} = (\frac{A}{Amp})^2 \Rightarrow 10^6(Amp) = A$

---

16. Which effect provides direct experiment evidence that light is a transverse, rather than a longitudinal wave motion?

A Light can be diffracted.
B Two coherent light waves can be made to interfere.
C The intensity of light from a point source falls off inversely as the square of the distance from the source.
D Light can be polarised.

Helping concepts

Sound, a longitudinal wave, can be diffracted, can be made to interfere, whose intensity falls off inversely as the square of distance from the source, but cannot be polarised.

Light, a transverse wave, can be diffracted, can be made to interfere, whose intensity falls off inversely as the square of distance from the source, can also be polarised.

---

17. Which one of the following summarises the change in wave characteristics on going from infra-red to X-rays in the electromagnetic spectrum?

	frequency	wavelength (in a vacuum)	speed (in a vacuum)
A	decreases	increases	decreases
B	decreases	increases	remains constant
C	remains constant	decreases	decreases
D	increases	decreases	remains constant

Helping concepts

Although infra-red has longer wavelength (750 nm to 10^5 nm) than X-rays, both travels at the speed of light in vacuum. Hence, frequency increases from the order of 10^{14} Hz to 10^{18} Hz when going from infra-red to X-rays in the electromagnetic spectrum.

---

18. A plane wave of amplitude A is incident on a surface of area S placed so that it is perpendicular to the direction of travel of the wave. The energy per unit time reaching the surface is E.

    The amplitude of the wave is increased to $2A$ and the area of the surface is reduced to $\frac{1}{2}S$.

    How much energy per unit time reaches this smaller surface?

    A $4E$ B $2E$

    C E D $\frac{1}{2}E$

Helping concepts

energy $\propto$ amplitude

Hence, the energy per unit time that reaches the smaller surface is $2E$ since the amplitude of the wave is doubled.

---

19. Data transmitted along glass-cables is in the form of pulses of monochromatic red light each of duration 2.5 ns.

    Which of the following is the best estimate of the number of wavelengths in eqch pulse?

    A 10^3 B 10^6

    C 10^9 D 10^{12}

Helping concepts

The wavelength of the red light is 7.5×10^{-7} m. Its frequency is thus given by

$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^8}{7.5 \times 10^{-7}} = 4.0 \times 10^{14} \text{ Hz}$$

Hence, the number of wavelength, n, in each pulse of duration 2.5 ns is calculated to be

$$n = ft = (4.0 \times 10^{14})(2.5 \times 10^{-9}) = 10^6$$

---

20. Progressive waves of frequency 300 Hz are superimposed to produce a system of stationary waves in which adjacent nodes are 1.5 m apart. What is the speed of the progressive waves?

    A 100 ms^{-1} B 200 ms^{-1}

    C 450 ms^{-1} D 900 ms^{-1}

Helping concepts

The distance 1.5 m corresponds to half of a wavelength, λ.

The wavelength is thus given by

$$\lambda = 2(1.5) = 3.0 \text{ m}$$

The speed of the wave,

$$v = f\lambda = (300)(3) = 900 \text{ ms}^{-1}$$

---

21. A sound wave of amplitude 0.20 mm has an intensity of 3.0 Wm^{-2}.

    What will be the intensity of a sound wave of the same frequency which has an amplitude of 0.40 mm?

    A 4.2 Wm^{-2} B 6.0 Wm^{-2}

    C 9.0 Wm^{-2} D 12 Wm^{-2}

Helping concepts

For sound wave at particular frequency, its intensity I is proportional to the square of its amplitude A,

i.e. $I \propto A^2$ or $\frac{I_1}{I_2} = (\frac{A_1}{A_2})^2$.

Given $I_1 = 3.0$ Wm^{-2}, $A_1 = 0.20$ mm and $A_2 = 0.40$ mm. I_2 is thus given by

$$I_2 = I_1(\frac{A_2}{A_1})^2 = 3.0(\frac{0.4}{0.2})^2 = 12 \text{ Wm}^{-2}$$

---

22. Two coherent waves, of intensities I and $9I$, meet in phase at a point.

    What is the resultant intensity at that point?

    A $4I$ B $8I$

    C $10I$ D $16I$

Helping concepts

Intensity I is proportional to amplitude A^2. Hence, the amplitudes of the two waves are A and $3A$ respectively.

Since the waves meet in phase, constructive interference takes place. Therefore, the resultant amplitude at that point is $A+3A=4A$ and the resultant intensity, $(4)^2I = 16I$.

---

23. The table shows the wavelengths of electromagnetic waves in various parts of the spectrum.

For which line in the table is X in the ultra-violet region and Y in the microwave region of the spectrum?

	X	Y
A	1×10^{-7} m	1×10^{-2} m
B	1×10^{-7} m	1×10^{-6} m
C	1×10^{-10} m	1×10^{-2} m
D	1×10^{-10} m	1×10^{-6} m

Helping concepts

The spectrum for the microwave, visible light and ultra-violet ray is

3×10^{-2} m	7.5×10^{-7} m	4.5×10^{-7} m
microwave	red light	ultraviolet ray

---

24. The intensity of a wave depends on the amplitude. The intensity is also proportional to the square of the frequency.

A wave has frequency 3.0 Hz, amplitude 1.5 cm and intensity I.

What is the intensity of a similar wave of frequency 6.0 Hz and amplitude 0.5 cm?

A $\frac{4}{9}I$ B $\frac{4}{3}I$

C $\frac{9}{4}I$ D $36I$

Helping concepts

$$I \propto A \text{ and } I \propto f^2 \Rightarrow I \propto Af^2$$

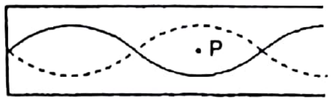
$I \propto (1.5)(3)^2$------(1)

$I' \propto (0.5)(6)^2$------(2)

$\frac{(2)}{(1)}: I' = I(\frac{0.5}{1.5})(\frac{6}{3})^2 = \frac{4}{3}I$

---

25. The diagram represents a longitudinal, stationary sound wave set up in a horizontal tube containing air.



Which statement about a molecule in the air at point P is correct?

A It oscillates horizontally and experiences fluctuating pressure.

B It oscillates horizontally and experiences no variation of pressure.

C It oscillates vertically and experiences fluctuating pressure.

D It oscillates vertically and experiences no variation of pressure.

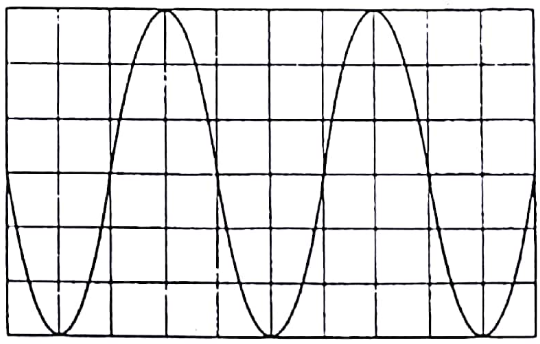
Helping concepts

Air molecules oscillate horizontally or in parallel to the tube as it is a longitudinal wave.

Displacement antinode at P will correspond to a pressure node and vice versa.

---

26. The cathode-ray oscilloscope (c.r.o.) display shows the waveform produced by an electronic circuit. The c.r.o. time-base is set at 10 ms per division.



What is the period of the signal shown?

A 20 ms B 30 ms

C 40 ms D 80 ms

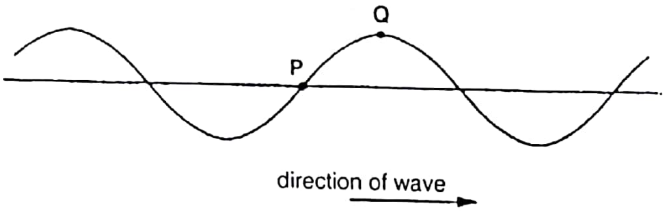
Helping concepts

1 period of wave = 4 divisions

∴ 4 divisions × 10ms/division = 40 ms

27. The diagram shows a transverse wave on a rope. The wave is travelling from left to right.

At the instant shown, the points **P** and **Q** on the rope have zero displacement and maximum displacement respectively.



Which of the following describes the direction of motion, if any, of the points **P** and **Q** at this instant?

	point P	point Q
A	downwards	stationary
B	stationary	downwards
C	stationary	upwards
D	upwards	stationary

Helping concepts

Point **P** is about to be displaced downwards while point **Q** is momentarily stationary.

28. A sound wave is emitted from a point source. The intensity of the sound wave is inversely proportional to the square of the distance from the source. At a distance r from the source, the amplitude of the wave is $8X$.

What is the amplitude at a distance $2r$ from the source?

A $8X$ **B** $4X$
C $2X$ **D** X

Helping concepts

Given $I \propto \frac{1}{r^2}$ and $I \propto A^2$ where A = amplitude of sound wave.

$$\therefore A^2 \propto \frac{1}{r^2} \Rightarrow \begin{cases} (8X)^2 \propto \frac{1}{r^2} \text{------(1)} \\ A^2 \propto \frac{1}{(2r)^2} \text{------(2)} \end{cases}$$

$$\frac{(2)}{(1)}: \left(\frac{A}{8X}\right)^2 = \left(\frac{r}{2r}\right)^2 \Rightarrow A = 4X$$

29. A star emits electromagnetic waves of wavelengths 50 μm, 5 μm, 0.5 μm and 0.05 μm.

To which regions of the electromagnetic spectrum do they belong?

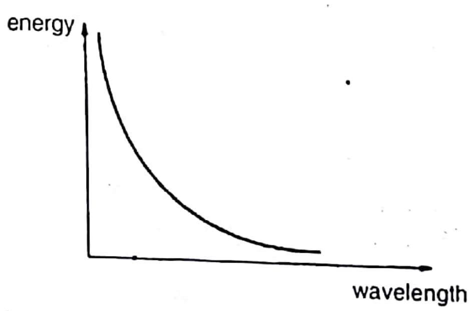
	50 μm	5 μm	0.5 μm	0.05 μm
A	infra - red	infra - red	visible	ultra - violet
B	infra - red	visible	ultra - violet	X - ray
C	microwave	visible	visible	ultra - violet
D	radio	infra - red	visible	ultra - violet

Helping concepts

From the electromagnetic spectrum, the typical wavelengths are listed below:

spectrum	typical wavelength / m
gamma rays	$< 10^{-12}$
X-rays	10^{-10}
ultra-violet	10^{-8}
visible light	$4.0 \text{ to } 7.0 \times 10^{-7}$
infra-red	10^{-4}
microwave	10^{-2}
radio wave	> 1

30. The diagram shows the relationship between the energy of electromagnetic radiation and the wavelength of the waves.



Which of the following has the lowest energy?

A infra-red **B** microwaves
C ultra-violet **D** X-rays

Helping concepts

From the diagram, we observe that the electromagnetic radiation with largest wavelength has the smallest energy.

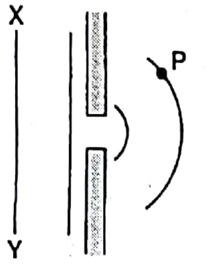
Order of the radiation in decreasing wavelength or increasing frequency is

microwaves, infra-red, ultra-violet, X-rays.

Since microwaves has the largest wavelength among the four, its thus has the lowest energy.

---

31. A monochromatic plane wave of speed c and wavelength λ is diffracted at a small aperture. The diagram illustrates successive wavefronts.



After what time will some portion of the wavefront XY reach P?

A $\frac{3\lambda}{2c}$ B $\frac{2\lambda}{c}$

C $\frac{3\lambda}{c}$ D $\frac{4\lambda}{c}$

Helping concepts

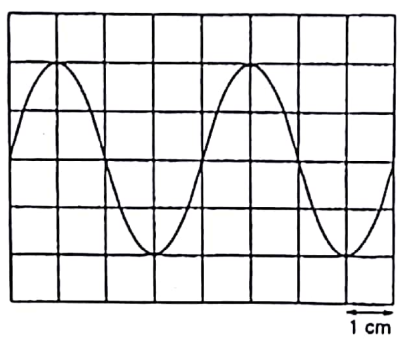
Distance between successive wavefront is a wavelength λ.

Hence, between wavelength **XY** and point **P**, the path difference is 3λ.

Time taken from plane **XY** to reach **P** is thus $t = \frac{3\lambda}{c}$.

---

32. A sound wave is displayed on the screen of a cathode-ray oscilloscope. The time-base of the c.r.o. is set at 2.5 ms/cm.



What is the frequency of the sound wave?

A 50 Hz B 100 Hz

C 200 Hz D 400 Hz

Helping concepts

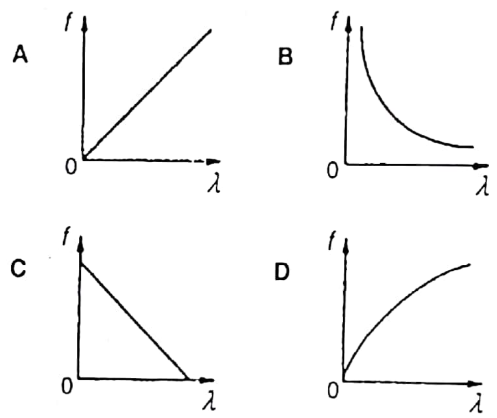
Period of wave occupies 4 squares $= 4 \times 2.5 = 10$ ms

Frequency, $f = \frac{1}{T} = \frac{1}{10\text{ ms}} = 100$ Hz

---

33. A sound wave of frequency f and wavelength λ travels through air. It may be assumed that its speed is independent of the frequency.

Which graph correctly shows the variation of f with λ?



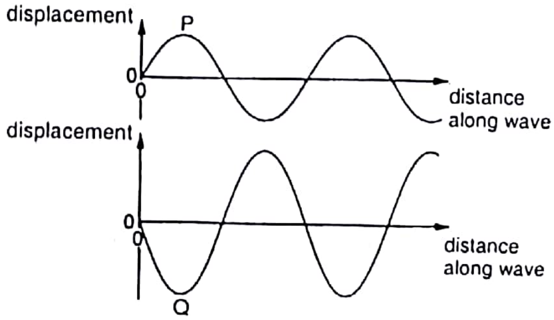
Helping concepts

Assuming the speed of the wave is constant.

Since $v = f\lambda$, f can be said to be inversely proportional to λ, i.e. $f \propto \frac{1}{\lambda}$.

---

34. The diagram shows the displacements at the same instant of two waves, P and Q, of equal frequency and having amplitude of Y and $2Y$, respectively.



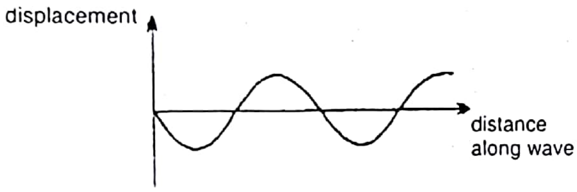
The waves are superimposed to give a resultant wave.

What is the amplitude of the resultant wave and what is the phase difference between the resultant wave and wave P?

	amplitude of resultant wave	(phaser difference between resultant wave and wave P) / radians
A	Y	0
B	Y	π
C	$3Y$	0
D	$3Y$	π

Helping *concepts*

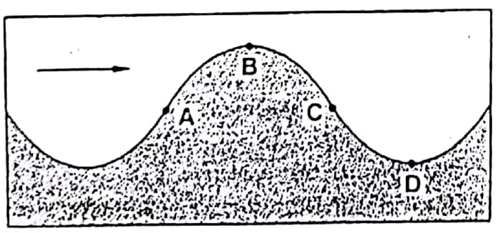
The resultant wave would look like this:



Its amplitude is Y and it is in antiphase with wave P, i.e. phase difference between resultant wave and wave P = π rad.

35. The diagram shows a vertical cross-section through a water wave moving from left to right.

At which point is the water moving upwards with maximum speed?



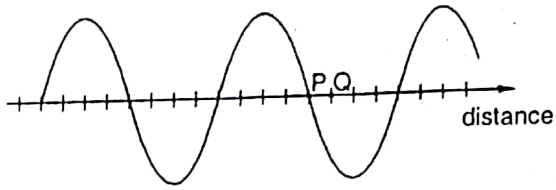
Helping *concepts*

The particle will move to the displacement to its left in the same location as wave moves from left to right.

Only **C** is moving upwards and is maximum as it is at equilibrium position in the simple harmonic motion.

36. The diagram shows a transverse wave at a particular instant. The wave is travelling to the right.

The frequency of the wave is 12.5 Hz.



At the instant shown the displacement is zero at the point P.

What is the shortest time to elapse before the displacement is zero at point Q?

A 0.01 s B 0.03 s

C 0.08 s D 0.10 s

Helping *concepts*

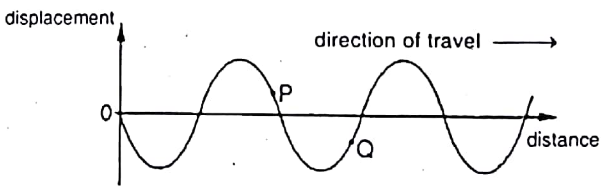
The zero displacement at P will move to Q in $\frac{1}{8}\lambda$ distance away.

Period of wave, $T = \frac{1}{f} = \frac{1}{12.5} = 0.08$ s

1 wavelength takes 0.08 s.

$\therefore \frac{1}{8}$ wavelength takes $\frac{1}{8}(0.08) = 0.01$ s.

37. A transverse progressive wave travels along a rope. The graph shows the variation of displacement with distance along the rope, at a certain time. The wave is travelling to the right.



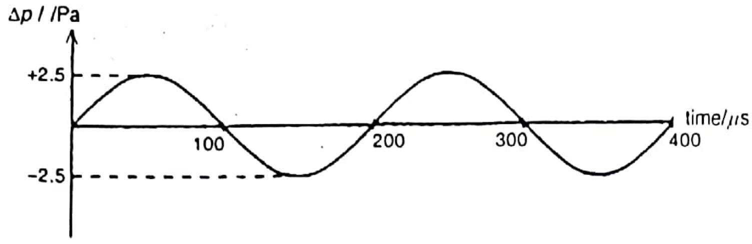
In which direction are P and Q moving.

	movement of P	movement of Q
A	downwards	downwards
B	downwards	upwards
C	upwards	downwards
D	upwards	upwards

Helping *concepts*

As wave is travelling from left to right, particle P will take the displacement of the wave to its left, i.e. upwards. Particle Q will be moving downwards.

38. The diagram below represents the variation with time of pressure at a point in air through which a sound wave is travelling at 340 ms^{-1}.



What is the frequency of the wave?

A 1.7 Hz **B** 5.0×10^3 Hz

C 1.0×10^4 Hz **D** 3.1×10^4 Hz

Helping *concepts*

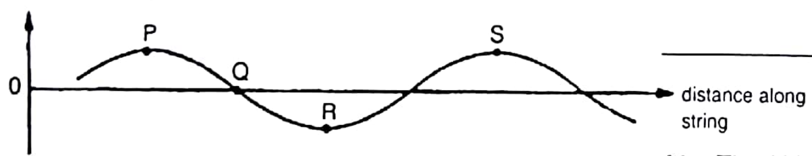
Period of the sound wave, $T = 200\ \mu s$

Frequency of the wave $= \dfrac{1}{T}$

$= \dfrac{1}{200 \times 10^{-6}}$

$= 5$ kHz or 5.0×10^3 Hz

39. The graph shows the shape at a particular instant of part of a transverse wave travelling along a string.



Which statement about the motion of elements of the string is correct?

A The speed of the element at P is a maximum.

B The displacement of the element at Q is always zero.

C The energy of the element at R is entirely kinetic.

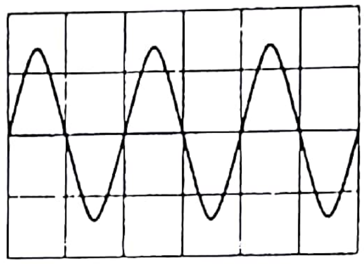
D The acceleration of the element at S is a maximum.

Helping *concepts*

The string particle at maximum displacement has maximum acceleration, i.e. $a = -\omega^2 A$.

Since it is a transverse wave, displacement at each of this points will varying as time passes.

40. An alternating p.d. is applied across the Y-plates of a cathode-ray oscilloscope (c.r.o.) and produces the trace shown below.



If the peak voltage of the alternating p.d. is 2.8 V and its frequency is 50 Hz, what are the time-base and Y-gain settings of the c.r.o.?

	time-base setting	Y-gain
A	10 $\mu s\ cm^{-1}$	2.0 $V\ cm^{-1}$
B	20 $\mu s\ cm^{-1}$	1.0 $V\ cm^{-1}$
C	10 $ms\ cm^{-1}$	2.0 $V\ cm^{-1}$
D	20 $ms\ cm^{-1}$	1.0 $V\ cm^{-1}$

Helping *concepts*

Peak voltage of wavelength = 2.8 V

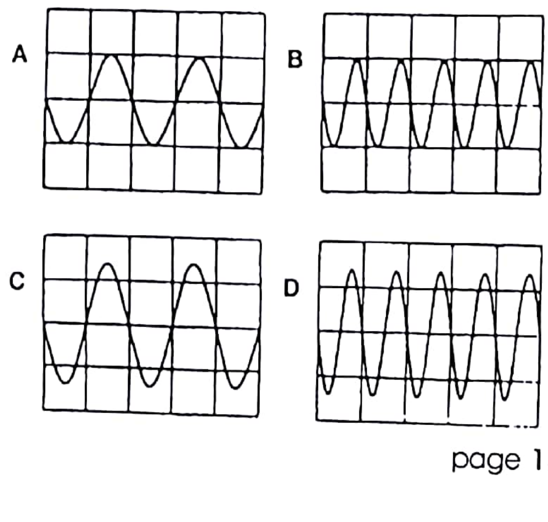
Period of waveform $= \dfrac{1}{f} = \dfrac{1}{50} = 20$ ms

If t and y are the time-base and Y-gain setting of the c.r.o. respectively, then

$$\begin{cases} 2t = 20 \Rightarrow t = 10\ ms\ cm^{-1} \\ 1.4y = 2.8 \Rightarrow y = 2\ V\ cm^{-1} \end{cases}$$

41. The Y-input terminals of an oscilloscope are connected to a voltage supply of peak value 5.0 V and frequency 50 Hz. The time-base is set at 10 ms per division and the Y-gain at 5V per division.

Assuming that all diagrams are drawn to scale, which trace will be obtained?



Helping concepts

Horizontal axis is the time-scale for the sinusoidal signal.

Period of the signal is $T = \frac{1}{f} = \frac{1}{50} = 0.02\text{ s} = 20\text{ ms}$.

For a time-base of 10 ms per division, the period of the signal covers 20/10 or 2 divisions of the horizontal axis.

The vertical axis is scaled to 5 V per division. Since the signal is 10 V peak to peak, the signal sweeps across two divisions of the vertical axis from peak to peak periodically.

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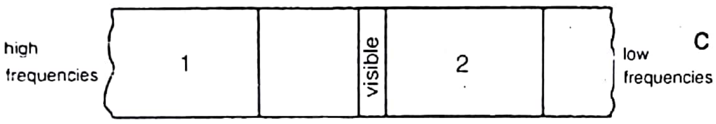
42. The diagram illustrates part of the electromagnetic spectrum.



Which labels are correct for the regions marked 1 and 2?

	1	2
A	infra - red	X - rays
B	microwaves	X - rays
C	ultra - violet	microwaves
D	X - rays	infra - red

Helping concepts

wavelength ⟶

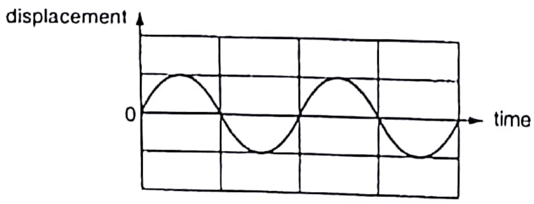
gamma rays	X-rays	ultra-violet	visible light	infra-red	micro-wave	radio-wave

⟵ frequency

Electromagnetic Spectrum

---

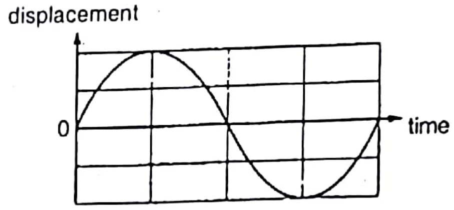
43. A displacement-time graph is shown for a particular wave.



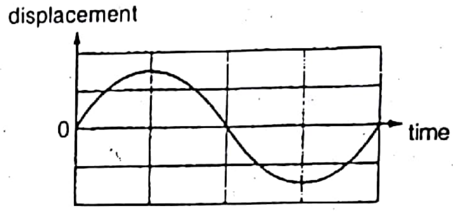
A second wave of similar type has twice the intensity and half the frequency.

When drawn on the same axes, what would the second wave look like?

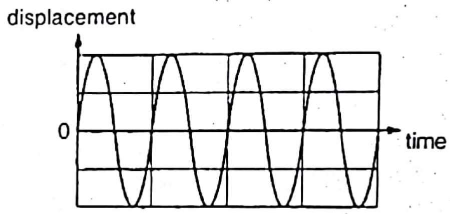
A



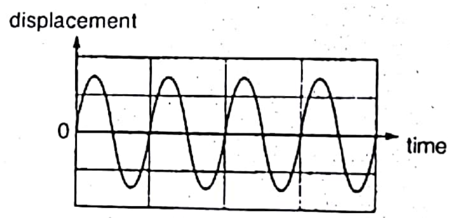
B



C



D



Helping concepts

intensity $\propto$ (amplitude)^2

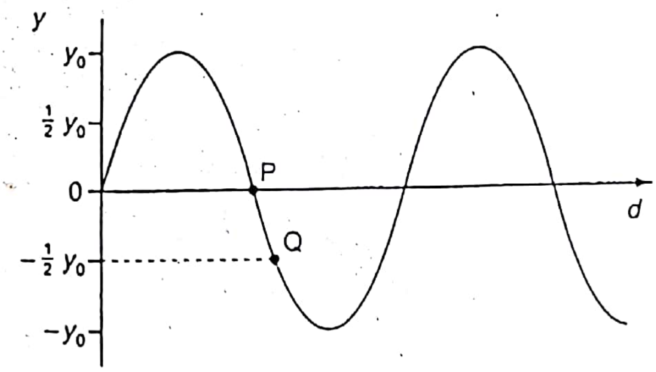
$2 \times \text{intensity} \propto (\sqrt{2} \cdot \text{amplitude})^2$

$\Rightarrow$ new amplitude $= \sqrt{2}A = 1.4A$

The frequency is halved means its period is doubled, i.e. the waver takes a longer time to complete one cycle.

---

44. The diagram shows the variation with distance d along a sinusoidal wave of displacement y of particles in the wave. The amplitude of the wave is y_0.



What is the phase angle between the two particles P and Q in the wave?

A 30° B 45°
C 90° D 180°

Helping concepts

$$y = y_0 \sin\theta$$

At P,

$$y = 0$$

$$\therefore \sin\theta_P = 0 \Rightarrow \theta_P = 180^\circ$$

At Q,

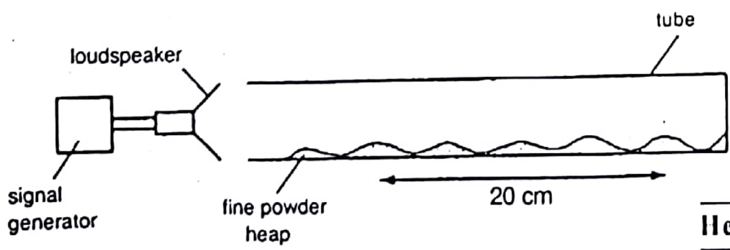
$$-\frac{1}{2}y_0 = y_0 \sin\theta_Q$$

$$\sin\theta_Q = -\frac{1}{2}$$

$$\theta_Q = 210^\circ$$

$$\therefore \theta_Q - \theta_P = 210^\circ - 180^\circ = 30^\circ$$

45. A long horizontal tube, containing a fine powder, is closed at one end. A loudspeaker, connected to a signal generator, is positioned at the other end.



At a particular frequency, a stationary wave is set up inside the tube and the powder forms heaps at the nodes. The speed of sound is 330 ms⁻¹.

What type of wave is the stationary wave and what is its frequency?

	type of wave	frequency / kHz
A	longitudinal	3.3
B	transverse	3.3
C	longitudinal	6.6
D	transverse	6.6

Helping concepts

$2\lambda = 20$ cm $\Rightarrow \lambda = 10$ cm

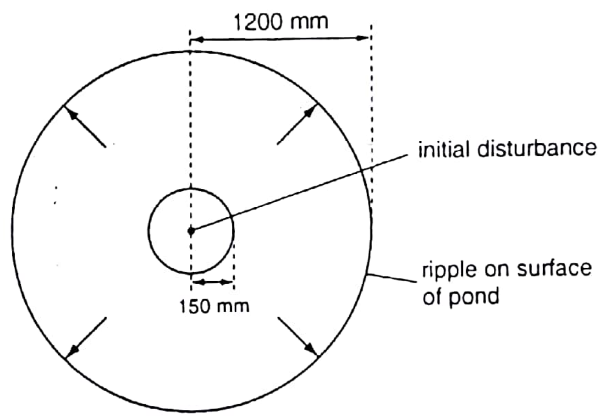
$$\text{Frequency} = \frac{\text{speed}}{\text{wavelength}} = \frac{330}{0.10} = 3.3 \text{ kHz}$$

Sound waves are longitudinal waves.

46. Ripples on the surface of a pond spread out in circles from the point of an initial disturbance.

Assume that the energy of the wave is spread over the entire circumference of the ripple.

For one such ripple, the amplitude of the ripple at a distance of 150 mm from the disturbance is 2.0 mm.



What will be the amplitude of the ripple at a distance of 1200 mm from the disturbance?

(Assume that no energy is lost in the propagation of the ripple.)

A 0.031 mm B 0.13 mm
C 0.25 mm D 0.71 mm

Helping concepts

Intensity, $I \propto (\text{Amplitude})^2$ and $I \propto \frac{1}{\text{area}} = \frac{1}{\pi r^2}$

$$\therefore (\text{Amplitude})^2 \propto \frac{1}{\pi r^2} \Rightarrow \text{Amplitude} \propto \frac{1}{r}$$

where r = radius of circle.

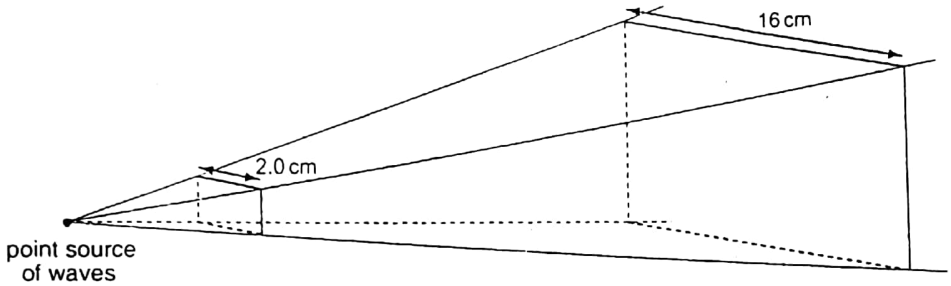
$$2.0 \text{ mm} \propto \frac{1}{150 \text{ mm}} \text{-----}(1)$$

$$A \propto \frac{1}{1200 \text{ mm}} \text{-----}(2)$$

$$\frac{(2)}{(1)}: \frac{A}{2.0 \text{ mm}} = \frac{150 \text{ mm}}{1200 \text{ mm}} \Rightarrow A = 0.25 \text{ mm}$$

---

47. Waves from a point source pass through an area that is 2.0 cm wide, as shown.



Within this area, the intensity of the waves is I and their amplitude is A. The waves reach a second area of width 16 cm.

What will be the intensity and amplitude of the waves when they reach the second area?

	intensity	amplitude
A	$\frac{I}{8}$	$\frac{A}{4}$
B	$\frac{I}{64}$	$\frac{A}{4}$
C	$\frac{I}{64}$	$\frac{A}{8}$
D	$\frac{I}{256}$	$\frac{A}{16}$

Helping *concepts*

The second area is 16 cm/2 cm = 8 times further than the first area of intensity I and amplitude A, using similar triangles.

$$I \propto \frac{1}{r^2}$$

where r is the distance from source to area.

$$I \propto \frac{1}{r^2} \text{-----}(1)$$

$$I_N \propto \frac{1}{(8r)^2} \text{-----}(2)$$

where I_N is the new intensity at the area of width of 16 cm.

$$\frac{(2)}{(1)}: \frac{I_N}{I} = \frac{1}{64} \Rightarrow I_N = \frac{I}{64}$$

As intensity, $I \propto A^2$ and A is amplitude,

$$I \propto A^2 \text{-----}(1)$$

$$\frac{I}{64} \propto (A_N)^2 \text{-----}(2)$$

where A_N is the new amplitude at the area of width of 16 cm.

$$\frac{(2)}{(1)}: \frac{1}{64} = (\frac{A_N}{A})^2 \Rightarrow A_N = \frac{1}{8}A$$

TOPIC 11

Superposition

Key content that you will be examined on:

1. Stationary waves
2. Diffraction
3. Interference
4. Two-source interference patterns
5. Diffraction grating

Topic 11 Superposition

1. Where, in a standing wave, do the vibrations of the medium occur?

   A only at the nodes
   B only at the antinodes
   C at all points between the nodes
   D at all points between the antinodes

Helping concepts

In a standing wave, only the nodes are permenantly at rest. The rest of the stationary waves are vibrating.

2. When the light from two lamps falls on a screen, no interference pattern can be obtained.

   Why is this?

   A The lamps are not point sources.
   B The lamps emit light of different amplitudes.
   C The light from the lamps is not coherent.
   D The light from the lamps is white.

Helping concepts

Only coherent light sources can produce diffraction and interference pattern. Two wave-trains are said to be coherent if they both have the same frequency, in-phase or a constant phase difference.

3. A diffraction grating has a spacing of 1.6×10^{-6} m. A beam of light is incident normally on the grating. The first order maximum makes an angle of 20° with the undeviated beam.

   What is the wavelength of the incident light?

   A 210 nm B 270 nm
   C 420 nm D 550 nm

Helping concepts

$d\sin\theta = n\lambda$

$$\lambda = \frac{d\sin\theta}{n} = \frac{1.6\times10^{-6}\times\sin20^{\circ}}{1} = 550\text{ nm}$$

4. A sound wave is set up in a long tube, closed at one end. The length of the tube is adjusted until the sound from the tube is loudest.

   What is the nature of the sound wave in the tube?

   A longitudinal and progressive
   B longitudinal and stationary
   C transverse and progressive
   D transverse and stationary

Helping concepts

By definition, sound waves are progressive and **longitudinal**. In this case, sound waves are reflected from the closed end and interfere with incoming waves. These will form **stationary** waves.

5. A parallel beam of white light is incident normally on a diffraction grating. It is noted that the second-order and third-order spectra partially overlap.

   Which wavelength in the third-order spectrum appears at the same angle as the wavelength of 600 nm in the second-order spectrum?

   A 300 nm B 400 nm
   C 600 nm D 900 nm

Helping concepts

From the formula $d\sin\theta = n\lambda$, we have

$$2\times600\times10^{-9} = 3\lambda_3 \Rightarrow \lambda_3 = 400\times10^{-9}\text{ m}$$

6. Fringes of separation y are observed on a screen 1.00 m from a Young's slit arrangement that is illuminated by yellow light of wavelength 600 nm.

   At what distance from the slits would fringes of the same separation y be observed when using blue light of wavelength 400 nm?

   A 0.33 m B 0.67 m
   C 0.75 m D 1.50 m

Helping concepts

$$y = \frac{\lambda D}{d}$$

If y is the same and d is fixed,

$$\lambda_b D_b = \lambda_y D_y \Rightarrow D_b = \frac{\lambda_y}{\lambda_b} D_y = \frac{600}{400} \times 1.00 = 1.50 \text{ m}$$

7. Monochromatic light is incident normally on a diffraction grating. Second-order diffraction is observed at an angle of 38.9°.

At which angles will the first and third orders be observed?

	first order	third order
A	18.3°	57.2°
B	18.3°	70.4°
C	19.5°	58.5°
D	19.5°	77.8°

Helping concepts

$d \sin 38.9° = 2\lambda$ ----- (1)

$d \sin\theta = 3\lambda$ ----- (2)

$\frac{(2)}{(1)}$: $\sin\theta = \frac{3}{2}\sin 38.9° \Rightarrow \theta = 70.4°$

8. A beam of monochromatic light of wavelength 600 nm is incident normally on a diffraction grating that has 3.0×10^5 lines per metre.

What is the total number of images produced by light transmitted through this grating?

A 5 B 8

C 9 D 11

Helping concepts

Using $d\sin\theta = n\lambda$,

$$\left(\frac{1}{3 \times 10^5}\right)\sin 90° = n(600 \times 10^{-9})$$

$$n = 5.6 \approx 5 \text{ (integer)}$$

Total bright fringes seen is 5 (one side) + 1 (central bright fringe) + 5 (the other side) = 11.

9. A sound wave of frequency 400 Hz is travelling in a gas at a speed of 320 ms^{-1}.

What is the phase difference between two points 0.2 m apart in the direction of travel?

A $\frac{\pi}{4}$ rad B $\frac{\pi}{2}$ rad

C $\frac{2\pi}{5}$ rad D $\frac{4\pi}{5}$ rad

Helping concepts

Using formula $v = f\lambda$,

$$\text{wavelength, } \lambda = \frac{320}{400} = 0.8 \text{ m}$$

$$\text{Phase difference} = \frac{0.2}{0.8} \times 2\pi = \frac{\pi}{2} \text{ rad}$$

10. Light of frequency 6.0×10^{14} Hz passes through a diffraction grating with 4.0×10^3 lines per centimetre.

What is the angle between the two third-order diffraction maxima?

A 12° B 23°

C 37° D 74°

Helping concepts

$$d\sin\theta = n\lambda$$

$$\left(\frac{1 \times 10^{-2}}{4.0 \times 10^3}\right)\sin\theta = 3\left(\frac{3 \times 10^8}{6.0 \times 10^{14}}\right)$$

$$\theta = 37°$$

Angle between two third-order diffraction pattern is 2 × 37° = 74°.

11. Monochromatic light of wavelength λ is incident normally on a diffraction grating with the separation d.

At which angle with the normal to the grating is a diffracted beam observed?

A $\sin^{-1}\frac{2\lambda}{d}$ B $\sin^{-1}\frac{\lambda}{2d}$

C $\sin^{-1}\frac{d}{\lambda}$ D $\sin^{-1}\frac{2d}{\lambda}$

Helping concepts

For diffraction grating,

$$d\sin\theta = n\lambda$$

$$\theta = \sin^{-1}(\frac{n\lambda}{d})$$

where $n = 1, 2, 3, ...$

12. When monochromatic light of wavelength 5.0×10^{-7} m is incident normally on a plane diffraction grating, the second-order diffraction lines are formed at angles of 30° to the normal to the grating. What is the number of lines per millimetre of the grating?

A 250
B 500
C 1000
D 2000

Helping concepts

$$d\sin\theta = n\lambda$$

$$d = \frac{n\lambda}{\sin\theta} = \frac{(2)(5.0\times10^{-7})}{\sin 30^{\circ}} = 2.0\times10^{-6}\text{ m} = 2.0\times10^{-3}\text{ mm}$$

$\therefore$ Number of lines per mm $= \frac{1}{2.0\times10^{-3}} = 500$

13. Light of wavelength λ is incident normally on a diffraction grating for which the slit spacing is equal to 3λ.

What is the sine of the angle between the second-order maximum and the normal?

A $\frac{1}{6}$
B $\frac{1}{3}$
C $\frac{2}{3}$
D 1

Helping concepts

The sine of the angle between the second-order maximum and the normal is given by

$$d\sin\theta = n\lambda$$

Given $n = 2$ and $d = 3\lambda$.

$$\sin\theta = \frac{2\lambda}{d} = \frac{2\lambda}{3\lambda} = \frac{2}{3}$$

14. Light of wavelength 600 nm falls on a pair of slits, forming fringes 3.0 mm apart on a screen.

What is the fringe spacing when light of wavelength 300 nm is used and the slit separation is halved?

A 0.75 mm
B 1.5 mm
C 3.0 mm
D 6.0 mm

Helping concepts

$$y = \frac{\lambda D}{d}$$

From constant D,

$$\frac{y_2}{y_1} = \frac{\lambda_2 d_1}{\lambda_1 d_2} \Rightarrow y_2 = \frac{300}{600}\times\frac{1}{1/2}\times 3.0 = 3.0\text{ mm}$$

15. Two monochromatic radiations X and Y are incident normally on a diffraction grating. The second-order intensity maximum for X coincides with the third-order intensity maximum for Y.

What is the ratio $\frac{\text{wavelength of X}}{\text{wavelength of Y}}$?

A $\frac{1}{2}$
B $\frac{2}{3}$
C $\frac{3}{2}$
D $\frac{2}{1}$

Helping concepts

Using the formula $d\sin\theta = 2\lambda_X$ and $d\sin\theta = 3\lambda_Y$, we have

$$2\lambda_X = 3\lambda_Y \Rightarrow \frac{\lambda_X}{\lambda_Y} = \frac{3}{2}$$

16. The frequency of a certain wave is 500 Hz and its speed is 340 ms^{-1}.

What is the phase difference between the motions of two points on the wave 0.17 m apart?

A $\frac{\pi}{4}$ rad   B $\frac{\pi}{2}$ rad

C $\frac{3\pi}{4}$ rad   D π rad

Helping concepts

Wavelength of wave, $\lambda = \frac{\text{speed}}{\text{frequency}} = \frac{340}{500} = 0.78$ m

Using $\frac{\Delta\phi}{2\pi} = \frac{\Delta x}{\lambda}$,

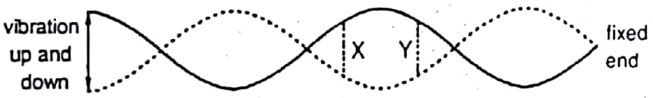
$$\frac{\Delta\phi}{2\pi} = \frac{0.17}{0.78} \Rightarrow \Delta\phi = \frac{\pi}{2} \text{ rad}$$

where $\Delta\phi$ = phase difference,

Δx = distance apart.

---

17. The diagram shows a long rope fixed at one end. The other end is moved up and down, setting up a stationary wave.



What is the phase difference between the oscillations at X and Y?

A 0   B $\frac{1}{4}\pi$ rad

C $\frac{1}{2}\pi$ rad   D $\frac{3}{4}\pi$ rad

Helping concepts

Particles of rope within two nodes are of the same phase. Hence, phase difference is zero.

---

18. A two-slit arrangement is set up to produce interference fringes on a screen. The fringes are too close together for convenient observation when a monochromatic source of violet light is used.

In which way would it be possible to increase the separation of the fringes?

A Decrease the distance between the screen and the slits.

B Increase the distance between the two slits.

C Increase the width of each slit.

D Use a monochromatic source of red light.

Helping concepts

$$x = \frac{\lambda D}{a}$$

where x = fringe separation,

λ = wavelength of light,

D = distance between slits and screen,

a = slit separation.

---

19. Light of frequency 6.0×10^{14} Hz passes through a diffraction grating with 4.0×10^3 lines per centimetre.

What is the angle between the two third-order diffraction maxima?

A 12°   B 23°

C 37°   D 74°

Helping concepts

$$d\sin\theta = n\lambda$$

4.0×10^3 lines cm^{-1} $\equiv 4.0 \times 10^5$ lines m^{-1}

$$\lambda = \frac{v}{f} = \frac{3.0 \times 10^8}{6.0 \times 10^{14}} = 5.0 \times 10^{-7} \text{ m}$$

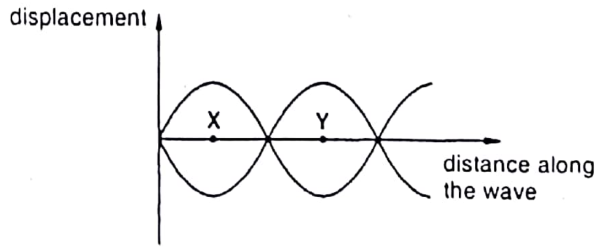
$$\sin\theta = \frac{n\lambda}{d} = \frac{(3)(5.0 \times 10^{-7})}{\left(\frac{1}{4.0 \times 10^5}\right)} = 0.60 \Rightarrow \theta = 36.9^\circ$$

The angle between 2 maxima is

$$2\theta = 2(36.9^\circ) = 74^\circ$$

---

20. The graph represents a stationary wave at two different times.



What does the distance XY represent?

A half the amplitude

B half the frequency

C half the period

D half the wavelength

Helping concepts

XY is the distance between adjacent antinodes of the stationary wave which is half the wavelength.

---

21. A double-slit light interference experiment is set up.

Under which conditions will the separation of bright fringes be greatest?

	distance between slits	distance from slits to screen	wavelength of source
A	small	large	short
B	small	large	long
C	large	small	short
D	large	small	long

Helping concepts

$$\lambda = \frac{ax}{d} \Rightarrow x = \frac{\lambda d}{a}$$

where λ = wavelength of light,
a = separation of two slits,
x = fringe separation,
d = distance from slits and screen.

For x to be large, λ and d have to be large and a to be small.

---

22. Coherent monochromatic light illuminates two narrow parallel slits and the interference pattern that results is observed on a screen some distance beyond the slits.

Which modification increases the separation between the dark lines of the interference pattern?

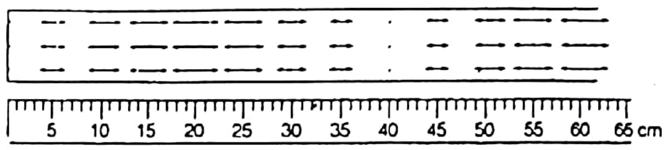
A decreasing the distance between the screen and the slits
B increasing the distance between the slits
C using monochromatic light of higher frequency
D using monochromatic light of longer wavelength

Helping concepts

The separation between the dark fringes is given by the formula $y = \frac{\lambda D}{a}$. This can be increased by using light of a longer wavelength, increasing the distance between the screen and the slits, or decreasing the distance between the slits.

---

23. A stationary sound wave is set up in a pipe using an oscillator of frequency 440 Hz. The extent of the vibration of the molecules in the pipe is illustrated. A centimetre scale is shown alongside the pipe.



What is the speed of sound in the pipe?

A 176 ms^{-1} B 328 ms^{-1}
C 337 ms^{-1} D 352 ms^{-1}

Helping concepts

Distance between 2 nodes = 40 cm

Length of wavelength = 2 × 40 = 80 cm

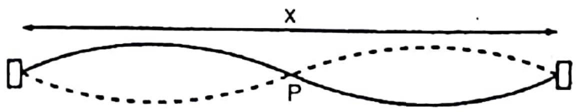
Speed of wave, $v = f\lambda$

$= (440)(80 \times 10^{-2})$

$= 352\ ms^{-1}$

---

24. The diagram represents a stationary wave on a stretched string.



What is represented by point P and by the length x?

	point P	length x
A	antinode	one wavelength
B	antinode	two wavelengths
C	node	one wavelength
D	node	two wavelengths

Helping concepts

P is a node that is permenantly at rest in a stationary wave.

Length x is equivalent to one wavelength.

25. The frequency of the fundamental mode of transverse vibration of a stretched wire 1000 mm long is 256 Hz. When the wire is shortened to 400 mm at the same tension, what is the fundamental frequency?

A 162 Hz **B** 312 Hz

C 416 Hz **D** 640 Hz

Helping concepts

The frequency of the fundamental mode of a stretched wire is

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

where l is the length of the wire,
T is the tension in the wire,
μ is the mass per unit length of the string.

Since T and μ are held constant,

$$f \propto \frac{1}{l}$$

Given $f = 256$ Hz when $l = 1000$ mm.

At $l = 400$ mm, frequency is calculated to be

$$\frac{f}{256} = \frac{1000}{400} \Rightarrow f = 640 \text{ Hz}$$

---

26. Monochromatic light is incident on a diffraction grating and a diffraction pattern is observed.

Which line of the table gives the effect of replacing the grating with one that has more lines per metre?

	no. of orders of diffraction visible	angle between 1st and 2nd orders of diffraction
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

Helping concepts

For a diffraction grating,

$$d\sin\theta = n\lambda$$

where d = distance between 2 lines in a grating,
n = orders of light,
θ = angle between the zero order and nth order.

For a grating with more lines per metre, d is smaller. n will be smaller as λ is constant and $\sin\theta = 1$ for maximum value.

Since n is smaller for $0 \le \theta \le 90°$, this means the orders are more spread out with larger angle between one another.

---

27. When monochromatic light of wavelength 5.0×10^{-7} m is incident normally on a plane diffraction grating, the second-order diffraction lines are formed at angles of 30° to the normal to the grating.

What is the number of lines per millimetre of the grating?

A 250 **B** 500

C 1000 **D** 2000

Helping concepts

When monochromatic light passes through a plane diffraction grating, bright or principal maxima are obtained when

$$d\sin\theta = n\lambda$$

where d = spacing of lines,
λ = wavelength of light,
n = order of bright image.

Given $\theta = 30°$, $n = 2$, $\lambda = 5.0 \times 10^{-7}$ m.

$$\therefore\ d = \frac{2(5.0 \times 10^{-7})}{\sin 30°} = 2 \times 10^{-6} \text{ m}$$

Hence, number of lines per millimetre of the grating is

$$\frac{1}{d} \times 10^{-3} = \frac{1}{2} \times 10^{6} \times 10^{-3} = 500$$

---

28. A diffraction grating is ruled with 600 lines per millimetre. When monochromatic light falls normally on the grating, the first-order diffracted beams are observed on the far side of the grating each making an angle of 15° with the normal to the grating.

What is the frequency of the light?

A 1.2×10^{13} Hz

B 4.7×10^{13} Hz

C 1.9×10^{14} Hz

D 7.0×10^{14} Hz

Helping concepts

The angle of diffraction, θ_n, for nth order diffraction pattern of the light is given by

$$d\sin\theta_n = n\lambda$$

where d = spacing between adjacent slits in diffraction grating $= \frac{10^{-3}}{600}$ m,

$n = 1$ for first-order diffraction beam,

$\theta_1 = 15°$.

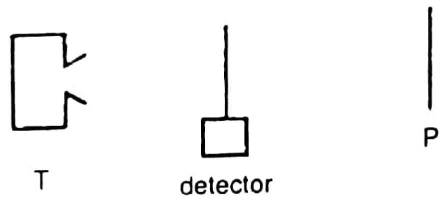
$$\therefore \lambda = \frac{d\sin\theta_1}{1} = \frac{10^{-3}}{600}\sin 15° = 4.3\times10^{-7}\text{ m}$$

Hence, frequency of light, $f = \frac{c}{f}$

$$= \frac{3\times10^{8}}{4.3\times10^{-7}}$$

$$= 7.0\times10^{14}\text{ Hz}$$

29. In the diagram, T represents a transmitter of microwaves and P represents a metal plate.



The detector is connected to a galvanometer. The distance TP is much greater than the wavelength of the microwaves.

As the detector is moved between T and P, what happens to the galvanometer reading?

A It decreases steadily.

B It reaches a maximum at P.

C It reaches a maximum midway between T and P.

D It increases and decreases regularly.

Helping concepts

Since TP is much greater than the wavelength of the microwaves, stationary waves are formed along TP. The galvanometer reading is low at nodes and high at antinodes.

30. A narrow beam of monochromatic light falls at normal incidence on a diffraction grating. Third-order diffracted beams are formed at angles of 45° to the original direction.

What is the highest order of diffracted beam produced by this grating?

A 3rd **B** 4th

C 5th **D** 6th

Helping concepts

When monochromatic light passes through a plane diffraction grating, bright or principal maxima are obtained from

$$d\sin\theta = n\lambda$$

where d = spacing of lines,

λ = wavelength of light,

n = order of bright image.

Given $n = 3$ occurs at 45°.

$$\therefore d\sin 45° = 3\lambda \Rightarrow \frac{\lambda}{d} = \frac{1}{3}\sin 45°$$

$$\therefore \sin\theta = n\left(\frac{\lambda}{d}\right) = \frac{n}{3}\sin 45° = \frac{n}{3\sqrt{2}}$$

Since maximum angle allowed is 90°, the highest order of diffracted beam is thus given by

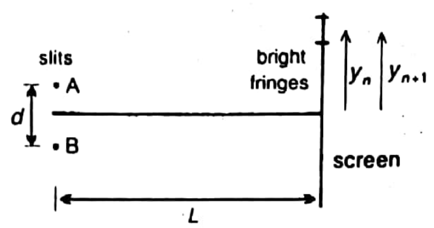
$$n = \text{truncated integer of } 3\sqrt{2} = 4$$

i.e. highest order $n_{max} = 4$.

31. Under which of the following sets of conditions will the separation of the bright fringes of a double-slit interference pattern be greatest?

	distance between slits	distance from slits to screen	wavelength of source
A	small	small	short
B	small	large	short
C	small	large	long
D	large	small	short

Helping concepts



It can be shown that the separation of the bright fringes of a double-slit interference pattern is given by

$$y_{n+1} - y_n = \frac{L\lambda}{d}$$

where L is the distance from slits to screen,
d is the distance between slits,
λ is the wavelength of source.

Hence, separation can be increased by increasing L, decreasing d or using a source of longer wavelength λ.

---

32. In a diffraction grating experiment, the first-order image of the 435.8 nm blue light from a commercial mercury vapour discharge lamp occurred at an angle of 15.8°. A first-order red line was also observed at 23.7°, thought to be produced by an impurity in the mercury?

The wavelengths of red lines of various elements are listed below. Which element is the impurity in the mercury lamp?

	element	wavelength/nm
A	zinc	636.0
B	cadmium	643.3
C	hydrogen	656.3
D	neon	670.8

Helping concepts

The first-order image of the 435.8 nm (λ_1) blue light occurred at an angle of 15.8° (θ_1). If d is the grating spacing, then

$$d\sin\theta_1 = \lambda_1 \Rightarrow d = \frac{435.8}{\sin 15.8} = 1600.56 \text{ nm}$$

Thus, the wavelength (λ_2) of red line of the impurity in the mercury is

$$d\sin\theta_2 = \lambda_2$$

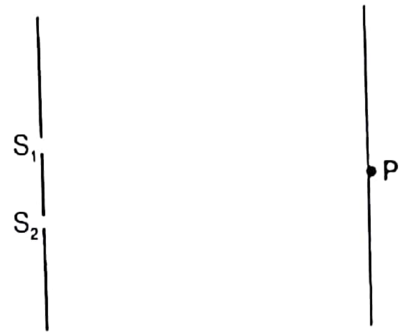
where $\theta_2 = 23.7°$.

$\therefore \lambda_2 = (1600.56)(\sin 23.7°) = 643.3$ nm

Hence, the impurity is cadmium and the associated red line's waverlength is 643.3 nm.

---

33. Coherent light is incident on two fine parallel slits, S_1 and S_2 as shown in the diagram.



If a dark fringe occurs at **P**, which of the following gives possible phase differences for the light waves arriving at **P** from S_1 and S_2?

A $2\pi, 4\pi, 6\pi...$　　B $\pi, 3\pi, 5\pi...$

C $\pi, 2\pi, 3\pi...$　　D $\frac{1}{2}\pi, \frac{5}{2}\pi, \frac{9}{2}\pi...$

Helping concepts

By principle of superposition at **P**, the optical path difference for two coherent light waves from S_1 and S_2 must be $(m+\frac{1}{2})\lambda$ if dark fringes occurs at **P**,

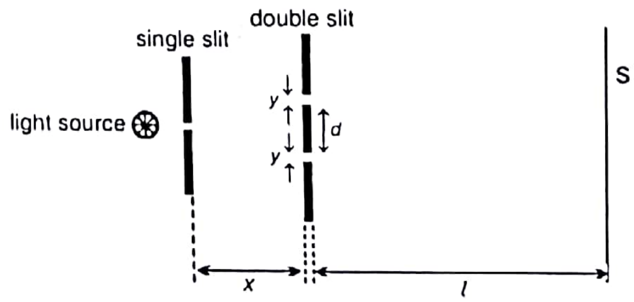
where λ = wavelength of the monochromatic light wave,
m = positive integers, $m = 0, 1, 2, ...$

$\therefore$ Phase difference $= (m+\frac{1}{2})2\pi = 2m\pi + \pi$

where $m = 0, 1, 2, ...$

---

34. In the Young's slits arrangement shown, a pattern of equally-spaced, parallel fringes appears on a screen placed at **S**.



Which quantity, if increased, would cause the separation of the fringes to increase?

A x　　B y

C d　　D l

Helping concepts

It can be shown that the separation of the fringes of a double-slit interference pattern is given by

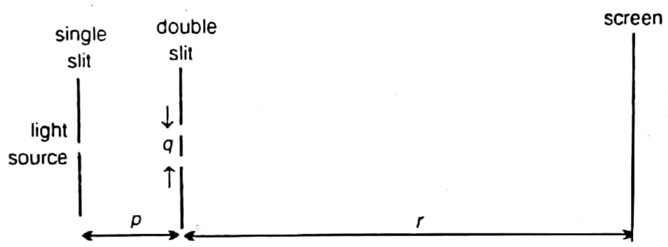
$$\text{fringe separation} = \frac{\lambda l}{d}.$$

To increase fringe separation, one could

1. increase wavelength of light or decrease its frequency,
2. increase the distance l or/and
3. decrease the distance d between slits.

---

35. A teacher sets up the apparatus shown to demonstrate a two slit interference pattern on the screen.



The teacher wishes to increase the fringe spacing.

Which change to the apparatus will increase the fringe spacing?

A decreasing the distance p

B decreasing the distance q

C decreasing the distance r

D decreasing the wavelength of the light

Helping concepts

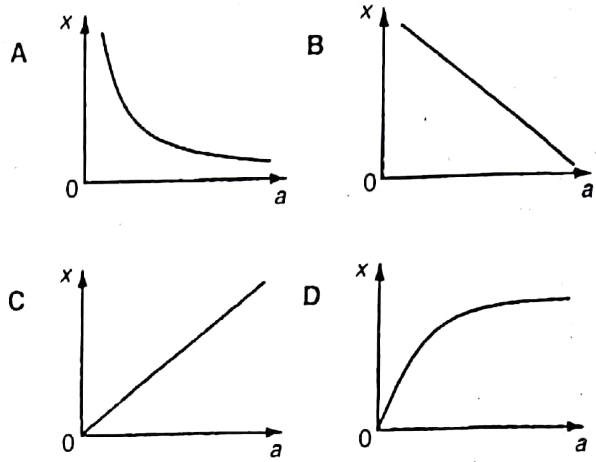
$$\text{Fringe spacing} = \frac{\lambda q}{r}$$

Decreasing q decreases the fringe spacing.

---

36. A double-slit interference experiment uses coherent monochromatic light.

Which graph shows how the distance x between fringes varies with slit separation a, when the distance from the double slits to the screen is kept constant?



Helping concepts

Wavelength light of $\lambda = \frac{ax}{D} \Rightarrow x = \lambda D(\frac{1}{a})$

---

37. An organ pipe of length l has one end closed but the other end open.

What is the wavelength of the fundamental note emitted?

A slightly smaller than $4l$

B slightly larger than $4l$

C roughly equal to $\frac{3l}{2}$

D slightly larger than $2l$

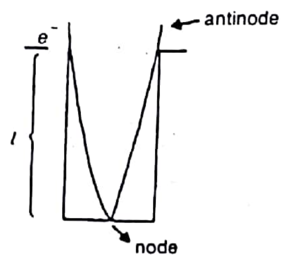
Helping concepts

Antinode occurs at position slightly above the open end.

If e is the end error of the stationary wave, then

$$e + l = \frac{\lambda}{4}$$

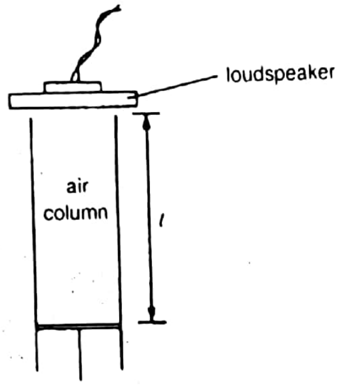
$$\Rightarrow \lambda = 4l + 4e > 4l$$



where λ is the wavelength of the fundamental note. That is, wavelength of the fundamental note is slightly larger than $4l$.

---

38. The length l of an air column is slowly increased from zero while a note of constant frequency is produced by a loudspeaker placed above it.



When l reaches 17 cm, the sound increases greatly in volume. What is the wavelength of the sound wave produced by the loudspeaker?

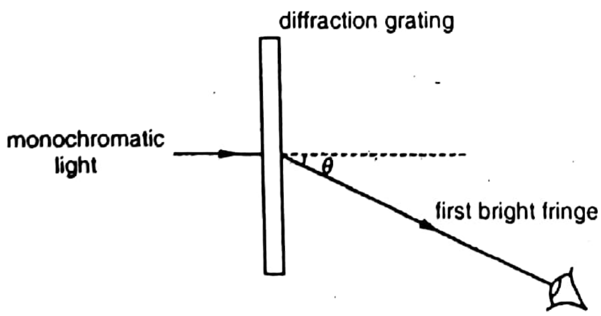
A 8.5 cm B 17 cm
C 34 cm D 68 cm

Helping concepts

When l = 17 cm, there is an antinode at the loudspeaker and a node at the plunger.

$\therefore \lambda = 4l = 68$ cm

39. A source of monochromatic light is viewed through a diffraction grating.



Which of the following causes the angle θ to increase?

A decreasing the distance between adjacent slits on the grating

B decreasing the wavelength of the monochromatic light

C increasing the distance of the eye from the grating

D increasing the number of slits of the grating but keeping the slit spacing the same

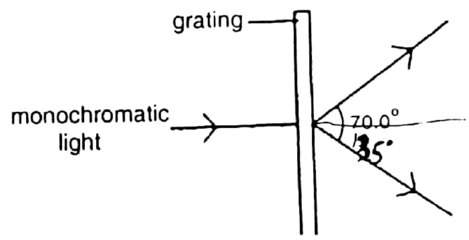
Helping concepts

For diffraction grating,

$$d \sin\theta = n\lambda \Rightarrow \sin\theta = \frac{n\lambda}{d}$$

where d is the distance between adjacent slits.

40. A diffraction grating is used to measure the wavelength of monochromatic light, as shown in the diagram.



The spacing of the slits in the grating is 1.00×10^{-6} m. The angle between the first order diffraction maxima is 70.0°.

What is the wavelength of the light?

A 287 nm B 470 nm
C 574 nm D 940 nm

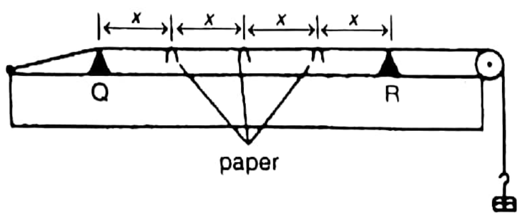
Helping concepts

$$\theta = \frac{70^\circ}{2} = 35^\circ$$

Using $d\sin\theta = n\lambda$,

$$\lambda = \frac{d}{n}\sin\theta = \frac{(1.00 \times 10^{-6})}{1}\sin 35^\circ = 5.74 \times 10^{-7} \text{ m}$$

41. A wire is stretched over two supports, Q and R, a distance $4x$ apart. Three light pieces of paper rest on the wire, as shown.



When the wire is made to vibrate at one particular frequency, the middle piece of paper stays on, but the others fall off the wire.

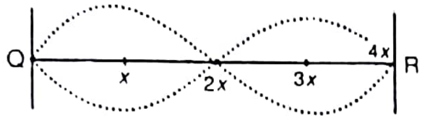
What is the wavelength of the vibration produced on the wire?

A $2x$ B $3x$

C $4x$ D $8x$

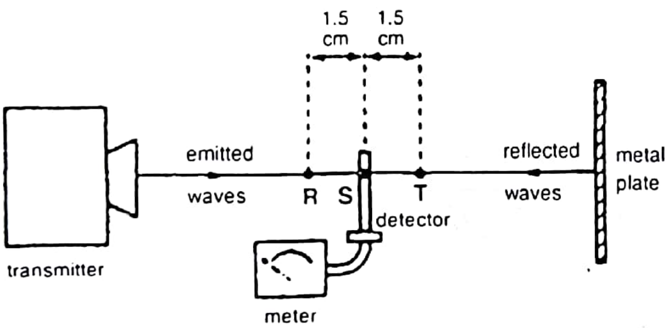
Helping concepts

The wave produced in the string can be represented in the following diagram.



Wavelength of wave in string, $\lambda = 4x$.

42. A microwave transmitter emits waves which are reflected from a metal plate, as shown in the diagram. A detector responds to the stationary waves produced. R, S and T are three successive points at which the meter shows zero intensity.



What is the frequency of the waves?

A 9.0×10^6 Hz

B 1.0×10^8 Hz

C 1.0×10^{10} Hz

D 2.0×10^{10} Hz

Helping concepts

R, S and T are three successive nodes. Distance between R and T gives the wavelength, λ, of the waves,

$$\lambda = 2 \times 1.5 = 3.0 \text{ cm} = 3.0 \times 10^{-2} \text{ m}$$

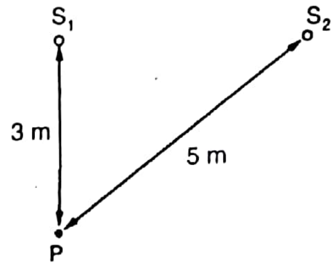
Frequency of the wave $= \frac{c}{\lambda}$

$$= \frac{3 \times 10^8}{3.0 \times 10^{-2}}$$

$$= 1.0 \times 10^{10} \text{ Hz}$$

43. Water waves of wavelength 4 m are produced by two generators, S_1 and S_2, as shown.

Each generator, when operated by itself, produces waves which have an amplitude A at **P**, which is 3 m from S_1 and 5 m from S_2.



When the generators are operated in phase, what is the amplitude of oscillation at **P**?

A 0 B $\frac{1}{2}A$

C A D $2A$.

Helping concepts

The path difference of the two waves at **P**

$= 5 - 3$

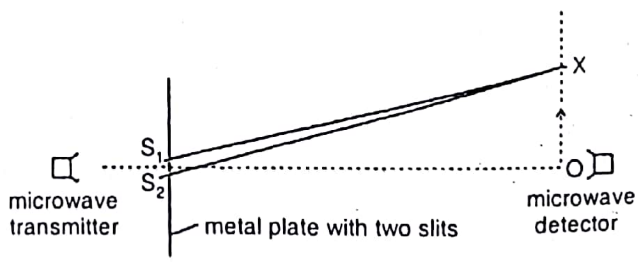
$= 2$

$= \frac{1}{2}(4)$

$= \frac{1}{2}$ wavelength of the sources S_1 and S_2

That is, the two waves are out of phase at point **P** since the generators are operated in phase and of the same amplitude A. The resultant wave at **P** has thus a magnitude $= A - A = 0$.

44. The diagram shows an experiment which has been set up to demonstrate two-source interference, using microwaves of wavelength λ.



The detector is moved from O in the direction of the arrow.

The signal detected decreases until the detector reaches the point X, and then starts to increase again as the detector moves beyond X.

Which equation correctly determines the position of X?

A $OX = \frac{\lambda}{2}$ **B** $OX = \lambda$

C $S_2X - S_1X = \frac{\lambda}{2}$ **D** $S_2X - S_1X = \lambda$

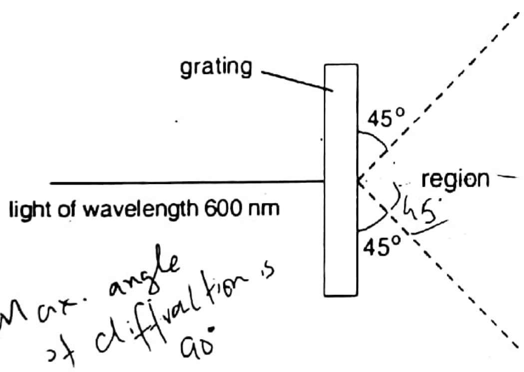
Helping *concepts*

X is the first minimum for sources S_1 and S_2.

$\therefore$ Path difference $= S_2X - S_1X = \frac{\lambda}{2}$

---

45. A parallel beam of light of wavelength 600 nm is incident normally on a diffraction grating. The grating has 500 lines per millimetre.



How many beams of coherent light emerges from the grating within the shaded 90° region shown in the diagram?

A 2 **B** 3

C 4 **D** 5

Helping *concepts*

For diffraction grating, $d\sin\theta = n\lambda$.

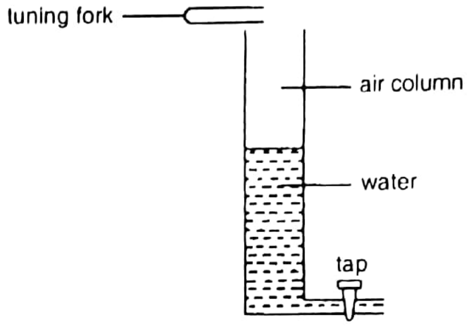
$\therefore \left(\frac{10^{-3}}{500}\right)\sin 45° = n(600 \times 10^{-9})$

$n = 2.4 \approx 2$ (integer)

Hence, total observable beam is $2 + 1 + 2 = 5$.

---

46. The diagram shows an experiment to produce a stationary wave in an air column. A tuning fork, placed above the column, vibrates and produces a sound wave. The length of the air column can be varied by altering the volume of the water in the tube.



The tube is filled and then water is allowed to run out of it.

The first two resonances occur when the air column lengths are 0.14 m and 0.46 m.

What is the wavelength of the sound wave?

A 0.32 m **B** 0.56 m

C 0.60 m **D** 0.64 m

Helping *concepts*

First resonance occurs when air column length = 0.14 m

$\therefore \frac{1}{4}\lambda + \text{end correction} = 0.14$

Second resonance occurs when air column length = 0.46 m

$\therefore \frac{3}{4}\lambda + \text{end correction} = 0.46$

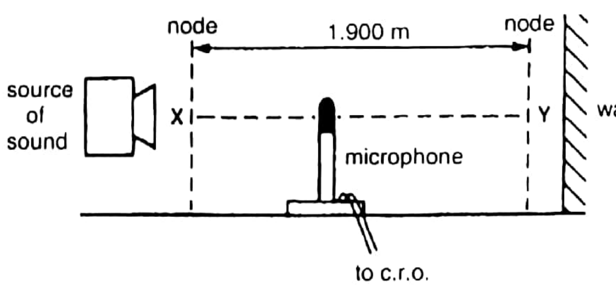
$\Rightarrow \frac{3}{4}\lambda + (0.14 - \frac{1}{4}\lambda) = 0.46$

$\Rightarrow \frac{1}{2}\lambda = 0.32$

$\Rightarrow \lambda = 0.64$ m

---

47. A source of sound of frequency 2500 Hz is placed several metres from a plane reflecting wall in a large chamber containing a gas. A microphone, connected to a cathode-ray oscilloscope, is used to detect nodes and antinodes along the line **XY** between the source and the wall.



The microphone is moved from one node through 20 antinodes to another node, a distance of 1.900 m.

What is the speed of sound in the gas?

A 238 ms^{-1} B 250 ms^{-1}

C 330 ms^{-1} D 475 ms^{-1}

Helping concepts

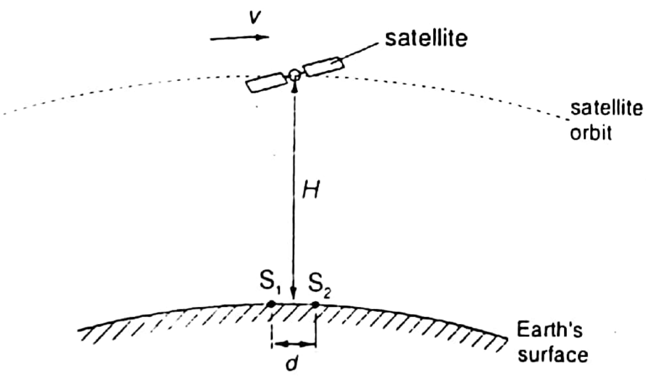
The distance 1.900 m corresponds to 10 wavelengths of the sound wave, since distance between two adjacent antinodes is equal to $\frac{1}{2}$ wavelength.

i.e. wavelength of the stationary wave $= \frac{1.900}{10} = 0.190$ m.

$\therefore$ Speed of sound wave $= f\lambda = 2500 \times 0.190 = 475\ ms^{-1}$

48. Two coherent sources S_1 and S_2 of radio waves are separated by a distance d.

A satellite is travelling overhead in the direction shown.



The satellite, travelling at speed v and at altitude H, deflects f maxima of density of the radio waves per unit time.

What is the wavelength of the radio waves?

A $\frac{d}{fH}$ B $\frac{df}{H}$

C $\frac{df}{vH}$ D $\frac{dv}{fH}$

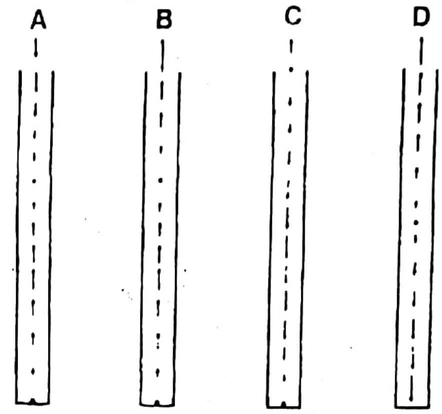
Helping concepts

Similar to Young's double slit experiment,

$$\lambda = \frac{ax}{D} = \frac{d}{H}\left(\frac{v}{f}\right)$$

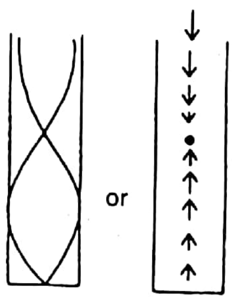
49. The arrows on the diagrams represent the movement of the air molecules in a pipe in which a stationary longitudinal wave has been set up. The length of each arrow represents the amplitude of the motion, and the arrow head shows the direction of motion at a particular instant.

Which diagram shows a possible stationary wave in which there are two displacement nodes and two displacement antinodes?



Helping concepts

Longitudinal waves travelling along the pipe are reflected at the ends of the tube. Interference between these two oppositive waves due to the movement of the air molecules give rise to the standing longitudinal wave. The closed end is a displacement node while the open end is a displacement antinode. For a stationary wave of two displacement nodes and two displacement antinodes, it must be as follow:



50. Standing waves are set up in a tube of length L, which is closed at one end. The speed of sound in the air in the tube is v.

When the tube resonates, which series of frequencies is generated?

A $\frac{1}{4}\frac{v}{L}, \frac{1}{2}\frac{v}{L}, \frac{3}{4}\frac{v}{L}, \frac{v}{L}, \ldots$

B $\frac{1}{4}\frac{v}{L}, \frac{3}{4}\frac{v}{L}, \frac{5}{4}\frac{v}{L}, \frac{7}{4}\frac{v}{L}, \ldots$

C $\frac{1}{2}\frac{v}{L}, \frac{v}{L}, \frac{3}{2}\frac{v}{L}, 2\frac{v}{L}, \ldots$

D $\frac{1}{2}\frac{v}{L}, \frac{3}{2}\frac{v}{L}, \frac{5}{2}\frac{v}{L}, \frac{7}{5}\frac{v}{L}, \ldots$

Helping concepts

For the fundamental frequency, f_0,

$$\frac{\lambda_0}{4} = L \Rightarrow \lambda_0 = 4L$$

where L is the fixed length of tube.

$\therefore$ Frequency, $f_0 = \frac{v}{\lambda_0} = \frac{v}{4L}$

For the next higher frequency, f_1, i.e. third harmonics, or first overtone,

$$\frac{3\lambda_1}{4} = L \Rightarrow \lambda_1 = \frac{4L}{3}$$

$\therefore$ Frequency, $f_1 = \frac{v}{\lambda_1} = \frac{3v}{4L}$

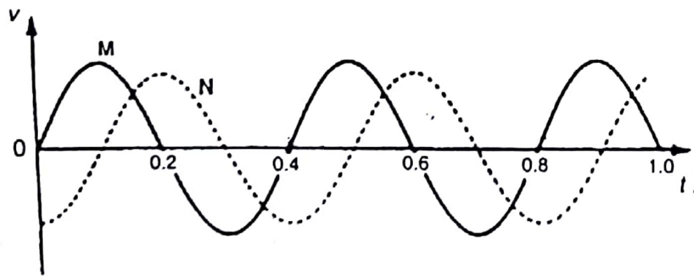
For the next higher frequency, f_2, i.e. fifth harmonics, or second overtone,

$$\frac{5\lambda_2}{4} = L \Rightarrow \lambda_2 = \frac{4L}{5}$$

$\therefore$ Frequency, $f_2 = \frac{v}{\lambda_2} = \frac{5v}{4L}$

---

51. Two sinusoidal voltages of the same frequency are shown in the diagram.



What is the frequency and the phase relationship between the voltages?

	frequency / Hz	phase lead of N over M / rad
A	0.4	$-\frac{\pi}{4}$
B	2.5	$-\frac{\pi}{2}$
C	2.5	$+\frac{\pi}{2}$
D	2.5	$-\frac{\pi}{4}$

Helping concepts

Period of the sinusoidal voltages, $T = 0.4$ s.

The frequency of the voltages is thus

$$f = \frac{1}{T} = \frac{1}{0.4} = 2.5 \text{ Hz}$$

N lags M by 0.1 s which is equivalent to $(\frac{0.1}{0.4})2\pi$ or $\frac{\pi}{2}$ rad.

Hence, phase lead of N over M is $-\frac{\pi}{2}$ rad.

---

52. T is a microwave transmitter placed at a fixed distance from a flat reflecting surface S.

A small microwave receiver is moved steadily from T towards S and receives signals of alternate maxima and minima of intensity.

The distance between successive maxima is 15 mm.

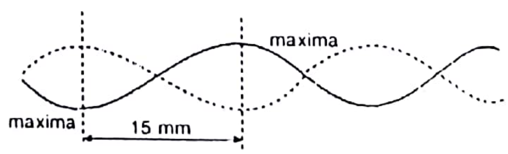
What is the frequency of the microwaves?

A 1.0×10^7 Hz B 2.0×10^7 Hz

C 1.0×10^{10} Hz D 2.0×10^{10} Hz

Helping concepts

Stationary waves are formed between S and T.



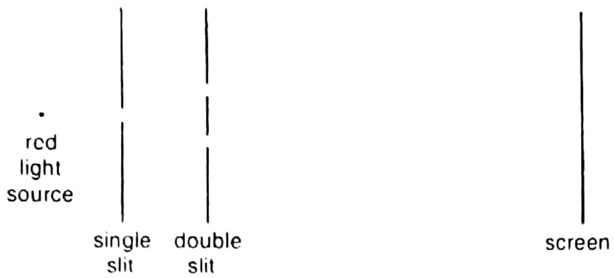
Wavelength of microwaves = $2 \times 15 = 30$ mm

Speed of microwaves = 3.0×10^8 ms^{-1}

$$\text{Frequency} = \frac{\text{speed}}{\text{wavelength}} = \frac{3.0 \times 10^8 \text{ ms}^{-1}}{30 \times 10^{-3} \text{ m}} = 1.0 \times 10^{10} \text{ Hz}$$

---

53. A double-slit interference experiment is set up as shown.



Fringes are formed on the screen. The distance between successive bright fringes is found to be 4 mm.

Two changes are then made to the experimental arrangement. The double slit is replaced by another double slit which has half the spacing. The screen is moved so that its distance from the double slit is twice as great.

What is now the distance between successive bright fringes?

A 1 mm B 4 mm
C 8 mm D 16 mm

Helping concepts

For Young's double slit experiment,

$$\lambda = \frac{ax}{D} \Rightarrow x = \frac{\lambda D}{a}$$

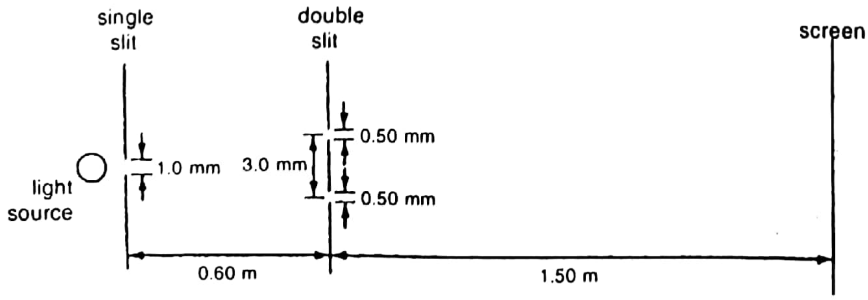
For scenario 1,

$$4 \text{ mm} = \frac{\lambda D}{a}$$

For scenario 2,

$$x = \frac{\lambda(2D)}{(\frac{1}{2}a)} = 4\frac{\lambda D}{a} = 4(4) = 16 \text{ mm}$$

54. A student sets up an experiment to demonstrate double slit interference, using light of wavelength 6.0×10^{-7} m. The main features of the apparatus, and some of the dimensions, are illustrated.



What is the separation of the bright fringes on the screen?

A 0.12 mm B 0.30 mm
C 0.90 mm D 1.80 mm

Helping concepts

For Young's double slit experiment,

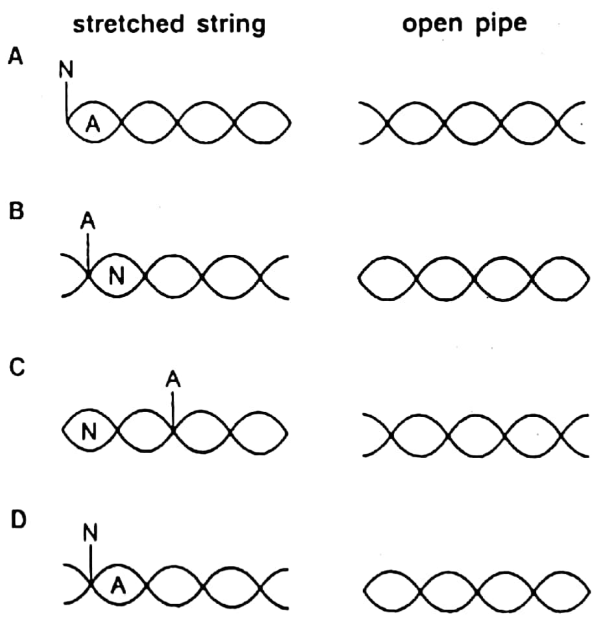
$$\lambda = \frac{ax}{d}$$

where a = distance between 2 slits,
d = distance between slits and screen,
x = fringe separation,
λ = wavelength of light.

$$\therefore x = \frac{\lambda d}{a} = \frac{(6.0 \times 10^{-7})(1.50)}{(3.0 \times 10^{-3})} = 0.30 \text{ mm}$$

55. The four pairs of diagrams represent standing waves formed in a stretched string and in a pipe open at both ends.

If nodes are marked N and antinodes are marked A, which pair of diagrams is labelled correctly?



Helping concepts

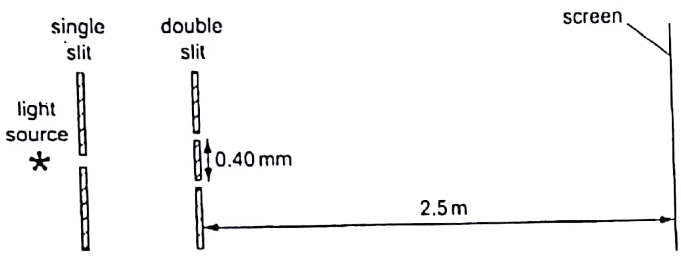
For stretched string, both ends must be a node.

For open pipe, both ends must be an antinode.

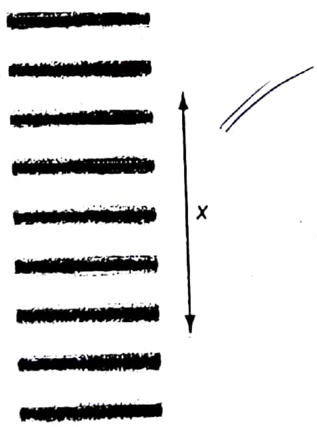
A node should be represented at point of zero displacement (or equilibrium) and antinode at point of maximum displacement.

---

56. A two-source interference experiment is set up as shown.



The source emits light of wavelength 600 nm. The interference pattern on the screen is shown below.



What is the distance x?

A 3.8×10^{-4} m   B 1.9×10^{-3} m

C 3.8×10^{-3} m   D 1.9×10^{-2} m

Helping concepts

Young's double slit experiment,

$$\text{fringe separation} = \frac{\lambda D}{a} = \frac{(600 \times 10^{-9})(2.5)}{(0.40 \times 10^{-3})} = 3.75 \text{ mm}$$

For the question, x = 5(fringe separation)

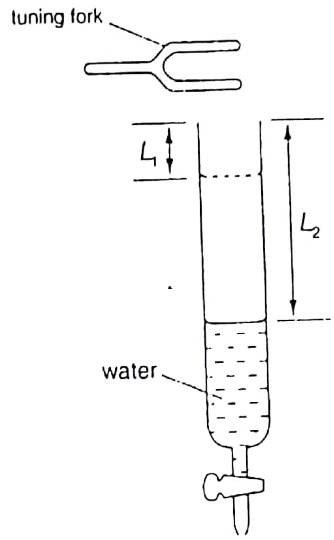
= 5(3.75)

= 19 mm

= 1.9×10^{-2} m

---

57. A turning fork is made to vibrate above a tube filled with water. The water is allowed to run out of the tube.



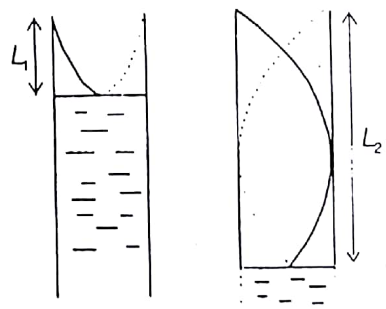
A loud sound is heard when the length of the air column is L_1 and again when the length is L_2.

What is the wavelength of the sound in the tube?

A $2L_1$ B $L_2 - L_1$

C $2(L_2 - L_1)$ D $2L_2$

Helping concepts



Let λ be the wavelength of stationary sound wave.

$$\frac{\lambda}{4} = L_1 + e \text{-----}(1)$$

$$\frac{3}{4}\lambda = L_2 + e \text{-----}(2)$$

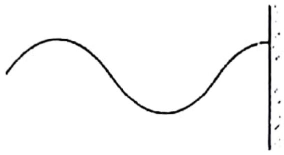
where e is the constant value of end correction.

(2) − (1): $L_2 - L_1 = \frac{1}{2}\lambda$

$\lambda = 2(L_2 - L_1)$

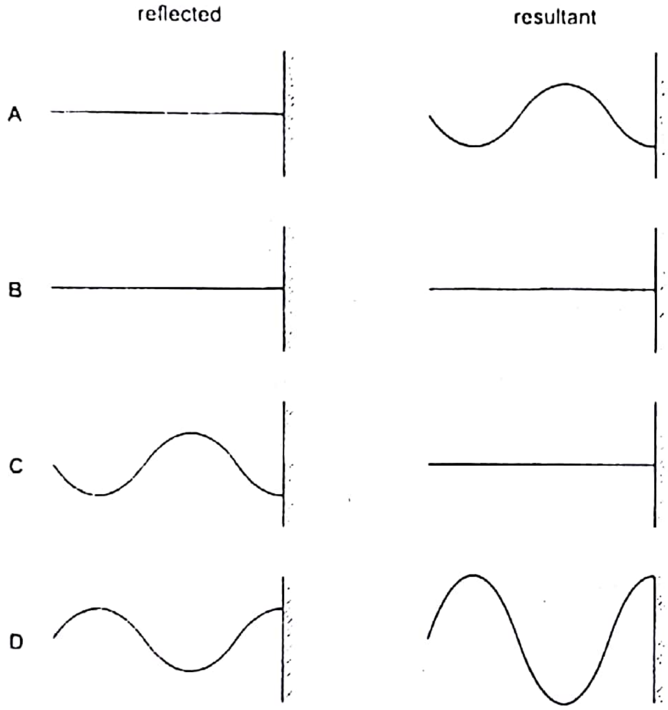
---

58. A continuous progressive wave is incident on a barrier. The diagram shows just the incident wave at one instant.



The wave is being reflected from the barrier, forming a stationary wave.

Which diagrams represent the reflected wave and the resultant wave at the same instant?

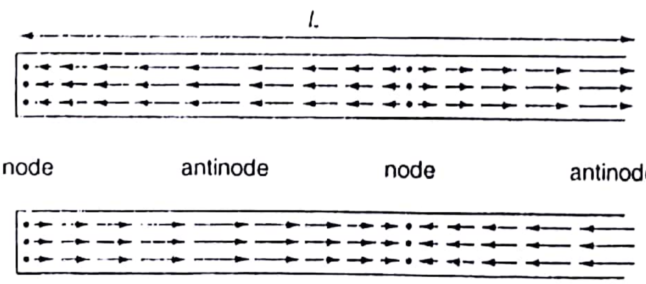


Helping concepts

Reflected wave is in anti-phase to the original wave.

The resultant wave at that instant will be zero displacement as the incident and reflected waves cancel out each other.

59. The diagrams show particle movement in an air column when a stationary wave exists in the column.



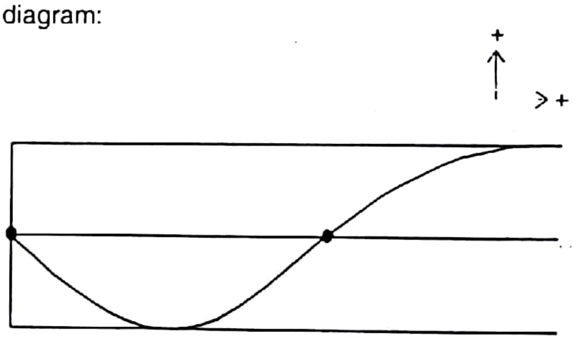
The first diagram shows the displacement of some particles at one instant and the second diagram shows the displacement of some particles half a cycle later.

What is the length L of the column in terms of the wavelength λ, and at which position within the column does the pressure change by the largest amount?

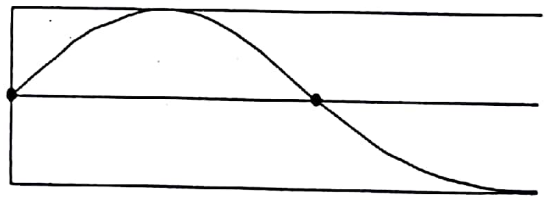
	length L	maximum pressure change at
A	$\frac{3}{4}\lambda$	node
B	$\frac{3}{4}\lambda$	antinode
C	$\frac{3}{2}\lambda$	node
D	$\frac{3}{2}\lambda$	antinode

Helping concepts

First diagram:



Second diagram:



Taking right-wards pointing arrows as positive displacement upwards for the 2 diagrams above.

It is clear that $\frac{3}{4}\lambda = L$ from both diagrams 1 and 2.

In the first diagram, at the node, it is a rare fraction (low pressure) as the particles are moving away from one another.

In the second diagram, at the node, it is a compression (high pressure) as the particles are moving towards one another.

Therefore, the pressure change is the greatest.

TOPIC 12

Electric Fields

Key content that you will be examined on:

1. Concept of an electric field
2. Force between point charges
3. Electric field of a point charge
4. Uniform electric fields
5. Electric potential

Topic 12 Electric Fields

1. Which of the following statements about an electric field is **incorrect**?

   A The electric field strength due to a point charge varies as $1/r^2$ where r is the distance from the charge.

   B Electric field strength is a vector quantity.

   C The electric field strength at a point is a measure of the force exerted on a unit positive charge at that point.

   D The electric field strength is zero at all points where the potential is zero.

Helping concepts

The electric field strength is zero at all points if the potential gradient is zero at these points. Zero potential at these points do not imply that the potential gradient is also zero. Hence, statement D is incorrect.

---

2. What is the value of the potential gradient at a point in an electric field?

   A the electrical potential energy of a unit positive charge at that point

   B the electric field strength at that point

   C the force acting on a unit negative charge at that point

   D the work done to move unit negative charge from infinity to that point

Helping concepts

Potential gradient = $\frac{dV}{dr}$ = numerically equal to the electrical field strength in an electric field.

---

3. Electric field strength is defined as force per unit positive charge on a small test charge.

   Why is it necessary for the test charge to be small?

   A so that the test charge does not distort the electric field

   B so that the force on the test charge is small

   C so that the test charge does not create any forces on nearby charges

   D so that Coulomb's law for point charges is obeyed

Helping concepts

The test charge should not change or affect the field it is going to measure.

---

4. The electric field strength between a pair of parallel plates is E. The separation of the plates is doubled and the potential difference between the plates is increased by a factor of four.

   What is the new electric field strength?

   A E B $2E$

   C $4E$ D $8E$

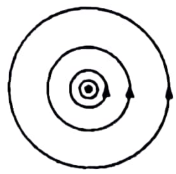
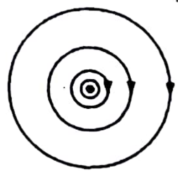
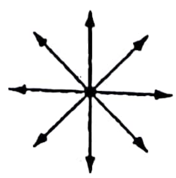
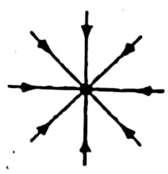
Helping concepts

$$E = \frac{V}{d}$$

$$E_{new} = \frac{4V}{2d} = 2E$$

---

5. Which diagram represents the electric fields of a negative point charge, shown by •.

A

B

C

D


Helping concepts

Electric field of a negative charge radiates inwards towards itself.

6. The charge on the uranium nucleus is 1.5×10^{-17} C and the charge on the α-particle is 3.2×10^{-19} C.

   What is the electrostatic force between a uranium nucleus and an α-particle separated by 1.0×10^{-13} m?

   A 4.3×10^{-33} N B 4.3×10^{-20} N

   C 4.3×10^{-13} N D 4.3 N

Helping concepts

The electrostatic force F is given by

$$F = \frac{Q_1Q_2}{4\pi\varepsilon_0 d^2}$$

$$= \frac{(1.5 \times 10^{-17})(3.2 \times 10^{-19})}{4\pi(8.854 \times 10^{-12})(1.0 \times 10^{-13})^2}$$

$$= 4.3 \text{ N}$$

7. In Millikan's experiment, oil drop are used to measure the elementary charge *e*.

   Which statement about the behaviour of the oil drops during the experiment is correct?

   A When an oil drop becomes charged, the size of the charge must equal *e*.

   B When an oil drop is stationary, it must carry a charge.

   C When an oil drop moves upwards, only the electric force is acting on it.

   D When no electric field acts, all drops move downwards with the same constant velocity.

Helping concepts

For an oil drop to be stationary, there must exist an upward force to counter the downward force of its own weight. This upward force is created when the oil drop is charged and placed in an electric field with the appropriate polarity so that the oil drop is attracted to the upper plate.

8. A point electric charge $-q$ is brought from a point P_1 in space to another point P_2 by an external agent. The electric potentials at points P_1 and P_2 are V_1 and V_2 respectively.

   What is the work done on the charge?

   A $q(V_2 + V_1)$ B $q(-V_2 - V_1)$

   C $q(V_2 - V_1)$ D $q(V_1 - V_2)$

Helping concepts

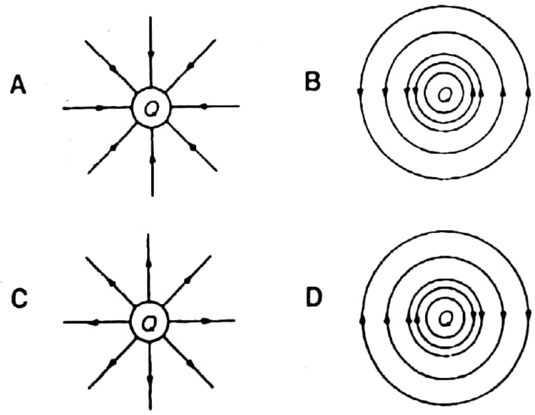
Electric potential energy at P_1 and P_2 is $(-q)V_1$ and $(-q)V_2$ respectively.

Work done = change in electric potential energy

$$= (-q)V_2 - (-q)V_1$$

$$= q(V_1 - V_2)$$

9. Which diagram represents the electric field in the vicinity of a positive electric charge of magnitude Q?



Helping concepts

By definition, electric fields are pointing away from a positive charge in a radial direction.

10. A gold nucleus (radius r) is represented by the symbol $^{197}_{79}Au$. Taking e as the elementary charge and ε_0 as the permittivity of free space, what is the electric field strength at the surface of an isolated gold nucleus?

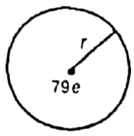
    A zero B $\frac{79e}{4\pi\varepsilon_0 r^2}$

    C $\frac{197e}{4\pi\varepsilon_0 r^2}$ D $\frac{79e^2}{4\pi\varepsilon_0 r^2}$

Helping concepts

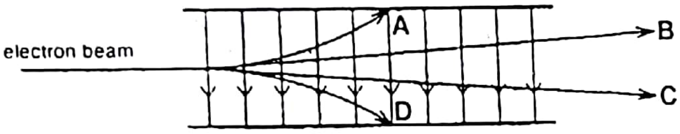
Electric field strength at distance r from the centre of the nucleus Er is

$$Er = \frac{79e}{4\pi\varepsilon_0 r^2}$$



since charge with the nucleus is $79e$.

11. Which path shows a possible movement of an electron in the electric field shown?



Helping concepts

A positive charge will move in the same direction as electric field, and vice versa for a negative charge.

12. In an experiment to demonstrate Coulomb's law in electrostatics, the force F between two small charged spheres is measured for various distance r between their centres.

A graph is plotted of $\lg F$ (y-axis) against $\lg r$ (x-axis).

What is the slope of this graph?

A -2 B $-\frac{1}{2}$

C $-\lg 2$ D $+\frac{1}{2}$

Helping concepts

Force F between two small charged spheres at a distance r apart is given by

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$$

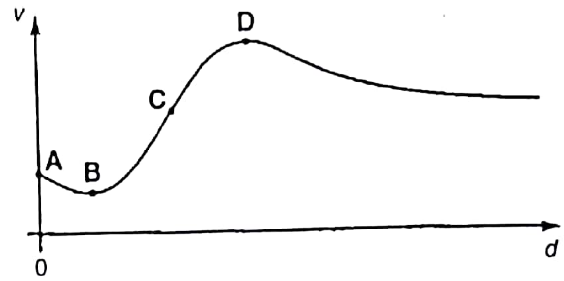
where Q_1 and Q_2 are charges on the charged spheres.

$$\therefore \lg F = \lg\left(\frac{Q_1Q_2}{4\pi\varepsilon_0}\right) - 2\lg r$$

The graph of $\lg E$ against $\lg r$ is thus a straight line of gradient equals to -2.

13. The diagram shows the variation of the electric potential V with distance d along a straight line in a particular electric field.

At which point is the magnitude of the electric field greatest?

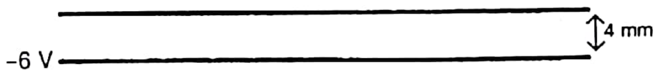


Helping concepts

$$E = \frac{dV}{dx}$$

That is, electric field is the gradient of the graph. The steepest gradient will be the one with the biggest value.

14. The large horizontal metal plates are separated by 4 mm. The lower plate is at a potential of -6 V.



What potential should be applied to the upper plate to create an electric field of strength 4000 Vm^{-1} **upwards** in the space between the plates?

A $+22$ V B $+10$ V

C -10 V D -22 V

Helping concepts

To create an electric field acting upwards, ther upper plate is at a potential lower than -6 V.

Using $E = \frac{V}{d}$,

$$V = (4000)(4 \times 10^{-3}) = 16 \text{ V}$$

Potential of upper plate $= -6 - 16 = -22$ V

15. In discussing electric fields, the terms 'electric field strength', 'electric potential' and 'potential gradient' are used.

Which statement about these terms is **correct**?

A Electric field strength at a point is the work done in bringing unit positive charge from infinity to the point.

B Electric potential and potential gradient are both scalar quantities.

C The potential gradient at a point is numerically equal to the electric field strength at that point.

D Unit potential gradient exists between any two points, if one joule of work is done in transporting one coulomb of charge between the points.

Helping concepts

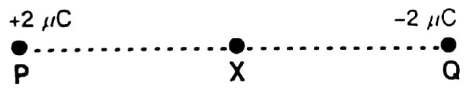
A Electric field strength is the force exerted by the field on a unit charge.

B Potential gradient is a vector quantity.

D Unit potential gradient exists between any two points if a force of 1 N is required to transport one coulomb of charge from the point at lower potential to the point at higher potential.

---

16. Charges of +2 μC and −2 μC are situated at points **P** and **Q** respectively, as shown. **X** is midway between **P** and **Q**.



Which of the following correctly describes the electric field and the electric potential at point **X**?

	electric field	electric potential
A	towards Q	zero
B	towards Q	negative
C	towards P	zero
D	towards P	positive

Helping concepts

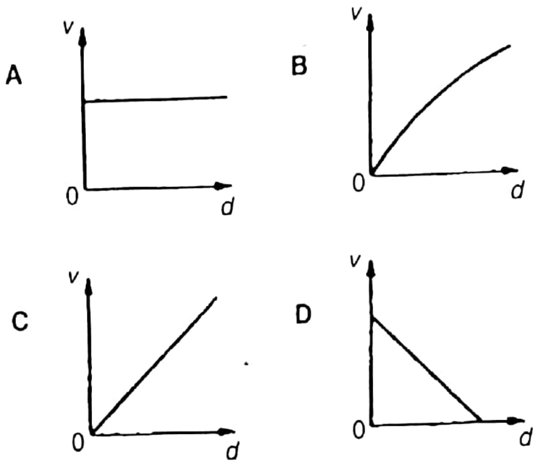
Electric fields act from higher potential to lower potential, thus towards **Q**.

Electric potential is zero since **X** is midway between **P** and **Q**.

---

17. A constant electric field is to be maintained between two large parallel plates for which the separation d can be varied.

Which graph shows the potential difference V between the plates must be adjusted to keep the field strength at a constant value?



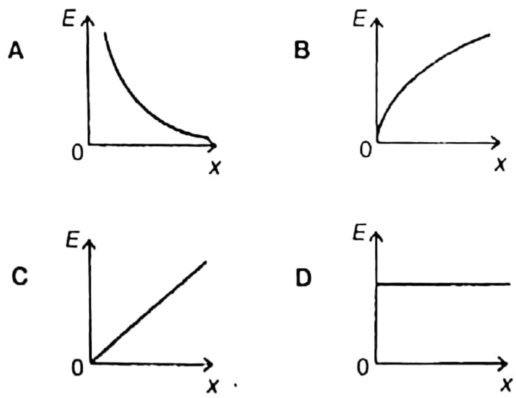
Helping concepts

From the equation $E = \frac{V}{d}$, we can see that if the electric field is to be kept constant, then $V \propto d$.

---

18. Two parallel conducting plates are connected to a battery, one plate to the positive terminal and the other plate to the negative. The plate separation is gradually increased, the plates remaining connected to the battery.

Which graph shows how the electric field E between the plates depends on the plate separation x?

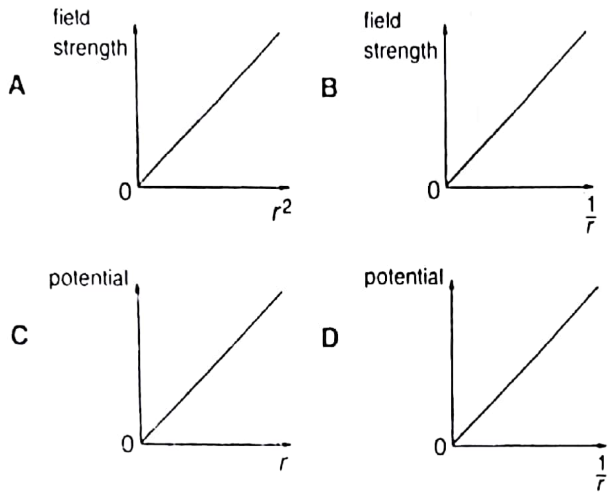


Helping concepts

For a parallel plate,

$$E = \frac{V}{x} = \text{constant.}$$

19. Which graph correctly relates the electric field strength or electric potential in the field of a point charge, with distance r from the charge?

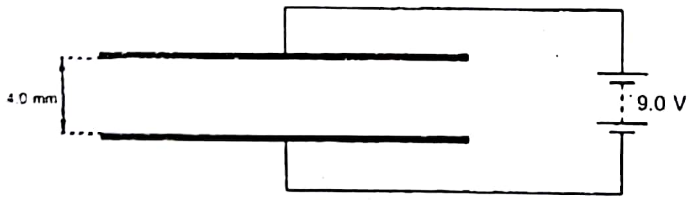


Helping concepts

$$E \propto \frac{1}{r^2} \text{ and } V \propto \frac{1}{r}.$$

Straight line graphs are obtained when plotting E against $\frac{1}{r^2}$ and when plotting V against $\frac{1}{r}$.

20. The diagram shows a pair metal plates 4.0 mm apart connected to a 9.0 V battery.



What is the electric field between the plates?

A 4.4×10^{-4} NC^{-1}

B 3.6×10^{-2} NC^{-1}

C 36 NC^{-1}

D 2.3×10^{3} NC^{-1}

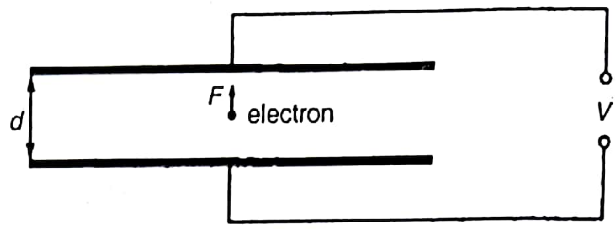
Helping concepts

For a parallel plate,

$$\text{electric field, } E = \frac{\text{potential difference}}{\text{distance between 2 plates}} = \frac{9.0 \text{ V}}{4.0 \times 10^{-3} \text{ m}} = 2.3 \times 10^{3} \text{ NC}^{-1}$$

21. An electron of charge e is introduced between two metal plates a distance d apart.

A potential difference V is applied to the plates as shown in the diagram.



Which expression gives the electric force F on the electron?

A $\frac{eV}{d}$ B eVd

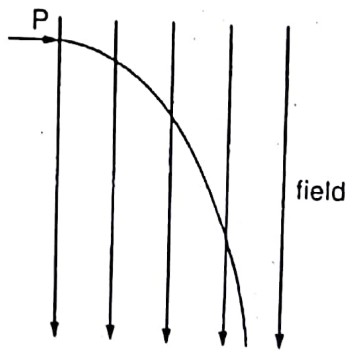
C $\frac{V}{ed}$ D $\frac{dV}{e}$

Helping concepts

$$\text{Force, } F = qE = e\left(\frac{V}{d}\right)$$

where electric field, $E = \frac{\text{potential difference, } V}{\text{distance, } d}$.

22. A charged particle is projected horizontally at P into a uniform vertical field. The particle follows the path shown.



Ignoring gravitational effects, what describes a possible state of charge of the particle and the nature of the field?

	charge	field
A	negative	electric
B	negative	magnetic
C	positive	electric
D	positive	magnetic

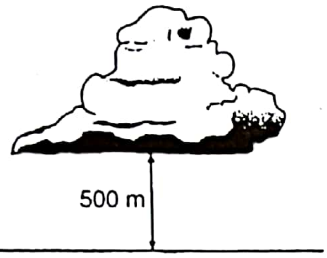
Helping concepts

Since the path is parabolic, the field is electric in nature.

As the charge moves downward, the charge is thus positive.

---

23. The diagram shows a thunder-cloud whose base is 500 m above the ground.



The potential difference between the base of the cloud and the ground is 200 MV. A raindrop with a charge of 4.0×10^{-12} C is in the region between the cloud and the ground.

What is the electrical force on the raindrop?

A 1.6×10^{-6} N **B** 8.0×10^{-4} N

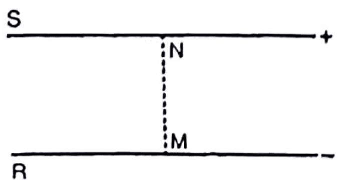
C 1.6×10^{-3} N **D** 0.40 N

Helping concepts

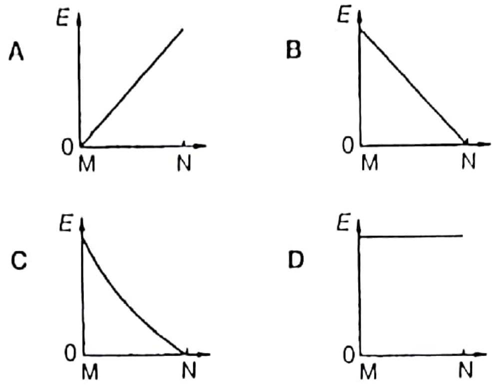
$$F = qE$$
$$= q\left(\frac{V}{d}\right)$$
$$= (4.0 \times 10^{-12})\left(\frac{200 \times 10^{6}}{500}\right)$$
$$= 1.6 \times 10^{-6} \text{ N}$$

---

24. In the diagram, R and S are parallel conducting plates. Plate S is at positive potential with respect to plate R. MN is a line perpendicular to the plates.



Which graph shows the variation along the line MN of the magnitude *E* of the electric field strength?

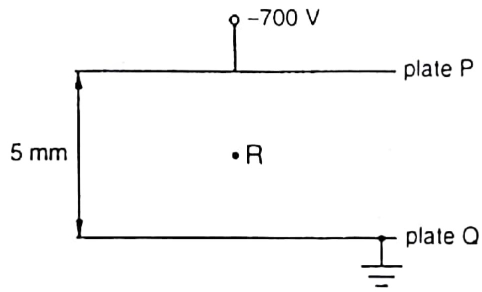


Helping concepts

Electric field of two parallel plates is constant.

---

25. The diagram shows two metal plates P and Q between which there is a potential difference of 700 V. Plate Q is earthed.



What is the magnitude and direction of the electric field at point R?

A 1.4×10^{2} NC^{-1} from P towards Q

B 1.4×10^{2} NC^{-1} from Q towards P

C 1.4×10^{5} NC^{-1} from P towards Q

D 1.4×10^{5} NC^{-1} from Q towards P

Helping concepts

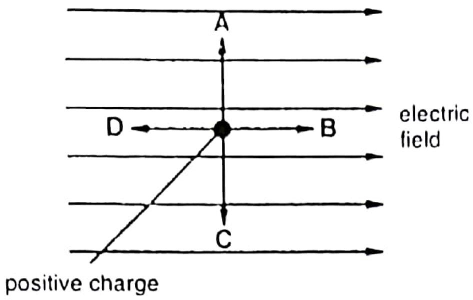
$$E = \frac{V}{d} = \frac{700}{5 \times 10^{-3}} = 1.4 \times 10^{5} \text{ NC}^{-1}$$

Electric field is from high to low potential, i.e. Q to P.

---

26. A positive charge is in a uniform electric field, as shown.

In which of the directions shown must the charge be moved in order to gain electric potential energy?



Helping *concepts*

The positive charge should be moved opposite to the direction of the electric field in order to gain electric potential energy.

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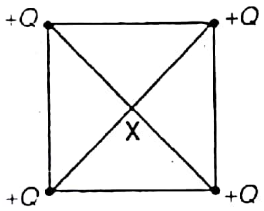
27. Four identical point charges are arranged at the corners of a square as shown.



Which statement about the values of the electric field strength E and the electric potential V at point X in the middle of the square is true?

	E	V
A	not zero	zero
B	not zero	not zero
C	zero	not zero
D	zero	zero

Helping *concepts*

Since X is equidistant from all four charges which are all identical, the electric field strength at X is zero. However, the electric potential at X is not zero as energy is required to move per unit charge from infinity to point X.

---

28. The electrons in a cathode-ray tube are accelerated from cathode to anode by a potential difference of 2000 V.

If this p.d. is increased to 8000 V, the electrons will arrive at the anode with

A twice the kinetic energy and four times the velocity.

B four times the kinetic energy and twice the velocity.

C four times the kinetic energy and sixteen times the velocity.

D sixteen times the kinetic energy and four times the velocity.

Helping *concepts*

If the potential difference is V and an electron is accelerated from zero velocity to reach the anode in distance s,

$$\text{acceleration, } a = \frac{eV}{m_e}$$

where m_e is the mass of an electron.

$\therefore$ Final velocity, $u = \sqrt{2as} = \sqrt{\dfrac{2eVs}{m_e}}$

Hence, kinetic energy, $KE = \frac{1}{2}m_e u^2 = eVs$

Given that the potential difference is increased from 2000 V to 8000 V, by a factor of 4.

Final velocity of electron is thus double $(\sqrt{4} = 2)$ and its kinetic energy is four times higher.

---

29. Drops **X** and **Y**, of the same oil, remained stationary in air in the same vertical electric field. After the field was switched off, **X** fell more quickly than **Y**.

Which deduction can be made?

A **X** had a greater charge than **Y**.

B **Y** had a greater charge than **X**.

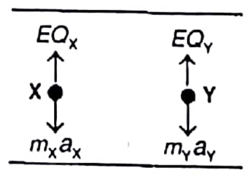
C Both **X** and **Y** were positively charged.

D The charges on **X** and **Y** were identical in sign and magnitude.

Helping *concepts*

$F_X = m_X a_X = EQ_X$

$F_Y = m_Y a_Y = EQ_Y$

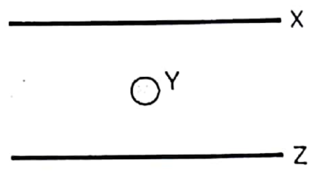


Given $a_X > a_Y$.

$\therefore$ $F_X > F_Y$ since drops **X** and **Y** are of the same oil.

Hence, $Q_X > Q_Y$, i.e. **X** has a greater charge than **Y**.

30. The diagram shows two charged horizontal metal plates X and Z. The magnitudes of the charges on the plates are equal. Between the plates, suspended stationary in the uniform electric field, is a charged sphere Y.



What could be the signs of the charges on the three components?

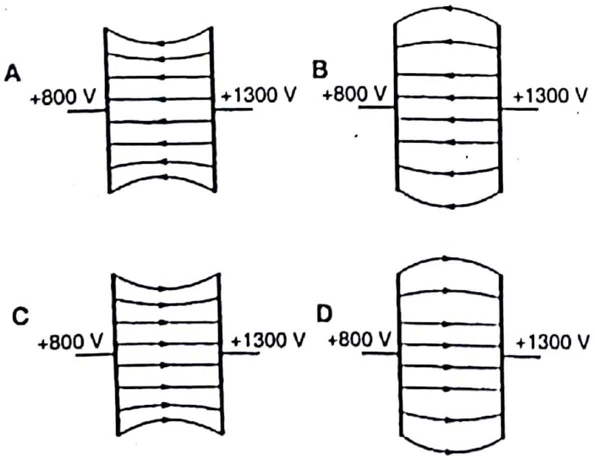
	plate X	plate Y	plate Z
A	negative	positive	negative
B	negative	positive	positive
C	positive	positive	negative
D	positive	negative	positive

Helping *concepts*

There is weight of Y in downwards direction. There must be an upwards force to make Y stationary.

Y and Z should be of same type (either positive or negative). Compared to Y and Z, X should be of opposite sign.

31. Two parallel metal plates are at potentials of +800 V and +1300 V. Which diagram best shows the electric field between the metal plates?

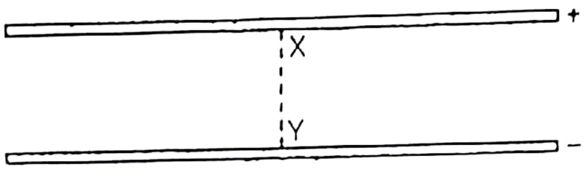


Helping *concepts*

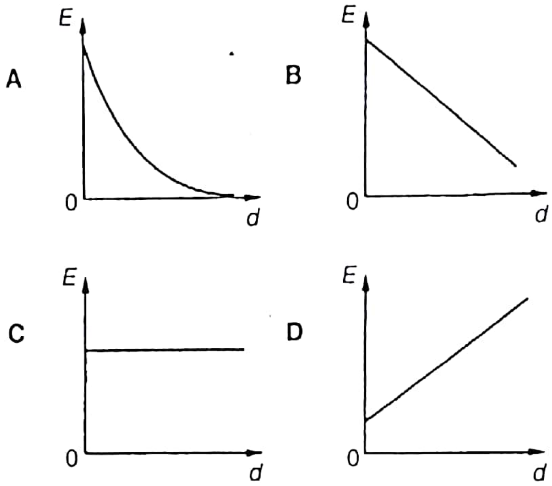
Electric field lines travel from high potential values to low potential values.

Near the ends of the parallel plates, there is some 'outwards bending' of the parallel plates.

32. An electric field exists in the space between two charged metal plates.



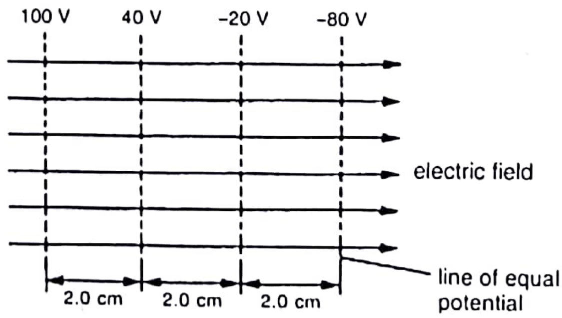
Which of the following graphs shows the variation of electric field strength E with distance d from X along the line XY?



Helping *concepts*

Electric field at a point is the potential gradient at that point, i.e. $E = \frac{V_+ - V_-}{d}$, provided the plates separation is small enough.

33. The diagram shows a uniform electric field in which the lines of equal potential are spaced 2.0 cm apart.



Which is the value of the electric force that is exerted on a charge of +5.0 μC when placed in the field?

A 6.0×10^{-6} N   **B** 1.5×10^{-2} N

C 3.0×10^{3} N   **D** 6.0×10^{4} N

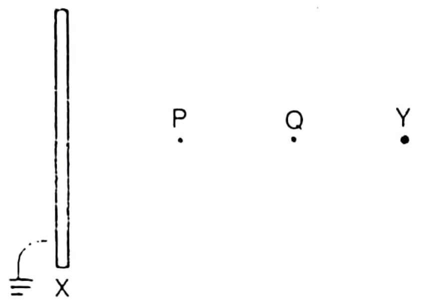
Helping concepts

$$E = \frac{\Delta V}{\Delta d} = \frac{100 - 40}{0.02} = 3000\ \text{V m}^{-1}$$

$$F = qE = (5.0 \times 10^{-6})(3000) = 0.015\ \text{N}$$

---

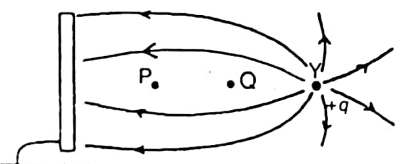
34. A point charge is placed at Y in front of an earthed metal sheet X. P and Q are two points between X and Y as shown in the diagram.



If the electric field strengths at P and Q are respectively E_P and E_Q, which one of the following statements is correct?

A $E_P = 0$ B $E_Q = 0$
C $E_P > E_Q$ D $E_Q > E_P$

Helping concepts



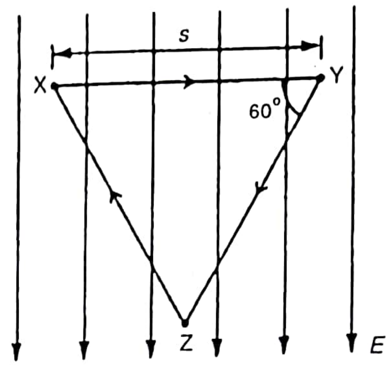
The diagram shows the electric field distribution from the point charge (positive) at Y to the earthed metal sheet X.

The point closer to the point charge Y has higher potential and hence, its field strength is higher than the other point further away from Y.

Hence, $E_Q > E_P$.

---

35. The diagram below shows three points X, Y and Z forming an equilateral triangle of side s in a uniform electric field of strength E. A unit positive test charge is moved from X to Y, from Y to Z, and from Z back to X.



Which one of the following correctly gives the work done against electric forces in moving the charge along the various parts of this path?

	X to Y	Y to Z	Z to X
A	0	$-Es\cos 60°$	$+Es\cos 60°$
B	$+Es$	$+Es\sin 60°$	$-Es\sin 60°$
C	0	$+Es\sin 60°$	$-Es\sin 60°$
D	0	$-Es\sin 60°$	$+Es\sin 60°$

Helping concepts

From $E = -\frac{dV}{dx}$, work done in moving a unit positive test charge in a uniform electric field of strength E is given by

$$\begin{aligned} \text{work done} &= V \\ &= \int dV \\ &= -\int E\,dx \\ &= -E\int dx \\ &= -Ed \end{aligned}$$

where d is the distance travel parallel to the direction of E.

From X to Y,

$d = 0 \Rightarrow$ work done $= 0$

From Y to Z,

$d = +s\sin 60° \Rightarrow$ work done $= -Es\sin 60°$

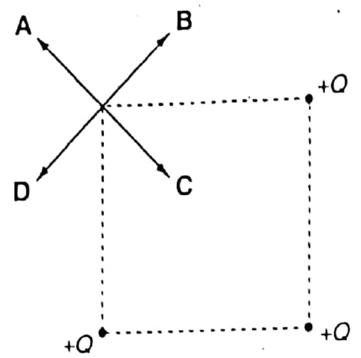
From Z to X,

$d = -s\sin 60° \Rightarrow$ work done $= +Es\sin 60°$

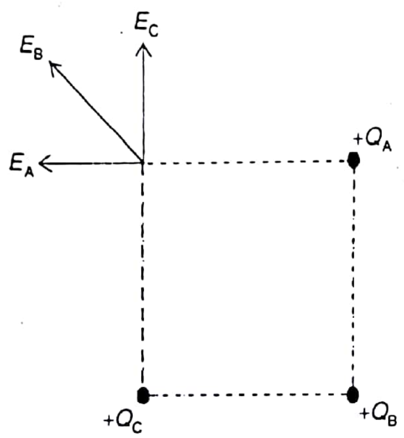
---

36. The diagram shows point charges, each of magnitude Q, placed at three corners of a square.

What is the direction of the resultant electric field at the fourth corner?



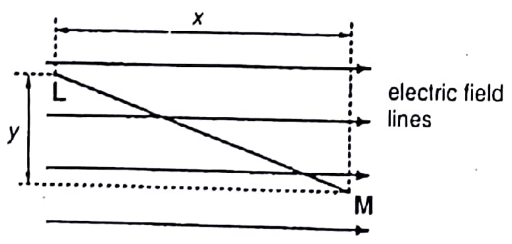
Helping concepts



The vector sum of E_A and E_C is in the same direction of E_B. This is because of the square arrangement of 3 charges.

Hence, resultant electric field is in the direction of **A**.

37. A small positive charge, placed at a point **L** inside a uniform electric field, experiences a force of magnitude F.



The charge is moved from point **L** to point **M**.

What is the change in the potential energy of the charge?

A gain of Fx

B gain of $F\sqrt{x^2+y^2}$

C loss of Fx

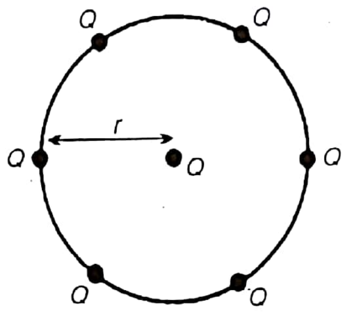
D loss of $F\sqrt{x^2+y^2}$

Helping concepts

A positive charge moves along the electric field lines from a high potential to low potential, and work is done only by moving parallel to field line.

$$\Delta PE = F \cdot x$$

38. A point charge is surrounded symmetrically by six identical charges at distance r as shown in the diagram.



How much work is done by the forces of electrostatic repulsion when the point charge at the centre is removed to infinity?

A zero

B $\dfrac{6Q}{4\pi\varepsilon_0 r}$

C $\dfrac{6Q^2}{4\pi\varepsilon_0 r}$

D $\dfrac{6Q}{4\pi\varepsilon_0 r^2}$

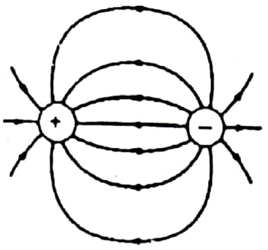
Helping concepts

The potential of the point charge due to individual charges surrounding it is $U = \dfrac{Q^2}{4\pi\varepsilon_0 r}$. Since the six charges are identical, the resultant potential of the point charge is $6U$ or $\dfrac{6Q^2}{4\pi\varepsilon_0 r}$. Hence, the work done on moving the point charge to infinity is $\dfrac{6Q^2}{4\pi\varepsilon_0 r}$.

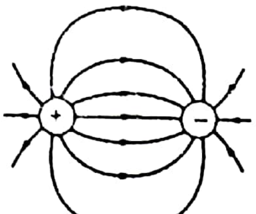
39. A positive charge and a negative charge of equal magnitude are placed a short distance apart.

Which diagram best represents the associated electric field?

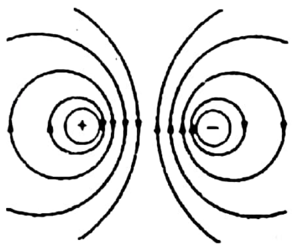
A



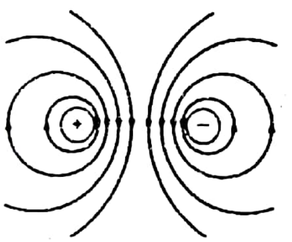
B



C



D



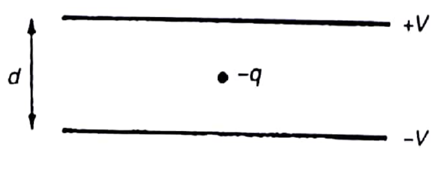
Helping concepts

The concept of the electric field is represented in diagram by lines of force, which form a convenient way of visualising electric field patterns. The lines of force are always originated from a positive charge and ended on a negative charge; the direction of which is the direction that a positive charge would move when placed in the electric field.

Hence, diagram B best represents the electric field pattern of the two unlike charges.

---

40. An oil droplet has a charge $-q$ and is situated between two parallel horizontal metal plates as shown in the diagram.



The separation of the plates is d. The droplet is observed to be stationary when the upper plate is at potential $+V$ and the lower at potential $-V$.

For this to occur, the weight of the droplet is equal in magnitude to

A $\frac{Vq}{d}$ B $\frac{2Vq}{d}$

C $\frac{Vd}{q}$ D $\frac{2Vq}{d}$

Helping concepts

The electric field acting on the oil droplet is $E = \frac{2V}{d}$.

The electric force acting upwards on the oil droplet is $F = qE = \frac{2qV}{d}$.

Since the charge is stationary, this electric force balances the gravitational force acting on the oil droplet whose weight is thus equal numerically to $\frac{2qV}{d}$.

---

41. An oil drop of mass m, carrying a charge q, is in the region between two horizontal plates. When the potential difference between the upper and lower plates is V, the drop is stationary. The potential difference is then increased to $2V$.

What is the initial upward acceleration of the drop?

A g B $2g$

C $\frac{2qV}{m} - g$ D $\frac{2qV}{m}$

Helping concepts

Initially, when the oil drop was stationary, upward force due to electric field is $qE = \frac{qV}{d}$, where d is the distance between the two plates. This balances the weight of the oil drops, mg. Thus, $mg = \frac{qV}{d}$.

When the potential difference was increased to $2V$, the upward force acting on the oil drop is thus $\frac{2qV}{d}$.

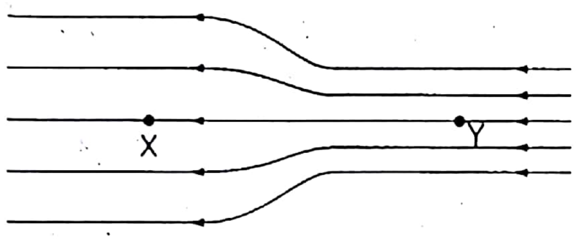
By Newton's 2nd law, $\frac{2qV}{d} - mg = ma$, where a is the upward acceleration of the oil drop. Thus, $a = \frac{2qV}{md} - g$.

Since $mg = \frac{qV}{d}$,

$$a = 2g - g = g$$

---

42. X and Y are two points on a field line in a region of electric field. The electric potentials at points X and Y are V_X and V_Y respectively.



An electron, initially at rest at X, accelerates towards Y.

The speed of the electron at Y is proportional to which expression below?

A $\sqrt{(V_Y - V_X)}$ B $V_Y - V_X$

C $(V_Y - V_X)^2$ D $V_Y^2 - V_X^2$

Helping concepts

loss in electric potential energy = gain in kinetic energy

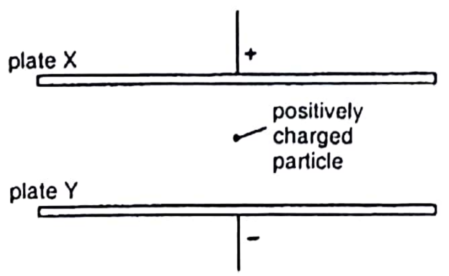
$$q(V_Y - V_X) = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2q(V_Y - V_X)}{m}}$$

$\therefore$ $v \propto \sqrt{(V_Y - V_X)}$ as $\sqrt{\frac{2q}{m}}$ is constant.

---

43. Two large parallel metal plates X and Y are situated in a vacuum as shown.



Plates X and Y carry equal opposite charges.

What happens to the force on a positively charged particle as it moves from plate X to plate Y?

A It decreases because the positively charged particle is moving away from the positively charged plate.

B It decreases because the positively charged particle is moving in the direction of the electric field between the plates.

C It increases because the positively charged particle is moving closer to a negatively charged plate.

D It remains constant because the positively charged particle is in the uniform electric field between the plates.

Helping concepts

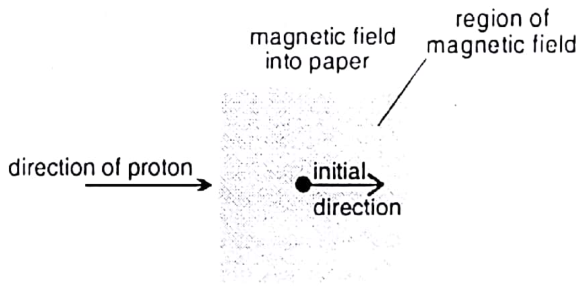
Electric force, $F = qE$.

Now E is constant for parallel plates.

Hence, F is constant.

---

44. A proton is travelling through a vacuum in a uniform magnetic field. Initially, the velocity of the proton is normal to the field.



What effect does the magnetic field have on the speed and on the path of the proton?

	speed	path
A	constant	circle anticlockwise
B	constant	circle clockwise
C	increases	circle anticlockwise
D	increases	circle clockwise

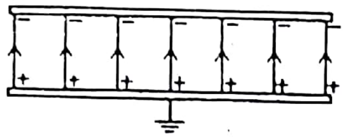
Helping concepts

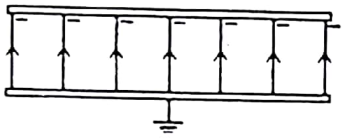
Magnetic force on moving charge is perpendicular to its velocity. There is no work done and therefore, speed remains constant.

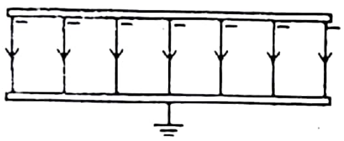
By Fleming's left hand rule, the force is pointing upwards and proton will move in anticlockwise direction.

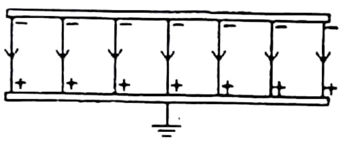
45. Two parallel, conducting plates with air between them are placed close to one another. The top plate is given a negative charge and the bottom one is earthed.

Which diagram best represents the field and distrubution of charges in this situation?

A


B


C


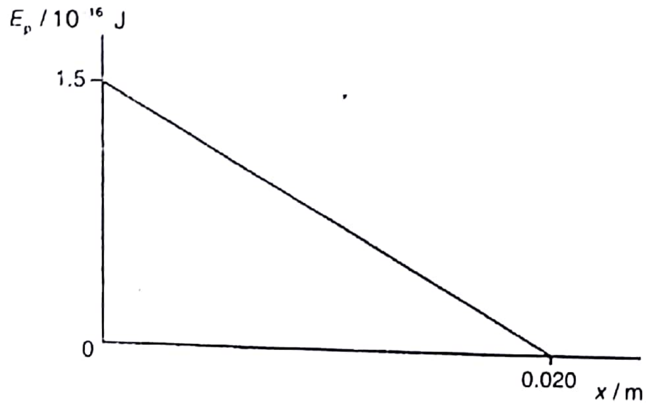
D


Helping concepts

Since the bottom plate is earthed, electrons from the bottom plate will be repelled by the negative charge on the top plate and travel to earth, leaving the bottom plate to be positively charged. Electric field lines start from positive toward negative charges.

---

46. Two charged plates are 0.020 m apart, producing a uniform electric field. The potential energy E_p of an electron in the field varies with displacement x from one of the plates as shown.



What is the magnitude of the force on the electron?

A 3.0×10^{-18} N B 7.5×10^{-17} N
C 3.8×10^{-15} N D 7.5×10^{-15} N

Helping concepts

For a uniform electric field,

$$E = \frac{V}{d}$$

where V is the potential,
x is the distance between plates.

$$\therefore\ E = \frac{E_p / e}{x}$$

where E_p is the potential energy = eV.

$$\therefore\ \frac{F}{e} = \frac{E_p}{xe} \quad (\because\ E = \frac{F}{e})$$

$$\Rightarrow F = \frac{E_p}{d}$$

= gradient of the graph

$$= \frac{1.5 \times 10^{-16}}{0.020}$$

$= 7.5 \times 10^{-15}$ N

---

47. In an experiment to measure the electron charge, an oil drop with an excess of two electron charges is held stationary between two parallel horizontal plates when the potential difference between them is 150 V.

A second oil drop, of mass twice that of the first, is held stationary with 200 V between the plates. Neglecting the upthrust of the air, how many excess electron charges does the second drop carry?

A 2 B 3
C 4 D 6

Helping concepts

The charge q on the oil drop is related to the potential difference V between the plates of separation d by the equation below.

$$F = q\frac{V}{d} = mg$$

where m is the mass of the oil drop (upthrust of the air is neglected).

For the first oil drop, we have

$$F_1 = \frac{2eV_1}{d} = m_1 g$$

For the second oil drop, we have

$$F_2 = q\frac{V_2}{d} = m_2 g$$

Taking the ratio of the forces, yield

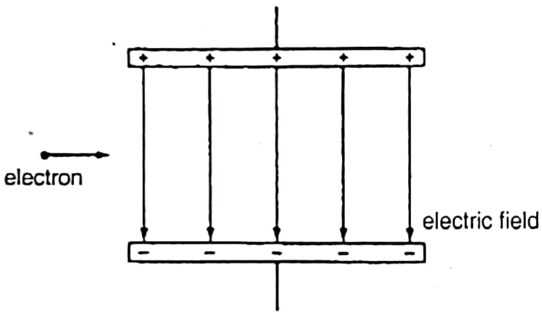
$$\frac{F_2}{F_1} = (\frac{q}{2e})(\frac{V_2}{V_1}) = \frac{m_2}{m_1}$$

$$\Rightarrow q = (\frac{m_2}{m_1})(\frac{V_1}{V_2})2e = (\frac{2m_1}{m_1})(\frac{150}{200})2e = 3e$$

Thus, the second oil drop carries an excess of 3 electron charges.

---

48. An electron, travelling horizontally at constant speed in a vacuum, enters a vertical electric field between two charged parallel plates as shown.



What are the horizontal and vertical components of the motion of this electron when it is in the field?

	horizontal component of motion	vertical component of motion
A	constant speed	acceleration upwards
B	constant speed	acceleration downwards
C	acceleration to the right	acceleration downwards
D	acceleration to the right	acceleration upwards

Helping *concepts*

There is no horizontal field which accelerates the electrons. The electron will be attracted to the positive plate and accelerate upwards. Note that the acceleration (and force) on an electron is opposite in direction to the electric field.

---

49. If the distance from a charged particle is doubled, how do the new values of field strength and potential due to the charge compare to the original values?

	field strength	potential
A	$\frac{1}{4}$	$\frac{1}{4}$
B	$\frac{1}{4}$	$\frac{1}{2}$
C	$\frac{1}{2}$	$\frac{1}{4}$
D	$\frac{1}{2}$	$\frac{1}{2}$

Helping *concepts*

Electric field, $E = \frac{Q}{4\pi\varepsilon_0 r^2}$

$$\Rightarrow \begin{cases} E \propto \frac{1}{r^2} \text{-----}(1) \\ E_{new} \propto \frac{1}{(2r)^2} \text{-----}(2) \end{cases}$$

$$\frac{(2)}{(1)}: \frac{E_{new}}{E} = \frac{1}{4} \Rightarrow E_{new} = \frac{1}{4}E$$

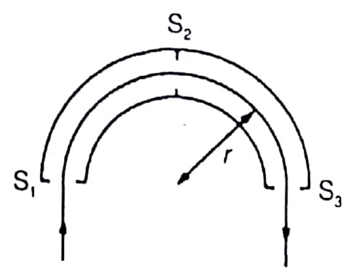
Electric potential, $V = \frac{Q}{4\pi\varepsilon_0 r}$

$$\Rightarrow \begin{cases} V \propto \frac{1}{r} \text{-----}(1) \\ V_{new} \propto \frac{1}{2r} \text{-----}(2) \end{cases}$$

$$\frac{(2)}{(1)}: \frac{V_{new}}{V} = \frac{1}{2} \Rightarrow V_{new} = \frac{1}{2}V$$

---

50. The diagram below shows an arrangement of two metallic half-cylinders with a common axis with a number of slits S that define a semicircular path of radius *r*, the whole being enclosed in a vacuum vessel. The outer half-cylinder is at a positive potential with respect to the innert one so that a constant radial electric field is maintained between them. A collimated beam of singly charged positive ions is injected at S_1.



Given that the incident beam contains ions of different masses and speeds, the beam which emerges at S_3 contains only ions that have the same

A mass.
B specific charge.
C speed.
D kinetic energy.

Helping concepts

The electric field E is acting perpendicular to the direction of motion of the beam of ions entering at S_1, passing through S_2 and leaving from S_3. Since the force F on the beam of ions emerging at S_3 is perpendicular to the motion of the ions, no work is done on the beam of ions and hence the force F cannot change the energy of the ions. Thus, the beams which emerges at S_3 contains only ions that have the same kinetic energy.

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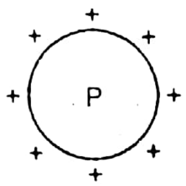
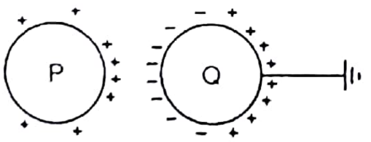
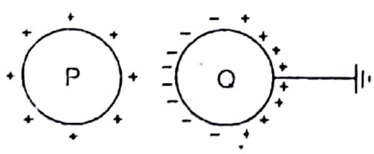
51. An isolated conducting sphere P has the charge distribution shown.

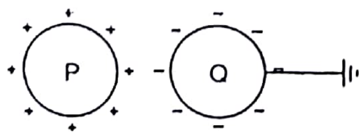


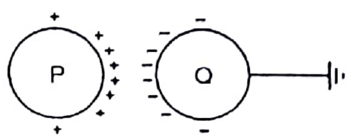
A similar sphere Q, connected to earth by a long wire, is brought close to P.

Which diagram shows the final distribution of charge on the two spheres?

A


B


C


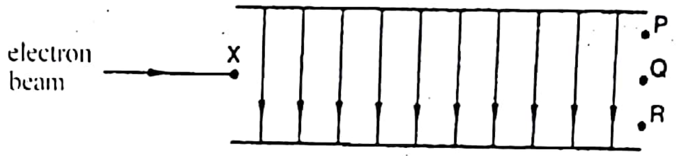
D


Helping concepts

Electrons on sphere Q would be attracted to the side on Q closer to P, leaving the other side positively charged. However, electrons from earth would neutralise the positive charges. The charges on P and Q redistribute so that they are on the sides of the spheres close to one another.

---

52. An electron beam enters a region in an evacuated tube in which there is a uniform electric field directed as shown in the diagram.



Which of the following is a possible path for the beam?

A a curved line from **X** to **P**
B a curved line from **X** to **R**
C the straight line **XQ**
D a line curving out of the plane of the diagram

Helping concepts

The force F on the electron beam carrying a charge q in the uniform electric field E is vertically upwards and is given by

$$F = qE$$

If m is the mass of an electron in the beam, then the acceleration of electron is

$$a = \frac{F}{m} = \frac{eE}{m}$$

and the vertical upward distance of the electron is

$$y = \frac{1}{2}at^2 = \frac{1}{2}\left(\frac{eE}{m}\right)t^2$$

But the horizontal distance travelled by the electron at speed v is given by

$$x = vt \text{ or } t = \frac{x}{v}$$

$\therefore\ y = \frac{1}{2}\left(\frac{eE}{m}\right)\left(\frac{x}{v}\right)^2 = \left(\frac{eE}{2mv^2}\right)x^2$ - an upward parabolic path by the electron.

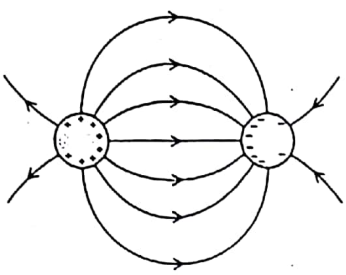
Thus, path of the beam is a parabolic line from **X** to **P**.

---

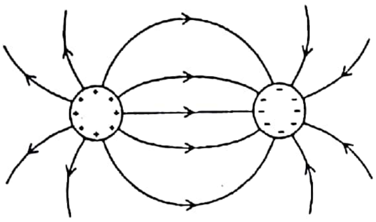
53. Two small metal spheres have equal but opposite charges.

Which diagram shows a possible distribution of charge on the spheres and the electric field near the spheres?

A



B



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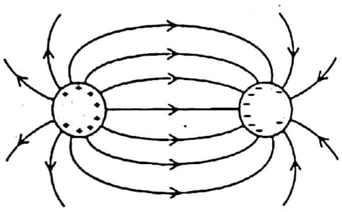
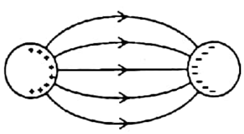


D



Helping *concepts*

The field lines should start from a '+' charge and end at a '−' charge in the diagram.

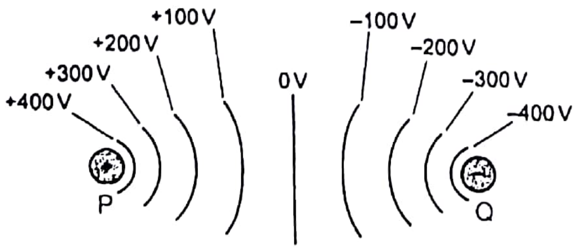
Option B is incorrect as the charges in each sphere cannot be equally distributed.

Option C is incorrect as some field lines do not start and end at charges.

Option D is incorrect as source field lines do not start and end at charges.

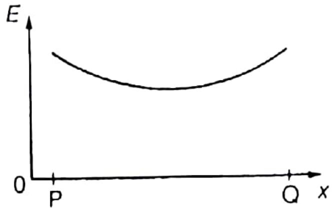
54. An object with a positive charge is placed at P and a similar object with a negative charge is placed at Q.

The diagram shows a number of lines along which the potential has a constant value.

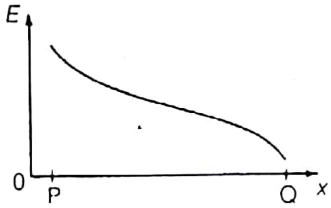


Which graph shows the variation with distance x along line PQ of the electric field strength E?

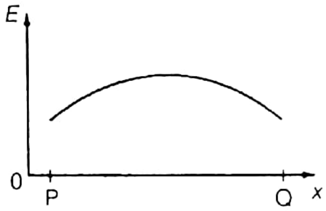
A



B



C

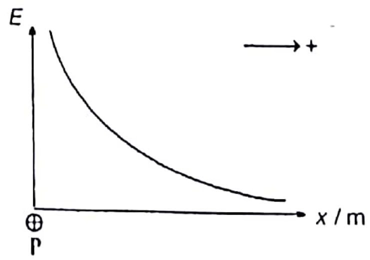


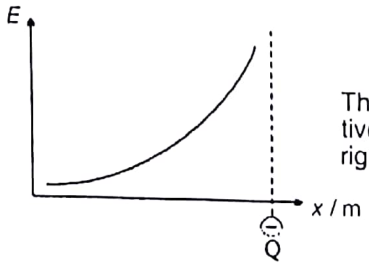
D

Helping *concepts*

By definition, $E = -\frac{dV}{dx}$.

$E = (-\frac{dV}{dx})$ at point P is negative as the value of V is positive.





The electric field of negative charge is also to the right-hand-side direction.

Since both electric fields of positive and negative charges are in the same direction, the resultant field is the addition of the two individual fields.

TOPIC 13

Current of Electricity

Key content that you will be examined on:

1. Electric current
2. Potential difference
3. Resistance and resistivity
4. Sources of electromotive force

Topic 13 Current of Electricity

1. The current in a resistor is 8.0 mA.

   What charge flows through the resistor in 0.020 s?

   A 0.16 mC B 1.6 mC
   C 4.0 mC D 0.40 mC

Helping concepts

$Q = It$
$= (8.0 \text{ mA})(0.020 \text{ s})$
$= 0.16 \text{ mC}$

2. What is a **correct** statement of Ohm's law?

   A The potential difference across a component equals the current providing the resistance and other physical conditions stay constant.
   B The potential difference across a component equals the current multiplied by the resistance.
   C The potential difference across a component is proportional to its resistance.
   D The potential difference across a component is proportional to the current in it providing physical conditions stay constant.

Helping concepts

By definition.

3. Which equation is used to define resistance?

   A energy = $(\text{current})^2$ × resistance × time
   B potential difference = current × resistance
   C power = $(\text{current})^2$ × resistance
   D resistivity = resistance × area ÷ length

Helping concepts

By Ohm's law,

$$R = \frac{V}{I} \Rightarrow V = R \times I$$

4. Which one of the following correctly names two types of conductor in both of which the motion of positive ions contributes to the transfer of charge?

   A metals and liquid electrolytes
   B n-type semiconductors and liquid electrolytes
   C n-type semiconductors and ionised gases
   D liquid electrolytes and ionised gases

Helping concepts

In liquid electrolytes and ionised gases, motion of positive and negative ions contributes to the transfer of charge. On the other hand, in metals and n-type semiconductors, motion of electrons contributes more to the transfer of charge.

5. The terminal voltage of a battery is observed to fall when the battery supplies a current to an external resistor.

   What quantities are needed to calculate the fall in voltage?

   A the battery's e.m.f. and its internal resistance
   B the battery's e.m.f. and the current
   C the current and the battery's internal resistance
   D the current and the external resistance

Helping concepts

By Kirchoff's 2nd law, fall in voltage is $E - Ir = IR$.
Hence, only current (I) and external resistance (R) is required.

6. Mains electrical equipment is sometimes provided with a neon indicator lamp to show when the equipment is switched on. What charge carriers convey the current in the neon?

   A electrons only
   B positive ions only
   C negative ions only
   D holes and electrons

Helping concepts

Typically, below 12 V, the charge carrier is electrons emitted by the cathode which has a heater element. The neon lamp will not produce light but can act as a diode.

Above 12 V, the noble gas (argon, neon etc.) breaks down into positive ions and electrons. Then there are 2 charge carriers. To produce visible light, ionisation is required.

---

7. A cell of e.m.f. E delivers a charge Q to an external circuit.

Which statement is correct?

A The energy dissipation in the external circuit is EQ.

B The energy dissipation within the cell is EQ.

C The external resistance is EQ.

D The total energy dissipation in the cell and the external circuit is EQ.

Helping concepts

The current supplied by the cell flows through the internal resistance of the battery as well as the external circuit. EQ measures the energy dissipated through the entire path.

---

8. A battery of e.m.f. 6.0 V and internal resistance 0.40 Ω is connected to an external resistor of resistance 2.9 Ω.

What is the power supplied to the external resistor?

A 1.3 W **B** 5.3 W

C 9.6 W **D** 12.4 W

Helping concepts

Current in circuit, $I = \dfrac{6.0}{(2.9 + 0.40)} = 1.82$ A

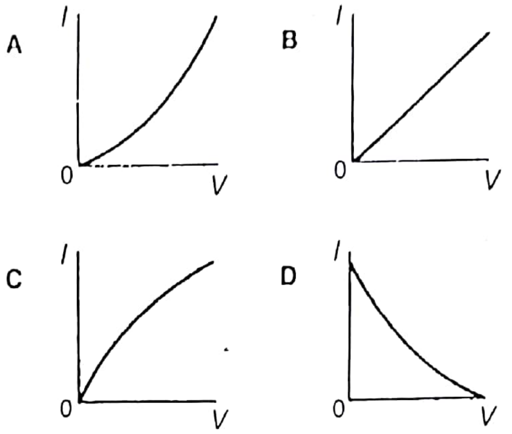
$\therefore$ Power supplied to the external resistor $= I^2R$

$= (1.82)^2(2.9)$

$= 9.6$ W

---

9. Which graph best represents the way in which the current I through a thermistor depends upon the potential difference V across it?



Helping concepts

Temperature of a thermistor increases as the potential difference across it increases. As temperature rises, resistance of the thermistor decreases and hence graph A best illustrates its I-V relationship.

---

10. Which statement describes the electrical potential difference between two points in a wire carrying a current?

A the force required to move a unit positive charge between the points

B the ratio of the energy dissipated between the points to the current

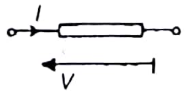
C the ratio of the power dissipated between the points to the current

D the ratio of the power dissipated between the points to the charge moved

Helping concepts

For a electrical potential difference of V between two points in a wire carrying current I, the power dissipated P is given by

power, $P = IV$ or $V = \dfrac{P}{I}$.



i.e. the ratio of power dissipated between the points to the current = V = electrical potential difference.

---

11. A generator produces 100 kW of power at a potential difference of 10 kV. The power is transmitted through cables of total resistance 5 Ω.

How much power is dissipated in the cables?

A 50 W B 250 W
C 500 W D 50 000 W

Helping concepts

Current through the cables,

$$I = \frac{\text{power}}{\text{potential difference}} = \frac{100 \times 10^3}{10 \times 10^3} = 10 \text{ A}$$

Power dissipated in the cables, $P = I^2R$

$= (10)^2(5)$

$= 500 \text{ W}$

12. A copper wire of cross-sectional area 2.0 mm² carries a current of 10 A.

How many electrons pass through a given cross-section of the wire in one second?

A 1.0×10^1 B 5.0×10^6
C 6.3×10^{19} D 3.1×10^{25}

Helping concepts

$$I = \frac{Q}{t} = \frac{Nq}{t}$$

where Q = total charge,
q = electronic charge.

$$\therefore \frac{I}{A} = \frac{N}{t} \cdot \frac{q}{A}$$

$$\Rightarrow \frac{N}{At} = \frac{I}{A} \cdot \frac{1}{q} = \left(\frac{10 \text{ A}}{2.0 \times 10^{-6} \text{ m}^2}\right)\left(\frac{1}{1.6 \times 10^{-19} \text{ C}}\right) = 6.3 \times 10^{19}$$

13. Two wires P and Q, each of the same length and the same material, are connected in parallel to a battery. The diameter of P is half that of Q.

What fraction of the total current passes through P?

A 0.20 B 0.25
C 0.33 D 0.50

Helping concepts

$$R = \rho\frac{l}{A} \Rightarrow R \propto \frac{1}{A} \Rightarrow R \propto \frac{1}{d^2}$$

for the same length and material.

For the same potential difference,

$$R \propto \frac{1}{I} \Rightarrow I \propto d^2$$

$$\therefore \frac{I_P}{I_Q} = \frac{d_P^2}{d_Q^2} = \frac{(\frac{1}{2}d)^2}{d^2} = \frac{1}{4} \Rightarrow I_P = \frac{1}{4}I_Q$$

Hence, $\frac{I_P}{I_P + I_Q} = \frac{1}{5} = 0.20$

14. A wire made of material with resistivity ρ has length l and area of cross-section A. It is connected to an electrical supply and has a potential difference V across it.

What is the energy supplied to the wire in time t?

A $\frac{V^2tA}{\rho l}$ B $\frac{VtA}{\rho l}$
C $\frac{V\rho lt}{A^2}$ D $\frac{V^2\rho lt}{A}$

Helping concepts

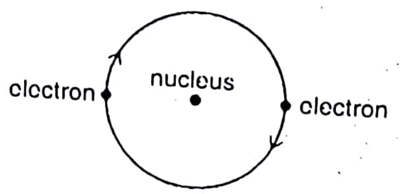
Energy, $E = Pt$

$$= \frac{V^2}{R}t$$

$$= \frac{V^2}{(\frac{\rho l}{A})}t$$

$$= \frac{V^2At}{\rho l}$$

15. The diagram shows a model of an atom in which two electrons move round a nucleus in a circular orbit. The electrons complete one full orbit in 1.0×10^{-15} s.



What is the current caused by the motion of the electrons in the orbit?

A 1.6×10^{-34} A B 3.2×10^{-34} A

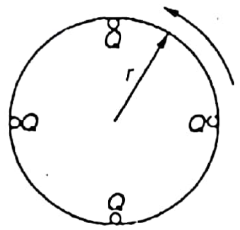
C 1.6×10^{-4} A D 3.2×10^{-4} A

Helping concepts

Using the formula $Q = It$,

$$I = \frac{2 \times 1.60 \times 10^{-19}}{1.0 \times 10^{-15}} = 3.2 \times 10^{-4} \text{ A}$$

16. Four small conductors, on the edge of an insulating disc of radius r, are each given a charge of Q. The frequency of rotation of the disc is f.



What is the equivalent electric current at the edge of the disc?

A $4Qf$ B $\frac{4Q}{f}$

C $8\pi Qf$ D $\frac{2Qf}{\pi r}$

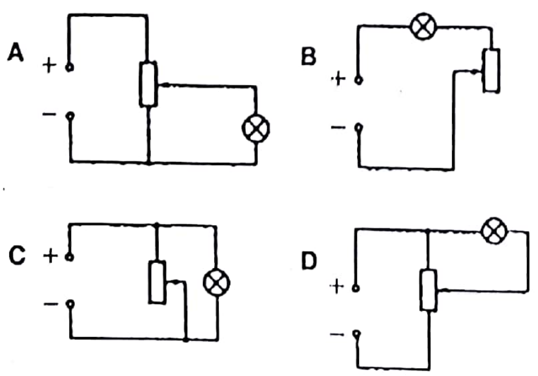
Helping concepts

$$\text{Equivalent electric current} = \frac{\text{charge}}{\text{period}} \text{ (or charge} \times \text{frequency)}$$

$$= 4Qf$$

17. A lamp is connected to a power supply of negligible internal resistance.

Which circuit could not be used as a practical means to vary the voltage across the lamp?



Helping concepts

The voltage across the lamp cannot be varied when the variable resistor is connected in parallel with the lamp.

18. The electron beam current in a cathode-ray oscilloscope is 50 μA. The time-base causes the beam to sweep horizontally across the screen at a speed of 1.0×10^4 cm s^{-1}.

What is the number of electrons arriving at the screen in one centimetre length of the horizontal trace?

A 3.1×10^{10} B 3.1×10^{13}

C 1.3×10^{13} D 8.0×10^{14}

Helping concepts

$$I = \frac{Q}{t} = \frac{Ne}{t}$$

$$\Rightarrow \frac{N}{t} = \frac{I}{e} = \frac{50 \times 10^{-6}}{1.6 \times 10^{-19}} = 3.13 \times 10^{14} \text{ s}^{-1}$$

These number of electrons is spread across 1.0×10^4 cm in 1 second.

$$\therefore \text{In 1 cm, number of electrons} = \frac{3.13 \times 10^{14}}{1.0 \times 10^4} = 3.1 \times 10^{10}$$

19. A thermocouple is connected across a galvanometer of resistance 30 Ω. One junction is immersed in water at 373 K and the other in ice at 273 K. The e.m.f. of the thermocouple is 90 μV for each 1 K difference in temperature between the junctions, and the thermocouple resistance is 6 Ω.

What current will flow in the galvanometer?

A 1.8 μA B 250 μA

C 300 μA D 1.5 μA

Helping concepts

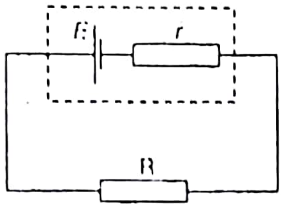
Temperature difference = 373 − 273 = 100 K

e.m.f. = $(100 \times 90\ \mu V) = 9000\ \mu V$

Total resistance = 30 + 6 = 36 Ω

$$\therefore \text{Current} = \frac{9000\ \mu V}{36\ \Omega} = 250\ \mu A$$

20. A cell of e.m.f. E is connected in series with a resistor R.



The potential difference across R is V_R. The potential difference across the internal resistance r of the cell is V_r.

What is the energy transferred by the cell in driving unit charge round the complete circuit?

A $V_R - V_r$ B V_R
C $E - V_r$ D E

Helping concepts

Energy transferred by the cell is equal to its e.m.f. E.

---

21. The filament of a 240 V, 100 W electric lamp heats up from room temperature to its operating temperature. As it heats up, its resistance increases by a factor of 16.

What is the resistance of this lamp at room temperature?

A 36 Ω   B 580 Ω
C 1.5 Ω   D 9.2 Ω

Helping concepts

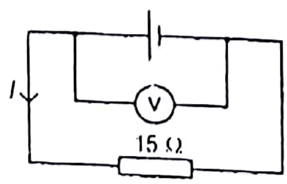
Using $P = \frac{V^2}{R}$,

$$100 = \frac{240^2}{16r}$$
$$r = 36\ \Omega$$

where r is the resistance at room temperature.

---

22. The e.m.f. of the cell in the following circuit is 9.0 V. The reading on the high-resistance voltmeter is 7.5 V.



What is the current I?

A 0.1 A   B 0.5 A
C 0.6 A   D 2.0 A

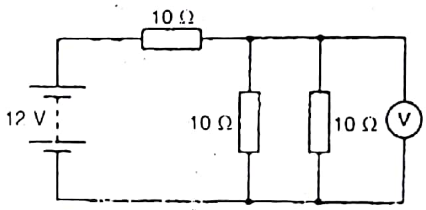
Helping concepts

p.d. across 15 Ω = p.d. across cell
= 7.5 V

$$\therefore\ I = \frac{V}{R} = \frac{7.5}{15} = 0.5\ \text{A}$$

---

23. In the circuit shown, the voltmeter has infinite resistance.

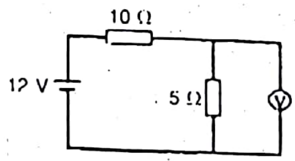


What is the voltmeter reading?

A 3 V   B 4 V
C 6 V   D 8 V

Helping concepts

Note that the 2 vertical resistors are in parallel.



Net resistance of 2 parallel resistors is

$$R = \left(\frac{1}{10} + \frac{1}{10}\right)^{-1} = 5\ \Omega$$

$\therefore$ The p.d. across 5 Ω, $V = \left(\frac{5}{5+10}\right)(12) = 4$ V

---

24. A resistor of resistance R has a power rating P when the current in the resistor is I.

What is the resistance of a resistor that has the power rating P for a current of $2I$?

A $\frac{1}{4}R$ B $\frac{1}{2}R$
C $2R$ D $4R$

Helping concepts

$$P = I^2R \text{-----}(1)$$

Let the unknown resistance be R_1.

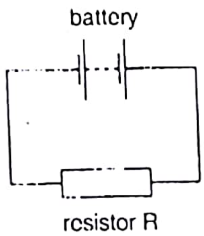
$$\therefore\ P = (2I)^2R_1 \text{-----}(2)$$

(1) = (2): $I^2R = (2I)^2R_1$

$$R_1 = \frac{1}{4}R$$

---

25. The diagram shows a battery connected in series with a resistor R.



The current in the circuit is I. Power P is dissipated in the resistor R. Power p is dissipated in the battery itself.

What is the electromotive force (e.m.f.) of the battery?

A $\frac{P}{I}$ B $\frac{P+p}{I}$

C $\frac{P}{I^2}$ D $\frac{P+p}{I^2}$

Helping concepts

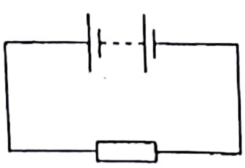
Total power = EI

$P + p = EI$

$\therefore$ Electromotive force (e.m.f.), $E = \frac{P+p}{I}$

---

26. In the circuit below, the battery converts an amount E of chemical energy to electrical energy when charge Q passes through the resistor in time t.



Which expressions give the e.m.f. of the battery and the current in the resistor?

	e.m.f.	current
A	EQ	Q/t
B	EQ	Qt
C	E/Q	Q/t
D	E/Q	Qt

Helping concepts

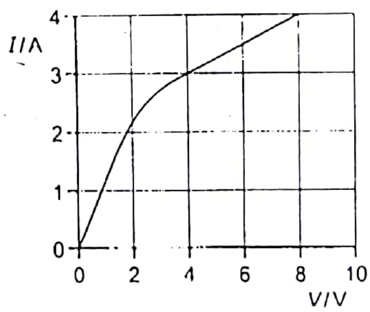
By definition,

$$\text{e.m.f.} = \frac{E}{Q}$$

$$\text{current} = \frac{Q}{t}$$

---

27. The graph plots current I against potential difference V for a filament lamp.



What is the resistance when the potential difference across the lamp is 6 V?

A 0.25 Ω B 0.58 Ω

C 1.7 Ω D 4.0 Ω

Helping concepts

Taking coordinate on the graph, (6V, 3.5A),

$$\text{resistance, } R = \frac{V}{I} = \frac{6\text{ V}}{3.5\text{ A}} = 1.7\ \Omega$$

Note that resistance at a point is the ratio of voltage to current. It is **not** the value of gradient at that point.

---

28. A cylindrical piece of a soft, electrically-conducting material has resistance R. It is rolled out so that its length is doubled but its volume stays constant.

What is its new resistance?

A $\frac{R}{2}$ B R

C $2R$ D $4R$

Helping concepts

$$R = \frac{\rho l}{A} \text{-----}(1)$$

where ρ = resistivity of material,

l = length, parallel to current flow,
A = cross-sectional area.

Volume of weight, $V = Al$

Subst. $A = \frac{V}{l}$ into (1),

$$R = \frac{\rho l}{(V/l)} = \frac{\rho l^2}{V}$$

Since length is doubled,

$$R_{new} = \frac{\rho(2l)^2}{V} = 4(\frac{\rho l^2}{V}) = 4R$$

---

29. Two wires made of the same material and of the same length are connected in parallel to the same voltage supply. Wire P has a diameter of 2 mm. Wire Q has a diameter of 1 mm.

What is the ratio $\frac{\text{current in P}}{\text{current in Q}}$?

A $\frac{1}{4}$ B $\frac{1}{2}$

C 2 D 4

Helping concepts

$$\frac{\text{resistance of Q}}{\text{resistance of P}} = \frac{\rho\frac{l}{A}}{\rho\frac{l}{A}}$$

$$= \frac{\pi(\frac{d_P}{2})^2}{\pi(\frac{d_Q}{2})^2} \quad (d_P \text{ is the diameter of P})$$

$$= (\frac{d_P}{d_Q})^2$$

$$= (\frac{2}{1})^2$$

$$= 4$$

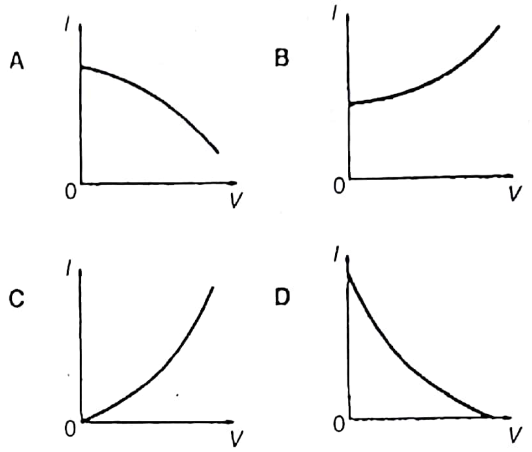
Since p.d. across P and Q is the same,

$$I_P R_P = I_Q R_Q \Rightarrow \frac{R_Q}{R_P} = \frac{I_P}{I_Q} = 4$$

---

30. The resistance of a thermistor decreases significantly as its temperature increases.

Which graph best represents the way in which the current I in the thermistor depends upon the potential difference V across it?



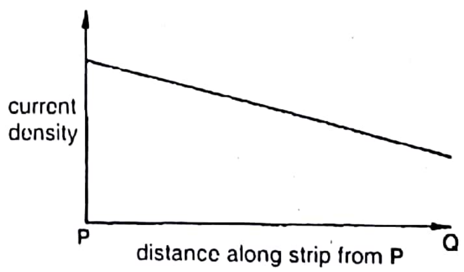
Helping concepts

If temperature of the thermistor remains constant, then its resistance would also be constant and its I-V curve would be a straight line.

However, as voltage V increases, current I through the thermistor increases and the temperature rises causing resistance of the thermistor decreases. As such, a relatively smaller increase in V is thus required to cause the same increase in current since resistance of the thermistor has decreased.

---

31. An electric current flows along an insulated strip PQ of metallic conductor. The current density in the strip varies as shown in the graph.



Which one of the following statements could explain this variation?

A The strip is narrower at **P** than at **Q**.

B The strip is narrower at **Q** than at **P**.

C The potential gradient along the strip is uniform.

D The current at **P** is greater than the current at **Q**.

Helping concepts

The current density at P is higher than at Q. For the same current flowing through the metallic conductor PQ, the cross-sectional area at P is narrower than at Q. The resistance per unit length r is given by

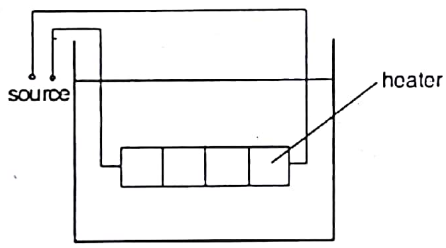
$$r = \rho\frac{1}{A}$$

where ρ is the resistivity,
A is the cross-sectional area of the conductor PQ.

Hence, r is inversely proportional to cross-sectional area A of the conductor.

---

32. The diagram shows a low-voltage circuit for heating the water in a fish tank.



The heater has a resistance of 3.0 Ω. The voltage source has an e.m.f. of 12 V and an internal resistance of 1.0 Ω.

At what rate does the voltage source supply energy to the heater?

A 27 W B 36 W
C 48 W D 64 W

Helping concepts

Using $P = \frac{V^2}{R}$,

p.d. V across heater $= (\frac{3}{3+1})(12) = 9$ V

$\therefore$ Power $= \frac{9^2}{3} = 27$ W

---

33. The resistivity of aluminium is 2.0 times that of silver. An aluminium wire of length l and diameter d has resistance R.

What is the diameter of a silver wire, also of length l and resistance R?

A $0.50d$ B $0.71d$
C $1.4d$ D $2.0d$

Helping concepts

Let the resistivity and diameter of silver be ρ and d_1 respectively.

$$R = \frac{\rho l}{A} = \frac{\rho l}{\pi(\frac{d_1}{2})^2} = \frac{4\rho l}{\pi d_1^2} \text{-----(1)}$$

For aluminium,

$$R = \frac{2\rho l}{A} = \frac{2\rho l}{\pi(\frac{d}{2})^2} = \frac{8\rho l}{\pi d^2} \text{-----(2)}$$

Since resistances of silver and aluminium are the same,

$$(1) = (2): \quad \frac{4\rho l}{\pi d_1^2} = \frac{8\rho l}{\pi d^2}$$

$$4d^2 = 8d_1^2$$

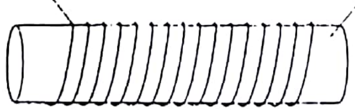
$$d_1^2 = \frac{1}{2}d^2$$

$$d_1 = \frac{1}{\sqrt{2}}d$$

$$= 0.71d$$

---

34. The material of a wire has resistivity 1.3×10^{-8} Ωm. The wire has diameter 0.50 mm and its length is just enough to enable it to be wound tightly round an insulating rod 30 times. The rod has diameter 1.5 cm.



What is the resistance of the wire?

A 1.1×10^{1} Ω B 9.4×10^{-2} Ω
C 7.0×10^{-4} Ω D 4.7×10^{-5} Ω

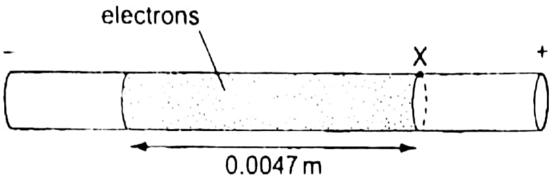
Helping concepts

$$R = \frac{\rho l}{A} = \frac{(1.3 \times 10^{-8})(30 \times \pi \times 1.5 \times 10^{-2})}{\pi(\frac{0.50}{2} \times 10^{-3})^2} = 9.4 \times 10^{-2}\ \Omega$$

(Remember to convert all values to SI units before substituting into the equation.)

---

35. Copper has 8.5×10^{28} conduction electrons per cubic metre. A piece of copper wire has an area of cross-section 3.2×10^{-7} m^2.



When a potential difference is applied to the wire, the electrons within a cylinder of length 0.0047 m all pass point X in 60 s.

What is the current in the wire?

A 0.34 A **B** 2.0 A

C 20 A **D** 340 A

Helping concepts

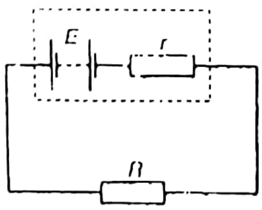
Total charge Q
= total number of electrons × charge of one electron

$$\therefore \text{Current, } I = \frac{Q}{t} = \frac{Nq}{t} = \frac{\rho Vq}{t} = \frac{\rho ALq}{t}$$

$$= \frac{(8.5 \times 10^{28})(3.2 \times 10^{-7})(0.0047)(1.6 \times 10^{-19})}{60}$$

$= 0.34$ A

36. A battery of electromotive force (e.m.f.) E and internal resistance r is connected in series with a resistor of resistance R as shown.



The battery transfers energy W at a constant rate in driving charge Q round the circuit in time t.

What is the e.m.f. E of the cell and the potential difference (p.d.) V across the external resistor?

	e.m.f. E	p.d. V
A	$\frac{W}{Q}$	RQ
B	$\frac{W}{Q}$	$R \times \frac{Q}{t}$
C	$(r + R) \times \frac{Q}{t}$	$\frac{W}{Q}$
D	$(r + R) \times \frac{W}{t}$	$\frac{W}{Q}$

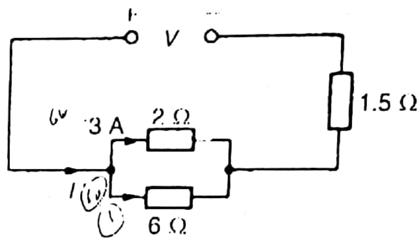
Helping concepts

By definition,

$$E = \frac{W}{Q}$$

$$\text{P.d. } V = RI = R\left(\frac{Q}{t}\right)$$

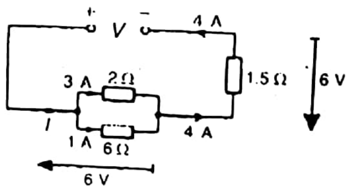
37. In the circuit shown, there is a current of 3 A in the 2 Ω resistor.



What are the values of the current I delivered by, and the voltage V across the power supply?

	I / A	V / V
A	3	10.5
B	4	9
C	4	12
D	12	18

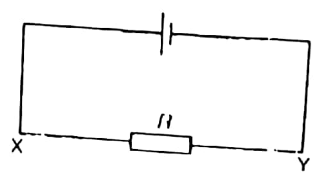
Helping concepts



Current delivered by the power supply = 3 A + 1 A
= 4 A

Voltage across the power supply = 6 V + 6 V
= 12 V

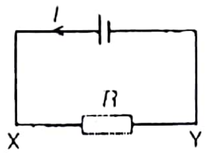
38. The current in the circuit is 4.8 A.



What is the rate of flow and the direction of flow of electrons through the resistor R?

A	3.0×10^{19} s^{-1}	in direction X to Y
B	6.0×10^{18} s^{-1}	in direction X to Y
C	3.0×10^{19} s^{-1}	in direction Y to X
D	6.0×10^{18} s^{-1}	in direction Y to X

Helping concepts



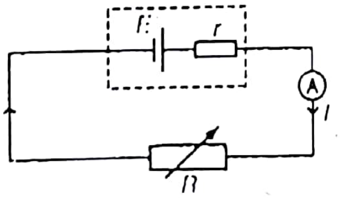
Conventional current, I (positive charge), is flowing anticlockwise direction.

In reality, electrons (negative charge) is flowing in the opposite direction, i.e. clockwise direction from Y to X.

By definition, $I = \frac{Q}{t} = (\frac{N}{t})q$

$$\Rightarrow \frac{N}{t} = \frac{I}{q} = \frac{4.8\text{ A}}{1.6 \times 10^{-19}\text{ C}} = 3.0 \times 10^{19}\text{ s}^{-1}$$

39. A battery of e.m.f. E and internal resistance r delivers a current I through a variable resistance R.



R is set at two different values and the corresponding currents I are measured using an ammeter of negligible resistance.

R/Ω	I/A
1.0	3.0
2.0	2.0

What is the value of the e.m.f. E?

A 3.0 V **B** 3.5 V

C 4.0 V **D** 6.0 V

Helping concepts

Using Kirchoff's 2nd law,

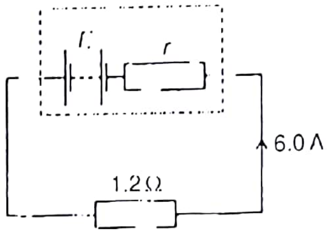
$$E = I(R + r)$$

$$\therefore \begin{cases} E = (3)(1 + r) \text{-----}(1) \\ E = (2)(2 + r) \text{-----}(2) \end{cases}$$

From (1): $r = \frac{E}{3} - 1$ -----(3)

Subst. (3) into (2): $E = (2)\left[(2 + (\frac{E}{3} - 1)\right] \Rightarrow E = 6.0\text{ V}$

40. A battery of internal resistance r and e.m.f. E can supply a current of 6.0 A to a resistor of resistance 1.2 Ω. The circuit is shown in the diagram.



When the resistor is changed to one having a value of 1.6 Ω, the current becomes 5.0 A.

What are the values of the e.m.f. E and internal resistance r?

	E / V	r / Ω
A	7.6	0.073
B	12	2.0
C	12	0.80
D	15	8.0

Helping concepts

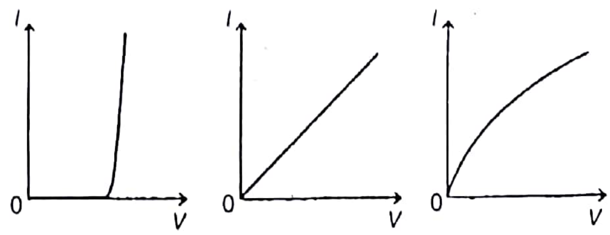
Using $E = IR + Ir$,

$$E = 6.0(1.2\ \Omega + r) \text{-----}(1)$$
$$E = 5.0(1.6\ \Omega + r) \text{-----}(2)$$

Solving (1) & (2),

$$E = 12\text{ V and } r = 0.80\ \Omega.$$

41. The graphs show the variation with potential difference V of the current I for three circuit elements.



graph X graph Y graph Z

The three circuit elements are a metal wire at constant temperature, a semi-conductor diode and a filament lamp.

Which row of the table correctly identifies these graphs?

	metal wire at constant temperature	semiconductor diode	filament lamp
A	X	Z	Y
B	Y	X	Z
C	Y	Z	X
D	Z	X	Y

Helping concepts

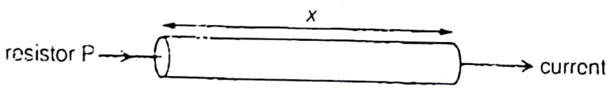
The ratio of V to I is resistance, which is the reciprocal of the gradient of I against V graph.

A metal wire at constant temperature will have a constant resistance.

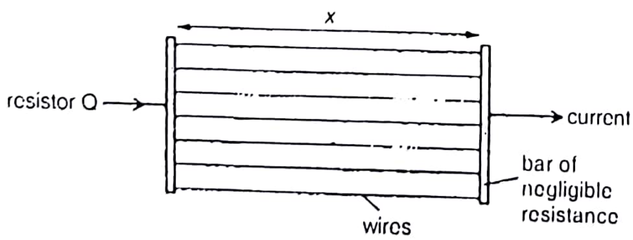
A semiconductor diode will experience a sudden increase in current when voltage is forward bias.

The resistance of filament lamp will increase as temperature (or current) increases.

42. A researcher has two pieces of copper of the same volume. All of the first piece is made into a cylindrical resistor P of length x.



All of the second piece is made into uniform wires each of the same length x which he connects between two bars of negligible resistance to form a resistor Q.



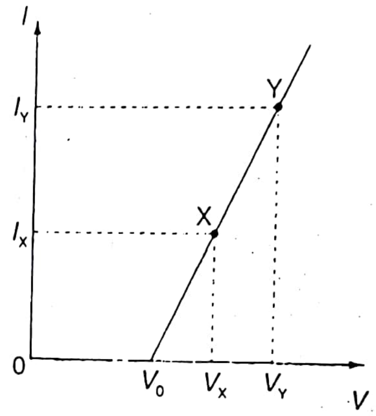
How do the electrical resistances of P and Q compare?

A P has a larger resistance than Q.
B Q has a larger resistance than P.
C P and Q have equal resistance.
D Q may has a larger or smaller resistance than P, depending on the number of wires made.

Helping concepts

Since P and Q have the same length of x, it also means that the cross-sectional areas of P and Q are the same. Hence, the resistances of P and Q are the same.

43. The graph shows the variation with potential difference V of the current I in an electrical component.



The resistance is measured for current I_Y and for current I_X.

What is the change in the resistance of the component?

A zero

B $\dfrac{V_Y - V_X}{I_Y - I_X}$

C $\dfrac{V_X}{I_X} - \dfrac{V_Y}{I_Y}$

D $\dfrac{V_Y - V_0}{I_Y} - \dfrac{V_X - V_0}{I_X}$

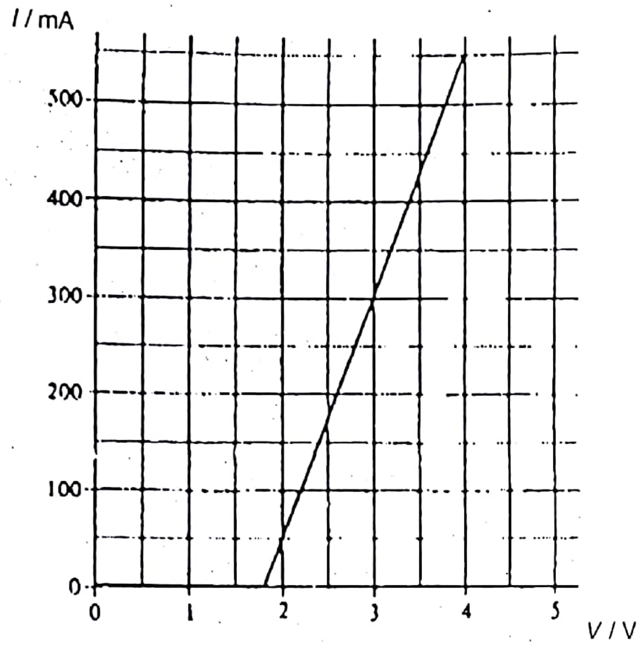
Helping concepts

Resistance at X $= \dfrac{V_X}{I_X}$

Resistance at Y $= \dfrac{V_Y}{I_Y}$

$\therefore$ Change in resistance $= \dfrac{V_X}{I_X} - \dfrac{V_Y}{I_Y}$

44. The diagram shows the relation between the direct current I in a certain conductor and the potential difference V across it. When $V < 1.8$ V, the current is negligible.



Which statement about the conductor is correct?

A It does not obey Ohm's law but when $V > 1.8$ V, its resistance is 4 Ω.

B It does not obey Ohm's law but when $V = 3$ V, its resistance is 10 Ω.

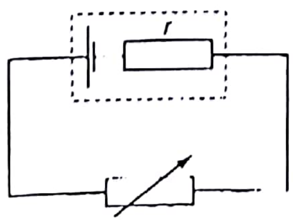
C It obeys Ohm's law but when $V > 1.8$ V and $V = 3$ V, its resistance is 10 Ω.

D It obeys Ohm's law but when $V > 1.8$ V, its resistance is not constant.

Helping concepts

Ohm's law states that the current through a conductor is directly proportional to the potential difference across it. The conductor illustrated in the graph does not obey Ohm's law, but when $V > 1.8$ V, resistance = gradient of graph = 4 Ω.

45. A cell has a constant electromotive force and internal resistance r. A variable resistor is connected across its terminals.



The resistance of the variable resistor is gradually increased from zero to $4r$.

What is the effect of this change on the terminal potential difference (p.d.) of the cell and also on the power dissipated in the variable resistor?

	terminal p.d.	power dissipation
A	constant	increases then decreases
B	constant	increases
C	increases	increases then decreases
D	increases	increases

Helping concepts

Let R be the resistance of the variable resistance.

Using potential divider method, terminal p.d. V across R is

$$V = \left(\frac{R}{R+r}\right) \times E$$

$$= \left(1 - \frac{r}{R+r}\right) \times E$$

As R increases, V increases.

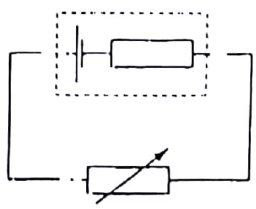
$$\therefore \text{Power dissipated, } P = \frac{V^2}{R}$$

$$= \frac{1}{R}\left(\frac{R}{R+r}\right)^2 E^2$$

R	0	r	$2r$	$3r$	$4r$
P	0	$\frac{E^2}{4r}$	$\frac{2E^2}{9r}$	$\frac{3E^2}{16r}$	$\frac{4E^2}{25r}$

The above table shows that the power increases to a maximum at $R = r$, and then power decreases as R increases beyond r.

46. A variable resistor is connected across the terminals of a cell as shown.



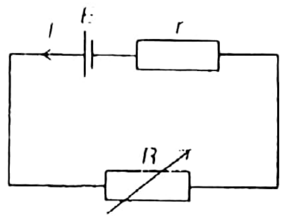
The cell has constant internal resistance.

The resistance of the variable resistor is gradually reduced.

What happens to the terminal potential difference and the power wasted in the internal resistance of the cell?

	terminal potential difference	power wasted in the cell
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

Helping concepts



$E = IR + Ir \Rightarrow I = \dfrac{E}{R+r}$ ------(1)

Terminal p.d. across R,

$$V = IR$$
$$= E - Ir \text{ -----(2)}$$

Subst. (1) into (2):

$$V = E - \left(\frac{E}{R+r}\right)r$$

As E and r remain constant, $R\downarrow$, $V\downarrow$.

Power wasted in cell, $P = I^2 r = \left(\dfrac{E}{R+r}\right)^2 r$

As E and r remain constant, $R\downarrow$, $P\uparrow$.

TOPIC 14

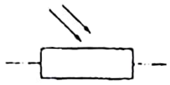
D.C. Circuits

Key content that you will be examined on:

1. Practical circuits
2. Series and parallel arrangements
3. Potential divider
4. Balanced potentials

Topic 14 D.C. Circuits

1. Which electrical component is represented by the following symbol?



A a diode

B a light-dependent resistor

C a resistor

D a thermistor

Helping concepts

Arrow signs indicate 'light'.  indicates resistor. Combining the two gives light-dependent resistor.

---

2. An electrical source with internal resistance r is used to operate a lamp of resistance R. What fraction of the total power is delivered to the lamp?

A $\frac{R+r}{R}$ B $\frac{R-r}{R}$

C $\frac{R}{R+r}$ D $\frac{R}{r}$

Helping concepts

$$\text{Power, } P = I^2R$$

In series, circuit I is common, i.e. power $\propto R$.

$\therefore$ Power fraction to lamp $= \frac{R}{r+R}$

---

3. A row of 25 decorative lights, connected in series, is connected to a mains transformer. When the supply is switched on, the lights do not work. The owner uses a voltmeter to test the circuit. When the voltmeter is connected across the third bulb in the row, a reading of zero is obtained.

Which of the following **cannot** be the only fault in the circuit?

A The filament of one of the other bulbs has broken.

B The filament of the third bulb has broken.

C The fuse in the mains transformer has blown.

D There is a break in the wire from the supply to the transformer.

Helping concepts

If the filament of the third bulb has broken, the voltmeter reading will be all the voltage supplied, and not zero.

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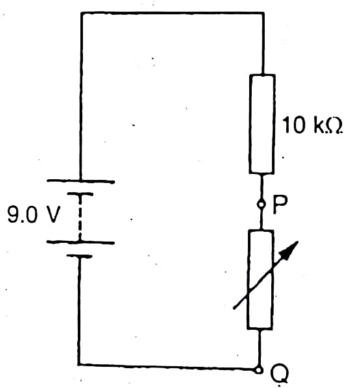
4. The diagram shows a potential divider connected a 9.0 V supply of negligible internal resistance.



What range of voltages can be obtained between P and Q?

A zero to 1.5 V B zero to 7.5 V

C 1.5 V to 7.5 V D 1.5 V to 9.0 V

Helping concepts

Range of variable resistor R is from $0\ \Omega$ to $50\ \text{k}\Omega$.

Potential difference across PQ $= \left(\frac{R}{r+R}\right) \times V$

For $R = 0$,

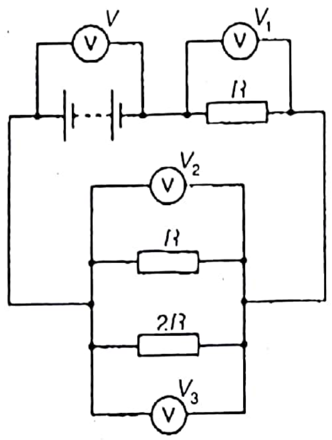
$$\text{p.d. of PQ} = 0$$

For $R = 50\ \text{k}\Omega$,

$$\text{p.d. of PQ} = \frac{50}{(15+50)} \times 9.0 = 7.5\ \text{V}$$

---

5. The diagram shows a circuit with four voltmeter readings V, V_1, V_2 and V_3.



Which equation relating the voltmeter readings must be true?

A $V = V_1 + V_2 + V_3$ **B** $V + V_1 = V_2 + V_3$

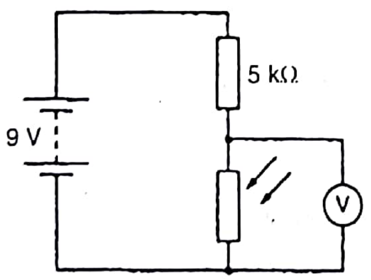
C $V_3 = 2(V_2)$ **D** $V - V_1 = V_3$

Helping concepts

In parallel, $V_2 = V_3$

In series, $V = V_1 + V_2$ or $V = V_1 + V_3 \Rightarrow V - V_1 = V_3$

6. A circuit is set up with an LDR and a fixed resistor as shown.



The voltmeter reads 4 V.

The light intensity is increased.

What is a possible voltmeter reading?

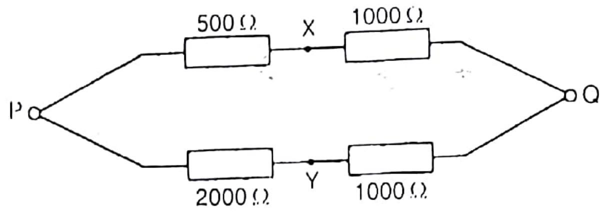
A 3 V **B** 4 V

C 6 V **D** 8 V

Helping concepts

For a LDR, resistance decreases when light intensity increase. When resistance dropped, p.d. across it dropped.

7. A p.d. of 12 V is connected between P and Q.



What is the p.d. between X and Y?

A 0 V **B** 4 V

C 6 V **D** 8 V

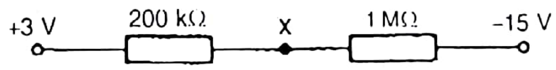
Helping concepts

p.d. of PX = $\left(\frac{500}{500+1000}\right)(12) = 4$ V

p.d. of PY = $\left(\frac{2000}{2000+1000}\right)(12) = 8$ V

$\therefore$ p.d. between X and Y = 8 − 4 = 4 V

8. Two resistors, of resistance 200 kΩ and 1 MΩ respectively, form a potential divider with outer junctions maintained at potentials of +3 V and −15 V.



What is the potential at the junction X between the resistors?

A +1 V **B** 0 V

C −0.6 V **D** −12 V

Helping concepts

Current through the resistors is

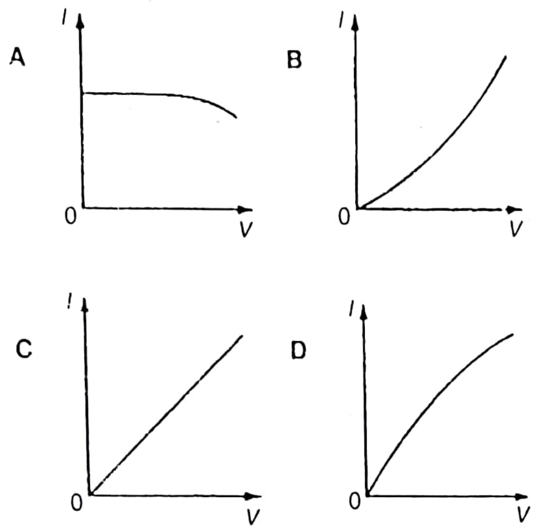
$$I = \frac{3-(-15)}{200+1000} = 0.015 \text{ mA}$$

Potential at X is thus

$$V_X = 3 - (200\times 10^3)(0.015\times 10^{-3}) = 0 \text{ V}$$

9. Some early electric lamps used carbon filaments. The resistance of these filaments decreases as their temperature increases.

Which graph shows how the current I in the filament varies with the potential difference V across it?



Helping concepts

Resistance is the ratio of V against I.

As current increases, temperature increases and the resistance decreases, i.e. the ratio of V against I will decrease.

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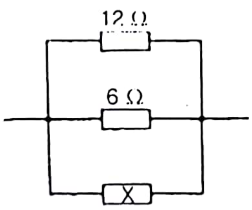
10. The diagram shows a parallel combination of three resistors.

The total resistance of the combination is 3 Ω.



What is the resistance of resistor X?

A 2 Ω B 3 Ω

C 6 Ω D 12 Ω

Helping concepts

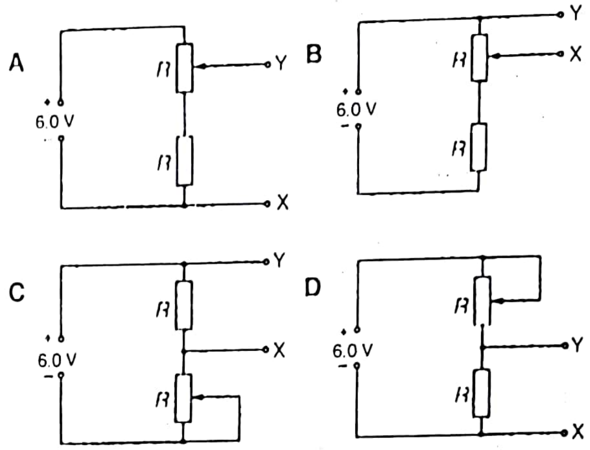
For parallel resistors,

$$\frac{1}{3} = \left(\frac{1}{12} + \frac{1}{6} + \frac{1}{x}\right) \Rightarrow x = 12\ \Omega$$

---

11. A potential divider has a constant supply of 6.0 V as shown in the diagrams.

Which circuit will provide a potential difference between X and Y that can be varied between zero and 3.0 V?



Helping concepts

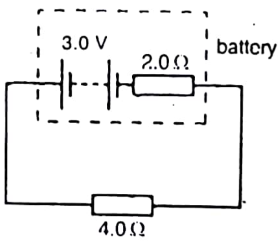
To get 0 V between X and Y, there should be possible for X and Y to be on the same wire without resistor between them.

Also, the two resistors are of the same value; the p.d. will be equal between them, i.e. 3 V.

Therefore, the slider must be able to move such that there is one resistor between X and Y.

---

12. A battery has an e.m.f. of 3.0 V and an internal resistance of 2.0 Ω.



The battery is connected to a load of 4.0 Ω.

What are the terminal potential difference V and output power P?

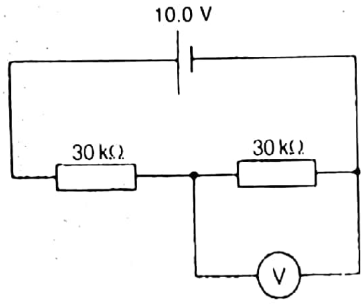
	V / V	P / W
A	1.0	0.50
B	1.0	1.5
C	2.0	1.0
D	2.0	1.5

Helping concepts

$$V = \left(\frac{4.0}{4.0 + 2.0}\right) \times 3.0 = 2.0\ \text{V}$$

$$P = \frac{V^2}{R} = \frac{(2.0)^2}{4.0} = 1.0\ \text{W}$$

13.



In the circuit, a 10.0 V supply of negligible internal resistance is joined to two 30 kΩ resistors in series. A voltmeter of resistance 60 kΩ is connected in parallel with one of the resistors.

What is the reading on the voltmeter?

A 4.0 V **B** 5.0 V
C 6.0 V **D** 6.7 V

Helping *concepts*

Effective resistance of 30 kΩ and 60 kΩ voltmeter,

$$R = \left(\frac{1}{30} + \frac{1}{60}\right)^{-1} \text{k}\Omega = 20 \text{ k}\Omega$$

Using potential divider method,

$$\text{p.d. across voltmeter, } V = \frac{20 \text{ k}\Omega}{20 \text{ k}\Omega + 30 \text{ k}\Omega} \times 10 \text{ V} = 4.0 \text{ V}$$

Helping *concepts*

Diagram 1 is the same as diagram 2.

In diagram 1, P and Q is parallel to R and S.

In diagram 2, P and R is parallel to Q and S.

14. When four identical lamps P, Q, R and S are connected as shown in diagram 1, they have normal brightness.

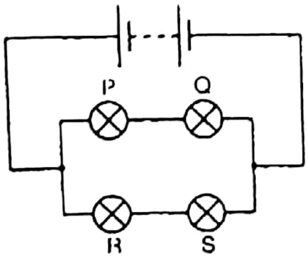


diagram 1

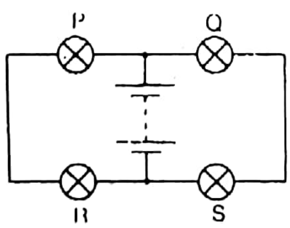


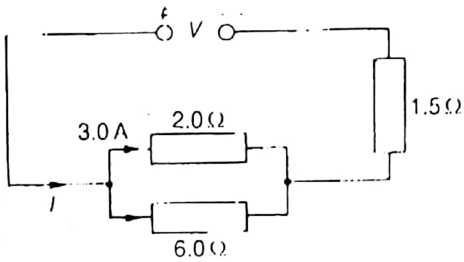
diagram 2

The four lamps and the battery are then connected as shown in diagram 2.

Which statement is correct?

A The lamps do not light.
B The lamps are less bright than normal.
C The lamps have normal brightness.
D The lamps are brighter than normal.

15. In the circuit shown, there is a current of 3.0 A in the 2.0 Ω resistor.



What are the values of the current I delivered by the power supply and the voltage V across it?

	I / A	V / V
A	3.0	10.5
B	4.0	9.0
C	4.0	12
D	12	18

Helping *concepts*

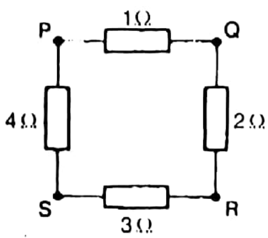
Potential difference across 2.0 Ω resistor = 3.0 × 2.0 = 6.0 V

$\therefore$ Current through 6.0 Ω resistor $= \frac{V}{R} = \frac{6.0}{6.0} = 1.0$ A

$\therefore$ Current through 1.5 Ω resistor = 1.0 + 3.0 = 4.0 A

Hence, voltage V = 6.0 + (4.0 × 1.5) = 12 V

16. Four resistors are connected as shown.



Between which two points does the **maximum** resistance of the combination occur?

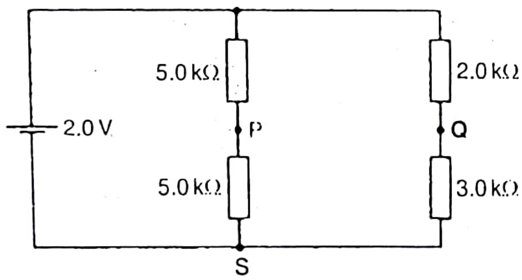
A P and Q B Q and S
C R and S D S and P

Helping concepts

The combined resistance for each of the following cases:

case	effective resistance
A	$\frac{9}{10}\ \Omega$
B	$\frac{5}{2} = \frac{25}{10}\ \Omega$
C	$\frac{21}{10}\ \Omega$
D	$\frac{12}{5} = \frac{24}{10}\ \Omega$

17. A cell of e.m.f. 2.0 V and negligible internal resistance is connected to the network of resistors shown.



V_1 is the potential difference between S and P. V_2 is the potential difference between S and Q.

What is the value of $V_1 - V_2$?

A +0.50 V B +0.20 V
C −0.20 V D −0.50 V

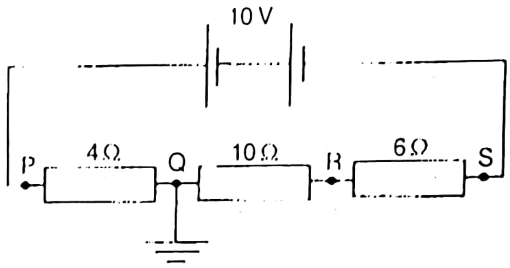
Helping concepts

$$V_1 = \frac{5.0\ k\Omega}{(5.0+5.0)\ k\Omega} \times 2.0\ V = 1.0\ V$$

$$V_2 = \frac{3.0\ k\Omega}{(3.0+2.0)\ k\Omega} \times 2.0\ V = 1.2\ V$$

$$\therefore\ V_1 - V_2 = 1.0 - 1.2 = -0.2\ V$$

18. The diagram shows three resistors of resistances 4 Ω, 10 Ω and 6 Ω connected in series. A potential difference of 10 V is maintained across them. Point Q is earthed.



Which of the following gives the potentials at points P, Q, R and S?

	P	Q	R	S
A	10 V	8 V	3 V	0
B	2 V	0	5 V	8 V
C	10 V	6 V	−4 V	−10 V
D	2 V	0	−5 V	−8 V

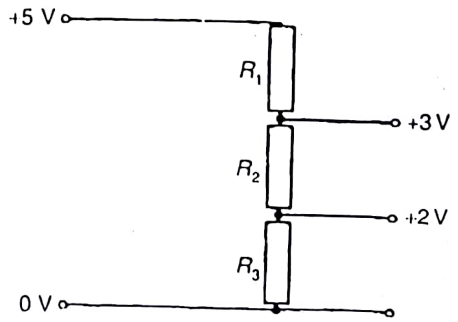
Helping concepts

$$\text{Current through circuit} = \frac{V}{R} = \frac{10}{4+10+6} = 0.5\ A$$

Potential at Q, $V_Q = 0$ V since it is earthed.

Point R should be at a lower potential than Q. Hence, (D) should be the correct answer.

19. A potential divider is used to give outputs of 2 V and 3 V from a 5 V source, as shown.



Which combination of resistances, R_1, R_2, R_3, gives the correct voltages?

	R_1 / kΩ	R_2 / kΩ	R_3 / kΩ
A	1	1	2
B	2	1	2
C	3	2	2
D	3	2	3

Helping concepts

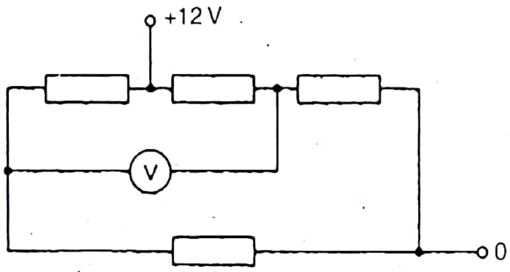
For resistors in series connection, current (I) is the same through the resistors. In other words, ratio of the voltage drop across each resistor with its resistance is the same.

$$\therefore\ I = \frac{5-3}{R_1} = \frac{3-2}{R_2} = \frac{2}{R_3}$$

i.e. $R_1 : R_2 : R_3 = 2 : 1 : 2$

---

20. In the circuit shown, all the resistors have the same resistance. The resistance of the voltmeter is infinite.



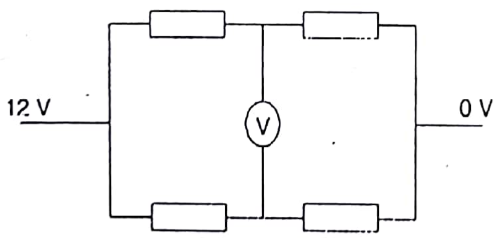
The potential difference between the input terminals is 12 V.

What is the reading on the voltmeter?

A zero B 4 V
C 6 V D 8 V

Helping concepts

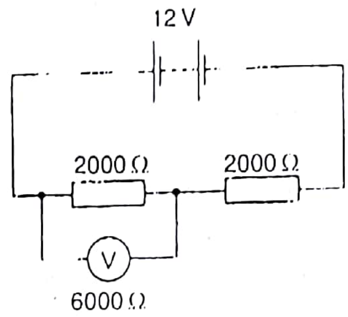
The similar re-drawn circuit diagram is as follows;



The potential across the voltmeter is the same as the resistors are the same. Hence, the p.d. across the voltmeter is the zero.

---

21. A 12 V battery of negligible internal resistance is connected across two 2000 Ω resistors in series. A voltmeter of resistance 6000 Ω is connected in parallel across one of the resistors.



What will be the reading on the voltmeter?

A 5.14 V B 6.00 V
C 6.86 V D 7.20 V

Helping concepts

To find effective resistance, R of 2000 Ω resistor and 6000 Ω voltmeter:

$$\frac{1}{R} = \frac{1}{2000} + \frac{1}{6000}$$

$$R = 1500\ \Omega$$

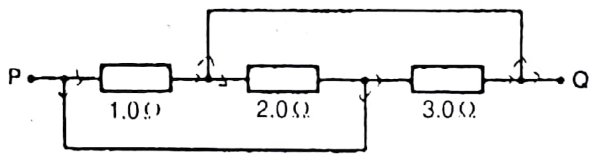
Using potential divider method,

$$V = \frac{1500\ \Omega}{1500\ \Omega + 2000\ \Omega} \times 12\ \text{V}$$

$$= 5.14\ \text{V}$$

---

22. Three resistors are connected as shown in the diagram using connecting wires of negligible resistance.

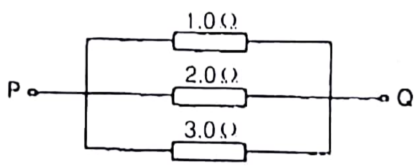


What is the approximate resistance between points **P** and **Q**?

A 0.5 Ω B 0.8 Ω
C 2.0 Ω D 2.2 Ω

Helping concepts

The circuit may be redrawn as follow:



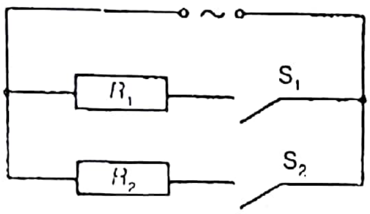
i.e. the resistors are in parallel.

Hence, the effective resistance R across **PQ** is given by

$$\frac{1}{R} = \frac{1}{1.0} + \frac{1}{2.0} + \frac{1}{3.0}$$

$$R = \frac{6}{6+3+2} = \frac{6}{11} \approx 0.5\ \Omega$$

23. An electric heater can be represented as two resistors of resistances R_1 and R_2 and two switches S_1 and S_2. The resistance R_2 is greater than that of R_1.



Which switches must be closed so that the heater produces the maximum possible power and the minimum non-zero power?

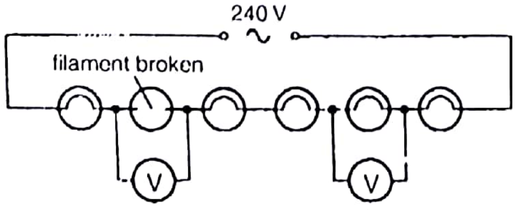
	max. possible power	min. non-zero power
A	S_1 and S_2	S_2
B	S_1 and S_2	S_1
C	S_1	S_2
D	S_2	S_1

Helping concepts

$$\text{Power, } P = \frac{V^2}{R}$$

Power is maximum for minimum R which happens for parallel resistors. Power is minimum for maximum R which is R_2.

24. A mains circuit contains six similar bulbs connected in series. One of the bulbs has a broken filament. Voltmeters X and Y of infinite resistance are placed in the circuit as shown.



What are the voltmeter readings?

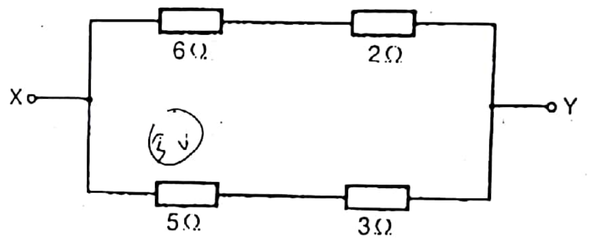
	X readings	Y readings
A	0 V	0 V
B	0 V	240 V
C	40 V	40 V
D	240 V	0 V

Helping concepts

Since no current flows through the circuit, all the voltage drops across the bulb that has a broken filament.

i.e. X = 240 V; Y = 0 V.

25. In the circuit shown, a potential difference of 3 V is applied across XY.

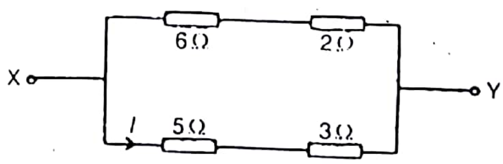


What is the current through the 5 Ω resistor?

A $\frac{15}{8}$ A B $\frac{3}{4}$ A

C $\frac{3}{5}$ A D $\frac{3}{8}$ A

Helping concepts



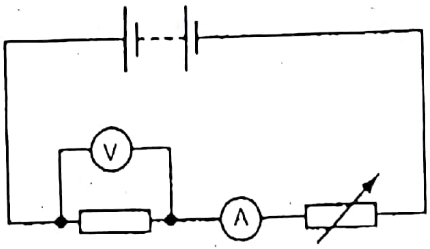
Potential difference across the 5 Ω and 3 Ω resistors = 3 V.

Using $V = IR$,

$$I = \frac{3}{8}\text{ A}$$

26. The diagram shows a battery, a fixed resistor, an ammeter and a variable resistor connected in series.

A voltmeter is connected across the fixed resistor.



The value of the variable resistor is reduced.

Which correctly describes the changes in the readings of the ammeter and of the voltmeter?

	ammeter	voltmeter
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

Helping concepts

As total resistance is reduced, current will increase,

$I = \frac{V}{R}$.

Potential difference across resistance,

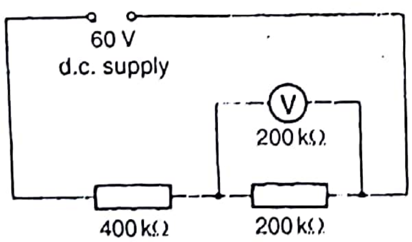
$$V = \frac{R}{R + r} \times E$$

where r is the variable resistance.

As r decreases, potential difference across voltmeter will increase.

---

27. A constant 60 V d.c. supply is connected across two resistors of resistance 400 kΩ and 200 kΩ.



What is the reading of the voltmeter, also of resistance 200 kΩ when connected across the second resistor as shown in the diagram?

A 12 V   **B** 15 V

C 20 V   **D** 30 V

Helping concepts

Effective resistance across voltmeter $= \frac{200}{2} = 100$ kΩ

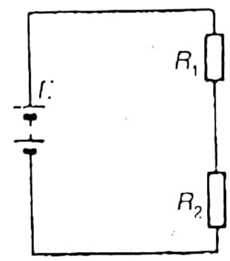
Total resistance across d.c. supply $= 400 + 100$

$= 500$ kΩ

$\therefore$ Voltage across the voltmeter $= \frac{100 \text{ k}\Omega}{500 \text{ k}\Omega}(60 \text{ V}) = 12$ V

---

28. A battery of e.m.f. E and negligible internal resistance is connected to two resistors of resistance R_1 and R_2 as shown in the circuit diagram.



What is the potential difference across the resistor of resistance R_2?

A $\frac{E(R_1 + R_2)}{R_1}$ **B** $\frac{E(R_1 + R_2)}{R_2}$

C $\frac{ER_1}{(R_1 + R_2)}$ **D** $\frac{ER_2}{(R_1 + R_2)}$

Helping concepts

Current in R_1 and R_2 is given by

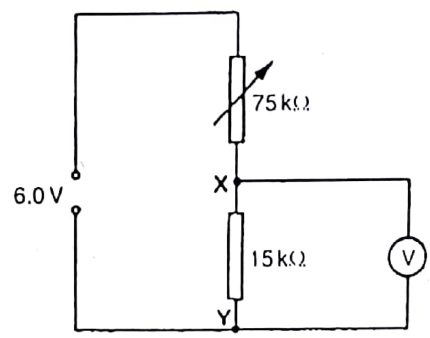
$$I = \frac{E}{R_1 + R_2}$$

$\therefore$ p.d. across the resistor of resistance $R_2 = IR_2$

$= \frac{ER_2}{R_1 + R_2}$

---

29. The diagram shows two resistors connected in a circuit with a power supply and a voltmeter.



What range of voltages can be obtained between points X and Y?

A zero to 1.0 V **B** zero to 6.0 V

C 1.0 V to 5.0 V **D** 1.0 V to 6.0 V

Helping concepts

Potential difference across XY,

$$V = (\frac{15\ \text{k}\Omega}{15\ \text{k}\Omega + R}) \times 6.0\ \text{V}$$

where R is the resistance of the variable resistor.

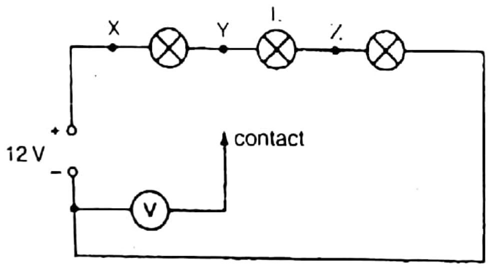
For $R = 75\ \text{k}\Omega$ (maximum),

$$V = (\frac{15}{15+75}) \times 6.0 = 1.0\ \text{V}$$

For $R = 0\ \Omega$ (minimum),

$$V = (\frac{15}{15+0}) \times 6.0 = 6.0\ \text{V}$$

30. The diagram shows three lamps in series with a 12 V supply.



To test the circuit, the contact is connected in turn to points X, Y and Z. The lamps **do not light** because lamp L has a broken filament.

Which line of the table below shows the readings of the voltmeter?

	reading at X	reading at Y	reading at Z
A	12 V	8 V	4 V
B	8 V	8 V	0 V
C	12 V	12 V	0 V
D	8 V	12 V	4 V

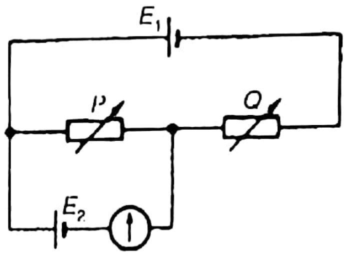
Helping concepts

The circuit is an open one.

The p.d. to X and Y = e.m.f. = 12 V as no current flow.

The p.d. to Z = 0 V as the voltmeter does not measure e.m.f. of source.

31. Two cells of e.m.f. E_1 and E_2 and of negligible internal resistance are connected with two variable resistors as shown in the diagram.



galvanometer

When the galvanometer deflection is zero, the values of the resistance are P and Q. What is the value of the ratio $\frac{E_2}{E_1}$?

A $\frac{P}{Q}$ **B** $\frac{P}{(P+Q)}$

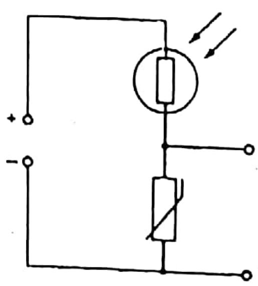
C $\frac{Q}{(P+Q)}$ **D** $\frac{(P+Q)}{P}$

Helping concepts

At zero deflection, voltage across P due to cells of e.m.f. E_1 must be equal to E_2.

$$\therefore E_2 = E_1(\frac{P}{P+Q}) \Rightarrow \frac{E_2}{E_1} = \frac{P}{P+Q}$$

32. The diagram shows a light-dependent resistor (LDR) and a thermistor forming a potential divider.



Under which set of conditions will the potential difference across the thermistor have the greatest value?

	illumination	temperature
A	low	low
B	high	low
C	low	high
D	high	high

Helping concepts

Let R_{LDR} be the resistance of LDR,

R_T be the resistance of thermistor.

Potential difference across thermistor,

$$V = \left(\frac{R_T}{R_T + R_{LDR}}\right) \times \text{e.m.f.}$$

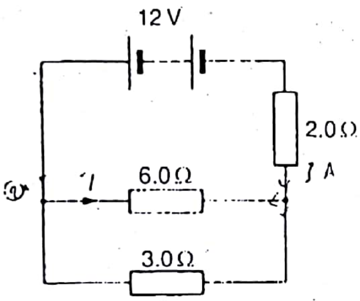
V is maximum if R_T is large and R_{LDR} is small.

R_T has large resistance if temperature is low.

R_{LDR} is low if light intensity is high.

---

33. The diagram shows a circuit in which the battery has negligible internal resistance.

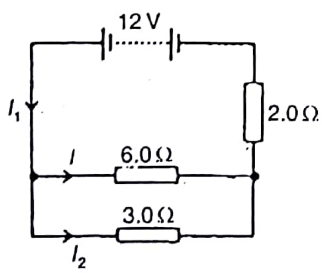


What is the value of the current I?

A. 1.0 A **B** 1.6 A

C 2.0 A **D** 3.0 A

Helping concepts



$$\text{Total resistance} = 2.0 + \frac{1}{\frac{1}{6.0} + \frac{1}{3.0}} = 4.0\ \Omega$$

$$\therefore I_1 = \frac{12}{4.0} = 3.0\ \text{A}$$

Potential difference across the 6.0 Ω resistor

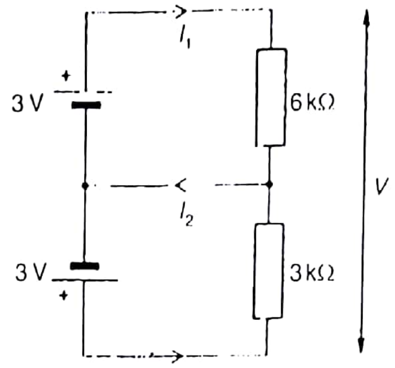
$= 12 - 3 \times 2.0$

$= 6$ V

$$\therefore I = \frac{6}{6.0} = 1.0\ \text{A}$$

---

34. In the circuit, two 3 V cells are connected to resistors of resistance 3 kΩ and 6 kΩ.



What are the correct values for the currents I_1 and I_2, and the total potential difference V across the pair of resistors?

	I_1 / mA	I_2 / mA	V / V
A	0.5	0.5	6
B	0.5	0.5	0
C	0.5	1.5	0
D	0.5	1.5	6

Helping concepts

Using $V = IR$,

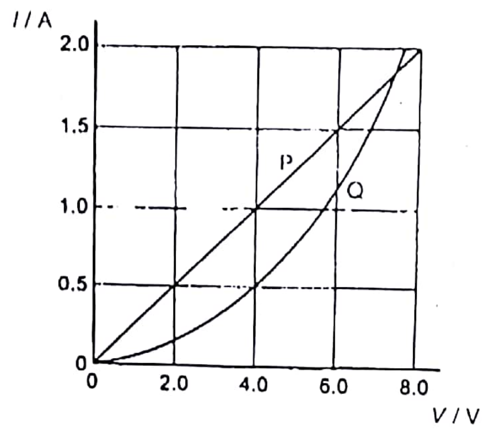
$$I_1 = \frac{3}{6 \times 10^3} = 5 \times 10^{-4}\ \text{A} = 0.5\ \text{mA}$$

$$I_2 = \frac{3}{3 \times 10^3} + 5 \times 10^{-4} = 1.5 \times 10^{-3}\ \text{A} = 1.5\ \text{mA}$$

Since the negative terminals of the two cells are at the same potential, the positive terminals are at the same potential too.

---

35. The I-V characteristics of two electrical components P and Q are shown below.



Which statement is correct?

A P is a resistor and Q is a filament lamp.

B The resistance of Q increases as the current in it increases.

C At 1.9 A the resistance of Q is approximately half that of P.

D At 0.5 A the power dissipated in Q is double that in P.

Helping concepts

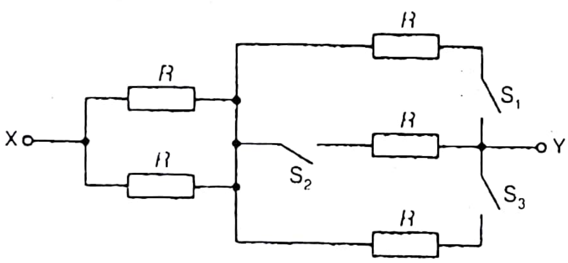
From the graph, it is deduced that P is an Ohmic conductor, e.g. metal.

Q is a thermistor, whose resistance decreases with increasing current.

At 1.9 A, the resistance of P and Q is the same.

Power = IV. Since voltage of Q is doubled of P for same current of 0.5 A, power of Q is 2 times of P.

36. A network is constructed using five resistors, each of resistance R, and three switches S_1, S_2 and S_3.



Which switch combination will give rise to the maximum total resistance between points X and Y?

	S_1	S_2	S_3
A	closed	closed	closed
B	closed	open	closed
C	open	closed	closed
D	open	closed	open

Helping concepts

For option A, 2 parallel resistors are in series with 3 parallel resistors.

$\therefore$ Total resistance $= (\frac{1}{R}+\frac{1}{R})^{-1}+(\frac{1}{R}+\frac{1}{R}+\frac{1}{R})^{-1} = \frac{5R}{6}$

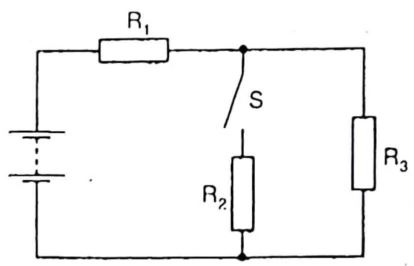
For options B and C, 2 parallel resistors are in series with 2 parallel resistors.

$\therefore$ Total resistance $= (\frac{1}{R}+\frac{1}{R})^{-1}+(\frac{1}{R}+\frac{1}{R})^{-1} = R$

For option D, 2 parallel resistors are in series with one resistor.

$\therefore$ Total resistance $= (\frac{1}{R}+\frac{1}{R})^{-1}+R = \frac{3R}{2}$

37. The diagram shows a network of resistors R_1, R_2 and R_3 connected to a battery of negligible internal resistance.



When the switch S is closed, the potential difference (p.d.) across R_2 (originally zero) rapidly increases to a steady value.

What happens to the potential difference (p.d.) across each of the other two resistors, and to the power output of the battery?

	p.d. across R_1	p.d. across R_3	battery power output
A	decreases	decreases	decreases
B	decreases	stays the same	decreases
C	increases	decreases	increases
D	increases	stays the same	increases

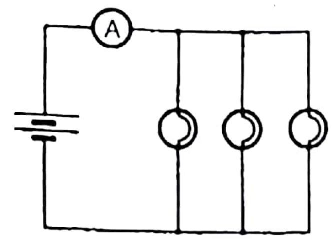
Helping concepts

When S is closed, net resistance of parallel R_1 and R_2 will decrease.

The overall resistance will be smaller when S is closed. The new current will be higher, i.e. power output of battery will increase.

Potential difference across R_1 will also increase. Current flowing through R_3 will be smaller than before.

38. Three similar light bulbs are connected to a constant-voltage d.c. supply as shown in the diagram. Each bulb operates at normal brightness and the ammeter (of negligible resistance) registers a steady current.



The filament of one of the bulbs breaks. What happens to the ammeter reading and to the brightness of the remaining bulbs?

	ammeter reading	bulb brightness
A	increases	increases
B	increases	unchanged
C	unchanged	unchanged
D	decreases	unchanged

Helping concepts

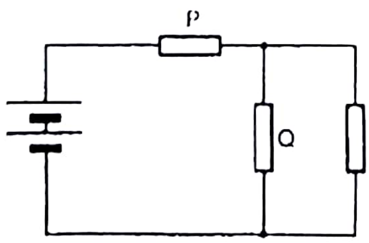
Suppose V is the voltage of the supply and R is the resistance of each bulb, then $R_T = \frac{R}{3}$ and current in ammeter, $I = \frac{V}{R_T} = 3\frac{V}{R}$, provided all 3 bulbs are working properly.

If 1 bulb has broken down, then $R_T = \frac{R}{2}$ and $I = 2\frac{V}{R}$.

Hence, current reading decreases and since current through each bulb is V/R, the same as before, brightness of bulb is not affected.

---

39. The resistors P, Q and R in the circuit have equal resistance.



The battery, of negligible internal resistance, supplies a total power of 12 W.

What is the power dissipated by heating in resistor R?

A 2 W **B** 3 W
C 4 W **D** 6 W

Helping concepts

Let the resistance of P, Q and R be r.

The total resistance across the battery is thus

$$r_{total} = r + \frac{r}{2} = \frac{3}{2}r$$

Current through P, $I_P = \sqrt{\frac{power}{r_{total}}} = \sqrt{\frac{12}{\frac{3}{2}r}} = \sqrt{\frac{8}{r}}$

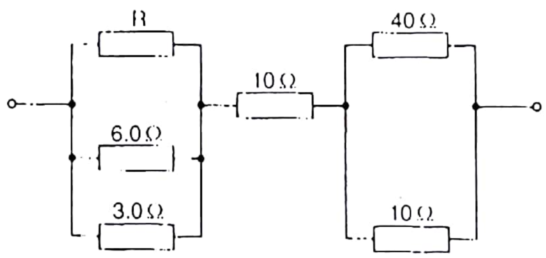
Current through R, $I_R = \frac{1}{2}I_P = \sqrt{\frac{2}{r}}$

Power dissipated in R is thus

$$P_R = I_R^2 r = (\frac{2}{r})r = 2\ \text{W}$$

---

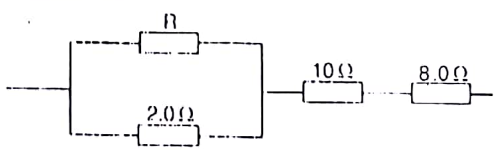
40. In the arrangement shown, R is a resistor that has an unknown resistance between zero and infinity.



Between what limits must the resistance of the whole arrangement lie?

	min. resistance / Ω	max. resistance / Ω
A	18	20
B	20	20
C	20	infinity
D	23	56

Helping concepts



The resistors arrangement can be simplified to the above values.

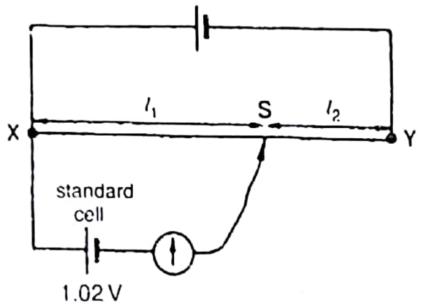
When $R = 0$, 2.0 Ω is bypassed by current.

∴ Net resistance, $R_{total} = 10 + 8 = 18\ \Omega$

When R = infinity, all current will pass through 2.0 Ω.

∴ Net resistance, $R_{total} = 2 + 10 + 8 = 20\ \Omega$

40. A standard cell of e.m.f. 1.02 V is used to find the potential difference across the wire **XY** as shown in the diagram. It is found that there is no current in the galvanometer when the sliding contact is at **S**, l_1 from **X** and l_2 from **Y**.



What is the potential difference across **XY**?

A $1.02(\frac{l_2}{l_1})$ V **B** $1.02(\frac{l_1}{l_2})$ V

C $1.02(\frac{l_1+l_2}{l_2})$ V **D** $1.02(\frac{l_1+l_2}{l_1})$ V

Helping concepts (D)

Potential across **XS** is 1.02 V at the length of l_1.

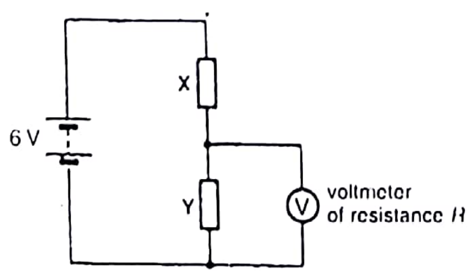
Potential across **SY** is $(\frac{1.02\text{ V}}{l_1})l_2$ or $1.02(\frac{l_2}{l_1})$ V.

Potential across **XY** = potential across **XS** + potential across **SY**

$$= 1.02 + 1.02(\frac{l_2}{l_1})$$

$$= 1.02(\frac{l_1+l_2}{l_1})\text{ V}$$

41. In the circuit shown, resistors **X** and **Y**, each of resistance R, are connected to a 6 V battery of negligible internal resistance. A voltmeter, also of resistance R, is connected across **Y**.



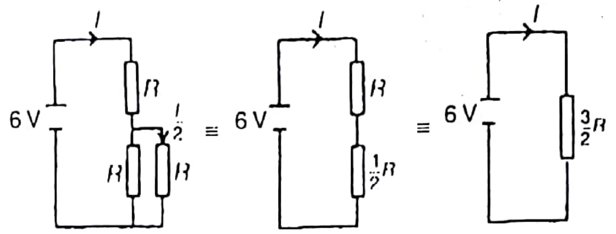
What is the reading of the voltmeter?

A zero **B** between zero and 3 V

C 3 V **D** between 3 V and 6 V

Helping concepts

The circuit may be redrawn as follow:

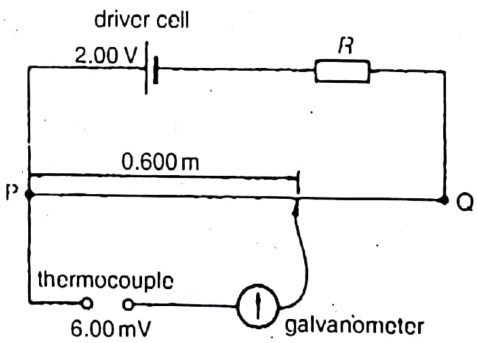


Current is given by $I = \frac{6}{\frac{3}{2}R} = \frac{4}{R}$ A.

∴ Current through the voltmeter is $\frac{I}{2}$ or $\frac{2}{R}$ A.

Hence, the reading of the voltmeter is $(\frac{2}{R})(R)$ or 2 V.

42. The diagram below shows a simple potentiometer circuit for measuring a small e.m.f. produced by a thermocouple.



The meter wire PQ has a resistance of 5 Ω and the driver cell has an e.m.f. of 2.00 V. If a balance point is obtained 0.600 m along PQ when measuring an e.m.f. of 6.00 mV, what is the value of the resistance R?

A 95 Ω **B** 195 Ω

C 495 Ω **D** 995 Ω

Helping concepts

The voltage per unit length on the meter wire PQ is

$$\frac{6.00\text{ mV}}{0.60\text{ m}} \text{ or } 10\text{ mV/m}.$$

∴ Potential across the meter wire PQ,

$$V = (10\text{ mV/m})(1\text{ m}) = 10\text{ mV}$$

Current drawn from the driver cell, $I = \frac{10\text{ mV}}{5\ \Omega} = 2$ mA

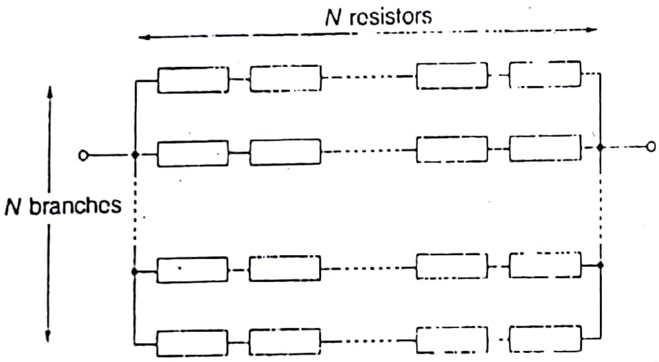
Resistance of resistor, $R = \dfrac{2\text{ V} - 10\text{ mV}}{2\text{ mA}}$

$= \dfrac{1990\text{ mV}}{2\text{ mA}}$

$= 995\ \Omega$

---

43. An array of resistors, each of resistance R, consists of N parallel branches. Each branch contains N resistors connected in series.



What is the total resistance of the array?

A $\dfrac{1}{RN}$

B $\dfrac{R}{N}$

C R

D NR

Helping concepts

Add the total N resistor in series of each branch, we have NR.

To find net resistance, R_T:

$$\frac{1}{R_T} = \underbrace{\frac{1}{NR} + \ldots + \frac{1}{NR}}_{N\text{ branches}}$$

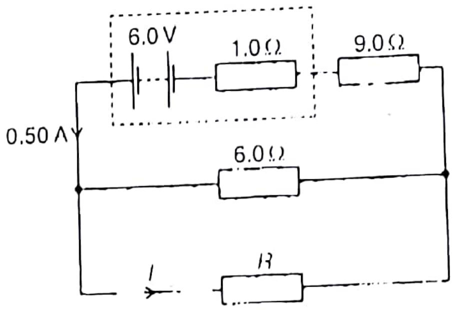
$$= N\left(\frac{1}{NR}\right)$$

$$= \frac{1}{R}$$

$$R_T = R$$

---

44. A battery of electromotive force (e.m.f.) 6.0 V and internal resistance 1.0 Ω is connected in series to a 9.0 Ω resistor and a parallel combination of resistors of resistance 6.0 Ω and R. The battery delivers a current of 0.50 A to the circuit.



What are the values of the unknown current I and resistance R as shown in the diagram?

	I / A	R / Ω
A	0.17	9.0
B	0.25	4.0
C	0.25	6.0
D	0.33	3.0

Helping concepts

Let the net parallel resistors of 6.0 Ω and R be R_{net}.

e.m.f. = sum of p.d. in circuit

$6.0 = (0.50)(1.0 + 9.0 + R_{net})$

$R_{net} = 2.0$ W

$$\therefore \frac{1}{R_{net}} = \frac{1}{6.0} + \frac{1}{R}$$

$$\frac{1}{2.0} = \frac{1}{6.0} + \frac{1}{R}$$

$$R = 3.0\ \Omega$$

Let current through 6.0 Ω be $(0.50 - I)$ A.

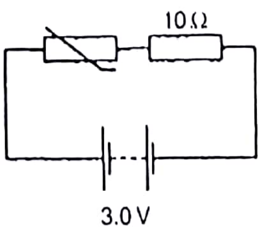
As p.d. of 6.0 Ω and 3.0 Ω is the same,

$(6.0)(0.50 - I) = (3.0)I$

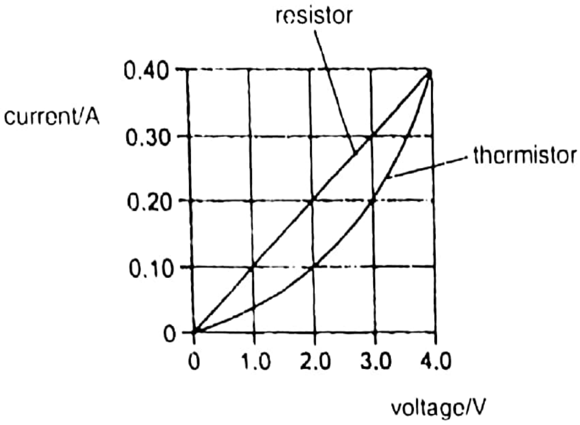
$I = 0.33$ A

---

45. A 10 Ω resistor and a thermistor are connected in series to a battery of e.m.f. 3.0 V and negligible internal resistance.



The graph shows the current-voltage characteristics of the resistor and of the thermistor.



What is the current in the circuit?

A 0.10 A B 0.20 A

C 0.30 A D 0.40 A

Helping concepts

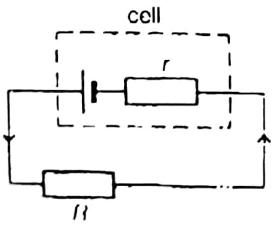
The total p.d. of the thermistor and 10 W resistor must be 3.0 V as they are in series.

By looking at the common value of the current (i.e. horizontally), the sum of the voltage must be 3.0 V.

The voltage of the resistor and thermistor is 1.0 V and 2.0 V respectively.

Hence, the common value of current through the resistor and thermistor is 0.10 A.

46. A cell of internal resistance r is connected to a load of resistance R.



Energy is dissipated in the load, but some thermal energy is also wasted in the cell. The efficiency of such an arrangement is found from the expression

$$\frac{\text{energy dissipated in the load}}{\text{energy dissipated in the complete circuit}}.$$

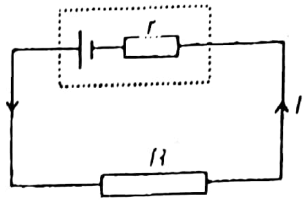
Which of the following gives the efficiency in this case?

A $\frac{r}{R}$ B $\frac{R}{r}$

C $\frac{r}{R+r}$ D $\frac{R}{R+r}$

Helping concepts

Assuming current I flows through the circuit.

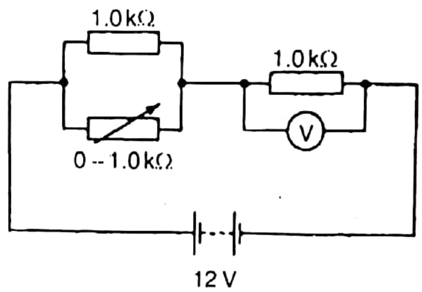


Energy dissipated in load $= I^2R$

Energy dissipated in the complete circuit $= I^2(r+R)$

$\therefore$ Efficiency $= \frac{I^2R}{I^2(R+r)} = \frac{R}{R+r}$

47. The diagram shows a resistor network connected to a 12 V battery of negligible internal resistance. The variable resistor has the range indicated, and the voltmeter has infinite resistance.

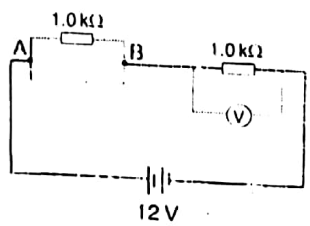


What are the maximum and minimum possible values of the voltmeter reading as the variable resistor is altered?

	maximum / V	minimum / V
A	4	0
B	8	4
C	8	6
D	12	8

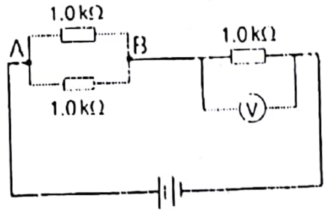
Helping concepts

For variable resistor = 0 Ω, the circuit is as follow:



The p.d. of voltmeter will be equal to e.m.f. of battery = 12 V.

For variable resistor = 1.0 kΩ, the effective circuit is as follow:

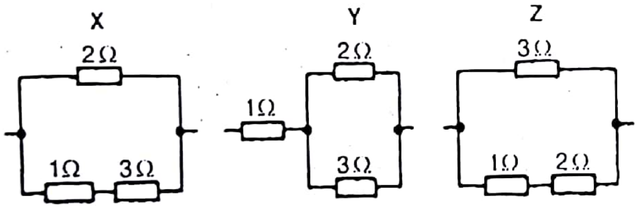


Effective resistance of AB $= (\frac{1}{1.0\ k\Omega} + \frac{1}{1.0\ k\Omega})^{-1}$
$= 0.50\ k\Omega$

Using potential divider method, the value of voltmeter is

$$\frac{1.0\ k\Omega}{(1.0 + 0.5)\ k\Omega} \times 12\ V = 8\ V$$

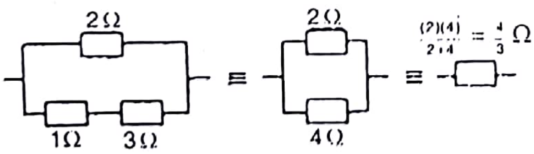
48. Three resistors of resistance 1 Ω, 2 Ω and 3 Ω respectively are used to make the combinations **X**, **Y** and **Z** shown in the diagrams.

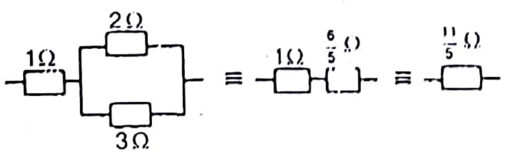


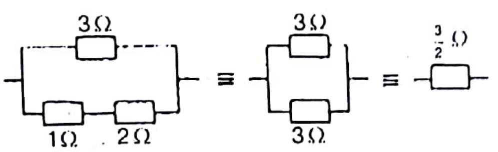
Which of the following gives the combinations in order of increasing resistance?

A XYZ **B** XZY
C YXZ **D** ZXY

Helping concepts

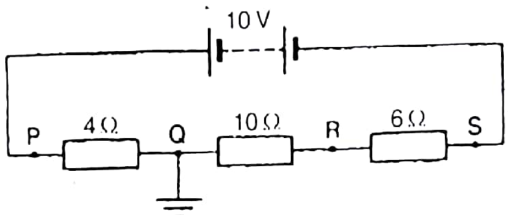
For X: 

For Y: 

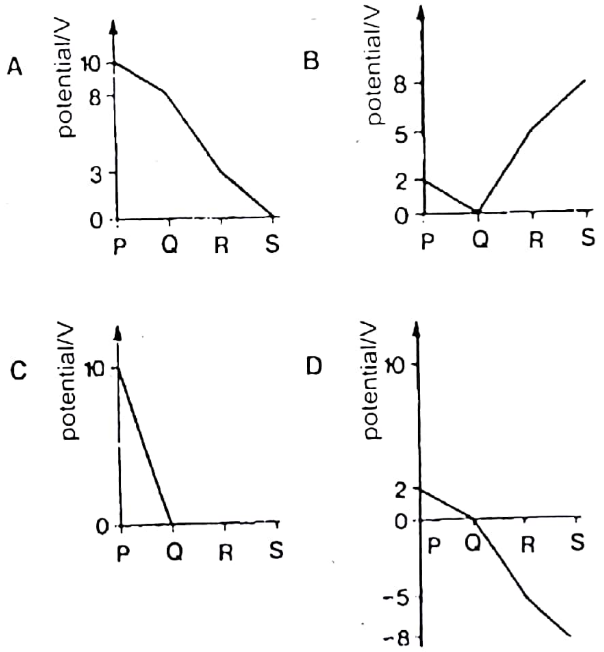
For Z: 

Now, $\frac{4}{3}\ \Omega < \frac{3}{2}\ \Omega < \frac{11}{5}\ \Omega$ and hence, only **XZY** gives the combinations in order of increasing resistance.

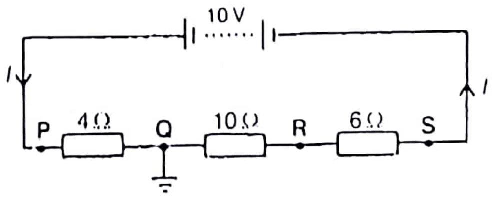
49. The diagram shows three resistors of resistances 4 Ω, 10 Ω and 6 Ω connected in series. A potential difference of 10 V is maintained across them, with point **Q** being earthed.



Which graph represents the change in potential along the resistor network?



Helping concepts



potential at point Q, $V_Q = 0\ V$

Current, $I = \frac{10}{4 + 10 + 6} = 0.5\ A$

Potential across the 4 Ω resistor,

$V_{PQ} = (4)(0.5) = 2\ V \Rightarrow V_P = 2\ V$

Potential across the 10 Ω resistor,

$$V_{QR} = (10)(0.5) = 5\text{ V} \Rightarrow V_R = -5\text{ V}$$

Potential across the 6 Ω resistor,

$$V_{RS} = (6)(0.5) = 3\text{ V} \Rightarrow V_S = -8\text{ V}$$

V = potential at X − 0 V

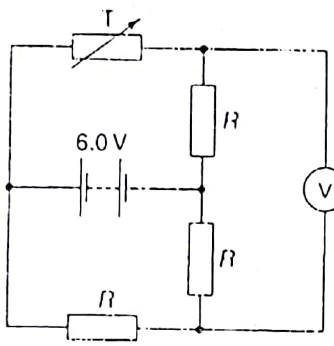
∴ 1.0 V = potential at X

Value of potential Y is still 3.0 V.

∴ The reading of voltmeter = 3.0 − 1.0 = 2.0 V

---

50. A battery of e.m.f. 6.0 V and negligible internal resistance is connected to three resistors, each of resistance R, and a variable resistor T, as shown.



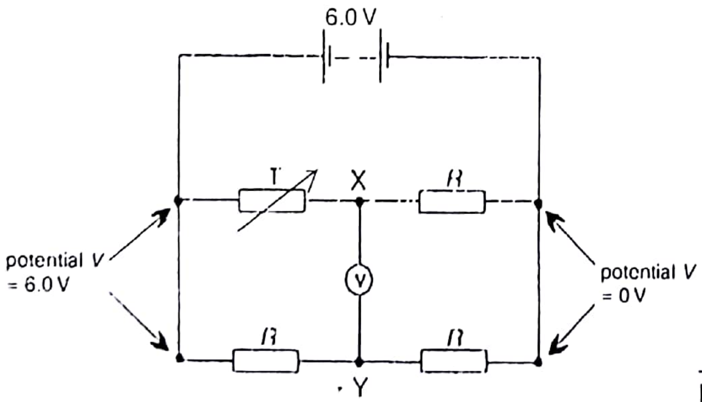
The resistance of T changes from R to $5R$.

What is the change in the reading of the high resistance voltmeter?

A zero B 2 V

C 4 V D 5 V

Helping concepts



equivalent circuit

When T = R, value of potential of X is 3.0 V.

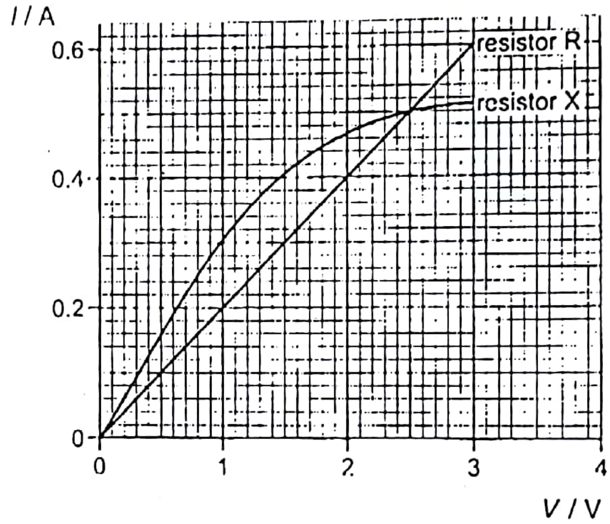
Potential Y is also 3.0 V.

Voltmeter will show **zero** as it measures the difference of potentials X and Y.

When T = 5R,

$$\text{potential difference across R, } V = \left(\frac{R}{R+5R}\right) \times 6\text{ V}$$
$$= 1.0\text{ V}$$

51. The graph shows the current-voltage (I-V) characteristics of two resistors R and X.



The resistors R and X are connected in series with a cell of negligible internal resistance. The current in the circuit is 0.3 A.

The resistors R and X are then connected in parallel with the same cell.

What is the e.m.f. of the cell and the current in the cell when the resistors are connected in parallel?

	e.m.f./V	current / A
A	1.0	0.3
B	1.5	0.7
C	2.5	0.5
D	2.5	1.0

Helping concepts

Coordinates on graph for R = (1.5 V, 0.3 A),

$$\therefore R = \frac{1.5}{0.3} = 5.0\ \Omega$$

Coordinates on graph for X = (1.0 V, 0.3 A),

$$\therefore X = \frac{1.0}{0.3} = 3.3\ \Omega$$

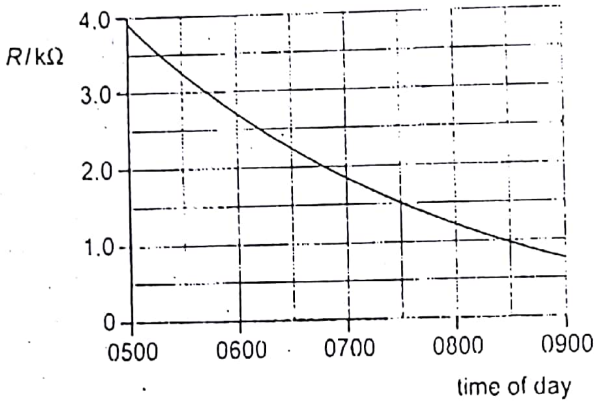
The e.m.f. of cell, E = sum of p.d. of R and X

= 1.5 + 1.0

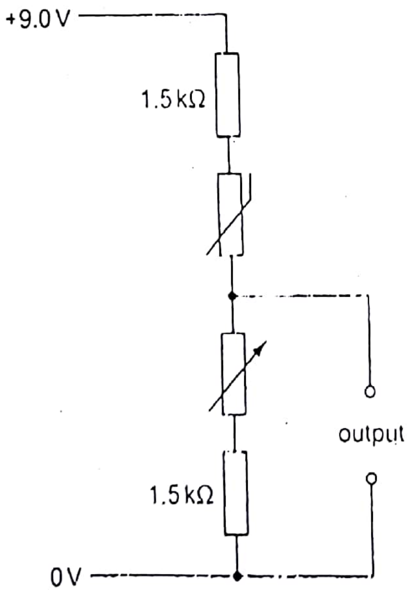
= 2.5 V

In parallel arrangement, p.d. across R and X is 2.5 V. From the graph, current through R and X is 0.5 A. Hence, total current from cell is 0.5 + 0.5 = 1.0 A.

52. The graph shows how the resistance R of a thermistor varies during part of a day.



The thermistor is connected in the potential divider circuit shown.



In order to obtain an output of 6.0 V at 0730, to which value should the variable resistor be set?

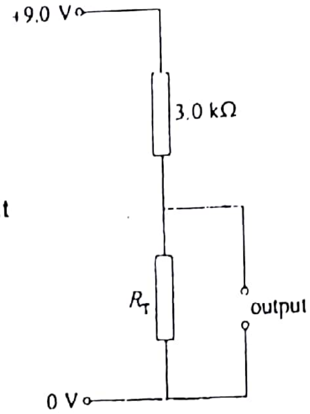
A 1.5 kΩ **B** 3.0 kΩ

C 4.5 kΩ **D** 6.0 kΩ

Helping concepts

At 0730, resistance of thermistor, R = 1.5 kΩ. (seen from graph)

equivalent circuit



Using formula for potential divider,

$$6.0 \text{ V} = \frac{R_T}{(R_T + 3.0 \text{ k}\Omega)} \times 9.0 \text{ V}$$

$$R_T = 6.0 \text{ k}\Omega$$

$\therefore\ R_v + 1.5 \text{ k}\Omega = 6.0 \text{ k}\Omega \Rightarrow R_v = 4.5 \text{ k}\Omega$

where R_v = variable resistor.

TOPIC

15

Electromagnetism

Key content that you will be examined on:

1. Force on a current-carrying conductor
2. Force on a moving charge
3. Magnetic fields due to currents
4. Force between current-carrying conductors

Topic 15

Electromagnetism

1. The acceleration of an electron of mass m and charge e, moving with uniform speed v at right angles to a magnetic field of flux density B, is given by

A $\frac{Bev}{m}$ B $\frac{Be}{m}$

C $\frac{Bv}{m}$ D $Bevm$

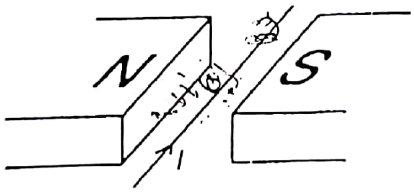
Helping concepts

Net force = magnetic force

$ma = Bev$

$a = \frac{Bev}{m}$

2. The diagram shows a wire, carrying a current I, placed between the poles of a magnet.



In which direction does the force on the wire act?

A downwards

B upwards

C towards the N pole of the magnet

D towards the S pole of the magnet

Helping concepts

As the magnetic field acts towards the left, and the current flows into the plane of the paper, the force on the wire acts downwards by Fleming's left hand rule.

3. Four particles independently move at the same speed in a direction perpendicular to the same magnetic field.

Which particle is deflected the most?

A a copper ion B a helium nucleus

C an electron D a proton

Helping concepts

The force exerted on a particle by the magnetic field is given by Bqv. As this force provides the necessary centripetal force to deflect the particle,

$$Bqv = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{Bq}$$

For a large deflection, r is small.

Among the four particles, the electron has the lowest $\frac{m}{q}$ ratio.

4. An electron is moving along the axis of a solenoid carrying a current.

Which of the following is a correct statement about the electromagnetic force acting on the electron?

A The force acts radially inwards.

B The force acts radially outwards.

C The force acts in the direction of motion.

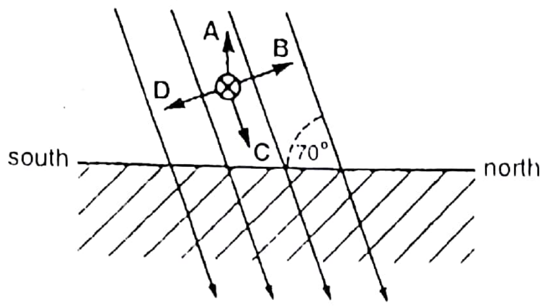
D No force acts.

Helping concepts

Electromagnetic force is only produced when the movement of the electron is perpendicular to the direction of the magnetic field. In this case, the magnetic field is parallel to the axis of the solenoid and thus no electromagnetic force is produced.

5. A horizontal power cable carries a steady current in an east-to-west direction, i.e. into the plane of the diagram.

Which arrow shows the direction of the force on the cable caused by the Earth's magnetic field, in a region where this field is at 70° to the horizontal?



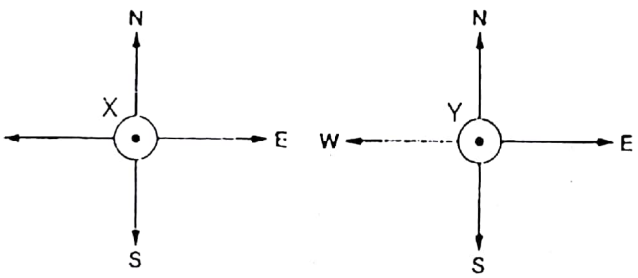
Earth's magnetic field

Helping concepts

By Fleming's left hand rule, the force is perpendicular to the Earth's magnetic field pointing towards the south direction.

---

6. X and Y are two straight parallel conductors carrying currents at right angles to, and out of, the plane of the paper.



Ignoring any effect of the Earth's magnetic field, what are the directions of the forces on X and Y?

	direction of force on X	direction of force on Y
A	N	S
B	S	N
C	E	W
D	W	E

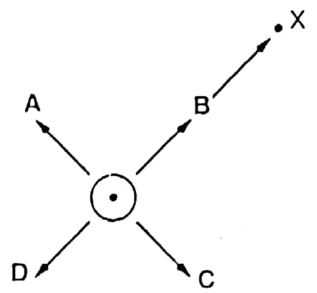
Helping concepts

The two conductors are attracted towards one another.

---

7. The diagram shows the cross-section of a straight wire that carries a steady current **out of** the plane of the paper towards the observer.

The arrows represent the directions of four magnetic fields, **A**, **B**, **C** and **D**.



Which field causes the wire to move towards the point X?

Helping concepts

Use Fleming's left hand rule to find the direction of magnetic field that will cause a force directed toward X.

---

8. A horizontal wire carries current at right angles to a horizontal magnetic field. The wire is then turned through 90° and so becomes parallel with the magnetic field.

What describes the initial and final force on the wire?

	initial force	final force
A	vertical	vertical
B	vertical	zero
C	zero	horizontal
D	zero	vertical

Helping concepts

$$F = BIL\sin\theta$$

where θ is the angle between B and I.

For magnetic field B and current I to be parallel,

$$\theta = 0^\circ \text{ or } 180^\circ.$$

$\therefore$ Force, $F = 0$

---

9. A charged particle, initially travelling in a vacuum in a straight line, enters a uniform field. This causes the particle to travel in a curved path that is not the arc of a circle.

Which type of field, and which initial direction of the particle with reference to the field, causes this to happen?

	field type	initial direction of the particle compared to the field
A	electric	parallel
B	electric	perpendicular
C	magnetic	parallel
D	magnetic	perpendicular

Helping concepts

The curve path is parabolic, as a result of a net force. This force must be perpendicular to its initial direction.

If the force is parallel, the particle will move in a straight line, at a faster speed.

10. Differently charged ions of several nuclides are all fired at the same speed into a region where there is a uniform magnetic field at right angles to their initial path.

Which ions travel in a circular path of the smallest radius?

A singly charged $^{6}_{3}Li$ ions

B doubly charged $^{6}_{3}Li$ ions

C doubly charged $^{12}_{6}C$ ions

D singly charged $^{16}_{8}O$ ions

Helping concepts

A moving charge will experience centripetal force in magnetic field.

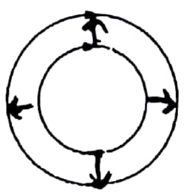
$$Bqv = \frac{mv^2}{r}$$

$$r = \frac{mv}{Bq}$$

For radius r to be small, mass m should be small and charge q should be big.

Note that velocity v and magnetic field B are the same for all ions.

11. A small flat circular coil lies inside a similar larger coil. Each coil carries a current as shown.



What is experienced by the small coil due to these currents?

A a torque about a horizontal axis

B a torque about a vertical axis

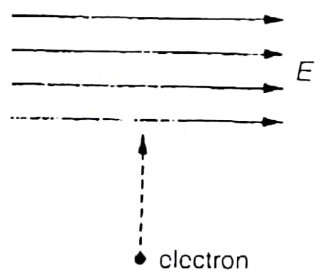
C a vertical force along the axis

D no resultant force

Helping concepts

The current through the larger coil gives rise to a magnetic field directed downwards (use Right Hand Grip Rule to find the direction). Using Fleming's left hand rule, it can seen that the force exerted on every section of the smaller coil is directed outward, away from the centre of the coil. Hence, there is no resultant force on the small coil.

12. An electron is projected at right angles to a uniform electric field E.



In the absence of other fields, in which direction is the electron deflected?

A into the plane of the paper

B out of the plane of the paper

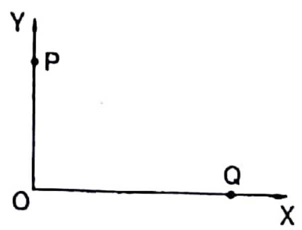
C to the left

D to the right

Helping concepts

The electron will deflect towards the end with higher electric potential.

13. The diagram shows a plane **OXY** with axes **OX** and **OY** at right angles.



Which of the following currents in a straight conductor will produce a magnetic field at O in the direction OX?

A at P into the plane of the diagram

B at P out of the plane of the diagram

C at Q into the plane of the diagram

D at Q out of the plane of the diagram

Helping concepts

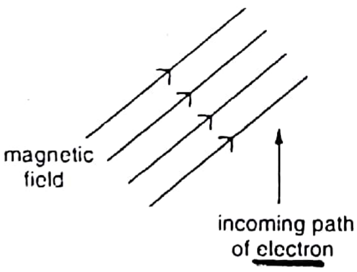
The following table summarises the directions of the magnetic fields produced by the various currents at locations P or Q.

current	magnetic field
A	at O in the direction opposite to OX
B	at O in the direction OX
C	at O in the direction OY
D	at O in the direction opposite to OY

---

14. The diagram shows an electron as it enters a magnetic field. The path of the electron and the magnetic field are in the plane of the paper.

In which direction is the electron initially deflected?



A into the plane of the paper

B out of the plane of the paper

C to the left of its incoming path

D to the right of its incoming path

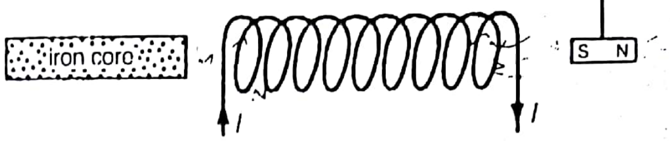
Helping concepts

Fleming's left hand rule is valid.

There is a horizontal component of magnetic field in the plane of the paper that producing the magnetic force on the electron.

---

15. The diagram shows a small magnet hanging on a thread near the end of a solenoid carrying a steady current I.



What happens to the magnet as the iron core is inserted into the solenoid?

A It moves towards the solenoid.

B It moves towards the solenoid and rotates through 180°.

C It moves away from the solenoid.

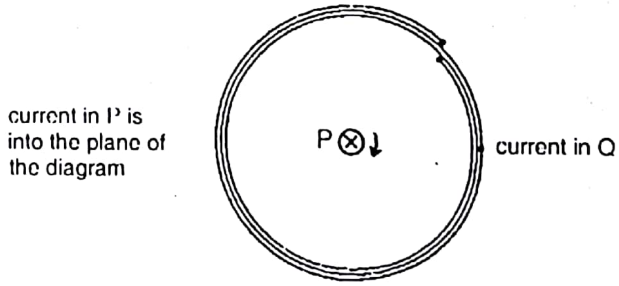
D It moves away from the solenoid and rotates through 180°.

Helping concepts

The solenoid acts like an electromagnet, with the north pole on the right end. The iron core increases the strength of the electromagnet.

---

16. A long straight wire P is placed along the axis of a flat circular coil Q. The wire and the coil each carry a current as shown.



What can be deduced about the force acting on each part of Q due to the current in P?

A The force is away from P.

B The force is towards P.

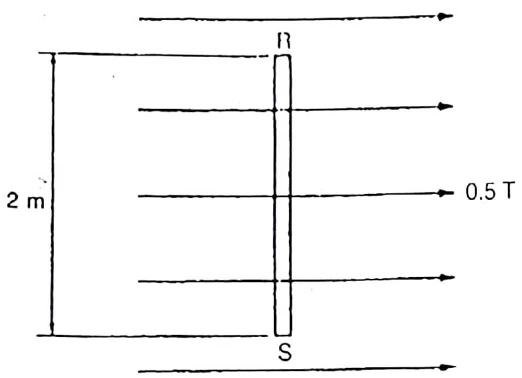
C The force is perpendicular to the plane of the diagram.

D There is no force in any direction.

Helping concepts

The current in P induces a magnetic field along the circumference of the circular coil of wire acting in a clockwise direction. Since this magnetic field is parallel to the current in each part of wire Q, the wire experiences no force in any direction.

17. The diagram shows a current-carrying conductor RS of length 2 m placed perpendicular to a magnetic field of flux density 0.5 T. The resulting force on the conductor is 1 N acting into the plane of the paper.



What is the magnitude and direction of the current?

A 1 A from R to S **B** 1 A from S to R
C 2 A from R to S **D** 2 A from S to R

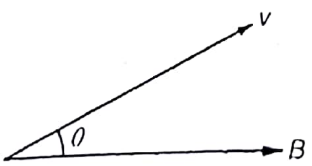
Helping concepts

By Fleming's left hand rule, the current in the conductor flows from S to R.

Using the formula $F = BIL\sin\theta$,

$$I = \frac{1}{0.5 \times 2} = 1\text{ A}$$

18. An electron of charge e and mass e_e is injected into a uniform magnetic field of flux density B in a vacuum. Its initial velocity v makes an angle θ with the direction of the field as shown.



Which of the following correctly describes the component of the electron velocity parallel to B in the subsequent motion?

A constant speed equal to $v\sin\theta$

B constant speed equal to $v\cos\theta$

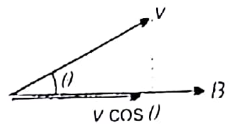
C speed increasing with acceleration $\frac{Bev}{m_e}$

D speed increasing with acceleration $\frac{Bev\cos\theta}{m_e}$

Helping concepts

Velocity along B is $v\cos\theta$.

$F_B = Bqv\sin\theta$



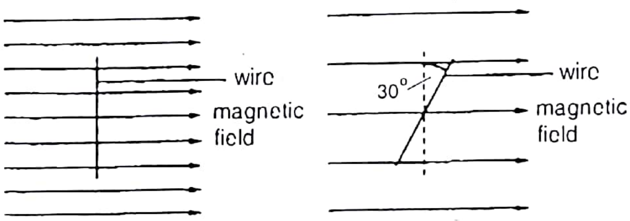
where θ is the angle between B and v.

As electron is travelling parallel to B, $F = 0$.

There is no net force and therefore no net acceleration.

19. A straight, horizontal, current-carrying wire lies at right angles to a horizontal magnetic field. The field exerts a vertical force of 8.0 mN on the wire.

The wire is rotated, in its horizontal plane, through 30° as shown. The flux density of the magnetic field is halved.



What is the vertical force on the wire?

A 2.0 mN **B** 3.5 mN
C 4.6 mN **D** 8.0 mN

Helping concepts

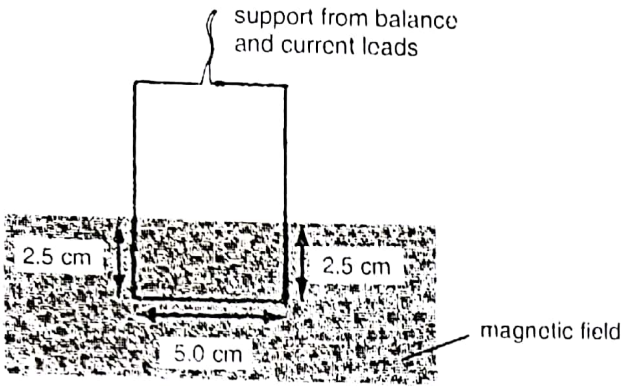
$$F = BIL$$

$$8.0\text{ mN} = BIL \text{-------} (1)$$

$$F = (\tfrac{1}{2}B)I(L\cos 30^\circ) \text{-------} (2)$$

$$\frac{(2)}{(1)}: \frac{F}{8.0\text{ mN}} = \frac{1}{2}\cos 30^\circ \Rightarrow F = 3.5\text{ mN}$$

20. A single-turn rectangular wire loop hangs from a balance reading in grams so that its lower part is in a region of uniform magnetic field. The direction of the field is at right-angles to the plane of the loop. The arrangement is as shown in the diagram.



When there is no current in the loop, the reading of the balance is 10.060 g. When the current in the loop is 3.0 A, the balance reading is 10.040g.

What is the magnitude of the flux density of the field?

A 6.5×10^{-4} T B 1.3×10^{-3} T

C 1.3×10^{-2} T D 6.6×10^{-1} T

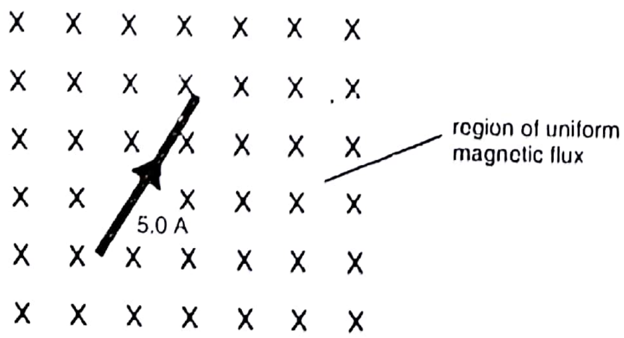
Helping concepts

$$F = BIL\sin\theta$$

$$F = \Delta mg$$
$$= (10.06 - 10.04) \times 10^{-3}(9.81)$$
$$= 1.96 \times 10^{-4} \text{ N}$$

$$\therefore B = \frac{F}{IL\sin\theta}$$
$$= \frac{1.96 \times 10^{-4}}{(3.0)(5.0 \times 10^{-2})\sin 90^\circ}$$
$$= 1.3 \times 10^{-3} \text{ T}$$

21. A wire of length 3.0 cm is placed at right angles to a magnetic field of flux density 0.040 T.



The wire carries a current of 5.0 A.

What is the magnitude of the force which the field exerts on the wire?

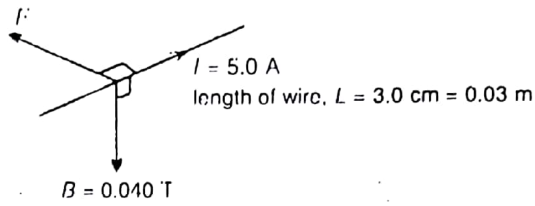
A less than 0.006 N

B 0.0060 N

C greater than 0.006 N but less than 0.6 N

D 0.60 N

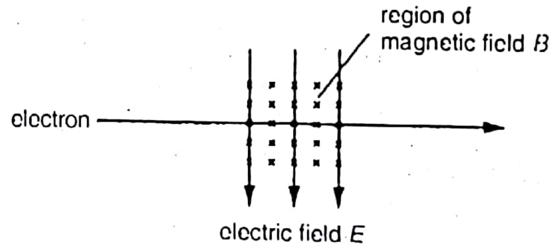
Helping concepts



Force acting on wire has a magnitude given by

$$F = BIL = (0.040)(5.0)(0.03) = 0.0060 \text{ N}$$

22. A beam of electrons enters a region in which there are magnetic and electric fields directed at right angles. It passes straight through without deviation.



A second beam of electrons travelling twice as fast as the first is then directed along the same line.

How is this second beam deviated?

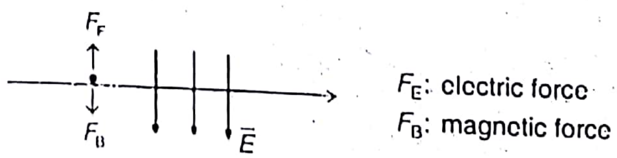
A downwards in the plane of the paper

B upwards in the plane of the paper

C out of the plane of the paper

D into the plane of the paper

Helping concepts



A straight through path implies $F_E = F_B$ for electrons.

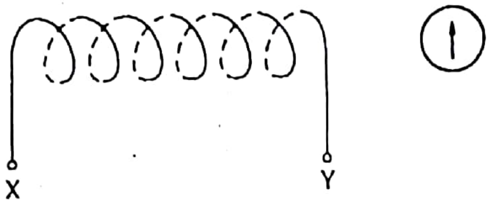
$$F_B = Bqv$$

As velocity is doubled, F_B will be doubled.

Hence, the electron will move downwards.

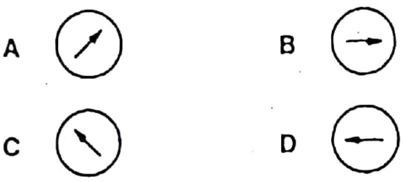
23. A plotting compass is placed near a solenoid.

When there is no current in the solenoid, the compass needle points due north as shown.



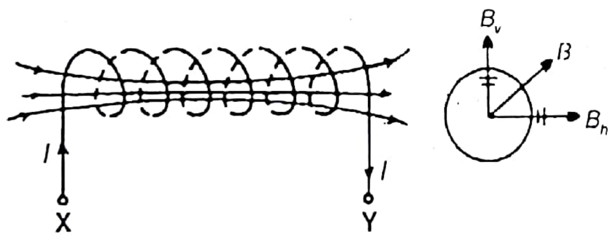
When there is a current from X to Y, the magnetic field of the solenoid at the compass is equal in magnitude to the Earth's magnetic field at that point.

In which direction does the plotting compass set?



Helping concepts

The magnetic field set up by current in the coil is as follows.



Since B_h, magnetic field experienced by the compass, is numerically equals to B_v, the Earth's magnetic field, the resultant field is B as indicated in the diagram. Deflection of needle in compass is thus best illustrated by diagram A.

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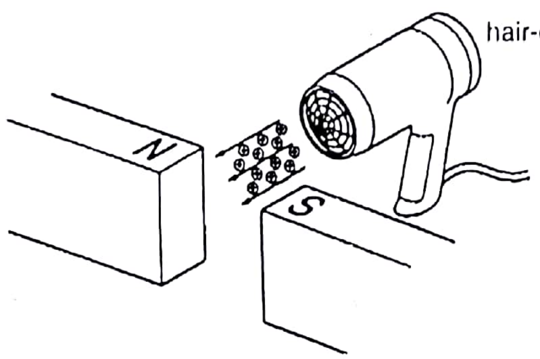
24. Hot air from a hair-dryer contains many positively charged ions. The motion of these ions constitutes an electric current.



The hot air is directed between the poles of a strong magnet, as shown.

What happens to the ions?

They are deflected

A towards the north pole N.

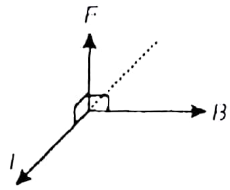
B towards the south pole S.

C downwards.

D upwards.

Helping concepts

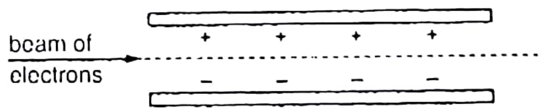
The motion of the positively charged ions forms the current flow I, through the magnetic field B as shown in the diagram below.



The magnetic force acting on the ions F is thus upwards as shown. Hence, the ions are deflected upwards.

---

25. A beam of electrons, travelling horizontally towards the right, passes between two horizontal charged parallel metal plates.



There is a vertical electric field between the plates. There is no deflection of the beam because of the presence of a uniform magnetic field in the region between the plates.

In which direction must this magnetic field be?

A out of the paper

B into the paper

C vertically upwards

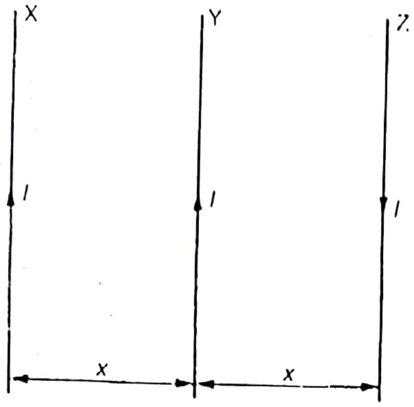
D vertically downwards

Helping concepts

The electric force on the electrons is vertically upwards by looking at the upper positive plate. This means that the magnetic force on the electrons must be vertically downwards, so that there is no deflection of the electrons, i.e. the electrons will travel in a straight line. Using Fleming's left hand rule, the magnetic field must be into the page.

---

26. The diagram shows three parallel wires X, Y and Z that carry currents of equal magnitude in the directions shown.



The resultant force experienced by Y due to the currents in X and Z is

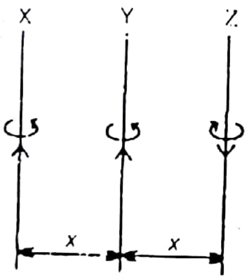
A perpendicular to the plane of the paper.

B to the left.

C to the right.

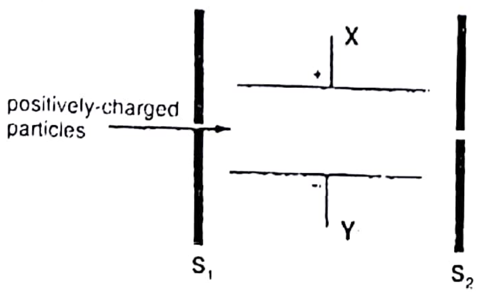
D zero.

Helping concepts



The directions of the magnetic fields caused by each of the current-carrying wires are as shown. On the left of wire Y, the magnetic field caused by wire X is neutralised, whereas on the right of wire Y, the magnetic field caused by wire Z is doubled. Therefore, Y moves to the left.

27. The diagram shows part of a velocity selector.



A beam of positively-charged particles, with a range of velocities, enters through the slit in S_1. An electric field is provided by two parallel plates X and Y with a p.d. between them of polarity as shown. The velocity selector is completed by the addition of an electromagnet to produce a magnetic field of a suitable strength and direction so that particles of only a particular velocity emerge from the slit in S_2.

What should be the direction of the magnetic field?

A from X to Y

B from Y to X

C perpendicular to and into the plane of the diagram

D perpendicular to and out of the plane of the diagram

Helping concepts

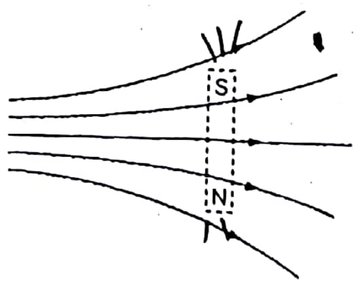
Ignoring the effect of gravitational field, then for particles to pass through the parallel plates without change in direction, we must have

force due to magnetic field in upwards direction = force due to electric field in downwards direction, to the positively-charged particles

i.e. $F_B \uparrow = F_E \downarrow$

By Fleming's left hand rule, the direction of the magnetic field must be perpendicular and pointing into the plane of the diagram.

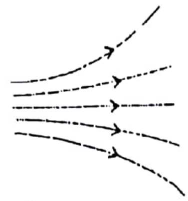
28. A bar magnet is to be placed in a non-uniform magnetic field as shown.



Which line of the table describes the subsequent motion of the magnet?

	rotation	movement
A	anticlockwise	to the left
B	anticlockwise	to the right
C	clockwise	to the left
D	clockwise	to the right

Helping concepts

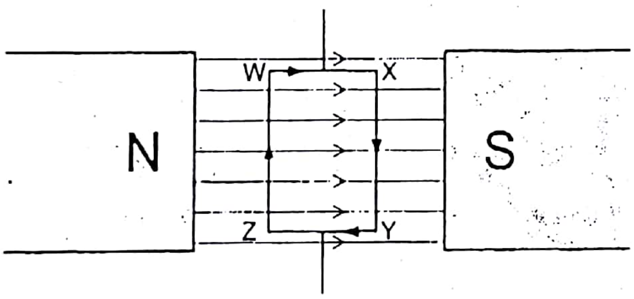


One conclusion is that the source of magnetic field is North pole.

Opposite poles attract and the magnet will turn clockwise as South pole of magnet will be attracted. Also the magnet will move to the left due to the non-uniform magnetic.

---

29. In the electric motor, a rectangular coil WXYZ has 20 turns and is in a uniform magnetic field of flux density 0.83 T.



The lengths of sides XY and ZW are 0.17 m and of sides WX and YZ are 0.11 m. The current in the coil is 4.5 A.

What is the maximum torque provided by the motor?

A 0.070 Nm   B 0.63 Nm

C 1.4 Nm   D 2.8. Nm

Helping concepts

Torque = couple (in this case)

$= F \times WX$

$= (N \cdot BIL) \times WX$

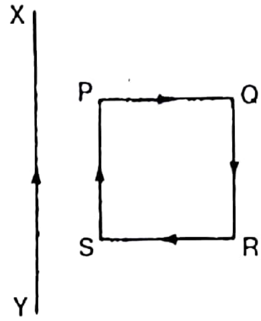
$= 20(0.83 \times 4.5 \times 0.17) \times (0.11)$

$= 1.4$ Nm

---

30. A long straight wire **XY** lies in the same plane as a square loop of wire **PQRS** which is free to move. The sides **PS** and **QR** are initially parallel to **XY**.

The wire and loop carry steady currents as shown in the diagram.



What will be the effect on the loop?

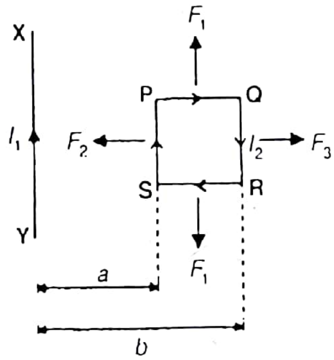
A It will move towards the long wire.

B It will move away from the long wire.

C It will rotate about an axis parallel to XY.

D It will be unaffected.

Helping concepts



The forces on **PQ** and **RS** are equal in magnitude and opposite in direction. Hence, no net resultant force in the **XY** direction. The force per unit length on **PS** due to current in **XY** and **PS** is given by

$$\frac{F_2}{l} = \frac{\mu_0 I_1 I_2}{2\pi a} \text{ towards XY.}$$

The force per unit length on **QR** due to current in **XY** and **QR** is given by

$$\frac{F_3}{l} = \frac{\mu_0 I_1 I_2}{2\pi b} \text{ away from XY.}$$

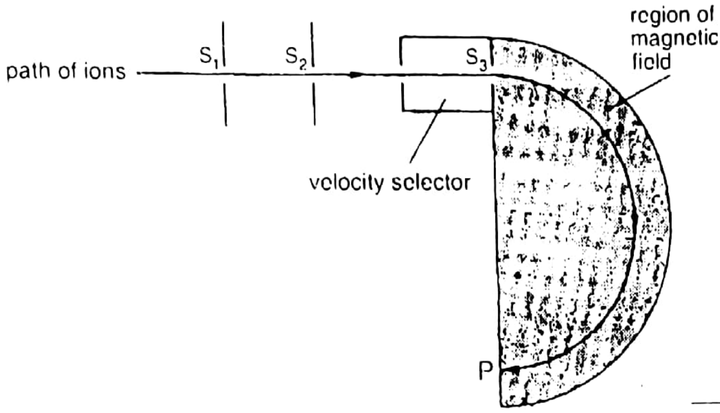
Hence, the net resultant force on wire **PQRS** is

$$F = F_2 - F_3 = \frac{\mu_0 I_1 I_2 (b - a)}{2\pi ab} \text{ towards XY.}$$

Therefore, the wire loop **PQRS** will move towards the long wire.

---

31. The diagram shows the principle of a simple form of mass spectrometer. Ions are passed through narrow slits, S_1 and S_2, and into a velocity selector. The selected ions, after passage through the slit S_3, are deviated by the uniform magnetic field.



Which of the following quantities must be the same for all ions arriving at point P?

A charge B $\frac{\text{charge}}{\text{mass}}$

C kinetic energy D mass

Helping *concepts*

For a given magnetic field B and electric field E, the velocity of the ions pass through the slit S_3 is of preselected value given by

$$v = \frac{E}{B}$$

Transversing at this speed, the ions arrive at point P provided that

$$\frac{mv^2}{R} = Bqv$$

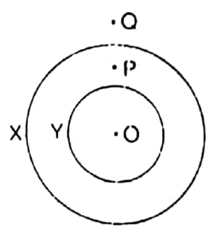
where R is the radius associated with the circular path taken by the ions.

$$\therefore \frac{v}{RB} = \frac{q}{m}$$

Hence, for a given magnetic field B and the selected velocity v, all ions will arrive at point P (same R) if the quantity q/m or charge/mass is the same.

---

32. X and Y are two coaxial circular coils lying on a table. O, P and Q are three points on the table.



Initially, there is a constant current in coil X and no current in coil Y.

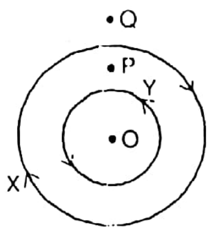
A small current is now passed through coil Y, which decreases the magnitude of the magnetic flux density at O.

How does the magnitude of the flux density change at P and Q?

	P	Q
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

Helping *concepts*

Assume current in X is in clockwise direction (magnetic field is into the page, using Right hand grip rule).



Since the magnetic flux density, B decreases at O when a current is passed in Y, the current in Y must be in the anticlockwise direction (magnetic field is out of the page).

At point P, the magnetic field due to wire X and Y is in the same direction (into the page). The resultant magnetic field at P will increase (using Right hand grip rule).

At point Q, the magnetic field due to wire X (out of the page) and wire Y (into the page) is in different direction. The resultant magnetic field at Q will decrease.

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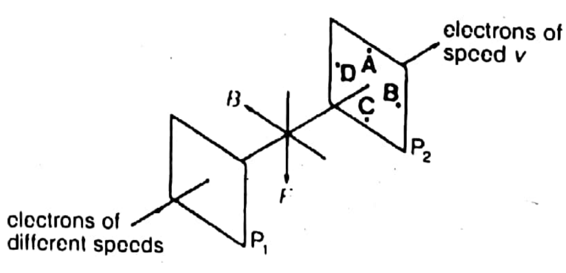
33. The diagram illustrates a method of velocity selection of charged particles.



A beam containing electrons of different speeds passes through a hole in plate P_1, P_2 is a plate, parallel to P_1, also with a hole in it. In the region between the plates, a uniform electric field of intensity E and a uniform magnetic field of flux density B are applied at right angles to each other, as shown. The magnitudes of E and B are adjusted so that only electrons of speed v pass undeviated through the holes in P_1 and P_2.

Which point indicates where electrons of a speed greater than v could strike P_2?

Helping concepts

Magnetic force, $F_B = Bqv$

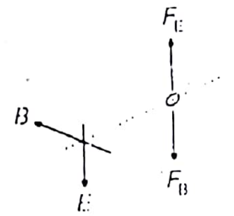
(direction of F_B is found using Fleming's left hand rule.)

On moving charge,

electric force, $F_E = qE$.

For electrons will higher speed,

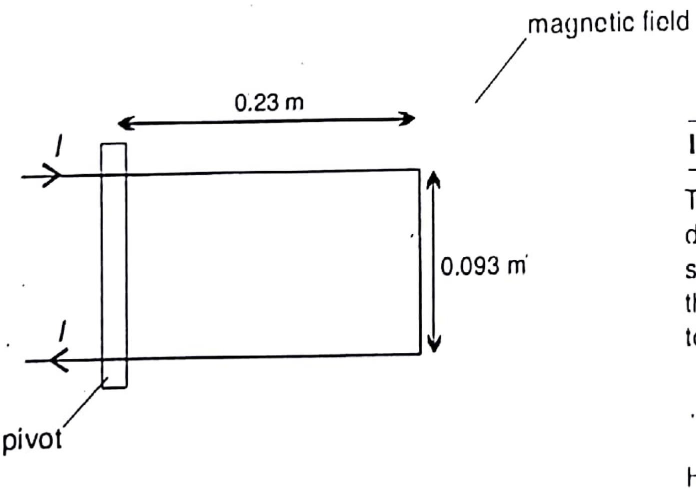
F_B will be higher than F_E.



Hence, electrons will move downwards to C when at P_2.

---

34. In order to determine the value of a current I, it is passed into a current balance. This consists of a U-shaped wire placed in a constant magnetic field of flux density 3.6×10^{-2} T. The U-shaped wire has length 0.23 m and the arms are 0.093 m apart, as shown in the diagram.



The U-shaped wire experiences a turning moment about the pivot of value 7.4×10^{-3} Nm.

What is the value of I?

A 0.044 A **B** 1.6 A

C 2.8 A **D** 9.6 A

Helping concepts

Resultant moment = $F \times d$

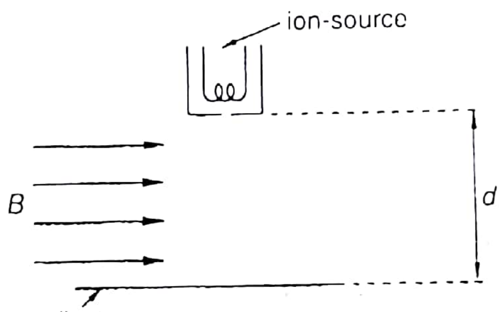
$$7.4 \times 10^{-3} = BIL \times d$$

$$7.4 \times 10^{-3} = (3.6 \times 10^{-2})(I)(0.093) \times (0.23)$$

$$I = 9.6 \text{ A}$$

---

35. An ion-source is at distance d from a flat, horizontal collector at the same potential as the source. A magnetic field of flux density B acts horizontally as shown in the diagram below. The field is uniform throughout the region between the source and the collector.



An ion of charge q and mass m is emitted vertically downwards at speed v. Under what conditions will the ion reach the collector?

A $v > \sqrt{\dfrac{2Bq}{m}}$ **B** $v < \sqrt{\dfrac{2Bq}{m}}$

C $v > \dfrac{dBq}{m}$ **D** $v < \dfrac{dBq}{m}$

Helping concepts

The ion of charge q and mass m emitted vertically downwards from the source must be at a minimum speed v_{min} such that the radius of the circular orbit of the ion in the presence of the magnetic field B is equal to the distance d.

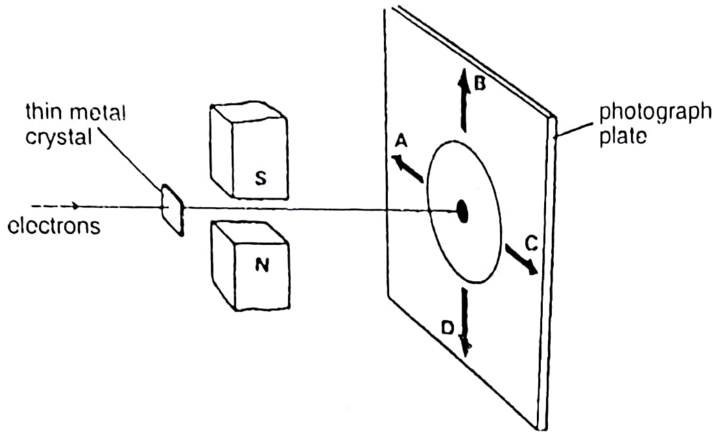
$\therefore$ Force, $F = Bqv_{min} = m\dfrac{v_{min}^2}{d} \Rightarrow v_{min} = \dfrac{dBq}{m}$

Hence, the speed v has to be greater than v_{min}, or

$v > v_{min} = \dfrac{dBq}{m}$.

---

36. G.P. Thomson's early experiments on the diffraction of electrons by crystals were criticised on the grounds that the beams affecting the photographic plate might be X-rays. He proved that this was not so by placing bar magnets on each side of the beam as shown in the diagram.



How would the magnetic field due to the magnets affect the diffraction ring?

A The ring would be deflected in the direction A.

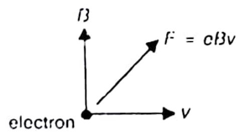
B The ring would be deflected in the direction B.

C The ring would be deflected in the direction C.

D The ring would be deflected in the direction D.

Helping concepts

The force F acting on the electron beam due to the magnet field of flux density B when electrons are travelling at speed v is shown below.

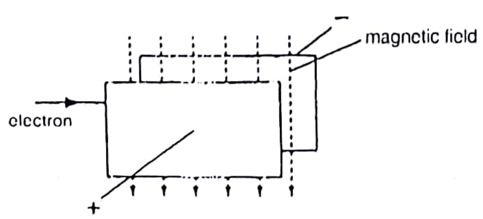


Hence, the beams are deflected towards **A**.

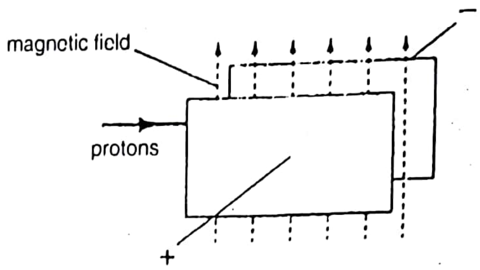
37. The diagrams show different particle beams entering a region between two metal plates in which there are uniform electric and magnetic fields.

In which arrangement would it be possible for the beam to pass through undeflected?

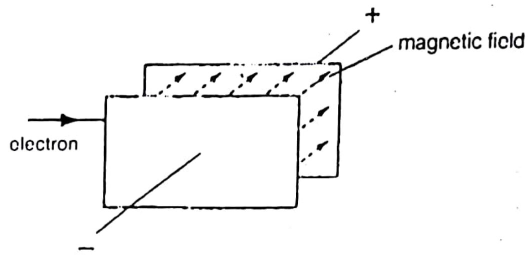
A



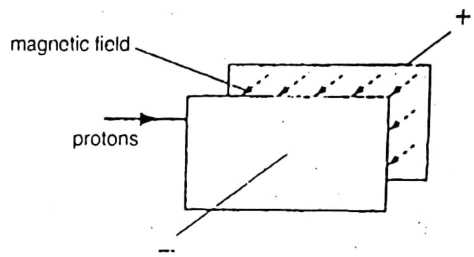
B



C



D



Helping concepts

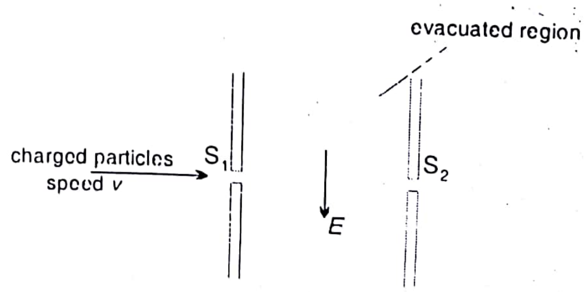
The net force must be zero, i.e. electric force must be in opposite direction and of the same magnitude as the magnetic force.

For option B, electric force on protons is into the page (in the same direction of electric field).

The magnetic force is out of the page (using Fleming's left hand rule).

38. A narrow parallel beam of charged particles, each with speed v, passes through a slit S_1 into an evacuated region, moving in the direction towards slit S_2.

The evacuated region is shown shaded on the diagram.



Uniform magnetic and electric fields are applied in the same evacuated region, with the electric field E in the direction shown. The particles continue to exit through slit S_2.

What is the magnitude and direction of the magnetic field?

	magnitude	direction
A	E/v	into the plane of the paper
B	E/v	out of the plane of the paper
C	Ev	into the plane of the paper
D	Ev	out of the plane of the paper

Helping concepts

In a cross-field velocity selector,

magnetic force = electric force

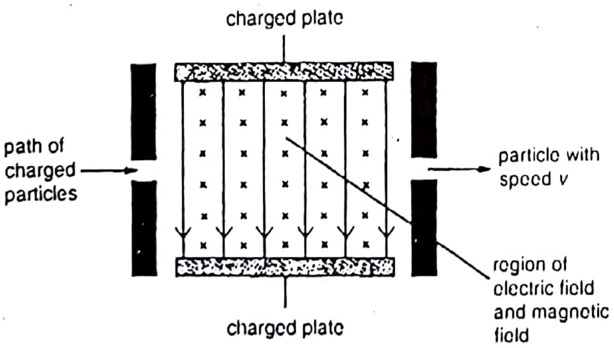
$$Bqv = qE$$

$$B = \frac{E}{v}$$

Assume charge is positive, using Fleming's left hand rule, the current is in the same direction as v, the force is upwards, and magnetic field is into the page.

If the assumption of charge is negative, the current is in the opposite direction as v, the force is downwards, and the magnetic field is still into the page. The outcome will remain unchanged.

39. The diagram shows a velocity selector for charged particles.



The charged plates give a uniform electric field of strength E. In the same region, there is a uniform magnetic field of flux density B, at right angles to the electric field.

Particles carrying charge Q and having speed v pass through undeviated, because the forces on them due to the electric and magnetic fields are equal in magnitude but opposite in direction.

What is the speed v of particles leaving the selector?

A $\frac{B}{E}$ B $\frac{E}{B}$

C $\frac{BQ}{E}$ D $\frac{EQ}{B}$

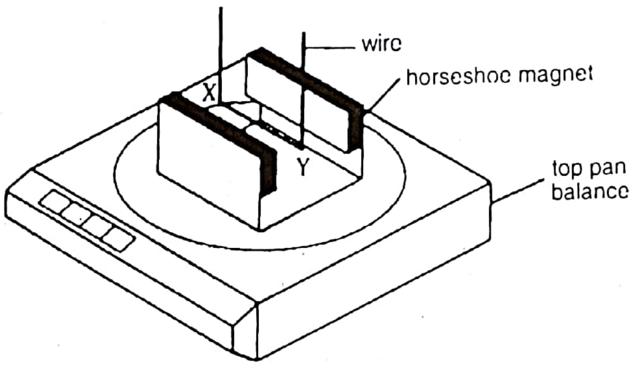
Helping concepts

Magnetic force = electric force

$$BQv = QE$$

$$\text{speed, } v = \frac{E}{B}$$

40. A horseshoe magnet rests on a top-pan balance with a wire situated between the poles of the magnet.



With no current in the wire, the reading on the balance is 142.0 g.

With a current of 2.0 A in the wire in the direction XY, the reading on the balance changes to 144.6 g.

What is the reading on the balance, when there is a current of 3.0 A in the wire in the direction YX?

A 138.1 g B 140.7 g

C 145.9 g D 148.5 g

Helping concepts

When a current flows through the wire immersed in the magnetic field of the horseshoe magnet, it experiences a magnet force. The horseshoe magnet experiences an equal and opposite force, giving rise to a change in the balance reading. When the direction of the current through the wire is reversed, the magnet force on the wire and hence the horseshoe magnet is also reversed. Hence, the balance reading should be less than 142.0 g.

The force on the wire, and hence that on the horseshoe magnet, is proportional to the current through the wire.

$$F = BIL$$

The difference in the balance reading due to a current of 3.0 A

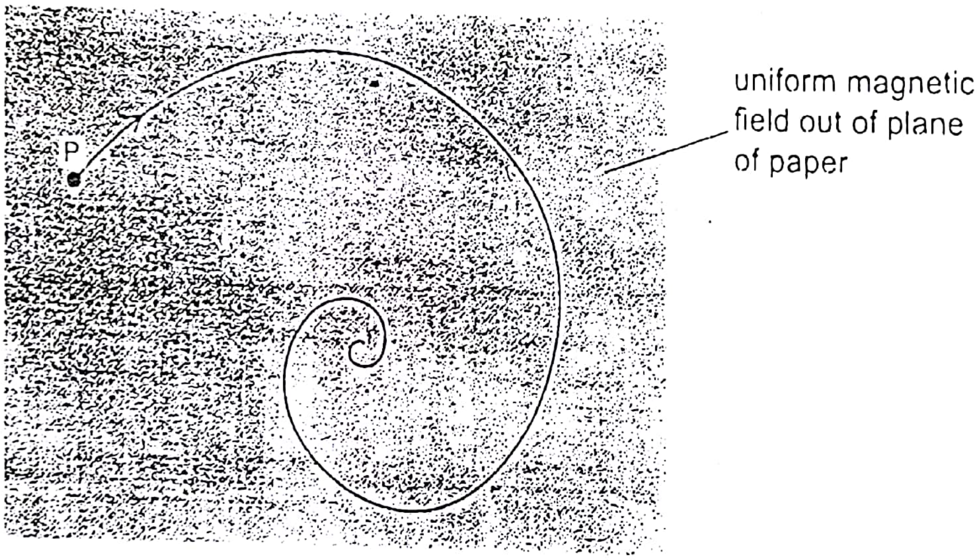
$= 3.0 \times \dfrac{(144.6 - 142.0)}{2.0}$

$= 3.9$ g

$\therefore$ New reading = 142.0 − 3.9 = 138.1 g

---

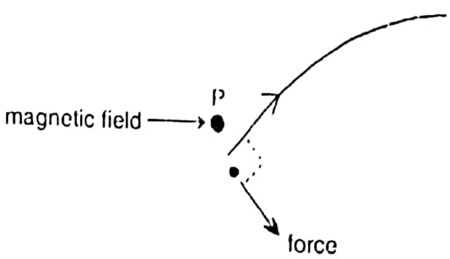
41. A charged particle is moving in a region where there is a uniform magnetic field acting out of the plane of the paper. The path of the particle begins at P and is as shown.



What can be deduced about the charge on the particle and its speed?

	charge	speed
A	negative	decreasing
B	negative	increasing
C	positive	decreasing
D	positive	increasing

Helping *concepts*



There is a net force acting perpendicular to the path of motion, towards the centre of the circular motion.

Using Fleming's left hand rule, the direction of current is in the same direction of its motion. This means the charge of particle is positive.

Net magnetic force = circular motion

$$Bqv = \frac{mv^2}{r}$$

$$r = \frac{mv}{Bq}$$

where m = mass of particle,
B = uniform magnetic field,
q = charge of particle.

Since radius r is decreasing, the velocity v of the particle will also decrease as m, B and q are constant.

TOPIC 16

Electromagnetic Induction

Key content that you will be examined on:

1. Magnetic flux
2. Laws of electromagnetic induction

Topic 16 Electromagnetic Induction

1. The function of a mains transformer is to convert

A one direct voltage to another direct voltage of different magnitude.

B one alternating voltage to another alternating voltage of different magnitude.

C a high value alternating voltage to a low value direct voltage.

D a low value alternating voltage to a high value direct voltage.

Helping concepts

Operation of transformer is based on the principle of electromagnetic induction and operates only alternating current, not direct current. It can either be a step-up or a step-down voltage mains transformer.

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2. A flat circuit coil of 120 turns, each of area 0.070 m², is placed with its axis parallel to a uniform magnetic field. The flux density of the field is changed steadily from 80 mT to 20 mT over a period of 4.0 s.

What is the e.m.f. induced in the coil during this time?

A 0 B 130 mV

C 170 mV D 500 mV

Helping concepts

$$q = NA\frac{\Delta B}{\Delta t}$$

$$= 120 \times 0.070 \times \frac{(80-20)\times 10^{-3}}{4.0}$$

$= 0.126$ V

≈ 130 mV

---

3. The secondary coil of an ideal transformer delivers an r.m.s. current of 2.5 A to a load resistor of resistance 8.0 Ω. The r.m.s. current in the primary is 10 A.

What is the r.m.s. potential difference across the primary coil?

A 3.5 V B 5.0 V

C 57 V D 80 V

Helping concepts

r.m.s. potential difference across the secondary coil

= (2.5)(8)

= 20 V

$$\frac{V_p}{V_s} = \frac{I_s}{I_p}$$

$$\Rightarrow V_p = \frac{I_s}{I_p} \times V_s = \frac{2.5}{10} \times 20 = 5.0 \text{ V}$$

---

4. A flat circular coil of diameter 30 mm has 500 turns and is situated so that the plane of the coil is perpendicular to a uniform magnetic field of flux density 20 mT. The flux density is reduced to zero and then increased to 20 mT in the opposite direction at a constant rate. The time taken for the whole operation is 60 ms.

What is the average value of the e.m.f. induced in the coil?

A 0 B 0.12 V

C 0.24 V D 0.94 V

Helping concepts

$$\text{Induced e.m.f. } E = -\frac{d\phi}{dt} = -\frac{d}{dt}(BA\cos\theta)$$

As B decreases at constant rate, E is positive.

As B increases at constant rate, E is negative.

The net e.m.f. is zero.

Hence, average value of e.m.f. is zero.

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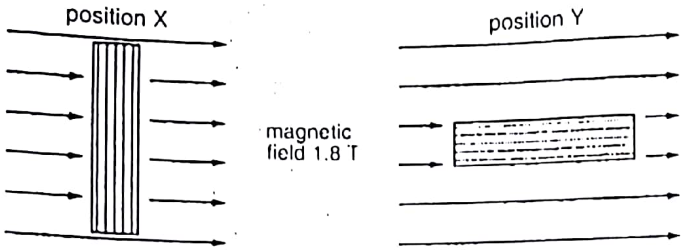
5. A circular coil of diameter 0.020 m has 3000 turns. It is rotated in a magnetic field of 1.8 T from position X to position Y in 0.060 s.



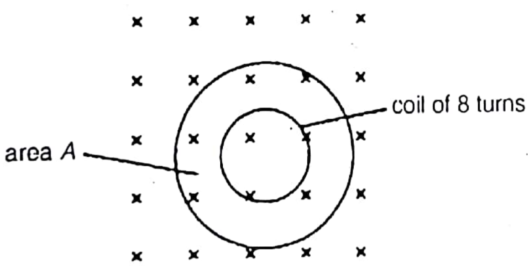
What is the average e.m.f. induced in the coil during the rotation?

A 28 V
B 36 V
C 113 V
D 1800 V

Helping concepts

$$E = \left|\frac{d\Phi}{dt}\right| = \frac{\Delta(NBA)}{\Delta t} = \frac{3000(1.8)\pi(\frac{0.02}{2})^2}{0.060} = 28\text{ V}$$

6. A uniform magnetic field of flux density B passes normally through a plane area A. In this plane lies a coil of eight turns of wire, each of area $\frac{1}{4}A$.



What is the magnetic flux linkage for the coil?

A $\frac{1}{4}BA$
B BA
C $2BA$
D $8BA$

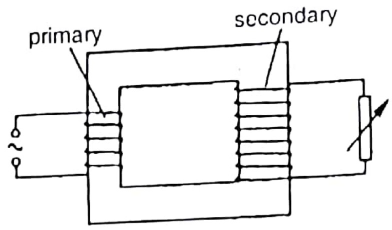
Helping concepts

Magnetic flux, $\phi = BA$

Magnetic flux linkage for the coil $= B \times 8 \times \frac{1}{4}A$

$= 2BA$

7. The primary coil of a transformer is connected to an alternating voltage supply. The secondary coil is connected across a variable resistor.



Which change will cause a decrease in the p.d. across the secondary coil?

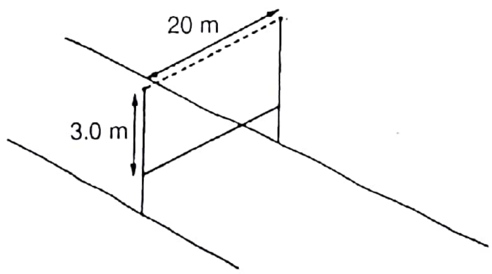
A increasing the cross-sectional area of the secondary coil
B increasing the current in the primary coil
C increasing the number of turns of the primary coil
D increasing the resistance of the variable resistor

Helping concepts

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

By increase number of primary coil will lower secondary voltage, V_s.

8. At the beginning of a horse-race, a horizontal straight wire of length 20 m is raised vertically through a height of 3.0 m in 0.20 s.



The horizontal component of the Earth's magnetic field strength perpendicular to the wire is 2.0×10^{-5} T.

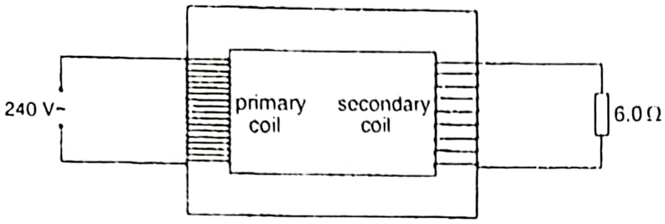
What is the average e.m.f. induced across the ends of the wire?

A zero
B 0.24 mV
C 1.2 mV
D 6.0 mV

Helping concepts

$$E = Blv = (2.0 \times 10^{-5})(20)(\frac{3.0}{0.20}) = 0.006\text{ V} = 6.0\text{ mV}$$

9. The diagram shows an iron-cored transformer assumed to be 100% efficient. The ratio of the secondary turns to the primary turns is 1 : 20.



A 240 V a.c. supply is connected to the primary coil and a 6.0 Ω resistor is connected to the secondary coil.

What is the current in the primary coil?

A 0.10 A B 0.14 A
C 2.0 A D 40 A

Helping concepts

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} \Rightarrow \frac{1}{20} = \frac{V_s}{240} \Rightarrow V_s = 12\text{ V}$$

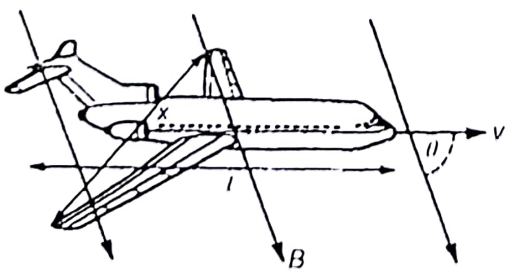
Since this is an ideal transformer,

$$V_p I_p = V_s I_s$$

$$\therefore\ 240 I_p = 12\left(\frac{12}{6.0}\right)$$

$$I_p = 0.1\text{ A}$$

10. The diagram represents an aircraft of length l, wingspan x, flying horizontally at speed v in a region where the Earth's magnetic field, of uniform flux density B, is inclined at an angle θ to the Earth's surface.



Which expression gives the magnitude of the e.m.f. generated between the wingtips by electromagnetic induction?

A $Blv\sin\theta$ B Blv
C Bxv D $Bxv\sin\theta$

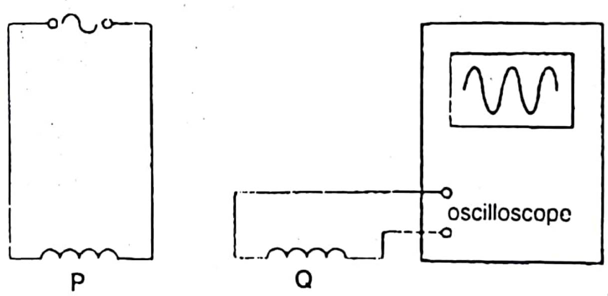
Helping concepts

By Faraday's law of electromagnetic induction, the induced e.m.f. is given by

$$\text{e.m.f.} = -\frac{d\phi}{dt}$$
$$= -\frac{d}{dt}(BA\sin\theta)$$
$$= -\frac{d}{dt}(Bxl\sin\theta)$$
$$= -Bx\sin\theta\left(\frac{dl}{dt}\right)$$
$$= -Bxv\sin\theta$$

Hence, induced e.m.f. has a magnitude of $Bxv\sin\theta$.

11. A coil **P** is connected to a 50 Hz alternating supply of constant peak voltage. Coil **P** lies close to a separate coil **Q** which is connected to the Y-input terminals of an oscilloscope. A sinusoidal trace appears on the screen of the oscilloscope.



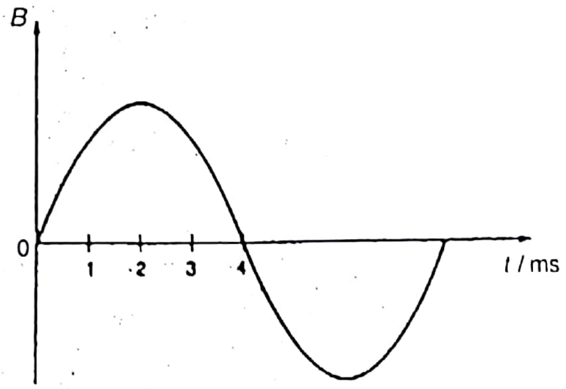
What would be the effect on the trace of linking the coils by a soft-iron core?

	height of trace	no. of cycles on screen
A	increases	increases
B	increases	stays the same
C	stays the same	increases
D	stays the same	stays the same

Helping concepts

The soft-iron core would enhance the magnetic flux linkage Φ between coils **P** and **Q**. Since magnitude of Φ has increased, magnitude of the induced e.m.f. would also increased though its frequency remains unchanged by Faraday's law of electromagnetic induction.

12. An e.m.f. is induced in a wire subjected to a changing magnetic field. The flux density B of this field varies with time t as shown.



At which value of t is the magnitude of the e.m.f. induced in the wire a maximum?

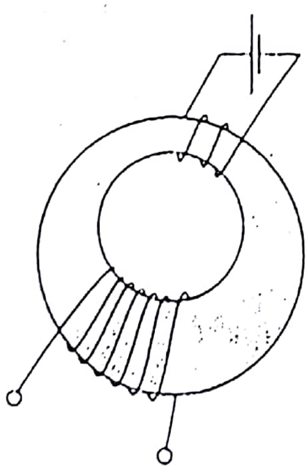
A 1 ms B 2 ms

C 3 ms D 4 ms

Helping concepts

Since induced e.m.f. $E = \frac{d(BA)}{dt}$, the induced e.m.f. is a maximum when the gradient of the B-t graph is maximum at $t = 4$ ms.

13. A soft-iron ring of variable cross-section has two coils wound around it. One coil has 7 turns. The other, of 3 turns, is connected to a d.c. supply.



Which quantity is the same inside each coil?

A magnetic field

B magnetic flux

C magnetic flux density

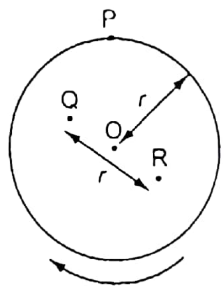
D magnetic flux linkage

Helping concepts

In a transformer, the primary arm and secondary arm have the same magnetic flux (ϕ). As the 3 turns coil and 7 turns coil are of different area, the respective magnetic flux density (or magnetic field) will be different.

Magnetic flux linkage, (Φ), will be different due to different number of turns ($\Phi = N\phi$).

14. An aluminium disc of radius r rotates about its centre at a constant speed. It is placed in a uniform magnetic field perpendicular to its surface. A steady electromotive force (e.m.f.) E is generated between the centre O and the rim at P.



What is the e.m.f. generated between points Q and R, each a distance $\frac{r}{2}$ from the centre?

A zero B $\frac{E}{4}$

C $\frac{E}{2}$ D E

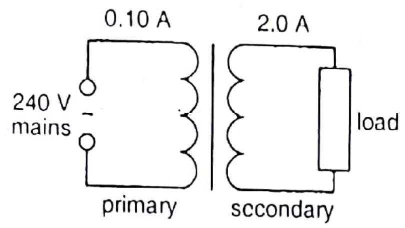
Helping concepts

The e.m.f. at each point, $E = Blv$ where l is the distance from point O.

e.m.f. of Q < e.m.f. of P

Since Q and R are of same distance from O, e.m.f. at Q and R will be the same, i.e. E. The e.m.f. between Q and R will be zero.

15. An ideal, mains-driven transformer supplies power to a load. In order to deliver a current of 2.0 A to the load, the primary coil draws a current of 0.10 A from the 240 V mains.



Which set of values in the table is correct?

	no. of turns on primary coil	no. of turns on secondary coil	p.d. across load / V
A	300	6000	12
B	6000	300	12
C	300	6000	4800
D	6000	300	4800

Helping concepts

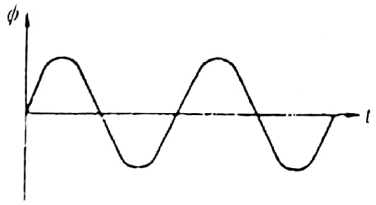
$$\frac{I_s}{I_p} = \frac{N_p}{N_s} = \frac{V_p}{V_s}$$

Since $I_s > I_p$, this transformer is a step-down transformer with the number of turns on the primary coil being larger than that on the secondary coil and $V_p > V_s$.

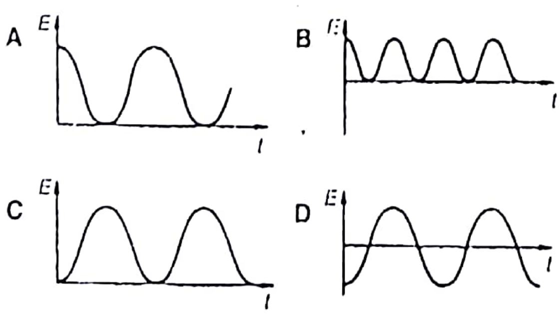
Hence, only (B) satisfies both conditions.

---

16. The magnetic flux ϕ through a coil varies with time t as shown in the diagram.



Which graph best represents the variation with t of the e.m.f. E induced in the coil?



Helping concepts

From the given graph of ϕ, we may define ϕ by the equation

$$\phi = \phi_0 \sin(\frac{2\pi t}{T})$$

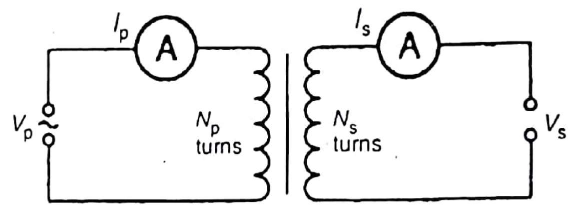
The induced e.m.f. E in the coil is thus given by

$$E = \frac{d\phi}{dt} = -\phi_0 \frac{2\pi}{T} \cos(\frac{2\pi t}{T})$$

Note: A negative cosine function which is best represented in graph D.

---

17. In a laboratory experiment to test a transformer, a student used the circuit shown in the diagram to take measurements.



Two of the original entries in the student's results table are missing as shown below.

V_p / V	I_p / mA	N_p turns	V_s / V	I_s / mA	N_s turns
240	2.0	?	?	50	50

Assuming the transformer was 100% efficient, what are the missing results?

	N_p turns	V_s / V
A	2	6000
B	50	9.6
C	480	1.0
D	1250	9.6

Helping concepts

Assume the transformer to be tested is an ideal one, then

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

Given $V_p = 240$ V,

$N_s = 50$ turns,

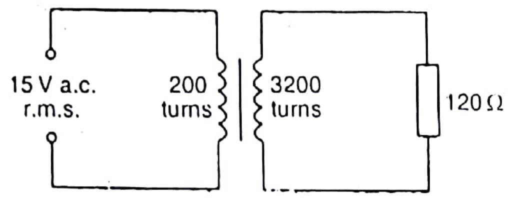
$I_s = 50$ mA,

$I_p = 2.0$ mA.

$$\therefore \frac{240}{V_s} = \frac{N_p}{50} = \frac{50}{2} = 25$$

$\Rightarrow V_s = 9.6$ V and $N_p = 1250$ turns

18. The primary of an ideal transformer has 200 turns and is connected to a 15 V root-mean-square (r.m.s.) supply. The secondary has 3200 turns and is connected to a resistor of resistance 120 Ω, as shown in the diagram.



What are possible values of the secondary voltage, the secondary current and the mean power dissipated in the resistor?

	secondary voltage / V r.m.s.	secondary current / A r.m.s.	resistor power / W
A	24	0.020	4.8
B	24	0.20	48
C	240	0.50	120
D	240	2.0	480

Helping concepts

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

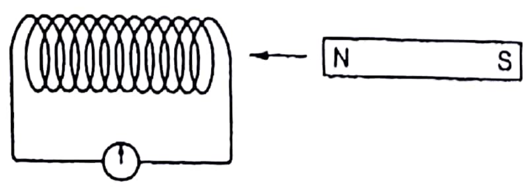
$$\frac{V_s}{15} = \frac{3200}{200}$$

$$V_s = 240 \text{ V}$$

Power across 120 Ω, $P = \frac{V^2}{R} = \frac{240^2}{120} = 480$ W

∴ Secondary current, $I = \frac{P}{V} = \frac{480}{240} = 2.0$ A

19. The North pole of a bar magnet is pushed into the end of a coil of wire. The maximum movement of the meter needle is 10 units to the left.



The South pole of the magnet is then pushed into the other end of the coil at twice the speed.

What is the maximum movement of the meter needle?

A less than 10 units to the left

B less than 10 units to the right

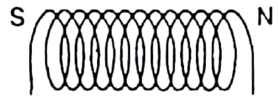
C more than 10 units to the left

D more than 10 units to the right

Helping concepts

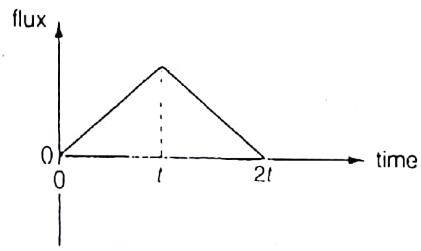
By Lenz's law, the magnetic field caused by induced current will be North on RHS of the coil.

The magnetic field will be South on LHS of coil caused by South pole of the magnet.

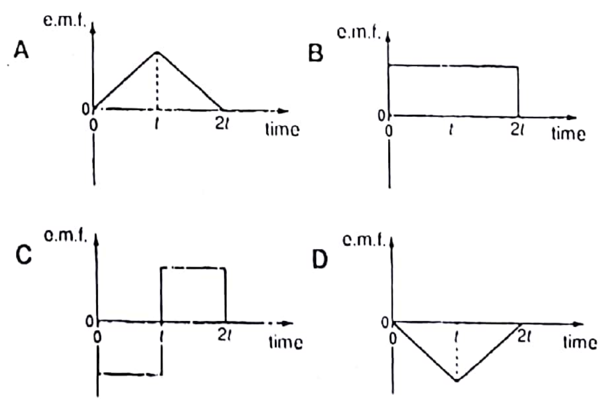


This means induced current flows in the same direction for both cases. As the rate of change of flux is faster, the magnitude of needle movement will be higher.

20. The graph shows the variation with time of the magnetic flux linking a coil.



Which graph shows the variation with time of the e.m.f. induced in the coil?



Helping concepts

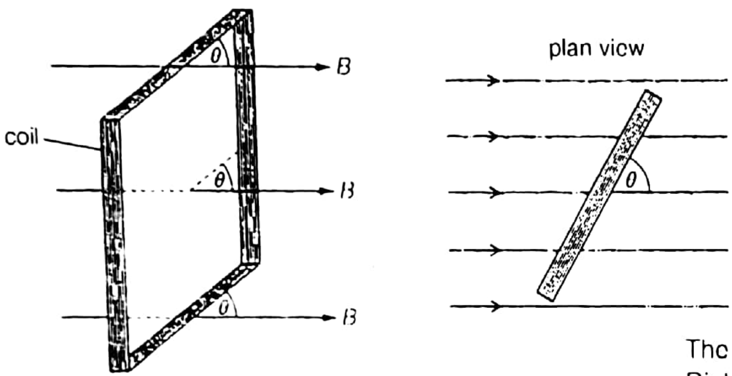
$$E = -\frac{d\phi}{dt}$$

Between time = 0 and t, e.m.f. E induced is negative and of constant value. This is because gradient of flux (ϕ) is positive, i.e. $\frac{d\phi}{dt} > 0$.

Between time $= t$ and $2t$, e.m.f. E induced is positive and of constant value. This is because gradient of flux (ϕ) is negative, i.e. $\frac{d\phi}{dt} < 0$.

---

21. A magnetic field of uniform flux density B is at an angle θ to the plane of a coil as shown.



The coil has N turns and the area of the coil is A.

What is the magnetic flux linkage of the coil?

A $BA\cos\theta$ B $BA\sin\theta$
C $BNA\cos\theta$ D $BNA\sin\theta$

Helping concepts

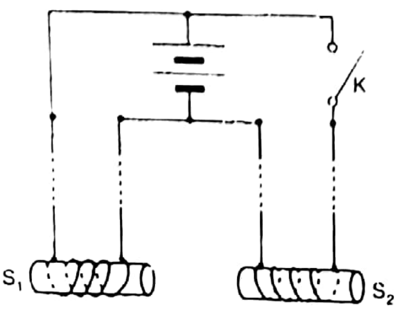
Magnetic flux linkage $\Phi = NBA\cos\alpha$

$= NBA\cos(90^\circ - \theta)$

$= NBA\sin\theta$

---

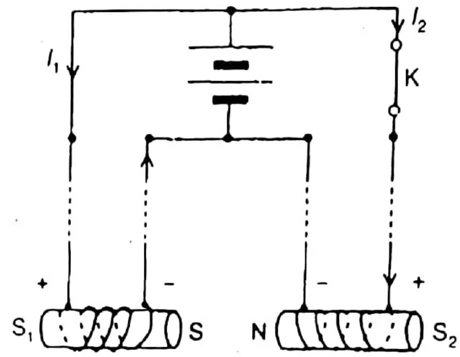
22. Two identical solenoids S_1 and S_2 are suspended coaxially and symmetrically by four long thin wires so that they may swing freely, as shown in the diagram.



When the switch K is closed, what happens to the solenoids?

A One turns in a clockwise direction, and the other in an anticlockwise direction.
B They both turn in a clockwise direction.
C They move away from each other.
D They move towards each other.

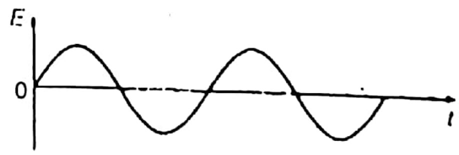
Helping concepts



The polarity of magnetic fields are determined by the Right hand cork screw rule for each solenoid. Hence, when switch K is closed, the attractive force causing them to move towards each other.

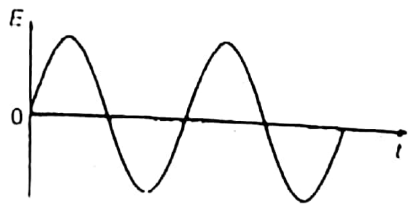
---

23. When a coil is rotated in a magnetic field, the induced e.m.f. E varies as shown.

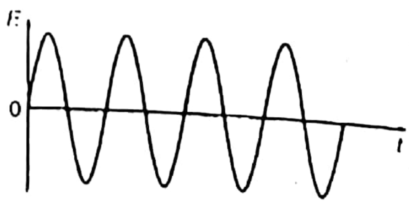


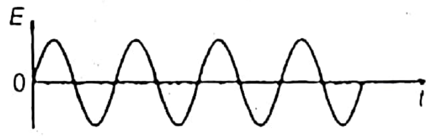
Which of the following graphs, drawn to the same scale, would be obtained if the speed of rotation of the coil were doubled?

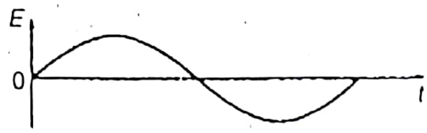
A



B



C


D


Helping concepts

Induced e.m.f. E is given by

$$E = -\frac{d}{dt}(N\phi) = -\frac{d}{dt}(NAB\cos\omega t) = NAB\omega\sin\omega t$$

Hence, when the speed of rotation of the coil is doubled, the peak value of E also doubles, as well as its frequency.

---

24. Diagram 1 shows an aluminium rod, moving at right angles to a uniform magnetic field. Diagram 2 shows the variation with time t of the distance s from O.

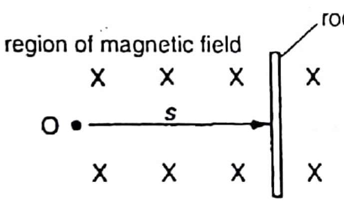


diagram 1

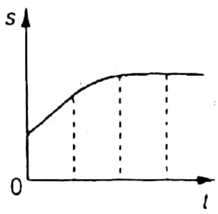
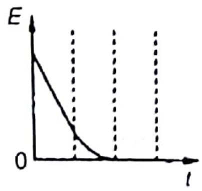
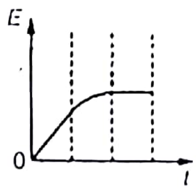
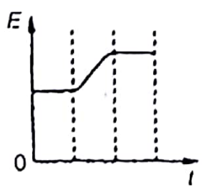


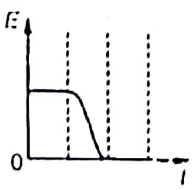
diagram 2

Which graph best shows the variation with t of the e.m.f. E induced in the rod?

A


B


C


D


Helping concepts

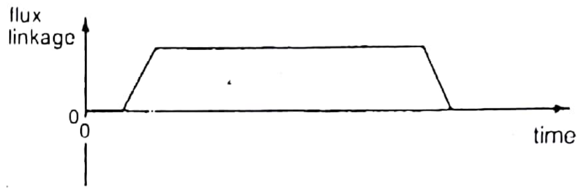
By Faraday's law, the magnitude of the induced e.m.f. is directly proportional to the rate of change of flux linkage.

When s increases, the rod is moving and cutting magnetic flux. Hence, e.m.f. is induced.

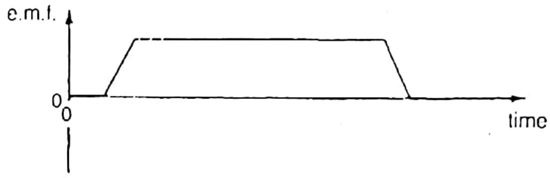
When s remains constant, the rod is stationary. Hence, there is no induced e.m.f.

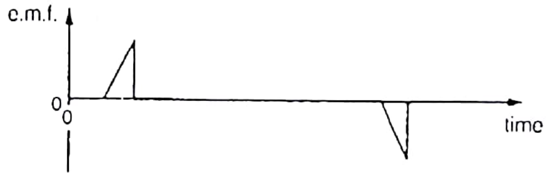
---

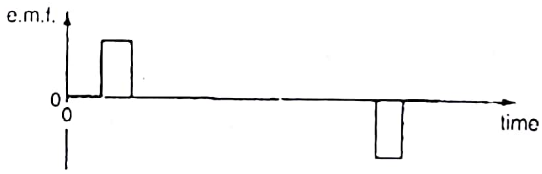
25. The magnetic flux linkage through a coil varies with time as shown.



Which graph shows the variation with time of the e.m.f. generated by the coil?

A


B


C


D

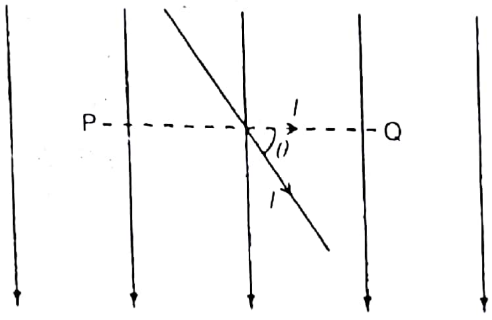

Helping concepts

$$E = -\frac{d\phi}{dt}$$

The rate of increase and decrease of magnetic flux linkage should correspond to two different signs of e.m.f. induced.

---

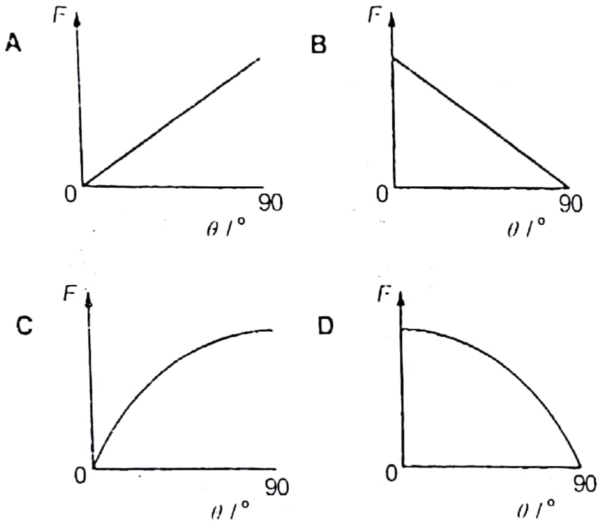
26. A straight wire PQ carrying a constant current I is placed at right angles to a uniform magnetic field, as shown by the dotted line in the diagram.



magnetic field

The wire is then rotated through an angle θ about an axis perpendicular to the plane of the diagram.

Which graph shows how the magnitude of the magnetic force F on the wire varies with θ in the range 0° to 90°?



Helping concepts

Magnetic force, $F = BIL\sin\theta$

where θ is the angle between the magnetic field and current.

In this diagram,

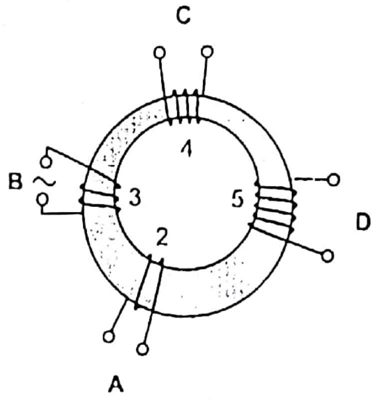
$$F = BIL\cos\theta$$

Hence, F is maximum for $\theta = 0$ and zero for $\theta = 90°$.

---

27. A soft-iron ring of variable cross-section has four coils wound around it at the positions shown. The coils have 2, 3, 4 and 5 turns. The 3-turn coil is connected to an a.c. supply.

In which coil does the magnitude of the magnetic flux density have the greatest variation?



Helping concepts

The magnetic flux (ϕ) in soft-iron core is the same at all location.

Now, $\phi = \vec{B} \cdot A$

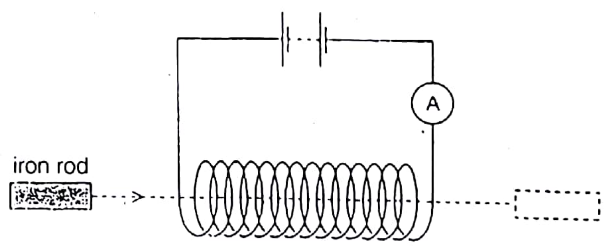
where $\vec{B}$ = magnetic flux density,
A = cross-section area of coil.

$\Rightarrow \phi_A = \phi_B = \phi_C = \phi_D$

Since area at **C** is the smallest, $\Delta\vec{B}$ (change in magnetic flux density) will be the greatest.

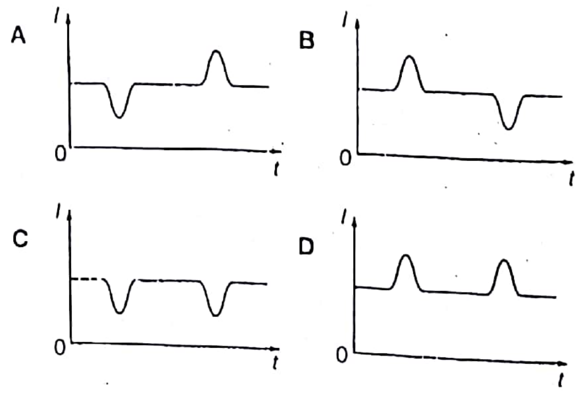
---

28. A solenoid with a large number of turns of wire is connected in series with an ammeter and a battery.



An iron rod is passed through the solenoid at constant speed.

Which graph shows the variation with time t of the reading I of the ammeter?



Helping concepts

The solenoid has uniform magnetic field, with current flowing through the wires. As iron rod passes into the solenoid, magnetic field will increase due to better permeability of iron.

By Lenz's law, the induced current in iron rod will be such that it will 'reduce' the 'increase' in magnetic field of solenoid.

As magnetic field of solenoid is reduced, current in the circuit will be reduced.

As the iron rod is passing within the solenoid, there is no change of magnetic flux linkage. Hence, no induced current in the iron rod and the current in the circuit is unaffected.

When the iron rod leaves the solenoid, the magnetic field of solenoid decreases.

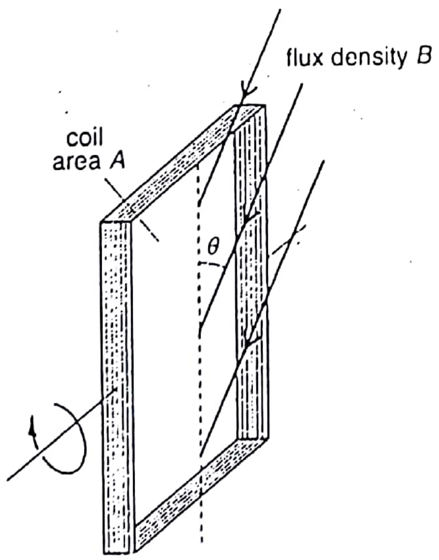
The induced current in iron rod will be in direction such that the magnetic field will increase the 'decrease' of the solenoid.

As the magnetic field of solenoid is increased, current in the circuit will increase.

---

29. A coil has area A and n turns.

A uniform magnetic field of flux density B acts at an angle θ to the plane of the coil, as shown.



What is the change in magnetic flux linkage when the coil rotates so that the angle θ is reduced to zero?

A $BAn\cos\theta$ **B** $BAn\sin\theta$

C $2BAn\cos\theta$ **D** $2BAn\sin\theta$

Helping concepts

Magnetic flux linkage at angle $\theta = NBA\cos\theta$
$= nBA\cos(90° - \theta)$
$= \underline{BAn\sin\theta}$

where θ is the angle between magnetic flux density B and the perpendicular line to the plane area of A.

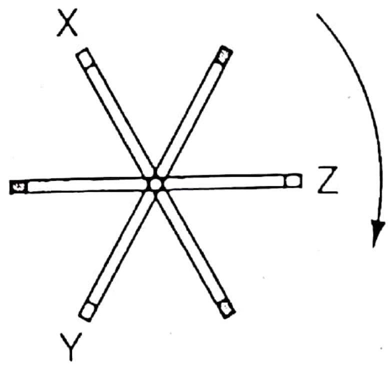
When the angle $\theta = 0$,

magnetic flux linkage $= NBA\cos 90° = \underline{0}$

$\therefore$ Change in magnetic flux linkage $= BAn\sin\theta - 0$
$= \underline{BAn\sin\theta}$

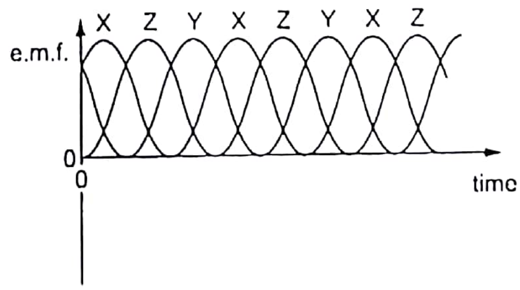
---

30. In a generator in a commercial power station, rectangular coils rotate in a strong magnetic field. There are three coils, all on the same axle, with angles of 120° between them, as shown in end view.

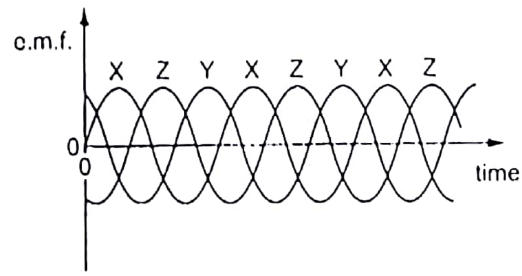


How will the three output e.m.f.s vary with time?

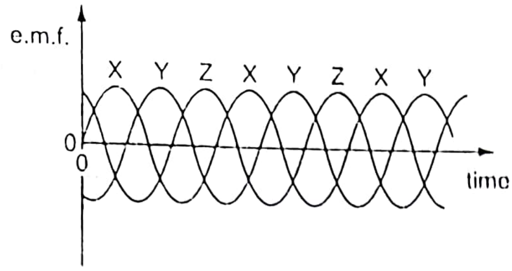
A



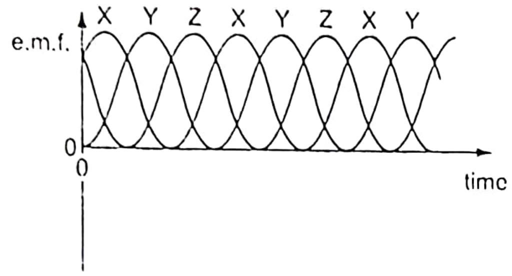
B



C



D



Helping concepts

Induced e.m.f. in the coils will be alternating in nature, i.e. values will be either positive or negative.

By comparing the unshaded part of the coil (refer to first diagram), as X is the first positive e.m.f. of all the options, the next positive e.m.f. should come from Y.

TOPIC 18

Quantum Physics

Key content that you will be examined on:

1. Energy of a photon
2. The photoelectric effect
3. Wave-particle duality
4. Energy levels in atoms
5. Line spectra
6. X-ray spectra
7. The uncertainty principle
8. Schrodinger model
9. Barrier tunnelling

Topic 18

Quantum Physics

1. Which of the following physical phenomena **cannot** be described only by the wave theory of electromagnetic radiation?

   A diffraction

   B interference

   C photoelectric emission

   D polarisation

Helping concepts

The emission of the photoelectrons from the metal surface can only be explained by Einstein's particle (photon) theory.

---

2. What is a reasonable estimate, to one significant figure, of the energy of a photon of violet light?

   A 4 eV B 6 eV

   C 3×10^{-19} J D 5×10^{-19} J

Helping concepts

Wavelength of violet light ≈ 400 nm

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{(400 \times 10^{-9})} \approx 5 \times 10^{-19}\ \text{J}$$

---

3. White light from a tungsten filament lamp is passed through sodium vapour and viewed through a diffraction grating.

   Which of the following best describes the spectrum which would be seen?

   A coloured lines on a black background

   B coloured lines on a white background

   C dark lines on a coloured background

   D dark lines on a white background

Helping concepts

When white light from the tungsten filament lamp passes through sodium vapour and viewed through a diffraction grating, a darken line is seen in the yellow part of the continuous spectrum. This is because sodium lamp emits only visible yellow light and the dark line corresponds to the absorption spectrum of sodium.

---

4. An electron has mass m_e and speed $0.02c$, where c is the speed of light in free space.

   What is the de Broglie wavelength of this electron, expressed in terms of the Planck constant h?

   A $\frac{h}{(0.02c)}$ B $\frac{(0.02c)}{h}$

   C $\frac{h}{(0.02c)m_e}$ D $\frac{(0.02c)m_e}{h}$

Helping concepts

de Broglie wavelength $= \frac{h}{p} = \frac{h}{m_e(0.02c)}$

---

5. An atom emits a spectral line of wavelength λ when an electron makes a transition between levels of energy E_1 and E_2.

   Which expression correctly relates λ, E_1 and E_2?

   A $\lambda = \frac{h}{c}(E_1 - E_2)$ B $\lambda = ch(E_1 - E_2)$

   C $\lambda = \frac{c}{h(E_1 - E_2)}$ D $\lambda = \frac{ch}{E_1 - E_2}$

Helping concepts

By quantum theory of radiation, the energy change ΔE between energy levels is proportional to the frequency of electromagnetic radiation f and is given by

$$\Delta E = hf = \frac{hc}{\lambda}$$

$$\therefore \lambda = \frac{hc}{\Delta E} = \frac{hc}{E_1 - E_2}$$

---

6. A sodium lamp is rated at 40 W. Of the power supplied, 12% is emitted as yellow light of wavelength 5.9×10^{-7} m.

How many quanta of yellow light are emitted per second from this lamp?

A 1.4×10^{19} B 1.2×10^{20}
C 3.6×10^{27} D 1.0×10^{40}

Helping concepts

$$E_{quanta} = \frac{hc}{\lambda}$$

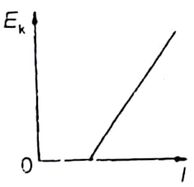
$$\text{Power, } P = \frac{E_{light}}{t} = \frac{NE_{quanta}}{t}$$

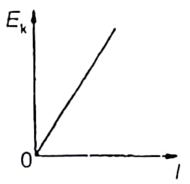
$$\frac{N}{t} = \frac{P}{E_{quanta}} = \frac{P\lambda}{hc} = \frac{(0.12)(40)(5.9 \times 10^{-7})}{(6.63 \times 10^{-34})(3.0 \times 10^{8})}$$

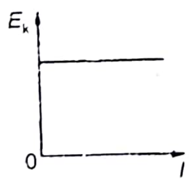
$$= 1.4 \times 10^{19}\ s^{-1}$$

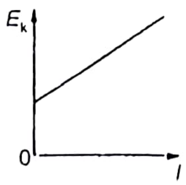
7. In a photoelectric emission experiment using light of a certain frequency, the maximum kinetic energy E_k of the emitted photoelectrons is measured.

Which graph represents the way in which E_k depends on the intensity I of the light?

A


B


C


D


Helping concepts

The maximum kinetic energy of emitted photoelectrons does not depend on the intensity of the light, but rather, on its frequency.

8. In the photoelectric effect, light falling on a metal surface causes electrons to be ejected from the surface.

Which statement is correct?

A Electrons are ejected only if the wavelength of the incident light is greater than some minimum value.

B The maximum energy of the electrons is independent of the intensity of the incident light.

C The maximum energy of the electrons is independent of the type of metal.

D The waves associated with the ejected electrons have the same wavelength as the incident light.

Helping concepts

The maximum energy of the electrons depends on the frequency of the incident light and the work function of the metal.

$$\frac{1}{2}mv_{max}^2 = hf - \phi$$

9. A metal surface is illuminated with a beam of monochromatic electromagnetic radiation.

What determines the maximum speed of the photoelectrons that are emitted from the surface?

A the intensity of the radiation only

B the frequency of the radiation only

C the intensity and the frequency of the radiation

D the frequency of the radiation and the work function of the metal

Helping concepts

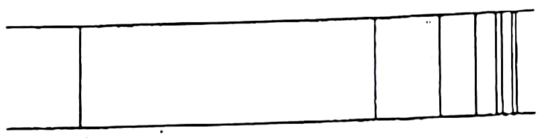
Photoelectric equation,

$$E = \phi + \tfrac{1}{2}mv^2$$
$$hf = \phi + \tfrac{1}{2}mv^2$$
$$\tfrac{1}{2}mv^2 = hf - \phi$$

where h is the Planck constant.

From equation, the maximum KE, i.e. the maximum speed depends on frequency of radiation f and work function of metal, ϕ.

10. The diagram shows part of a typical line emission spectrum. This spectrum extends through the visible region of the electromagnetic spectrum into the ultra-violet region.



X

Which statement is true for emission line X of the spectrum?

A It has the longest wavelength and is at the ultra-violet end of the spectrum.

B It has the highest frequency and is at the ultra-violet end of the spectrum.

C It has the lowest frequency and is the red end of the spectrum.

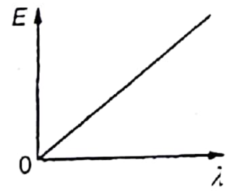
D It has the shortest wavelength and is at the red end of the spectrum.

Helping concepts

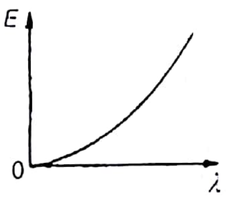
The emission line spectrum from left to right is in the increasing wavelength. The higher the wavelength, the smaller the frequency of the emission spectrum. Hence, the left-most line represents the ultra-violet emission while the right-most line is associated with the red light emission. Therefore, emission line X has the highest frequency (thus shortest wavelength) and is at the ultra-violet end of the spectrum.

11. Which graph shows how the energy E of a photon of light is related to its wavelength λ?

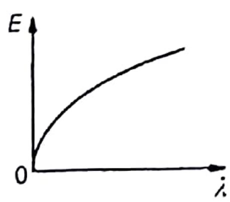
A



B



C



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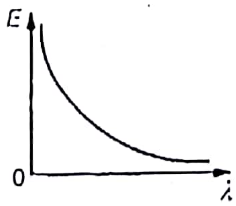


Helping concepts

Photon energy $E = hf = \frac{hc}{\lambda}$ in the usual notation.

$\therefore\ E \propto \frac{1}{\lambda}$

12. An atom makes a transition from a state of energy E_2 to one of lower energy E_1.

Which of the following gives the wavelength of the radiation emitted, in terms of the Planck constant h and the speed of light c?

A $\frac{E_2 - E_1}{hc}$ B $\frac{hc}{E_2} - \frac{hc}{E_1}$

C $\frac{hc}{E_2 - E_1}$ D $\frac{c}{h(E_2 - E_1)}$

Helping concepts

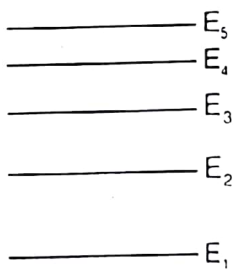
$$E_2 - E_1 = hf$$

where f is the frequency of the radiation emitted.

Since $f = \frac{c}{\lambda}$ where λ is the wavelength of the emitted radiation,

$$E_2 - E_1 = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E_2 - E_1}$$

13. The diagram shows the first five energy levels of an atom.



Photons of electromagnetic radiation are emitted when an electron falls from one energy level to a lower level.

Which transition corresponds to a photon with the greatest wavelength?

A E_2 to E_1

B E_5 to E_1

C E_4 to E_3

D E_5 to E_4

Helping concepts

Greatest wavelength means smallest energy transitions between levels, using $E = hf = \frac{hc}{\lambda}$.

14. In experiments on the photoelectric effect, different metals were illuminated with light from various monochromatic sources of different frequencies and variable intensities. It was found that, for a given metal, frequency and intensity, electrons were emitted with a spread of kinetic energies up to a maximum value.

On what does this maximum kinetic energy depend?

	metal	frequency of light	intensity of light
A	✗	✓	✓
B	✓	✓	✗
C	✓	✗	✓
D	✓	✓	✓

Helping concepts

In the equation $hf = W + \frac{1}{2}mv^2$, $\frac{1}{2}mv^2$ refers to the maximum kinetic energy of the emitted electrons; f is the frequency of the light and W is the work function that depends on the metal. The intensity of light does not feature in the equation at all.

15. The equation $hf = \phi + \frac{1}{2}mv^2_{max}$ is used when studying the photoelectric effect.

What is the meaning of each term in this equation?

	hf	ϕ	$\frac{1}{2}mv^2_{max}$
A	the energy of a photoelectron	the least energy required to release an electron	the maximum kinetic energy of a photon
B	the energy of a photoelectron	the work done by an incoming photon	the maximum kinetic energy of a photoelectron
C	the energy of a photon causing the photoelectric effect	the least energy required to release an electron	the maximum kinetic energy of a photoelectron
D	the energy of a photon causing the photoelectric effect	the work done by an incoming photon	the maximum kinetic energy of a photon

Helping concepts

From the definition of the photoelectric equation, hf= energy of photon.

ϕ = minimum work function energy to liberate an electron.

$\frac{1}{2}mv^2_{max}$ = maximum kinetic energy of an electron.

16. Light quanta of energy 3.5×10^{-19} J fall on the cathode of a photocell. The current through the cell is just reduced to zero by applying a stopping potential of 0.25 V.

What is the work function energy of the cathode?

A 2.9×10^{-19} J　　B 3.1×10^{-19} J

C 3.5×10^{-19} J　　D 3.9×10^{-19} J

Helping concepts

Einstein's photoelectric equation:

$$E_{max} = hf - W_0$$

where E_{max} is the maximum kinetic energy of electrons,
hf is the incident photon energy,
W_0 is the work function of the photocell.

If V_s is the stopping potential necessary to stop the electrons with maximum energy from reaching the anode, then

$$eV_s = E_{max}$$

From the equations, we may write

$$eV_s = hf - W_0$$
$$(1.6\times10^{-19})(0.25) = (3.5\times10^{-19}) - W_0$$
$$W_0 = (3.5\times10^{-19}) - (0.4\times10^{-19})$$
$$= 3.1\times10^{-19}\ \text{J}$$

17. Two beams, P and Q, of light of the same wavelength, fall upon the same metal surface causing photoemission of electrons. The photoelectric current produced by P is four times that produced by Q.

Which of the following gives the ratio

$$\frac{\text{wave amplitude of beam P}}{\text{wave amplitude of beam Q}}?$$

A $\frac{1}{4}$ B $\frac{1}{2}$

C 2 D 4

Helping concepts

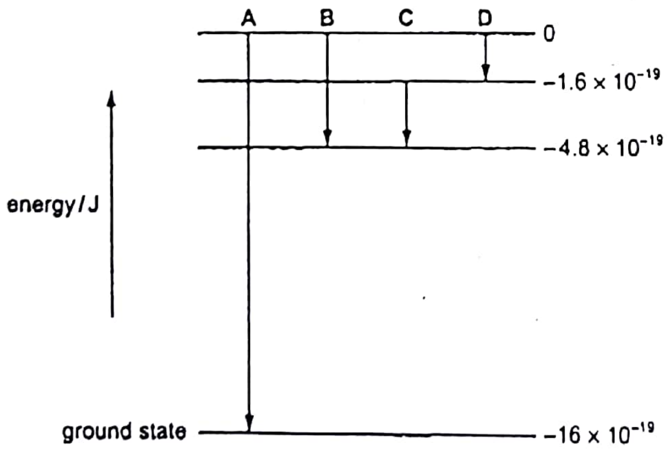
The photoelectric current detected is proportional to the number of electrons emitted, which in turn, directly proportional to the intensity of the light beam.

If I is the current detected and A is the amplitude of the light beam, we have $A^2 \propto I$ since intensity is proportional to square of light amplitude.

$$\therefore \frac{\text{wave amplitude of beam P}}{\text{wave amplitude of beam Q}} = \left(\frac{\text{current produced by P}}{\text{current produced by Q}}\right)^{\frac{1}{2}} = \left(\frac{4}{1}\right)^{\frac{1}{2}} = 2$$

18. The diagram illustrates the electron energy levels, along with four possible electron transitions, in an atom.

Which transition will produce a photon of wavelength 6.2×10^{-7} m?



Helping concepts

Energy, $E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{(6.2 \times 10^{-7})} = 3.2 \times 10^{-19}$ J

Hence, energy difference must be from

$$(-1.6 \times 10^{-19}) - (-4.8 \times 10^{-19}) = 3.2 \times 10^{-19} \text{ J}$$

19. Listed below are five phenomena connected with photons and/or charged particles:

1. alpha - particle emission
2. beta - particle emission
3. line emission spectra
4. line absorption spectra
5. electron diffraction

Which of these phenomena give direct evidence for the existence of discrete electronic energy levels in atoms?

A 1 and 5 only B 2 and 3 only

C 3 and 4 only D 2, 3, 4 and 5 only

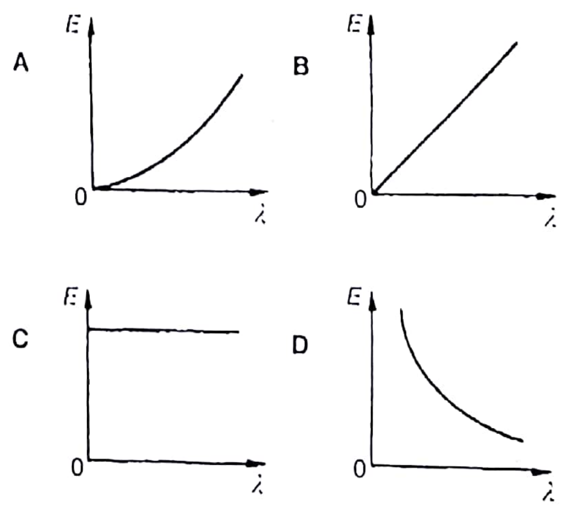
Helping concepts

Alpha (α) particle and beta (β) particle are actually helium nucleus and electron respectively. They are emitted by nucleus and hence is evidence that radioactivity is a nuclear process.

Line spectrum consists of discrete lines, each corresponding to a wavelength. The wavelengths are characteristic of the element emitting the light. When the continuous spectrum light from a carbon arc is seen through tube containing sodium vapour, an absorption spectrum is observed. A series of dark lines correspond to the wavelengths absorbed by the sodium atom is observed. Both spectra are direct evidence of discrete electronic energy levels in atoms.

Diffraction of a beam of electrons by a metal crystal (nickel) shows de Broglie's idea that electrons have wave properties.

20. Which curve shows the relationship between the energy E and the wavelength λ of a photon of electromagnetic radiation?



Helping concepts

Each photo has associated with it, an energy E is given by

$$E = hf = \frac{hc}{\lambda}$$

where f = frequency of the electromagnetic wave radiated,

λ = wavelength of the electromagnetic radiation.

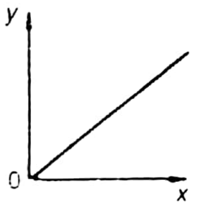
Hence, $E \propto \frac{1}{\lambda}$ since h and c are constants.

---

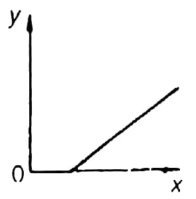
21. In an experiment on the photoelectric effect, an evacuated photocell with a pure metal cathode is used.

Which graph best represents the variation of y, the minimum potential difference needed to prevent current from flowing, when x, the frequency of the incident light, is varied?

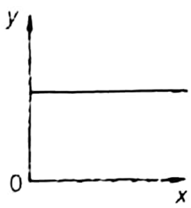
A



B



C



D

Helping concepts

Einstein's photoelectric equation:

$$eV = hf - hf_0$$

where e = electronic charge,

V = potential,

h = Planck constant,

f = frequency,

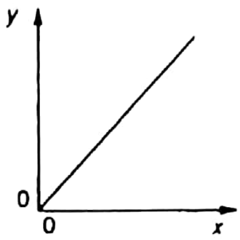
f_0 = threshold frequency.

$$\therefore\ V = \left(\frac{h}{e}\right)f - \left(\frac{hf_0}{e}\right)$$

which is similar to $y = mx + c$ - a straight line equation with a y-intercept.

---

22. In a series of photoelectric emission experiments on a certain metal surface, possible relationships between the following quantities were investigated: threshold frequency f_0, frequency of incident light f, light intensity P, photocurrent I, maximum kinetic energy of photoelectrons T_{max}.

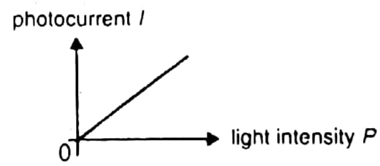


Two of these quantities, when plotted as a graph of y against x, give a straight line through the origin.

Which of the following correctly identifies x and y with the photoelectric quantities?

	x	y
A	I	f_0
B	f	T_{max}
C	P	I
D	P	T_{max}

Helping concepts



The rate of emission of photoelectrons (i.e. photocurrent) depends proportionally on the rate of incident photons.

---

23. An ultra-violet radiation source causes the emission of photoelectrons from a zinc plate.

How would the maximum kinetic energy E_k of the electroelectrons and the number of photoelectrons emitted per second n be affected by substituting a more intense source of the same wavelength?

	E_k	n
A	decreased	increased
B	unchanged	unchanged
C	unchanged	increased
D	increased	unchanged

Helping concepts

Using Einstein's photo theory, the maximum kinetic energy E_k of the emitted electrons is related to the frequency f and hence the wavelength λ of the incident light by the equation:

$$E_k = hf - W_0 = \frac{hc}{\lambda} - W_0 \text{ - - - - - (1)}$$

where c = speed of light,
W_0 = work function of the material
= minimum kinetic energy needed to free an electron out of the material.

For incident wave of the same wavelength, the maximum kinetic energy, E_k of the photoelectrons remains unchanged as easily deduced from (1).

The higher the intensity of the incident wave, the more the number of photons incident on the zinc plate surface; and hence more photoelectrons would be emitted. Thus, the number of photoelectrons emitted per second n would be increased for a more intense source.

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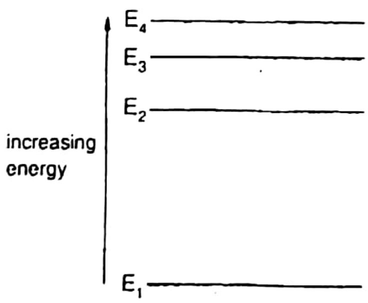
24. The diagram represents in simplified form some of the energy levels of the hydrogen atom. The energy axis has a linear scale.



If the transition of an electron from E_4 to E_2 were associated with the emission of blue light, which transition could be associated with the absorption of red light?

A E_4 to E_1 B E_3 to E_2
C E_2 to E_3 D E_1 to E_4

Helping concepts

Frequency of electromagnetic radiation f is related to the energy change ΔE of an atom by the equation

$$\Delta E = hf = \frac{hc}{\lambda}$$

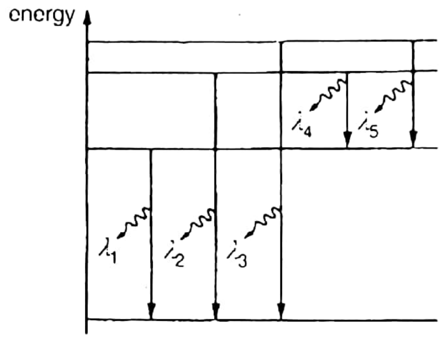
where h = Planck constant,
λ = wavelength of the electromagnetic radiation,
c = speed of light.

Blue light has a higher frequency than the red light and hence if absorption of red light is to occur, the corresponding change in energy level should be smaller. Thus the possible transitions associated with the absorption of red light are either E_2 to E_3 or E_3 to E_4.

Note: Absorption of electromagnetic radiation is always associated with a rise from lower energy level to a higher one.

---

25. An energy level diagram for an atom is shown drawn to scale. The electron transitions give rise to the emission of a spectrum of lines of wavelength, λ_1, λ_2, λ_3, λ_4, λ_5.



Which statement is correct?

A It can be deduced from the energy level diagram that $\lambda_1 > \lambda_2$.

B It can be deduced from the energy level diagram that $\lambda_3 = \lambda_1 + \lambda_5$.

C Of the five wavelengths, λ_4 is the shortest.

D The transition corresponding to wavelength λ_3 represents the ionisation of the atom.

Helping concepts

$\Delta E = hf - \frac{hc}{\lambda}$ because photo energy is quantised.

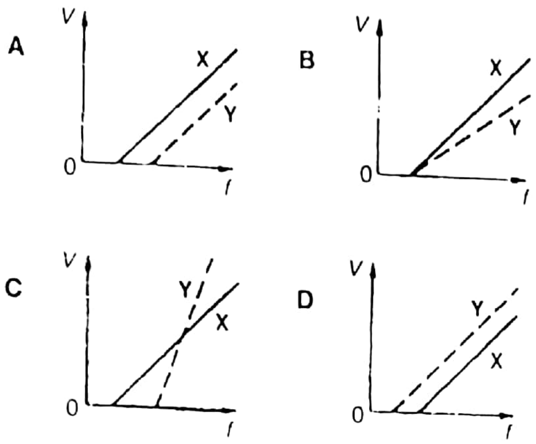
From the diagram,

$$\Delta E_2 > \Delta E_1 \Rightarrow \frac{hc}{\lambda_2} > \frac{hc}{\lambda_1} \text{ i.e. } \lambda_1 > \lambda_2$$

---

26. In a photoelectric experiment, electrons are ejected from metals **X** and **Y** by light of frequency f. The potential difference V required to stop the electrons is measured for various frequencies.

If **Y** has a greater work function than **X**, which graph illustrates the expected results?



Helping concepts

From the Einstein's photon theory, we have

$$eV = hf - W_0$$

where V = potential difference,
ϕ = work function of metal.

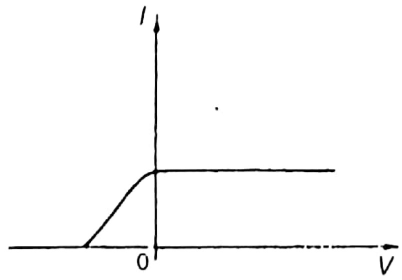
$$\phi_Y > \phi_X,\ f_Y > f_X$$

where f_Y = threshold frequency of **Y**,
f_X = threshold frequency of **X**.

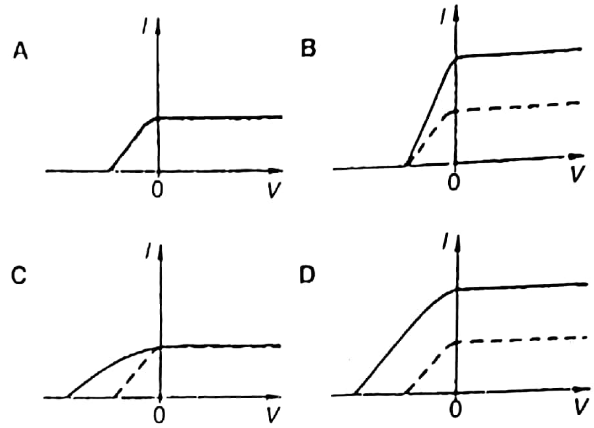
Furthermore, V versus f has a constant slope of $\frac{h}{e}$.

---

27. A metal surface in an evacuated tube is illuminated with monochromatic light causing the emission of photoelectrons which are collected at an adjacent electrode. For a given intensity of light, the way in which the photocurrent I depends on the potential difference V between the electrodes is as shown in the diagram below.



If the experiment were repeated with light of twice the intensity but the same wavelength, which of the graphs below would best represent the new relation between I and V? (in these graphs, the result of the original experiment is indicated by a broken line.)



Helping concepts

The intensity of light is proportional to the number of photons of light.

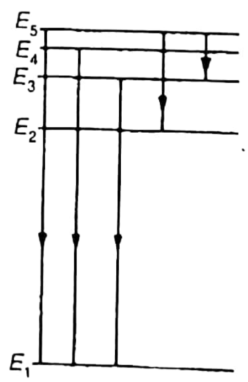
The relationship of light to the current is illustrated below:

intensity of light $\propto$ no. of light photons $\propto$ no. of emitted electrons $\propto$ current detected

Hence, as intensity of light is doubled, the current detected should be doubled.

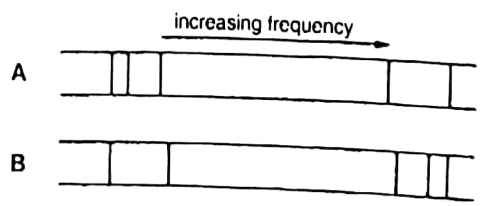
The stopping potential (x-intercept) remains unchanged.

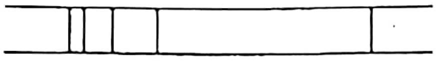
28.

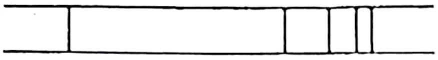


The scale drawing shows five energy levels of an atom. Five possible transitions between the levels are indicated. Each transition produces a photon of definite energy and frequency.

Which spectrum corresponds most closely to the transitions shown?



C 

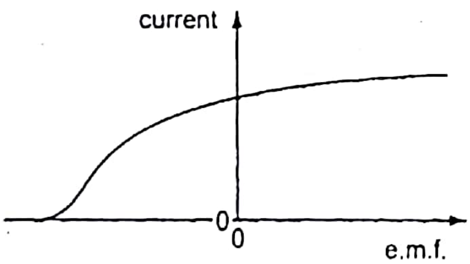
D 

Helping concepts

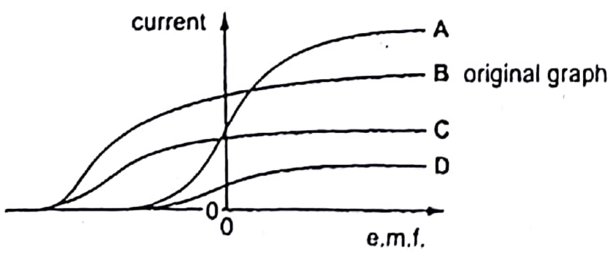
The greater the difference in the energy levels during the transition, the higher the frequency of the line represented in the spectrum since $E = hf$. Hence, there should be three lines of high frequency and two lines of comparatively lower frequencies in the spectrum.

29. A photocell is connected in a series circuit with a variable d.c. power supply and a sensitive ammeter.

The photocell is illuminated with ultra-violet radiation and photoelectrons are emitted. The electromotive force (e.m.f.) of the supply is then reduced and reversed and a graph is plotted of current against e.m.f. as shown.



Which graph is obtained if the experiment is repeated with a lower intensity of the same ultraviolet source?

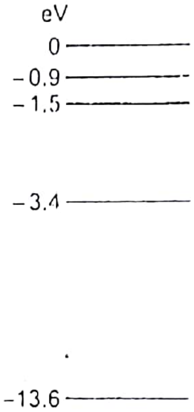


Helping concepts

Intensity of light source is proportional to the current detected.

The same ultra-violet source means the stopping potential of the emitted photoelectrons remains unchanged.

30. The diagram shows five energy levels of the hydrogen atom, labelled in the unit of electron-volt.



Which statement is **correct**?

A An atom in the level −3.4 eV can change levels by emitting photons of energy 1.9 eV, 2.5 eV, 3.4 eV and 10.2 eV.

B An atom in the level −3.4 eV can emit a photon of wavelength 650 nm to arrive in the level −1.5 eV.

C An electron with energy 10.2 eV colliding with an atom in level −13.6 eV can move it to the level −3.4 eV by losing all of its kinetic energy.

D Most hydrogen atoms will be found in the level with zero energy.

Helping concepts

Option A: An atom in the level −3.4 eV can change levels by emitting photons of energy 10.2 eV and absorbing photons of energy 1.9 eV, 2.5 eV and 3.4 eV.

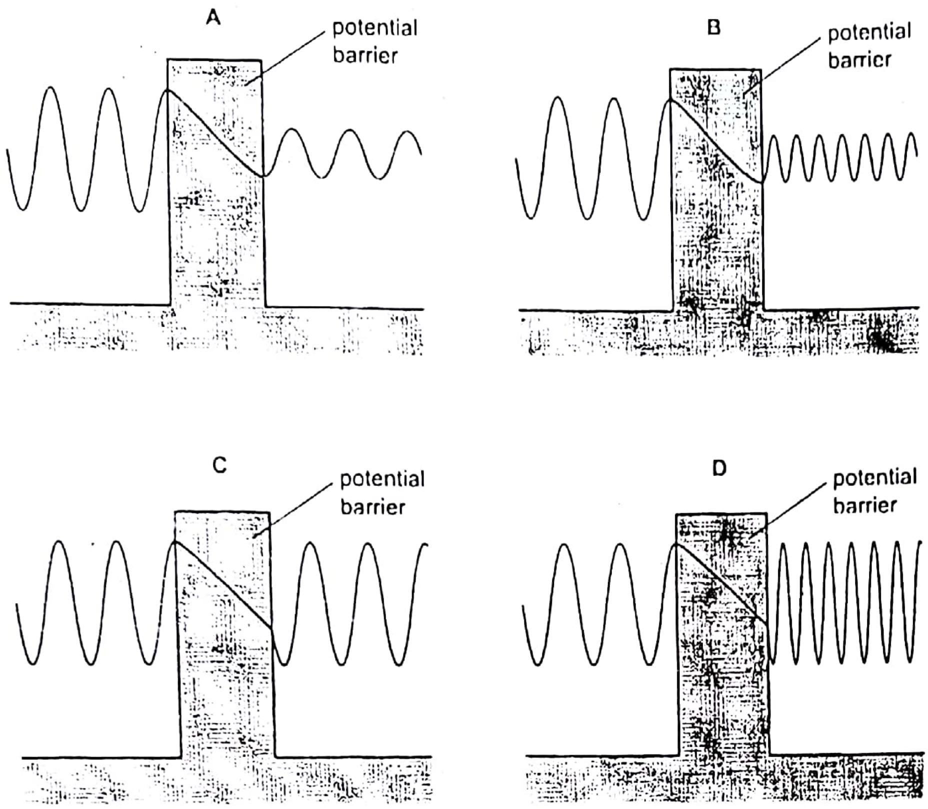
Option B: An atom in the level −3.4 eV can absorb a photon of wavelength 650 nm to arrive in the level −1.5 eV.

Option D: Most hydrogen atoms will be found in the level with −13.6 eV. This is the lowest energy level.

If the electrons are at the zero energy level, these electrons are at the highest energy level in the diagram shown above.

31. An electron of energy E is incident on the left-hand side of a potential barrier of energy U. The energy U is greater than E.

Which diagram represents the wave function of the electron to the right of the barrier?



Helping *concepts*

Amplitude of wave function after passing through barrier will be smaller, as probability is smaller. The period remains unchanged.

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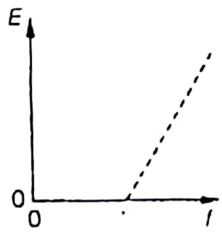
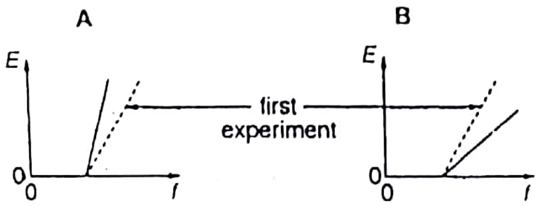
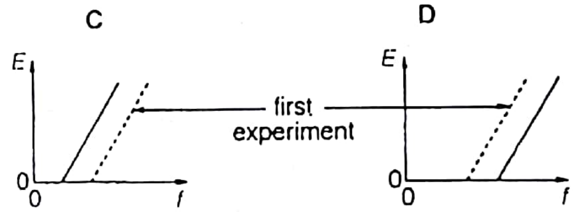
32. When electromagnetic radiation of frequency f falls on a particular metal surface, photoelectrons may be emitted. The graph shows the variation with f of the maximum kinetic energy E of these electrons.



Which graph obtained when the experiment is repeated using another metal of greater work function energy?





Helping *concepts*

Total energy supplied = $hf_0 + E$

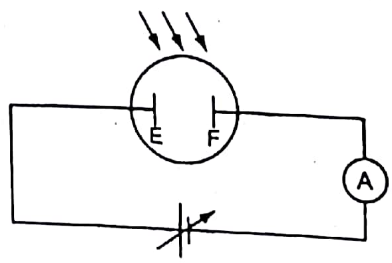
where E = KE of electrons.

$\therefore\ hf = hf_0 + E \Rightarrow E = hf - hf_0$

The gradient of E vs f graph is Planck constant, h. A higher work function means a higher threshold frequency, i.e. the graph will move to the left.

---

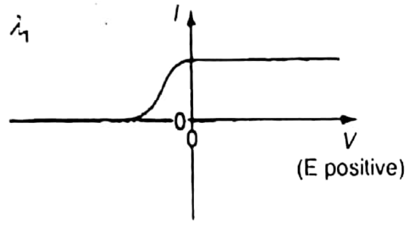
33. The diagram shows a circuit used for photoelectric emission experiments.



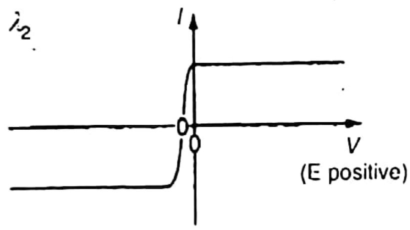
The two electrodes E and F are made of different metals. The work function of electrode E is ϕ_E, and the work function of electrode F is ϕ_F.

Current-voltage (*I-V*) characteristics are obtained when both electrodes are illuminated with monochromatic light.

When the wavelength of the light is λ_1, the *I-V* characteristic is as shown.



When the wavelength of the light is λ_2, the *I-V* characteristics is as shown.



Which line of the table relates the magnitudes of the wavelengths and the magnitudes of the work functions?

	wavelength	work function
A	λ_1 is less than λ_2	ϕ_E is less than ϕ_F
B	λ_1 is less than λ_2	ϕ_E is greater than ϕ_F
C	λ_1 is greater than λ_2	ϕ_E is less than ϕ_F
D	λ_1 is greater than λ_2	ϕ_E is greater than ϕ_F

Helping *concepts*

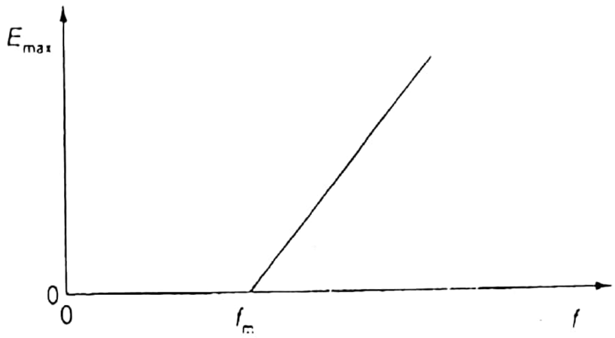
The first diagram is only for electrode F as there is only one result of current. It must be for electrode F as when the value of e.m.f. goes to negative from positive, the current of F will be stopped.

The second diagram is for electrodes E and F. One clue is that when the polarity (or signs) of battery is changed, the current still flows in opposite direction.

We can conclude that energy of wavelength λ_2 is greater than λ_1. This means the wavelength λ_2 is less than λ_1 $(E = \frac{hc}{\lambda})$.

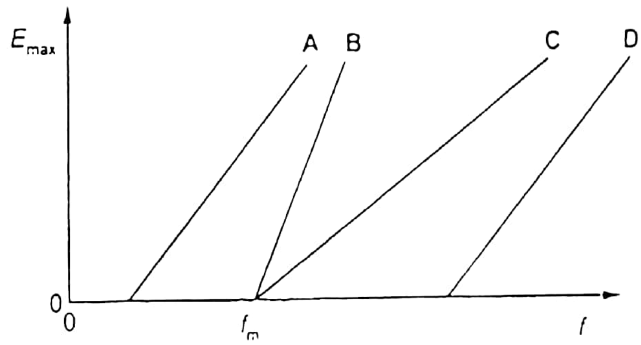
Also the wave function of F must be less than E, as electrons are liberated using longer wavelength λ_1.

34. The graph shows the variation of maximum kinetic energy E_{max} with frequency f, for photoelectrons emitted from the surface of a metal illuminated with electromagnetic radiation.



The metal is replaced with one that has a smaller work function.

Which line shows the variation of maximum kinetic energy with frequency for the new metal?



Helping *concepts*

Photoelectric equation, $E_{max} = hf - hf_0$

where E_{max} = y – axis,
frequency, f = x - axis,
constant, h = gradient.

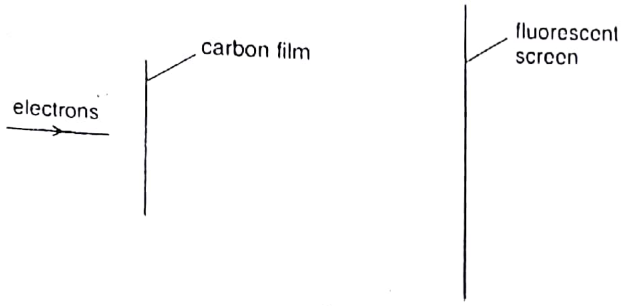
For $E_{max} = 0$,

$$0 = hf - hf_0$$
$$f = f_0$$

A smaller work function (hf_0) means the *x*-intercept (f_0) will be smaller in value.

The gradient of the new graph is the same as the previous graph, i.e. the gradient is the same.

35. Electrons with velocity *v* travel through a vacuum and are incident on a thin carbon film, as shown.



The electrons produce a pattern of concentric circles on the fluorescent screen.

What causes the pattern and which change to the pattern occurs when the velocity v is increased?

	cause	change to pattern
A	diffraction	diameters of circles increase
B	diffraction	diameters of circles decrease
C	refraction	diameters of circles increase
D	refraction	diameters of circles decrease

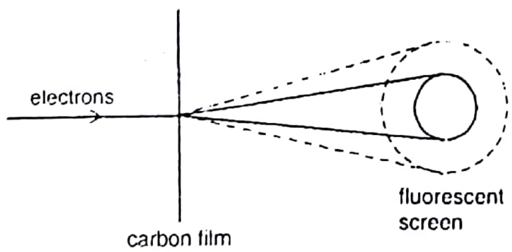
Helping concepts

By de Broglie's equation,

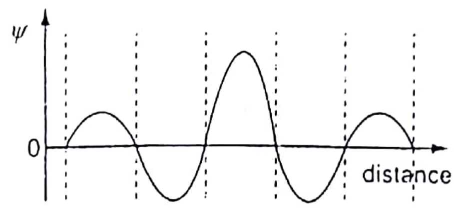
$$\lambda = \frac{h}{p}$$

As velocity increases, its momentum p also increases. This means its associated wavelength decreases.

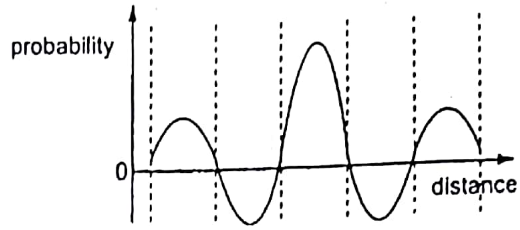
Using diffraction grating formula, $d\sin\theta = n\lambda$, as its wavelength decreases, the angle θ will decrease. This results in a smaller radius of circle seen and smaller diameter.

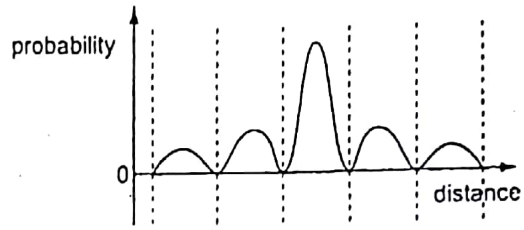


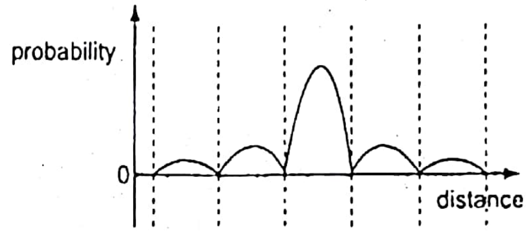
36. The sketch graph shows how the wave function ψ of an electron varies with position.

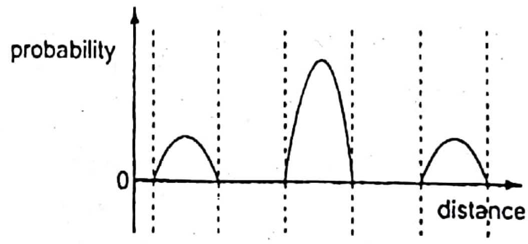


Which graph, drawn on the same horizontal scale, gives the probability of finding an electron at each position?

A


B


C


D


Helping concepts

$$\text{Probability} = |\psi|^2$$

Hence, graph of probability should be positive and slightly curved at the turning points due to the square function $|\psi|^2$ and not pointed shape such as option C.

TOPIC 19

Lasers and Semiconductors

Key content that you will be examined on:

1. Basic principles of lasers
2. Energy bands, conductors and insulators
3. Semiconductors
4. Depletion region of a p-n junction

Topic 19

Lasers and Semiconductors

1. What is the typical energy gap of a semiconductor?

A 0.10 eV B 1.0 eV
C 10.0 eV D 100 eV

Helping concepts

From experimental values, the typical value of band gap of a semiconductor is around 1.0 eV.

---

2. The main difference between intrinsic and extrinsic semiconductor, under ambient condition, is

A shape. B density.
C electrons. D resistivity.

Helping concepts (D)

An extrinsic semiconductor is doped with 'impurity' such as Group III or V elements to increase its conductivity or reduce its resistivity.

---

3. One use of a single p-n junction semiconductor in an electrical circuit is a

A rectifier. B transistor.
C battery. D diode.

Helping concepts

The presence of the depletion region of a p-n junction semiconductor allows its use as a diode, to allow the movement of the charge carriers to flow in one direction only.

---

4. Which of the following setup of semiconductor represents the diode as shown below?

A | p-type | n-type |

B | n-type | p-type |

C | p-type | n-type | p-type |

D | n-type | p-type | n-type |

Helping concepts

By definition, the diode as shown will have a p-type joined with a n-type semiconductor.

---

5. Which one of the following experiments is the use of laser ineffective?

A Young double-slit
B Photoelectric effect
C Diffraction grating
D Radioactivity

Helping concepts

Radioactivity is spontaneous, i.e. it will occur without external stimulus.

---

6. What are the charge carriers for a p-type silicon semiconductor?

	majority carriers	minority carriers
A	electrons	electrons
B	electrons	holes
C	holes	electrons
D	holes	holes

Helping concepts

The main conductor for a p-type semiconductor are holes. Electrons contribute in a lesser proportion.

---

7. Which of the following on laser is true?

A Electrons are emitted.

B Stimulated emission of electrons is needed.

C There is a population inversion of photons.

D- Coherent monochromatic light is emitted.

Helping concepts

For laser, a population inversion of electrons is needed. Upon stimulated by photons of the same energy difference between transition energy levels, photons will be emitted by the electrons transition to lower energy levels. Coherent monochromatic photons (electromagnetic radiation) are emitted.

8. Which one of the following atoms can act as an impurity to produce a n-type semiconductor when doped into pure semiconductor?

A Ga B Ge

C As D Se

Helping concepts

As is a Group V element with an extra electron when doped with pure semiconductor. This will form a 'negative' type (n-type) of charge carrier.

9. Elements in part of the Periodic Table

Group III	Group IV	Group V	Group VI
Ga	Ge	As	Se

Which one of the following elements can act as an impurity to produce a p-type semiconductor when doped into pure semiconductor?

A Ga C Ge

C As D Se

Helping concepts

Ga is a Group III element with a 'missing' electron when doped with pure semiconductor. This will form a 'positive' type (p-type) of charge carrier.

10. Energy bands form in solids because

A there are many atoms in the solid.

B the energy levels of the atoms are the same.

C the energy levels of the atoms in the solid are so close to each other such that they are essentially continuous.

D they are many conduction electrons and holes in solids which are grouped together when they are near to one another.

Helping concepts

The close energy levels between atoms formed the energy bands.

11. Why is laser monochromatic?

A There is a fixed energy gap between the meta-stable state of the electrons and the lower electron energy level.

B The photon emitted is coherent with the incoming photon.

C There is a population inversion of the electrons.

D Electrons are at the meta-stable state.

Helping concepts

The fixed energy gap causes the transition of the electrons will result in a common energy of the light emitted, which is of the same frequency of wavelength.

12. Laser is an acronym for

A light annihilation by stimulated emission of radiation.

B light amplification by stimulated emission of radiation.

C light amplitude of stimulated emission of radiation.

D light amplification by stimulated emission of radio.

Helping concepts

Light amplification by stimulated emission of radiation.

13. Energy levels in low-pressure gases are represented as lines whereas in solids, the levels are shown as bands.

What is responsible for the formation of bands?

A Atoms in solids are much closer together than those in gases.

B Atoms in solids are much denser than those in gases.

C Solids are better electrical conductors than gases.

D Solids are not fluids but gases are fluids.

Helping concepts

Fact. The denser material (solid) causes the energy levels to band together.

14. The depletion region at p-n junction arises because of

A diffusion of charges from p-type to n-type semiconductor and vice-versa.

B absence of charges.

C presence of the external battery.

D reverse bias of the battery.

Helping concepts

Charges move from p-type to n-type semiconductor and vice versa. In the process, an electric field is set up. This prevents further movement of the charge carriers.

15. Metals are better electrical conductors than semiconductors because

A there are more charge carriers in metals.

B of the overlap in valence and conduction bands in metals.

C the density of metals is higher than semiconductor.

D there is no doping in metals.

Helping concepts

The overlapping of valence and conduction band in metals allows the charge carriers (i.e. electrons) to move freely into the conduction state.

16. When a p-n junction is forward biased, what will happen to its depletion layer and potential barrier?

	depletion layer	potential barrier
A	decrease	decrease
B	decrease	increase
C	increase	decrease
D	increase	increase

Helping concepts

In theory, a forward-biased p-n junction will increase the diffusion current flowing through it. This will happen when the depletion layer and potential barrier decrease.

17. What is meant by *spontaneous emission* of electrons in solids?

A Electrons being emitted by the solids through photoelectric effect when irradiated with electromagnetic radiation.

B Incident electrons colliding with electrons in solids, and releasing double the number of incident electrons.

C Excited electrons going back to lower energy states immediately by releasing energy.

D Electrons in solids are emitted without any external stimulus through radiation.

Helping concepts

Electrons de-excited immediately to a lower energy state by releasing energy. All matters in the universe tend to lower energy state wherever possible.

18. What is meant by *stimulated emission* of electrons in lasers?

A Electrons are de-excited to lower energy state by incoming photons. The energy and frequency of the incoming and emitted photons are the same.

B Electrons are de-excited to lower energy state by incoming photons. The energy of the incoming and emitted photons is the same but with different frequency.

C Electrons are excited to higher energy state by incoming photons. These electrons will stay in the meta-stable state.

D Electrons are excited to higher energy state by incoming photons. These electrons will undergo spontaneous emission.

Helping concepts

Electrons, at the meta-stable states, are de-excited to lower energy state by incoming photons. The energy and frequency of the incoming and emitted photons are the same.

---

19. What is meant by *population inversion* of electrons in lasers?

A Electrons are de-excited to lower energy state by incoming photons. The energy and frequency of the incoming and emitted photons are the same.

B Electrons are de-excited to lower energy state by incoming photons. The energy of the incoming and emitted photons is the same but with different frequency.

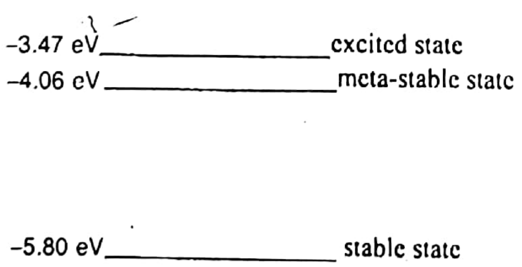
C Electrons are excited to higher energy state by incoming photons. These electrons will stay in the meta-stable state.

D Electrons are excited to higher energy state by incoming photons. These electrons will undergo spontaneous emission.

Helping concepts

Electrons are excited to higher energy state by incoming photons. These electrons will stay in the meta-stable state. These accumulated electrons will then undergo stimulated emission by incoming photons.

20.



A hypothetical laser with electronic structure as shown above will emit a monochromatic wavelength of energy

A 1.74 eV. B 2.33 eV.

C 4.06 eV. D 5.80 eV.

Helping concepts

Emitted laser will go from meta-stable to stable state.

$\therefore$ The energy level will be $|-5.80-(-4.06)| = 1.74$ eV.

---

21. Which statement about conduction of electricity in solids is **correct**?

A Free electrons are found both in the conduction band and in the valence band.

B In a metal, there is a large energy gap between the conduction and valence bands.

C The presence of impurities in an intrinsic semiconductor is used to increase its resistance.

D In an intrinsic semiconductor, electrons travel in the opposite direction to holes.

Helping concepts

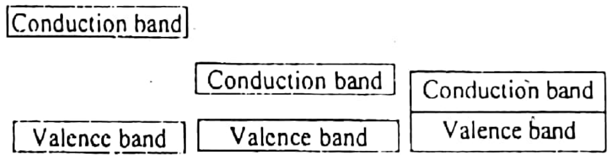
Free electrons are found only at conduction band.

There is a energy gap between conduction and valence bands in metal, though they are not necessarily large.

Impurities in intrinsic semiconductor reduces resistance.

---

22. Which one of the following materials correctly describes the energy bands as shown below?



A	insulators	semiconductors	metals
B	semiconductors	insulators	metals
C	metals	semiconductors	insulators
D	semiconductors	metals	insulators

Helping concepts

The ascending order of energy gap between conduction and valence band is metals, semiconductors and insulators.

---

23. The resistivity of the intrinsic semiconductor silicon decreases from 400 Ωm at 20 °C to 40 Ωm at 60 °C.

Which statement, using band theory, best explains the change in resistivity of silicon with increase in temperature?

A Conduction band electrons which carry current move faster.

B More electrons can move through the valence band taking part in conduction.

C More valence band electrons can be promoted to the conduction band.

D The energy gap between the valence and conduction bands decreases.

Helping *concepts*

As temperature increases, more electrons are excited to the conduction band, leaving behind holes in the valence band.

The number of charge carriers increases due to both excited electrons and holes.

The conductivity of the material increases and the resistivity decreases.

---

24. Which statement about the energy bands in an ideal intrinsic semiconductor is **correct**?

A The conduction band lies just below the valence band.

B The number of electrons in the conduction band equals the number of holes in the valence band.

C There is an energy gap of 5 eV to 10 eV between the valence and conduction bands.

D There is s small overlap between the valence and conduction bands.

Helping *concepts*

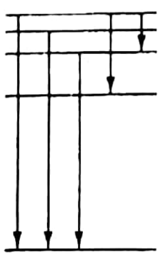
Option A: The conduction band lies just <u>above</u> the valence band.

Option C: There is an energy gap of <u>1 eV to 2 eV</u> between the valence and conduction bands.

Option D: There is <u>no</u> overlap between the valence and conduction bands.

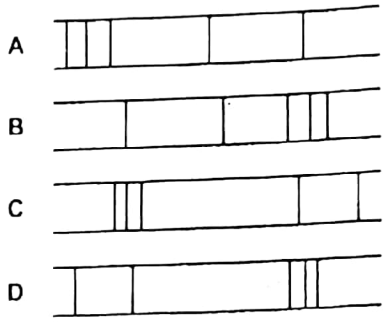
---

25. The diagram shows five energy levels of an atom. Five transitions between the levels are shown.



In the spectra below, the frequency scale is linear and increases to the right.

Which spectrum best corresponds to the five transitions between the levels shown above?



Helping *concepts*

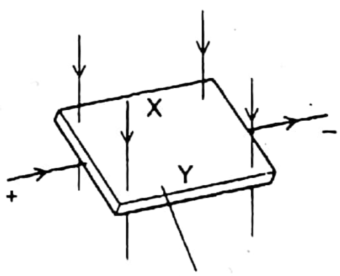
Frequency scale increases to the right ⇒ energy scale increases to the right.

The first three (three leftmost arrows in the top diagram) emission arrows are closed together and high energy.

The two rightmost arrows are closer to each other and low energy.

---

26. A thin slab of n-type semiconductor is connected at its ends to a battery causing a current through it.



n-type semiconductor

A uniform magnetic field is applied vertically downwards over the surface of the slab causing an electric field between sides X and Y of the slab.

Which row correctly describes the majority carriers of the electric current in the slab and the direction of the induced electric field?

	majority carriers	electric field direction
A	conduction electrons	from X to Y
B	conduction electrons	from Y to X
C	holes	from X to Y
D	holes	from Y to X

Helping concepts

For n-type semi-conductor, the majority carries are electrons, i.e. negatively charged.

Using Fleming's left hand rule for positive charge (moving from left to right as in diagram), the electrons (equivalent to the current as they are moving from right to left) will move to X.

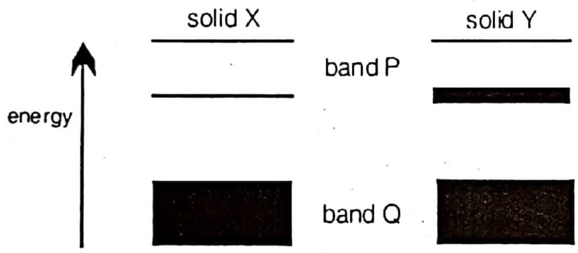
This will make X more negative than Y.

Electric field is in the direction from high to low (or positive to negative) potential,

i.e. Y to X.

---

27. The diagram illustrates the upper energy bands in two different classes of solid at absolute zero. The shaded areas represent occupied electron energy levels.



What are bands P and Q, and what are the classes X and Y of the solids?

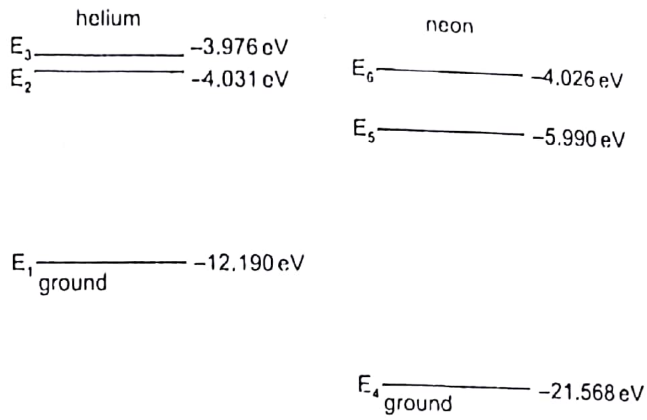
	band P	band Q	solid X	solid Y
A	conduction	valence	intrinsic semiconductor	metal
B	conduction	valence	metal	intrinsic semiconductor
C	valence	conduction	intrinsic semiconductor	metal
D	valence	conduction	metal	intrinsic semiconductor

Helping concepts

Conduction bands are of higher energy level than valence bands. Only in metals that electrons are found in conduction bands.

---

28. The diagram shows some of the energy levels of helium and neon. The energies of the levels are given in electron volts. The elements are the major constituents in a laser that emits red light.



Which transition between the labelled levels gives rise to the emission of the laser light?

A E_3 to E_2

B E_6 to E_5

C E_2 to E_1

D E_5 to E_4

Helping concepts

Red light $\approx$ 700 nm = 700×10^{-9} m

Energy of red light, $E = \frac{hc}{\lambda}$

$$= \frac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{(700 \times 10^{-9})}$$

$$= 2.84 \times 10^{-19} \text{ J}$$

$$= 1.78 \text{ eV}$$

Only E_6 to E_5 satisfies the energy difference to emit red light.

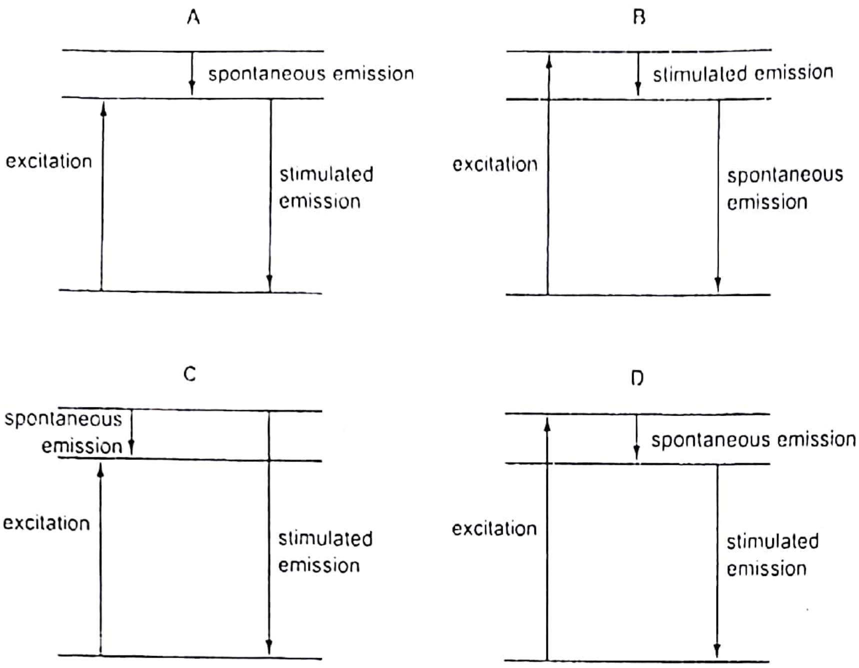
Note: 1. 1.6×10^{-19} J = 1.0 eV

2. Electromagnetic wave is emitted if the electron transition is from high to low energy level.

---

29. In a helium-neon laser, helium atoms collide with neon atoms and excite them. This produces a population inversion which allows stimulated emission.

Which neon energy level diagram correctly shows the excitation of the neon atoms by the helium atoms, the spontaneous infra-red emission from the neon, and the stimulated emission of red light?



Helping *concepts*

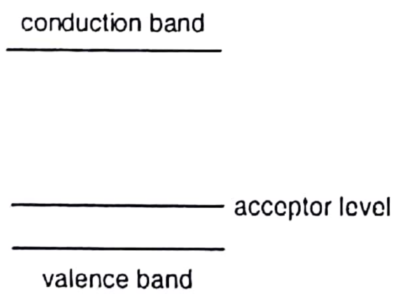
The length of excitation arrow (upwards direction) is equal to the sum of those by stimulated and spontaneous emission (both downwards direcion).

As spontaneous infra-red emission is of lower energy compared to stimulated emission red light, its length of arrow is shorter compared to red light emission.

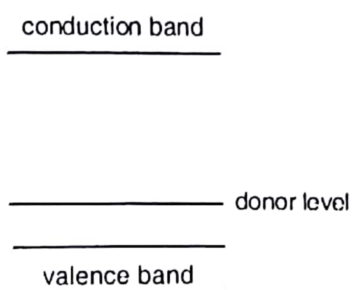
---

30. Which diagram represents the energy levels in an n-type semiconductor material?

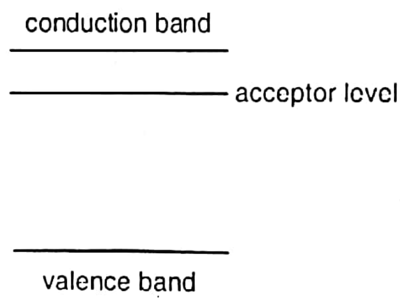
A



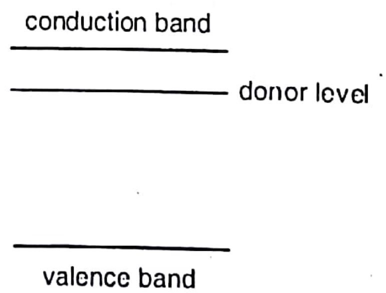
B



C



D



Helping *concepts*

In a n-type semi-conductor, the extra energy level lies just below the conduction band.

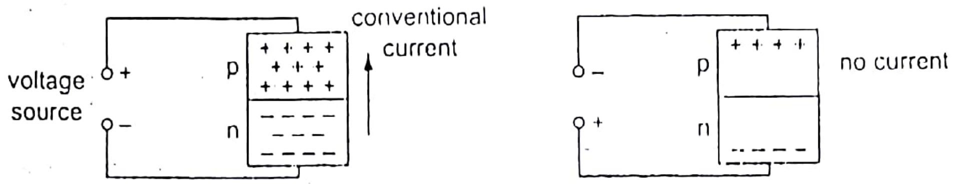
Since this level supplies electrons to the conduction band, it is called the donor level.

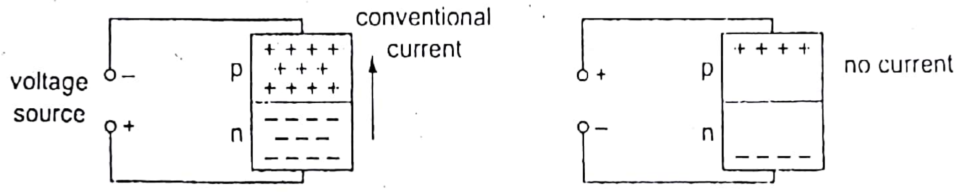
In a p-type semi-conductor, the extra energy level lies just above the valence band.

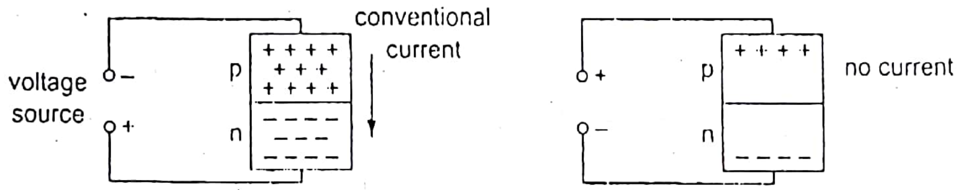
Since this level accepts electrons to facilitate the holes in the valence band to move, it is called the acceptor level.

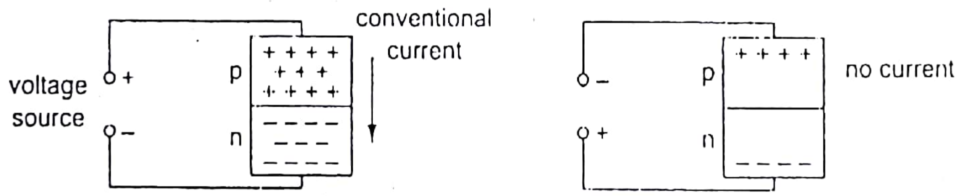
31. In the diagram below, the symbols + + + and − − − represent the majority carriers in the p-type and n-type sides of a p-n junction.

Which pair of diagrams illustrates how a p-n junction acts as a rectifier?

A


B


C


D


Helping *concepts*

For forward-bias of rectifier, the p-type junction is aligned to the positive polarity of the battery.

In the reverse-bias (where there is no current flow), the p-type junction is connected to the negative polarity of the battery.

TOPIC

Nuclear Physics

20

Key content that you will be examined on:

1. The nucleus
2. Isotopes
3. Mass defect and nuclear binding energy
4. Nuclear processes
5. Radioactive decay
6. Biological effect of radiation

Topic 20 Nuclear Physics

1. What is a correct order of magnitude estimate for the diameter of a typical atomic nucleus?

   A 10^{-14} m B 10^{-18} m
   C 10^{-22} m D 10^{-26} m

Helping concepts

By definition, size of nucleus is 10^{-14} m.

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2. Isotopes of a given element all have the same

   A charge/mass ratio.
   B neutron number.
   C nucleon number.
   D proton number.

Helping concepts

Isotopes have the same proton (atomic) number and different mass (nucleon) number.

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3. A detector is exposed to a radioactive source. Fluctuations in the count-rate are observed.

   What do these fluctuations indicate about radioactive decay?

   A It is random.
   B It is spontaneous.
   C It is exponential.
   D It is non-linear.

Helping concepts

Radioactive sources are random in nature, i.e. emission of radioactive particles is unpredictable.

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4. The half-life of a certain radioactive element is such that 7/8 of a given quantity decays in 12 days.

   What fraction remains undecayed after 24 days?

   A 0 B $\frac{1}{128}$
   C $\frac{1}{64}$ D $\frac{1}{32}$

Helping concepts

The radioactive element has 1/8 of a given quantity remains after 12 days.

After 24 days, or in additional 12 days, the fraction remains undecayed is

$$(\frac{1}{8})(\frac{1}{8}) \text{ or } \frac{1}{64}.$$

---

5. Which set of radioactive emissions corresponds to the descriptions given in the table headings?

	high-speed electrons	high-speed helium nuclei	high-frequency photons
A	α	β	γ
B	α	γ	β
C	β	α	γ
D	β	γ	α

Helping concepts

α-particles are helium nuclei.

β-particles are electrons.

γ-particles are photons.

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6. The symbol $^{77}_{32}Ge$ represents a nucleus of germanium that decays to a nucleus of arsenic by emitting a β-particle.

   What is the symbol of this arsenic nucleus?

   A $^{76}_{32}As$ B $^{78}_{32}As$
   C $^{78}_{31}As$ D $^{77}_{33}As$

Helping concepts

$$^{77}_{32}\text{Ge} \longrightarrow {}^{0}_{-1}\beta + {}^{77}_{33}\text{As}$$

---

7. A newly prepared radioactive nuclide has a decay constant λ of 10^{-6} s^{-1}.

What is the approximate half-life of the nuclide?

A 1 hour B 1 day
C 1 week D 1 month

Helping concepts

Decay constant, $\lambda = 10^{-6}$ s^{-1}

The half-life $T_{1/2}$ is thus given by

$$T_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{10^{-6}} = 0.693 \times 10^{6} \text{ s}$$
$$= 192.5 \text{ hrs} \approx 8 \text{ days} \approx 1.14 \text{ week} \approx 1 \text{ week}$$

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8. One reaction which might be used for controlled nuclear fusion is shown.

$$^{7}_{3}\text{Li} + {}^{2}_{1}\text{H} \longrightarrow 2({}^{4}_{2}\text{He}) + {}^{1}_{0}\text{X}$$

What is particle **X**?

A an α-particle B an electron
C a neutron D a proton

Helping concepts

By conservation of mass number and atomic number, the nuclear reaction equation may be re-written as

$$^{7}_{3}\text{Li} + {}^{2}_{1}\text{H} \longrightarrow 2({}^{4}_{2}\text{He}) + {}^{1}_{0}\text{n}$$

Hence, particle **X** is a neutron.

---

9. A student conducts an experiment using an α-particle source.

When considering safety precautions, what can be assumed to be the maximum range of α-particles in air?

A between 0 and 5 mm
B between 5 mm and 200 mm
C between 200 mm and 500 mm
D between 500 mm to 1000 mm

Helping concepts

By definition, range of α-particles is 5 mm to 200 mm.

---

10. The half-life of a certain radioactive isotope is 32 hours. What fraction of a sample would remain after 16 hours?

A 0.25 B 0.29
C 0.50 D 0.71

Helping concepts

The radioactive decay constant λ is given by

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{32} \text{ hr}^{-1}$$

From the equation $N = N_0 e^{-\lambda t}$, the fraction of a sample remaining after 16 hours is given by

$$\frac{N}{N_0} = e^{-\lambda t} = e^{-(\frac{0.693}{32})(16)} = e^{-0.3465} = 0.71$$

---

11. In order to trace the line of a water-pipe buried 0.4 m below the surface of a field, an engineer wishes to add a radioactive isotope to the water.

Which sort of isotope should be chosen?

	emitter	half-life
A	β	a few hours
B	β	several years
C	γ	a few hours
D	γ	several years

Helping concepts

A γ radioactive isotope of short half-life should be chosen. Lead water pipes can prevent the penetration of γ rays and its half-life of a few hours can have no harmful effects on humans, yet can be detected through the leakage of pipes.

---

12. The nucleus of one of the isotopes of nickel is represented by $^{60}_{28}Ni$.

Which line in the table correctly describes a neutral atom of this isotope?

	no. of protons	no. of neutrons	no. of orbital electrons
A	28	32	28
B	28	60	28
C	60	28	28
D	60	32	32

Helping concepts

Neutron = mass number – proton number

$= 60 - 28$

$= 32$

A neutral atom has equivalent number of protons and electrons.

13. Which equation correctly shows an α-particle causing a nuclear reaction?

A $^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}n$

B $^{17}_{8}O + ^{4}_{2}He \longrightarrow ^{20}_{9}F + ^{1}_{1}p$

C $^{17}_{8}O + ^{0}_{-1}e \longrightarrow ^{13}_{5}B + ^{4}_{2}He$

D $^{14}_{7}N + ^{1}_{1}p \longrightarrow ^{11}_{6}C + ^{4}_{2}He$

Helping concepts

α-particle, $^{4}_{2}He$, should be on the LHS of the equation.

Eqaution A is incorrect as neutron is $^{1}_{0}n$, not $^{1}_{1}n$.

14. Which of the following defines the decay constant λ of a radioactive nuclide?

A $\dfrac{\text{activity}}{\text{number of undecayed nuclei}}$

B $\dfrac{\text{half-life}}{0.693}$

C the number of nuclei that decay per unit time.

D the time for the activity of the nuclide to be reduced by a factor of 2.

Helping concepts

$A = \lambda N \Rightarrow \lambda = \dfrac{A}{N}$

15. A high energy α-particle collides with a $^{14}_{7}N$ nucleus to produce a $^{17}_{8}O$ nucleus.

What could be the other products of this collision?

A a γ-photon alone

B a γ-photon and a β-particle

C a γ-photon and a neutron

D a γ-photon and a proton

Helping concepts

From the laws of conservation of mass (nucleon number) and charge (proton number), the reaction can be represented by

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

Hence, the emitted particle is a proton.

16. Which two nuclei contain the same number of neutrons?

A $^{12}_{6}C$ and $^{14}_{6}C$ B $^{16}_{7}N$ and $^{15}_{8}O$

C $^{23}_{11}Na$ and $^{24}_{12}Mg$ D $^{32}_{14}Si$ and $^{32}_{15}P$

Helping concepts

$^{Z}_{A}X$ → mass number (protons + neutrons)

$^{Z}_{A}X$ → atomic number (protons only)

The number of neutrons of $^{23}_{11}Na = 23 - 11 = 12$

Number of neutrons of $^{24}_{12}Mg = 24 - 12 = 12$

17. Radon-220 is radioactive and decays to Polonium-216 with the emission of an α-particle. The equation for the radioactive decay is shown.

$$^{220}_{86}Rn \longrightarrow ^{216}_{84}Po + ^{4}_{2}He$$

How many neutrons are in the radon and polonium nuclei?

	Rn	Po
A	86	84
B	134	132
C	220	212
D	220	216

Helping concepts

Neutrons = mass number − proton number

For Rn: 220 − 86 = 134

Po: 216 − 84 = 132

18. A detector of ionising radiation gives a background count rate of 24 per minute.

A radioactive source is placed close to the detector and the reading is 532 counts per minute.

What will be the reading after two half-lives of the source?

A 127 B 133

C 151 D 157

Helping concepts

Actual reading due to radioactive source is 532 − 24 = 508 counts per minute at the start.

After two half lives, the counts per minute due to radioactive source is $(\frac{1}{2})^2(508) = 127$.

The total reading, including the constant background count is 127 + 24 = 151 counts per minute.

19. A source initially contains N_0 nuclei of a radioactive nuclide.

How many of these nuclei have decayed after a time interval of three half-lives?

A $\frac{N_0}{16}$ B $\frac{N_0}{8}$

C $\frac{7N_0}{8}$ D $\frac{15N_0}{16}$

Helping concepts

Number of nuclei remaining after three half-lives

$= (\frac{1}{2})^3 N_0 = \frac{1}{8}N_0$

∴ Number of nuclei that have decayed $= N_0 - \frac{1}{8}N_0$

$= \frac{7}{8}N_0$

20. The decay of a nucleus of neptunium is accompanied by the emission of a β-particle and γ-radiation.

What effect (if any) does this decay have on the proton number and the nucleon number of the nucleus?

	proton number	nucleon number
A	increases	decreases
B	decreases	increases
C	unchanged	decreases
D	increases	unchanged

Helping concepts

Let the original atom be $^{A}_{Z}X$.

$$^{A}_{Z}X \longrightarrow ^{A}_{Z+1}Y + ^{0}_{-1}\beta + \gamma$$

Hence, we can see the mass number A remains unchanged. The proton number Z increases.

21. Strontium-90 ($^{90}_{38}Sr$) is radioactive and emits β-particles.

Which equation could represent this nuclear decay?

A $^{90}_{38}Sr \longrightarrow ^{90}_{39}Sr + ^{0}_{-1}\beta$

B $^{90}_{38}Sr \longrightarrow ^{90}_{39}Y + ^{0}_{-1}\beta$

C $^{90}_{38}Sr \longrightarrow ^{90}_{37}Rb + ^{0}_{1}\beta$

D $^{90}_{38}Sr \longrightarrow ^{90}_{37}Sr + ^{0}_{1}\beta$

Helping concepts

The emission of β-particle will change the proton number of the element. β-particle is represented by $^{0}_{-1}\beta$.

22. Which conclusion can be drawn from the results of the experiment showing the scattering of α-particles by gold foil?

A Electrons orbit the atomic nucleus in well-defined paths.

B Nuclei of different isotopes contain different numbers of neutrons.

C The atomic nucleus contains protons and neutrons.

D The nucleus is very small compared with the size of the atom.

Helping concepts

Most of the α-particles pass through undeflected, hence showing that the nucleus is very small compared with the size of the atom.

23. Two deuterium nuclei fuse together to form a Helium-3 nucleus, with the release of a neutron. The reaction is represented by

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n + \text{energy}$$

The binding energies *per nucleon* are:

for $^{2}_{1}H$ 1.09 MeV,

for $^{3}_{2}He$ 2.54 MeV.

How much energy is released in this reaction?

A 0.36 MeV B 1.45 MeV

C 3.26 MeV D 5.44 MeV

Helping concepts

Binding energy of $^{2}_{1}H = 1.09 \times 2 = 2.18$ MeV

Binding energy of $^{3}_{2}H = 2.54 \times 3 = 7.62$ MeV

Energy released $= 7.62 - 2(2.18) = 3.26$ MeV

24. The initial activity of a sample of a radioactive isotope containing N_0 nuclei is A_0.

What is the number of unchanged nuclei when the activity has declined to $\frac{A_0}{2}$?

A $0.69N_0$ B $\frac{0.69N_0}{2}$

C $\frac{N_0}{2}$ D $\frac{N_0}{1.38}$

Helping concepts

The number of unchanged nuclei, N, and the activity, A, are in a constant ratio as $A = \lambda N$, where λ is the decay constant. When activity has halved, the number of unchanged nuclei has also halved.

25. A radioactive source produces 10^6 α-particles per second. When all the ions produced in air by these α-particles are collected, the ionisation current is about $0.01\,\mu A$.

If the charge on an ion is about 10^{-19} C, what is the best estimate of the average number of ions produced by each α-particle?

A 10^5 B 10^6

C 10^7 D 10^8

Helping concepts

No. of ions produced per second × charge of one ion = ionisation current

$\Rightarrow 10^6 \times n \times 10^{-19} = 0.01 \times 10^{-6}$

$\Rightarrow n = 10^5$

26. A nucleus of the nuclide $^{241}_{94}Pu$ decays by emission of a β-particle followed by the emission of an α-particle.

Which of the nuclides shown is formed?

A $^{239}_{93}Np$ B $^{239}_{91}Pa$

C $^{237}_{93}Np$ D $^{237}_{92}U$

Helping concepts

$$^{241}_{94}Pu \longrightarrow {}^{x}_{y}A + {}^{0}_{-1}\beta + {}^{4}_{2}He$$

$$\therefore \begin{cases} 241 = x + 0 + 4 \Rightarrow x = 237 \\ 94 = y + (-1) + 2 \Rightarrow y = 93 \end{cases}$$

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27. Which pair of nuclides has nuclei containing the same number of neutrons?

A $^{107}_{47}Ag$ and $^{104}_{45}Rh$

B $^{109}_{47}Ag$ and $^{109}_{46}Pd$

C $^{108}_{46}Pd$ and $^{109}_{47}Ag$

D $^{105}_{45}Rh$ and $^{106}_{45}Rh$

Helping concepts

For element $^{Z}_{A}X$,

number of neutrons = $Z - A$

	neutrons
A	60 and 59
B	62 and 63
C	62 and 62
D	60 and 61

---

28. $^{238}_{92}U$ decays through a series of transformations to a final stable nuclide. The particles emitted in the successive transformations are

$\alpha\,\beta\,\beta\,\alpha\,\alpha$.

Which nuclide is **not** produced during this series of transformations?

A $^{228}_{88}Ra$ B $^{230}_{90}Th$

C $^{234}_{91}Pa$ D $^{234}_{92}U$

Helping concepts

$$^{238}_{92}U \xrightarrow{\alpha} {}^{234}_{90}Q \xrightarrow{\beta} {}^{234}_{91}R \xrightarrow{\beta} {}^{234}_{92}S \xrightarrow{\alpha} {}^{230}_{90}T \xrightarrow{\alpha} {}^{226}_{88}Pb$$

$^{228}_{88}Ra$ is not produced during this series of transformations.

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29. In an experiment to investigate the nature of the atom, a very thin gold film was bombarded with α-particles.

What pattern of deflection of the α-particles was observed?

A A few α-particles were deflected through angles greater than a right angle.

B All α-particles were deflected from their original path.

C Most α-particles were deflected through angles greater than a right angle.

D No α-particles was deflected through an angle greater than a right angle.

Helping concepts

The experiment was first conducted by Rutherford, Geiger and Marsden in 1890. The majority of the α-particles were scattered through small angles, but a few were deviated by more than 90°. In view of these results, it was proposed that an atom has a positively charged core which contains most of the mass of the atom and which is surrounded by orbiting electrons.

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30. The radioactive decay of a certain nuclide is governed by the following relationship:

$$\frac{dn}{dt} = -\lambda n \text{ where } \lambda = 2.4 \times 10^{-8}\ s^{-1}.$$

What is the half-life of the nuclide?

A 2.9×10^{7} s B 1.3×10^{7} s

C 1.2×10^{-8} s D 3.4×10^{-8} s

Helping concepts

The half-life of the nuclide is related to the decay constant λ by the equation

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{2.4 \times 10^{-8}} = 2.9 \times 10^{7}\ s$$

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31. Each of the nuclei below is accelerated from rest through the same potential difference.

Which one completes the acceleration with the **lowest** speed?

A $^{1}_{1}H$ B $^{4}_{2}He$

C $^{7}_{3}Li$ D $^{9}_{4}Be$

Helping concepts

Potential energy = kinetic energy

$$eV = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2eV}{m}}$$

The speed v is the lowest if the ratio of $(\frac{e}{m})$ is the lowest. $^{7}_{3}Li$ has the smallest ratio of $(\frac{e}{m})$ of $(\frac{3}{7})$.

32. What is the decay constant of a radioactive substance?

A the constant of proportionality in the equation relating the rate of decay of the substance to the number of undecayed nuclei

B the number of disintegrations of the substance occurring in one half-life of the substance

C the number of disintegrations of the substance occurring per second

D the average time taken for half the nuclei initially present in the substance to decay

Helping concepts

$$\frac{dN}{dt} = -\lambda N \Rightarrow \lambda = \frac{-\frac{dN}{dt}}{N}$$

where $(\frac{dN}{dt})$ is the rate of decay of substance and N is the number of undecayed nuclei.

33. Protons and neutrons are thought to consist of smaller particles called quarks.

The 'up' quark has a charge of $\frac{2}{3}e$; a 'down' quark has a charge of $-\frac{1}{3}e$, where e is the elementary charge ($+1.6 \times 10^{-19}$ C).

How many up quarks and down quarks must a proton contain?

	up quarks	down quarks
A	0	3
B	1	1
C	1	2
D	2	1

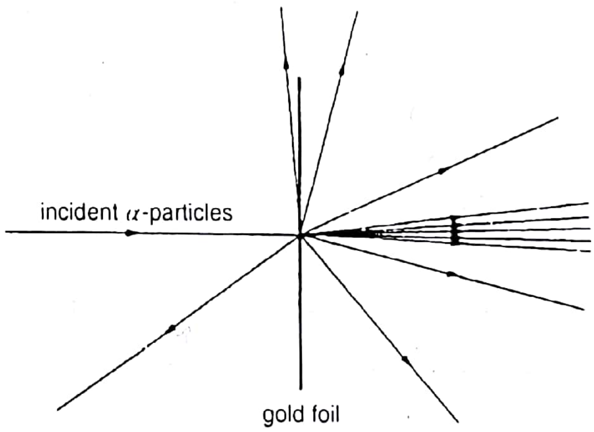
Helping concepts

Charge on proton is $+e$.

By simple addition,

$$2(\frac{2}{3}e) + (-\frac{e}{3}) = e$$

34. A thin gold foil is bombarded with α-particles as shown.



The results of this experiment provide information about the

A binding energy of a gold nucleus.

B energy levels of electrons in gold atoms.

C size of a gold nucleus.

D structure of a gold nucleus.

Helping concepts

Most of the α-particles pass straight through and very few get deflected, showing the size of the nucleus to be very small.

35. A radioactive isotope has a decay constant λ and a molar mass M.

Taking the Avogadro constant to be L, what is the activity of a sample of mass m of this isotope?

A λmML B $\frac{\lambda mL}{M}$

C $\frac{\lambda ML}{m}$ D $\frac{mL}{\lambda M}$

Helping concepts

The given sample of radioactive isotope of mass m constants $\frac{mL}{M}$ number of undecayed radioactive particles.

From the law of radioactive decay, its activity A is given by

$$|A| = \lambda(\frac{mL}{M}) = \frac{\lambda mL}{M}$$

Note: The formula includes the 'negative' sign. We can take the absolute value.

36. The following represents a sequence of radioactive decays involving two α-particles and one β-particle.

$$^{217}_{85}\text{At} \xrightarrow{\alpha} \text{V} \xrightarrow{\alpha} \text{W} \xrightarrow{\beta} \text{X}$$

What is the nuclide X?

A $^{213}_{85}\text{At}$ B $^{215}_{77}\text{Ir}$

C $^{209}_{82}\text{Pb}$ D $^{217}_{81}\text{Ti}$

Helping concepts

α-particle is ^4_2He and β-particle is $^0_{-1}\beta$.

$$^{217}_{85}\text{At} \longrightarrow 2\,^4_2\text{He} + ^0_{-1}\beta + ^Z_A\text{X}$$

Mass number: $217 = 2 \times 4 + 0 + Z \Rightarrow Z = 209$

Proton number: $85 = 2 \times 2 + (-1) + A \Rightarrow A = 82$

37. Nuclei of atoms can exist in excited states. When an excited nucleus returns to its state of lowest energy (the ground state), a γ-ray photon may be emitted.

The mass of a nucleus in its ground state is 59.9308u. The energy of the photon emitted when this nucleus returns from an excited state to the ground state is 2.13×10^{-13} J.

What is the mass of the nucleus is the excited state?

A 59.9280u B 59.9294u

C 59.9322u D 59.9337u

Helping concepts

$$E = \Delta mc^2$$

$$\Rightarrow \Delta m = \frac{E}{c^2} = \frac{2.13 \times 10^{-13}}{(3.0 \times 10^8)^2} = 2.37 \times 10^{-30}\text{ kg}$$

$$= 1.43 \times 10^{-3}u$$

$\therefore$ In excited state, the mass is

$$59.9308u + 0.0014u = 59.9322u$$

38. The nucleus Z has the notation ^y_xZ.

The mass defect of this nucleus is Δm.

What is the binding energy per nucleon of the nucleus?

A $\frac{\Delta m}{x}$ B $\frac{\Delta m}{y}$

C $\frac{c^2\Delta m}{x}$ D $\frac{c^2\Delta m}{y}$

Helping concepts

For ^y_xZ,

y = mass number or nucleon number,
x = proton number or atomic number.

$$\text{Binding energy per nucleon} = \frac{\text{energy change}}{\text{total number of nucleons}} = \frac{\Delta mc^2}{y}$$

39. When the nucleus of an atom absorbs one of the atom's orbital electrons, the process is known as k-capture.

Which equation (in which X denotes the appropriate particle) represents the process?

A $^{55}_{26}\text{Fe} + ^0_{-1}\text{X} \longrightarrow ^{55}_{25}\text{Mn}$

B $^{63}_{28}\text{Ni} \longrightarrow ^0_{-1}\text{X} + ^{63}_{29}\text{Cu}$

C $^{10}_{5}B + ^{1}_{0}X \longrightarrow ^{7}_{3}Li + ^{4}_{2}He$

D $^{7}_{3}Li + ^{1}_{1}X \longrightarrow ^{8}_{4}Be$

Helping concepts

When the nucleus of an atom absorbs one of the atom's orbital electrons, its total mass (nucleon) number A is constant before and after the event occurs. The proton number Z is reduced by 1 since absorption of an electron of its own has increased the neutron number by 1. Therefore, M and N are the atoms before and after the event, then the event can be written as

$$^{A}_{Z}M + ^{0}_{-1}X \longrightarrow {}_{Z-1}^{A}N$$

which is best represented by the equation in option A.

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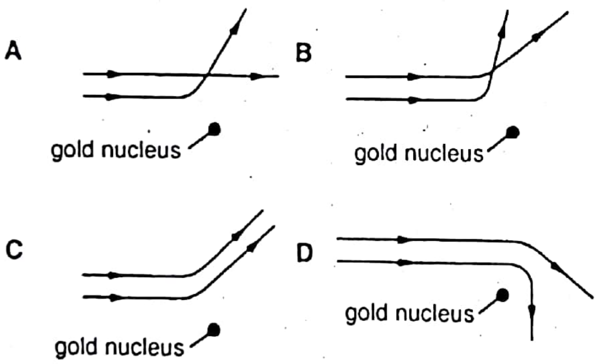
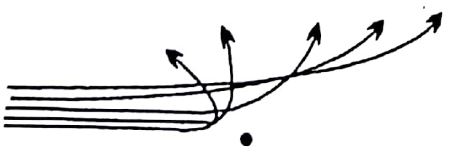
40. Two alpha-particles with equal energies are fired towards the nucleus of a gold atom.

Which diagram could represent their paths?



Helping concepts

The paths of α-particles could look like the following diagram:



α-particles that travel outside the influence of the nucleus will be undeflected.

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41. A nucleus has a nucleon number A, a proton number Z, and a binding energy B. The masses of the neutron and proton are m_n and m_p, respectively, and c is the speed of light.

The mass of the nucleus is given by the expression

A $(A-Z)m_n + Zm_p - \frac{B}{c^2}$

B $(A+Z)m_n + Zm_p + \frac{B}{c^2}$

C $Am_n + Zm_p - \frac{B}{c^2}$

D $Am_n + Zm_p + \frac{B}{c^2}$

Helping concepts

The neutron number is $A-Z$. By considering the binding energy of the nuclide, we may write

$$\left[(A-Z)m_n + Zm_p - \text{mass of the nucleus}\right]c^2 = B$$

i.e. mass of the nucleus $= (A-Z)m_n + Zm_p - \frac{B}{c^2}$.

---

42. Helium nuclei may result from the bombardment of lithium nuclei with protons. The reaction can be represented by the following nuclear equation:

$$^{7}_{3}Li + ^{1}_{1}p \rightarrow 2\left[^{4}_{2}He\right] + \text{energy}$$

The speed of light is c, and the masses of the particles are:

lithium m_L
helium m_H
proton m_P

What is the net energy released during such a reaction?

A $[2m_H - (m_L + m_P)]c^2$

B $[m_L + m_P) - 2m_H]c^2$

C $(2m_H + m_L + m_P)c^2$

D $\frac{(m_L + m_P) - 2m_H}{c^2}$

Helping concepts

Mass defect of this nuclear reaction is $(m_L + m_p) - 2m_H$.

By Einstein's mass-energy relation, the net energy released is thus

$$[(m_L + m_P) - 2m_H]c^2$$

---

43. High energy alpha-particles can transform Nitrogen-14 to Oxygen-17:

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

The sum of the rest masses of the nitrogen and helium nuclei is $18.006u$.

The sum of the rest masses of the oxygen and hydrogen nuclei is $18.007u$.

The energy equivalent of $0.001u$ is 1 MeV.

What do the data show?

A Mass of $0.001u$ has been converted into 1 MeV of energy.

B The kinetic energy of the products exceeds the kinetic energy of the reactants by 1 MeV.

C The kinetic energy of the reactants exceeds the kinetic energy of the products by 1 MeV.

D The reactants had only 1 MeV of kinetic energy and all of this was converted into mass.

Helping concepts

The reactants have a lower sum of rest mass than that of the products. By conservation of total energy, the reactants would have higher kinetic energy than the products.

44. The grid shows a number of nuclides arranged according to the number of protons and the number of neutrons in each.

A nucleus of the nuclide $^{8}_{3}Li$ decays by emitting a β-particle.

What is the resulting nuclide?

number of protons							
4					A	B	
3				$^{6}_{3}Li$	$^{7}_{3}Li$	$^{8}_{3}Li$	
2		$^{3}_{2}He$	$^{4}_{2}He$			C	D
1	$^{1}_{1}H$	$^{2}_{1}H$					
	0	1	2	3	4	5	6

number of neutrons

Helping concepts

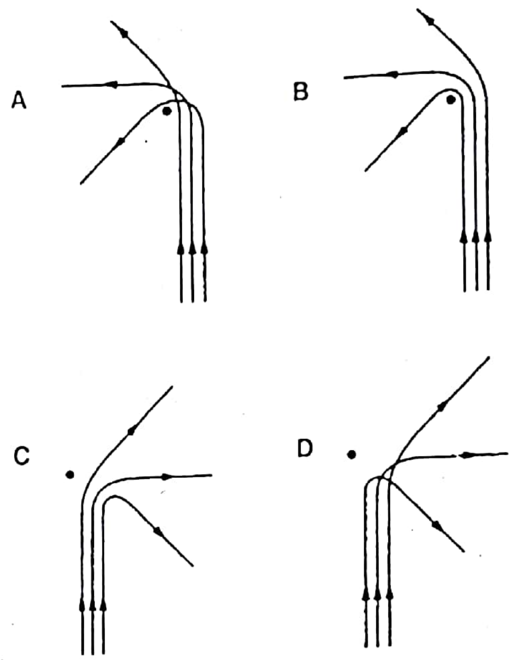
$$^{8}_{3}Li \longrightarrow ^{0}_{-1}\beta + ^{x}_{y}A$$

$8 = 0 + x \Rightarrow x = 8$ (mass number)

$3 = -1 + y \Rightarrow y = 4$ (proton number)

$\therefore$ Neutron $= x - y = 4$

45. Which diagram best represents the paths of α-particle scattered by a gold nucleus?



Helping concepts

Gold nucleus is positive. Hence, there will be repulsion of α-particles and nucleus.

The nearer the α-particle to the nucleus, the greater the angle of deflection.

46. A nucleus of bohrium $^{x}_{y}Bh$ decays to mendelevium $^{255}_{101}Md$ by a sequence of three α-particle emissions.

bohrium $^{x}_{y}Bh \longrightarrow$ dubnium + α

$\quad\longrightarrow$ lawrencium + α

$\quad\quad\longrightarrow$ mendelevium $^{255}_{101}Md + \alpha$

How many neutrons are there in a nucleus of $^{x}_{y}Bh$?

A 267 B 261

C 160 D 154

Helping concepts

$^{x}_{y}Bh \longrightarrow ^{255}_{101}Md + 3\alpha$

$^{x}_{y}Bh \longrightarrow ^{255}_{101}Md + 3(^{4}_{2}He)$

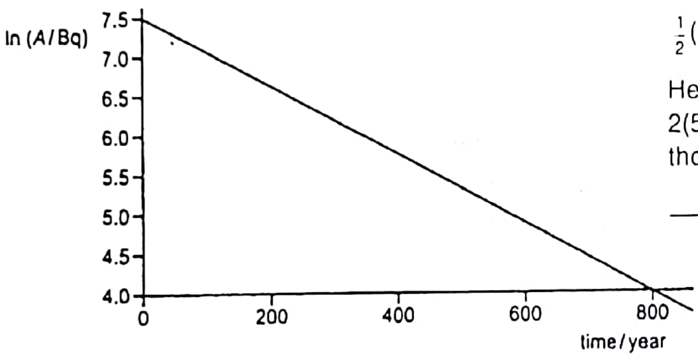
$x = 255 + 3(4) = 267$

$y = 101 + 3(2) = 107$

$\therefore$ Neutron number $= x - y = 267 - 107 = 160$

---

47. A graph of the natural logarithm of the activity A of a radioactive source plotted against time is given:



What is the half-life of the source in years?

A 0.0044 B 160

C 400 D 860

Helping concepts

$A = A_0 e^{-\lambda t} \Rightarrow \ln A = \ln A_0 - \lambda t$

Gradient, $\lambda = -\left(\frac{\Delta(\ln A)}{\Delta t}\right) = -\left(\frac{7.5-4}{0-800}\right)$

$\frac{\ln 2}{t_{1/2}} = 4.375 \times 10^{-3}$ year^{-1}

$\Rightarrow t_{1/2} = \frac{\ln 2}{4.375 \times 10^{-3}} \approx 160$ years

---

48. Radioactive ^{14}C dating was used to find the age of a wooden archaeological specimen. Measurements were taken in three situations for which the following count rates were obtained.

specimen	*count rate*
1 g sample of living wood	80 counts/min
1 g sample of archaeological specimen	35 counts/min
no sample	20 counts/min

If the half-life of ^{14}C is known to be 5700 years, what was the approximate age of the archaeological specimen?

A 2500 years B 7000 years

C 11000 years D 13000 years

Helping concepts

Eliminate the background radioactivity, the actual count rates for living wood is 60 counts/min while that of the specimen is 15 counts/min.

Since the half-life of ^{14}C is 5700 years, it takes 5700 years to decay from 60 counts/min to $\frac{1}{2}(60)$ or 30 counts/min and another 5700 years to decay further to $\frac{1}{2}(30)$ or 15 counts/min.

Hence, the age of the archaeological specimen is 2(5700) or approximately 11000 years to the nearest thousands.

---

49. Which sample of nuclide has the greatest initial activity?

	nuclide	amount / mole	half - life / day
A	$^{225}_{89}Ac$	0.003	10
B	$^{228}_{90}Th$	0.1	400
C	$^{228}_{88}Ra$	0.6	2100
D	$^{241}_{94}Pu$	1.0	4800

Helping concepts

Activity, $A = \lambda N$

$= \frac{\ln 2}{t_{1/2}}(n \cdot N_A)$

$= N_A(\ln 2)(\frac{n}{t_{1/2}})$

where n = amount of substance (mol),
$t_{1/2}$ = half - life,
N_A = Avogadro's number (6.02×10^{23} mol^{-1}).

$\therefore A \propto (\frac{n}{t_{1/2}})$

	$(\frac{n}{t_{1/2}})$ / mol day^{-1}
A	3.0×10^{-4}
B	2.5×10^{-4}
C	2.9×10^{-4}
D	2.1×10^{-4}

50. At time t, a sample of a radioactive substance contains N atoms of a particular nuclide.

At time $(t + \Delta t)$, where Δt is a short period of time, the number of atoms of the nuclide is $(N - \Delta N)$.

Which expression is equal to the decay constant of the nuclide?

A $\frac{\Delta N}{N}$ B $\frac{\Delta N}{\Delta t}$

C $\frac{\Delta N}{N\Delta t}$ D $\frac{N\Delta N}{\Delta t}$

Helping concepts

$$N = N_0 e^{-\lambda t} \text{-----(1)}$$
$$N - \Delta N = N_0 e^{-\lambda(t+\Delta t)} \text{-----(2)}$$

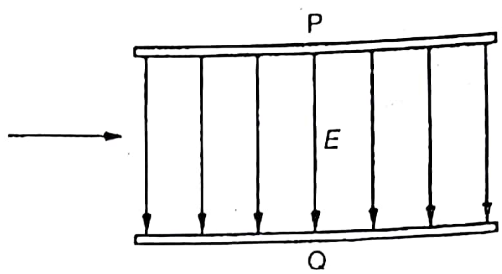
Subst. (1) into (2):

$$N - \Delta N = Ne^{\lambda t}e^{-\lambda(t+\Delta t)}$$
$$N - \Delta N = Ne^{-\lambda\Delta t}$$
$$N - Ne^{-\lambda\Delta t} = \Delta N$$
$$1 - e^{-\lambda\Delta t} = \frac{\Delta N}{N}$$

As Δt is very small, use Maclaurin's expression to approximate for $e^{-\lambda\Delta t}$, $e^{-\lambda\Delta t} \approx 1 + (-\lambda\Delta t) + ...$

$$\therefore\ 1 - (1 - \lambda\Delta t) = \frac{\Delta N}{N}$$
$$\lambda\Delta t = \frac{\Delta N}{N}$$
$$\text{decay constant, } \lambda = \frac{\Delta N}{N\Delta t}$$

51. An α-particle, a β-particle and a γ-photon enter a uniform electric field of strength E between two plates P and Q.



Which row correctly describes their deflections inside the electric field?

	deflection of α-particle	deflection of β-particle	deflection of γ-photon
A	towards P	towards Q	undeflected
B	towards P	undeflected	towards Q
C	towards Q	towards P	undeflected
D	towards Q	undeflected	towards P

Helping concepts

An α-particle is positively charged; a β-particle is negatively charged and a γ-photon is uncharged. In the presence of an electric field, the α-particle will deflect in the same direction as the field; a β-particle will deflect in the opposite direction and the γ-photon will be undeflected.

52. Samples of two radioactive nuclides, **X** and **Y**, each have equal activity A_0 at time $t = 0$. **X** has a half-life of 24 years and **Y** a half-life of 16 years.

The samples are mixed together.

What will be the total activity of the mixture at $t = 48$ years?

A $\frac{1}{12}A_0$ B $\frac{3}{16}A_0$

C $\frac{1}{4}A_0$ D $\frac{3}{8}A_0$

Helping concepts

Given: X has activity A_0 at $t = 0$ and its half-life is 24 years.

Y has activity A_0 at $t = 0$ and its half-life is 16 years.

At $t = 24$ years,

$$\text{activity of X} = \frac{1}{2}A_0$$

At $t = 48$ years,

$$\text{activity of } \mathbf{X} = \frac{1}{4}A_0$$

At $t = 16$ years,

$$\text{activity of } \mathbf{Y} = \frac{1}{2}A_0$$

At $t = 32$ years,

$$\text{activity of } \mathbf{Y} = \frac{1}{4}A_0$$

At $t = 48$ years,

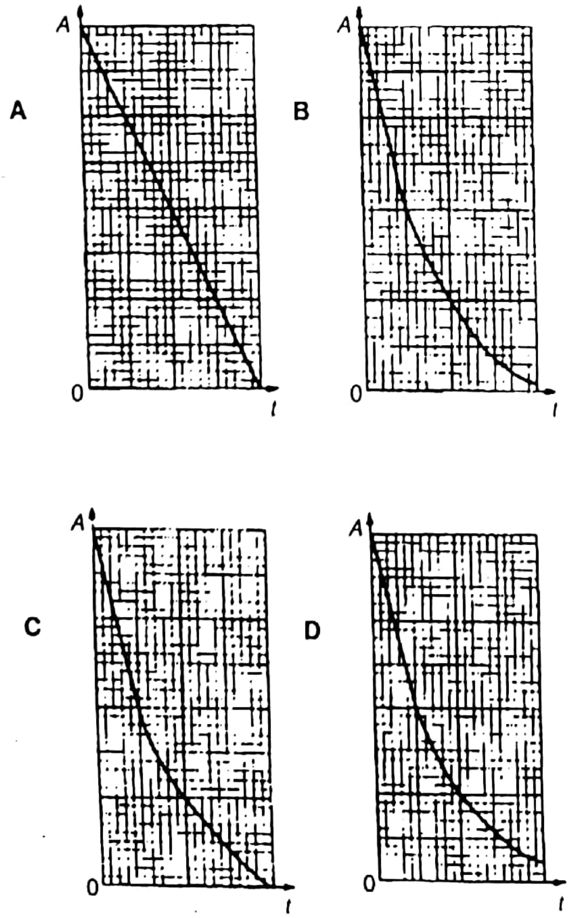
$$\text{activity of } \mathbf{Y} = \frac{1}{8}A_0$$

Hence, total activity of the mixture of **X** and **Y** at $t = 48$ years is

$$\frac{1}{4}A_0 + \frac{1}{8}A_0 = \frac{3}{8}A_0$$

53. A radioactive isotope decays by a one-stage process into a stable nuclide.

Which graph could represent the activity A of the isotope plotted against time t?



Helping concepts

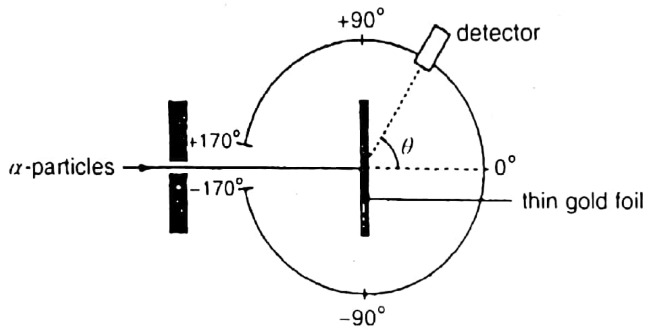
Disintegration of the radioactive isotope occurs exponentially according to the equation

$$A = \frac{dN}{dt} = -\lambda N$$

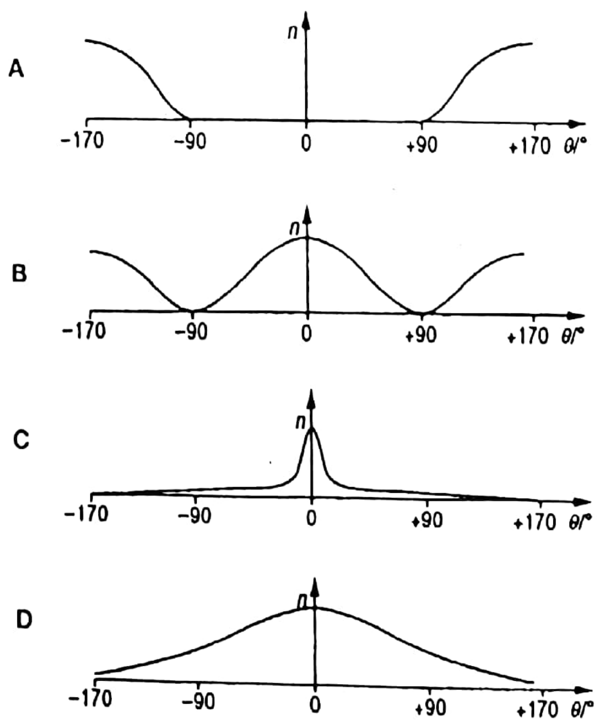
where A is the activity or rate of decay,
λ is the decay constant,
N is the number of disintegrating atoms.

When it becomes a stable nuclide, no further disintegration is possible and hence activity A has to be zero.

54. In an α-particle scattering experiment, a student determined the number n of α-particles incident per unit time on a detector held at various angular positions θ.



Which graph best represents the variation of n with θ?

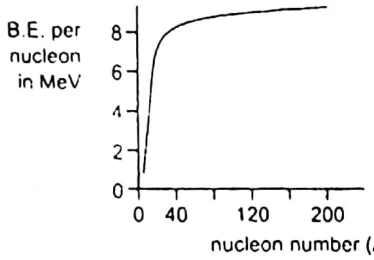


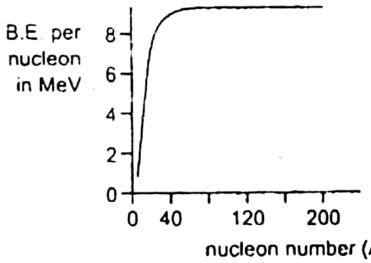
Helping concepts

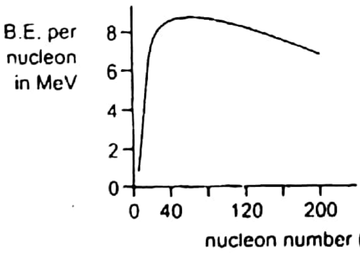
The experiment shows that most electrons passed through the gold foil without change in direction.

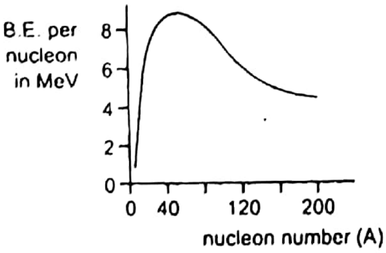
55. The binding energy (B.E.) per nucleon is a useful measure of the stability of a nucleus.

Which graph shows how the B.E. per nucleon varies with the nucleon number (A)?

A


B


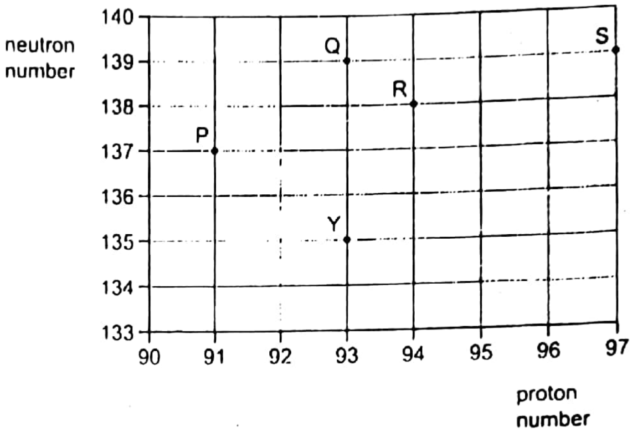
C


D


Helping concepts

The B.E. per nucleon will increase as nucleon number increases from 1 to a peak at 8.5 MeV at approximately nucleon number of 56 before decreasing in a linear trend.

56. Isotope Y forms after two successive decays. Each decay can be either alpha-emission or beta-emission. Four other isotopes, P, Q, R and S, are shown on the diagram.



How many of the isotopes P, Q, R and S could be the initial isotope that, after two successive decays, became Y?

A 1
B 2
C 3
D 4

Helping concepts

To find the original isotope before decay, isotope Y has to be added either with alpha or beta emission.

There are 4 possible isotopes with the following processes:

Process 1: Y + alpha + alpha

	Y	alpha	alpha	total
neutron	135	2	2	139
proton	93	2	2	97

Process 2: Y + alpha + beta

	Y	alpha	beta	total
neutron	135	2	0	137
proton	93	2	−1	94

Process 3: Y + beta + alpha

	Y	beta	alpha	total
neutron	135	0	2	137
proton	93	−1	2	94

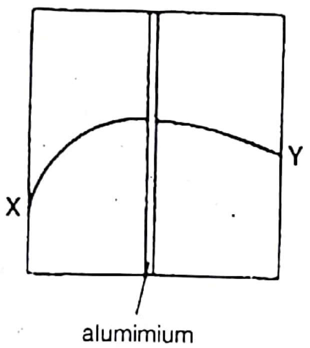
Process 4: Y + beta + beta

	Y	beta	beta	total
neutron	135	0	0	135
proton	93	−1	−1	91

Hence, there is only 1 isotope S that can be decayed by 2 alpha particles to form isotope Y.

---

57. Radiation from a radioactive source enters an evacuated region in which there is a uniform magnetic field perpendicular to the plane of the diagram. This region is divided into two by a sheet of aluminium about 1 mm thick. The curved, horizontal path followed by the radiation is shown in the diagram below.



Which of the following correctly descibes the type of radiation and its point of entry?

	type of radiation	point of entry
A	alpha	X
B	alpha	Y
C	beta	X
D	beta	Y

Helping concepts

γ-rays are electromagnetic waves of which no deflection is observed when a beam of γ-rays is allowed to pass through a magnetic field. Since the presence of magnetic field deflect the path of the radiation, particularly near X, the radiation must either be α-particles or β-particles.

α-particles can be cut out by the thin aluminium sheet about 1 mm thick which is not the case here. Hence, we conclude that the radiation must be β-particles.

The radius of circular orbit r of an β-particle in the presence of the magnetic field B is given by

$$r = \frac{mV}{qB}$$

where m is the mass of the β-particle,

q is the charge on the β-particle,

V is the speed of the β-particle.

The smaller the speed V, the smaller will be the radius of the circular orbit since r is directly proportional to V.

After the β-particles pass through the aluminium sheet, its speed V is reduced and the radius of the orbit is also reduced which is the case for the β-particles in the region near X. Thus, the point of entry of the β-particles must be at Y.

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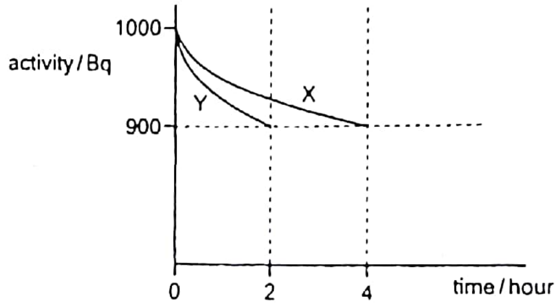
58. The graph shows how the activities of two isotopes X and Y vary with time.



What will be the ratio $\frac{\text{activity of X}}{\text{activity of Y}}$ after each has decayed for 8 hours?

A $\frac{9}{10}$ B $\frac{10}{9}$

C $\frac{81}{100}$ D $\frac{100}{81}$

Helping concepts

Note that the decay constants of X and Y are different and are defined as λX and λY.

Uisng activity, $A = A_0 e^{-\lambda t}$, we have

$$\begin{cases} 900 = 1000e^{-(\lambda X)(4)} \text{ -----(1)} \\ 900 = 1000e^{-(\lambda Y)(2)} \text{ -----(2)} \end{cases}$$

$$(1) = (2): \; e^{-(\lambda X)(4)} = e^{-(\lambda Y)(2)}$$

$$(\lambda X)(4) = (\lambda Y)(2)$$

$$2(\lambda X) = \lambda Y \text{ -----(3)}$$

To find the ratio of the activity at time $t = 8$ hours, we have

$$\begin{cases} A_X = 1000e^{-(\lambda X)(8)} \text{ -----(1)} \\ A_Y = 1000e^{-(\lambda Y)(8)} \text{ -----(2)} \end{cases}$$

$$\frac{(4)}{(5)}: \; \frac{A_X}{A_Y} = \frac{e^{-(\lambda X)(8)}}{e^{-(\lambda Y)(8)}} \text{ -----(6)}$$

AnSwERs

ANSWERS

Topic 1 Measurement

1. B	2. B	3. B	4. A	5. D
6. D	7. B	8. D	9. A	10. A
11. B	12. A	13. C	14. C	15. D
16. C	17. C	18. B	19. C	20. C
21. A	22. D	23. C	24. B	25. C
26. C	27. C	28. D	29. D	30. B
31. A	32. D	33. A	34. D	35. B
36. A	37. D	38. C	39. A	40. C
41. B	42. D	43. B	44. B	45. C
46. C	47. C	48. D	49. C	50. B
51. D	52. B	53. A	54. D	55. C
56. B	57. D	58. A	59. D	60. C
61. C				

Topic 2 Kinematics

1. D	2. B	3. D	4. D	5. A
6. D	7. A	8. A	9. D	10. D
11. B	12. B	13. D	14. A	15. A
16. C	17. D	18. D	19. D	20. D
21. A	22. B	23. D	24. B	25. C
26. C	27. D	28. C	29. D	30. A
31. B	32. D	33. C	34. D	35. C
36. C	37. A	38. A	39. D	40. C
41. D	42. B	43. A	44. C	45. B
46. D				

Topic 3 Dynamics

1. B	2. A	3. B	4. D	5. D
6. C	7. D	8. B	9. B	10. D
11. B	12. A	13. B	14. B	15. C
16. A	17. C	18. B	19. A	20. B
21. A	22. A	23. B	24. A	25. C
26. D	27. A	28. B	29. A	30. A
31. C	32. B	33. C	34. C	35. A
36. B	37. C	38. B	39. A	40. B
41. C	42. A	43. D		

Topic 4 Forces

1. C	2. B	3. D	4. D	5. C
6. C	7. D	8. C	9. B	10. C
11. A	12. B	13. C	14. B	15. A

16. B	17. D	18. B	19. A	20. B
21. B	22. A	23. B	24. B	25. D
26. C	27. C	28. B	29. D	30. B
31. C	32. D	33. A	34. D	35. B
36. A	37. A	38. C	39. C	40. A
41. A	42. D	43. B	44. D	45. D
46. D	47. A	48. C	49. B	50. C
51. C	52. B			

Topic 5 Work, Energy and Power

1. A	2. D	3. C	4. A	5. B
6. A	7. D	8. C	9. B	10. D
11. B	12. B	13. C	14. D	15. B
16. D	17. D	18. D	19. D	20. B
21. D	22. B	23. A	24. C	25. C
26. A	27. C	28. D	29. A	30. D
31. C	32. B	33. B	34. B	35. C
36. B	37. A	38. B	39. A	40. A
41. D	42. D	43. D	44. B	45. D
46. B				

Topic 6 Motion in a Circle

1. B	2. B	3. D	4. B	5. D
6. A	7. B	8. B	9. B	10. D
11. C	12. C	13. D	14. A	15. B
16. B	17. A	18. D	19. D	20. A
21. B	22. C	23. B	24. D	25. A
26. C				

Topic 7 Gravitational Field

1. D	2. C	3. C	4. D	5. D
6. B	7. C	8. A	9. C	10. B
11. B	12. D	13. D	14. A	15. C
16. D	17. A	18. B	19. A	20. C
21. A	22. A	23. D	24. B	25. B
26. C	27. C	28. B	29. B	30. D
31. A	32. D	33. B	34. A	35. B
36. D				

Topic 8 Oscillations

1. C	2. A	3. C	4. D	5. D
6. D	7. A	8. B	9. D	10. B
11. B	12. D	13. C	14. D	15. C
16. B	17. C	18. A	19. A	20. D
21. A	22. C	23. D	24. A	25. C
26. D	27. C	28. A	29. D	30. D
31. D				

Topic 9 Thermal Physics

1. B	2. C	3. C	4. C	5. C
6. A	7. B	8. D	9. B	10. B
11. D	12. C	13. C	14. B	15. B
16. C	17. D	18. D	19. A	20. A
21. D	22. C	23. D	24. B	25. C
26. C	27. D	28. C	29. D	30. A
31. C	32. D	33. C	34. A	35. C
36. D	37. D	38. B	39. A	40. C
41. B	42. D	43. A	44. D	45. B
46. A	47. B	48. A	49. C	50. B
51. C	52. C	53. C	54. D	55. D
56. A	57. C	58. B	59. C	60. C
61. D				

Topic 10 Wave Motion

1. A	2. C	3. D	4. B	5. D
6. C	7. B	8. D	9. B	10. B
11. A	12. B	13. B	14. D	15. A
16. D	17. D	18. B	19. B	20. D
21. D	22. D	23. A	24. B	25. B
26. C	27. A	28. B	29. A	30. B
31. C	32. B	33. B	34. B	35. C
36. A	37. C	38. B	39. D	40. C
41. A	42. D	43. B	44. A	45. A
46. C	47. C			

Topic 11 Superposition

1. C	2. C	3. D	4. B	5. B
6. D	7. B	8. D	9. B	10. D
11. A	12. B	13. C	14. C	15. C
16. B	17. A	18. D	19. D	20. D
21. B	22. D	23. D	24. C	25. D
26. B	27. B	28. D	29. D	30. B
31. C	32. B	33. B	34. D	35. B
36. A	37. B	38. D	39. A	40. C
41. C	42. C	43. A	44. C	45. D
46. D	47. D	48. D	49. A	50. B
51. B	52. C	53. D	54. B	55. A
56. D	57. C	58. C	59. A	

Topic 12 Electric Fields

1. D	2. B	3. A	4. B	5. D
6. D	7. B	8. D	9. C	10. B
11. A	12. A	13. C	14. D	15. C
16. A	17. C	18. D	19. D	20. D

21. A	22. C	23. A	24. D	25. D
26. D	27. C	28. B	29. A	30. B
31. B	32. C	33. B	34. D	35. D
36. A	37. C	38. C	39. B	40. B
41. A	42. A	43. D	44. A	45. A
46. D	47. B	48. A	49. B	50. D
51. D	52. A	53. A	54. A	

Topic 13 Current of Electricity

1. A	2. D	3. B	4. D	5. D
6. A	7. D	8. C	9. A	10. C
11. C	12. C	13. A	14. A	15. D
16. A	17. C	18. A	19. B	20. D
21. A	22. B	23. B	24. A	25. B
26. C	27. C	28. D	29. D	30. C
31. A	32. A	33. B	34. B	35. A
36. B	37. C	38. C	39. D	40. C
41. B	42. C	43. C	44. A	45. C
46. B				

Topic 14 D.C. Circuits

1. B	2. C	3. B	4. C	5. D
6. A	7. B	8. B	9. B	10. D
11. B	12. C	13. A	14. C	15. C
16. B	17. C	18. D	19. B	20. A
21. A	22. A	23. A	24. D	25. D
26. D	27. A	28. D	29. D	30. C
31. B	32. B	33. A	34. C	35. D
36. D	37. C	38. D	39. A	40. A
41. B	42. D	43. C	44. D	45. A
46. D	47. D	48. B	49. D	50. B
51. D	52. C			

Topic 15 Electromagnetism

1. A	2. A	3. C	4. D	5. D
6. C	7. C	8. B	9. B	10. B
11. D	12. C	13. B	14. B	15. A
16. D	17. B	18. B	19. B	20. B
21. B	22. B	23. A	24. D	25. B
26. B	27. C	28. A	29. C	30. A
31. B	32. C	33. C	34. D	35. C
36. A	37. B	38. A	39. B	40. A
41. C				

Topic 16 Electromagnetic Induction

1. B	2. B	3. B	4. A	5. A
6. C	7. C	8. D	9. A	10. D

11. B	12. D	13. B	14. A	15. B
16. D	17. D	18. D	19. C	20. C
21. D	22. D	23. B	24. D	25. C
26. D	27. C	28. A	29. B	30. C

Topic 17 Alternating Currents

1. B	2. A	3. A	4. B	5. C
6. D	7. A	8. A	9. D	10. D
11. C	12. C	13. B	14. D	15. C
16. D	17. A	18. C	19. D	20. A
21. B	22. C	23. D	24. B	25. A
26. D				

Topic 18 Quantum Physics

1. C	2. D	3. C	4. C	5. D
6. A	7. C	8. B	9. D	10. B
11. D	12. C	13. D	14. B	15. C
16. B	17. C	18. C	19. C	20. D
21. B	22. C	23. C	24. C	25. A
26. A	27. B	28. B	29. C	30. C
31. A	32. D	33. D	34. A	35. B
36. B				

Topic 19 Lasers and Semiconductors

1. B	2. D	3. D	4. A	5. D
6. C	7. D	8. C	9. B	10. C
11. A	12. B	13. A	14. A	15. B
16. A	17. C	18. A	19. C	20. A
21. D	22. A	23. C	24. B	25. D
26. B	27. A	28. B	29. D	30. D
31. D				

Topic 20 Nuclear Physics

1. A	2. D	3. A	4. C	5. C
6. D	7. C	8. C	9. B	10. D
11. C	12. A	13. B	14. A	15. D
16. C	17. B	18. C	19. C	20. D
21. B	22. D	23. C	24. C	25. A
26. C	27. C	28. A	29. A	30. A
31. C	32. A	33. D	34. C	35. B
36. C	37. C	38. D	39. A	40. B
41. A	42. B	43. C	44. A	45. D
46. C	47. B	48. C	49. A	50. C
51. C	52. D	53. C	54. C	55. C
56. A	57. D	58. D		

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