4

Matrix-Matching-Type Questions

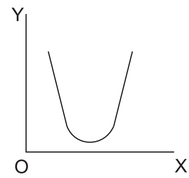
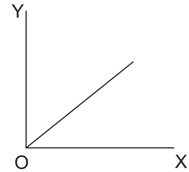
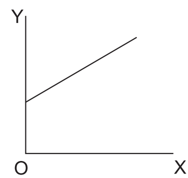
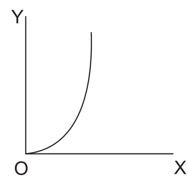
The questions given in this chapter contain two or more columns each. Match the contents of Column A with those of Column B, Column C, etc., by darkening the appropriate bubbles in the matrix given in the answer sheet.

4.1 General Physics

1. Some physical quantities are given in Column A and some SI units in which these quantities may be expressed are given in Column B.

Column A	*Column B*
(i) GM_eM_s, where G = universal gravitational constant M_e = mass of the earth M_s = mass of the sun	(a) V C m
(ii) $\dfrac{3RT}{M}$, where R = universal gas constant T = absolute temperature M = molar mass	(b) kg m^3 s^{-2}
(iii) $\dfrac{F^2}{q^2B^2}$, where F = force, q = charge B = magnetic flux density	(c) m^2 s^{-2}
(iv) $\dfrac{GM_e}{R_e}$, where G = universal gravitational constant M_e = mass of the earth R_e = radius of the earth	(d) F V^2 kg^{-1}

2. Column A gives a list of possible set of parameters measured in some experiments. The variations of the parameters in the form of graphs are shown in Column B.

Column A	***Column B***
(i) The potential energy of a simple pendulum (y-axis) as a function of its displacement (x-axis)	(a) 
(ii) Displacement (y-axis) as a function of time (x-axis) for a one-dimensional motion at zero or constant acceleration when the body is moving along the positive x-direction	(b) 
(iii) The range of a projectile (y-axis) as a function of its velocity (x-axis) when projected at a fixed angle	(c) 
(iv) The square of the time period (y-axis) of a simple pendulum as a function of its length (x-axis)	(d) 

3. Match Column A with Column B and select the correct answer from the codes given below the columns.

Column A	***Column B***
(i) Boltzmann constant	(a) $ML^2\,T^{-1}$
(ii) Coefficient of viscosity	(b) $ML^{-1}\,T^{-1}$
(iii) Planck constant	(c) $MLT^{-3}\,K^{-1}$
(iv) Thermal conductivity	(d) $ML^2T^{-2}\,K^{-1}$

Codes:

	(i)	(ii)	(iii)	(iv)
P →	(c)	(a)	(b)	(d)
Q →	(c)	(b)	(a)	(d)
R →	(d)	(b)	(a)	(c)
S →	(d)	(a)	(b)	(c)

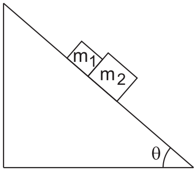
4. A person in a lift is holding a water jar which has a small hole at the lower end of its side. When the lift is at rest, the water jet coming out of the hole hits the floor of the lift at a distance d of 1.2 m from the person. In the following table, the states of the lift's motion are given in Column A and the distances where the water jet hits the floor of the lift are given in Column B. Match the statements in Column A with those in Column B and select the correct code.

Column A	*Column B*
(i) The lift is accelerating vertically up.	(a) $d = 1.2$ m
(ii) The lift is accelerating vertically down with an acceleration less than the gravitational acceleration.	(b) $d > 1.2$ m
(iii) The lift is moving vertically up with a constant speed.	(c) $d < 1.2$ m
(iv) The lift is falling freely.	(d) No water leaks out of the jar.

Codes:

P →	(i) – (b)	(ii) – (c)	(iii) – (b)	(iv) – (d)
Q →	(i) – (b)	(ii) – (c)	(iii) – (a)	(iv) – (d)
R →	(i) – (a)	(ii) – (a)	(iii) – (a)	(iv) – (d)
S →	(i) – (b)	(ii) – (c)	(iii) – (a)	(iv) – (a)

5. A block of mass m_1 = 1 kg and another one of mass m_2 = 2 kg are placed together (see figure) on an inclined plane with an angle of inclination θ. Various values of θ are given in Column A. The coefficient of friction between the block m_1 and the plane is always zero. The coefficients of static and dynamic frictions between the block m_2 and the plane are equal to μ = 0.3. In Column B, the expressions for the friction on the block m_2 are given. Match the correct expressions of the friction in Column B with the angles given in Column A, and choose the correct code.



[Useful information: tan 5.5° ≈ 0.1, tan 11.5° ≈ 0.2, tan 16.5° ≈ 0.3]

Column A	*Column B*
(i) $\theta = 5°$	(a) $m_2 g \sin\theta$
(ii) $\theta = 10°$	(b) $(m_1 + m_2)g \sin\theta$
(iii) $\theta = 15°$	(c) $\mu m_2 g \cos\theta$
(iv) $\theta = 20°$	(d) $\mu(m_1 + m_2)g \cos\theta$

Codes:

P →	(i) – (a)	(ii) – (a)	(iii) – (a)	(iv) – (c)
Q →	(i) – (b)	(ii) – (b)	(iii) – (b)	(iv) – (c)
R →	(i) – (b)	(ii) – (b)	(iii) – (b)	(iv) – (d)
S →	(i) – (b)	(ii) – (b)	(iii) – (c)	(iv) – (c)

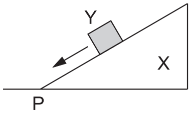
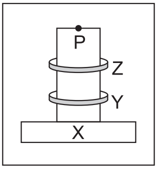
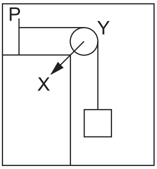
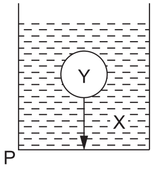
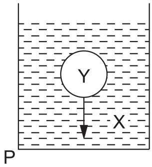
6. A particle of unit mass is moving along the x-axis under the influence of a force and its total energy is conserved. Four possible forms of the potential energy of the particle are given in Column A (a and U_0 are constants). Match the potential energies in Column A with the corresponding statement(s) in Column B.

Column A	*Column B*
(i) $U_1(x) = \frac{U_0}{2}\left[1 - \left(\frac{x}{a}\right)^2\right]^2$	(a) The force acting on the particle is zero at $x = a$.
(ii) $U_2(x) = \frac{U_0}{2}\left(\frac{x}{a}\right)^2$	(b) The force acting on the particle is zero at $x = 0$.
(iii) $U_3(x) = \frac{U_0}{2}\left(\frac{x}{a}\right)^2 \exp\left[-\left(\frac{x}{a}\right)^2\right]$	(c) The force acting on the particle is zero at $x = -a$.
(iv) $U_4(x) = \frac{U_0}{2}\left[\frac{x}{a} - \frac{1}{3}\left(\frac{x}{a}\right)^3\right]$	(d) The particle experiences an attractive force towards $x = 0$ in the region $\lvert x \rvert < a$.
	(e) The particle with total energy $\frac{U_0}{4}$ can oscillate about the point $x = -a$.

7. Column A describes some situations where a small object is in motion. Column B describes some characteristics of these motions. Match the situations in Column A with the characteristics in Column B.

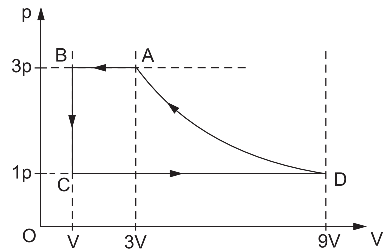
Column A	*Column B*
(i) The object moves along the x-axis under a conservative force in such a way that its speed and position satisfy $v = C_1\sqrt{C_2 - x^2}$, where C_1 and C_2 are positive constants.	(a) The object executes a simple harmonic motion.
(ii) The object moves along the x-axis in such a way that its velocity and displacement from the origin satisfy $v = -Kx$, where K is a positive constant.	(b) The object does not change its direction.
(iii) The object is attached to one end of a massless spring of a given spring constant. The other end of the spring is attached to the ceiling of an elevator. Initially everything is at rest. The elevator starts going upwards with a constant acceleration a. The motion of the object is observed from the elevator during the period it maintains the accelaration.	(c) The kinetic energy of the object keeps on decreasing.
(iv) The object is projected from the earth's surface vertically upwards with a speed $2\sqrt{GM/R_e}$, where M_e is the mass of the earth and R_e is the radius of the earth. Neglect forces from objects other than the earth.	(d) The object can change its direction only once.

8. Column B shows five systems in which two objects are labelled as X and Y. Also, in each case a point P is shown. Column A lists some statements about X and/or Y. Match these statements to the appropriate system(s) from Column B.

Column A	***Column B***
(i) The force exerted by X on Y has a magnitude Mg.	(a) Block Y of mass M left on a fixed inclined plane X, slides down it with a constant velocity. 
(ii) The gravitational potential energy of X is continuously increasing.	(b) Two ring magnets Y and Z, each of mass M are kept in a frictionless vertical plastic stand, so that they repel each other. Y rests on the base X, and Z hangs in the air in equilibrium. P is the topmost point of the stand on the common axis of the two rings. The whole system is in a lift moving up with a constant velocity. 
(iii) Mechanical energy of the system (X + Y) is continuously decreasing.	(c) A pulley Y of mass m_0 is fixed to a table through a clamp X. A block of mass M hangs from a string that goes over the pulley and is fixed at point P of the table. The whole system is kept in a lift moving upward with a constant velocity. 
(iv) The torque of the weight of Y about the point P is zero.	(d) A sphere Y of mass M is put in a nonviscous liquid X kept in a container at rest. The sphere is released and it moves down in the liquid. 
	(e) A sphere Y of mass M is falling with its terminal velocity in a viscous liquid X kept in a container. 

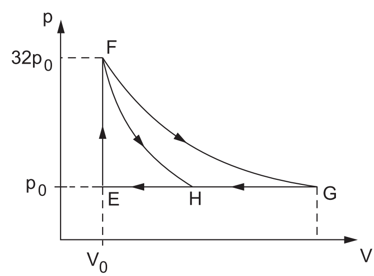
4.2 Heat and Thermodynamics

1. One mole of a monatomic gas is taken through a cycle ABCDA as shown in the *p–V* diagram. Column B gives the characteristics involved in the cycle. Match them with each of the processes given in Column A.



Column A	*Column B*
(i) Process A → B	(a) Internal energy decreases
(ii) Process B → C	(b) Internal energy increases
(iii) Process C → D	(c) Heat is lost
(iv) Process D → A	(d) Heat is gained
	(e) Work is done on the gas

2. One mole of a monatomic ideal gas is taken along two cyclic processes $E \to F \to G \to E$ & $E \to F \to H \to E$, as shown in the *p-V* diagram. The processes involved are purely isochoric, isobaric, isothermal or adiabatic.



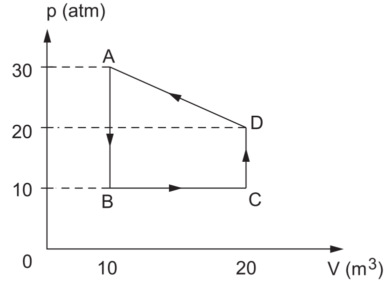
Match the paths given in Column A with the magnitudes of work done given in Column B and select the correct option (only one), using the codes given below the columns.

Column A	*Column B*
(i) G → E	(a) $160p_0V_0 \ln 2$
(ii) G → H	(b) $36p_0V_0$
(iii) F → H	(c) $24p_0V_0$
(iv) F → G	(d) $31p_0V_0$

Codes:

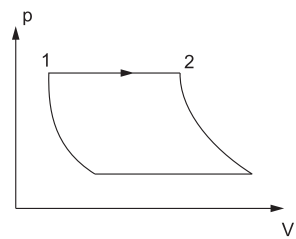
	(i)	(ii)	(iii)	(iv)
P →	(d)	(c)	(b)	(a)
Q →	(d)	(c)	(a)	(b)
R →	(c)	(a)	(b)	(d)
S →	(a)	(c)	(b)	(d)

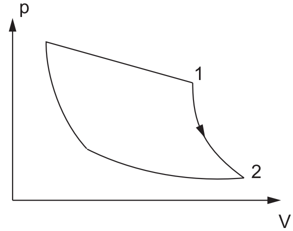
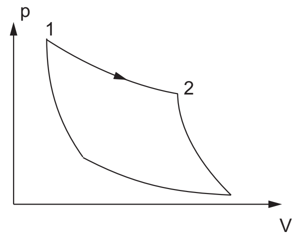
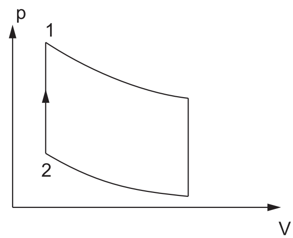
3. If the heat given to a process is considered to be positive, match the following options of Column A with their corresponding options given in Column B.



Column A	*Column B*
(i) A → B	(a) $\Delta W > 0$
(ii) B → C	(b) $\Delta Q < 0$
(iii) C → D	(c) $\Delta W < 0$
(iv) D → A	(d) $\Delta Q > 0$

4. An ideal gas is undergoing a cyclic thermodynamic process in different ways as shown in the corresponding *p-V* diagrams in Column C of the table. Consider only the path from the state 1 to state 2. *W* denotes the corresponding work done on the system. The equations and plots in the table have standard notations as used in the thermodynamic processes. Here γ is the ratio of the heat capacities at constant pressure and constant volume. The number of moles in the gas is n.

Column A	*Column B*	*Column C*
(i) $W_{1\to2} = \frac{1}{\gamma-1}(p_2V_2 - p_1V_1)$	(i) Isothermal	(a) 

(ii) $W_{1\to 2} = -pv_2 + pv_1$	(ii) Isochoric	(b) 
(iii) $W_{1\to 2} = 0$	(iii) Isobaric	(c) 
(iv) $W_{1\to 2} = -nRT \ln \dfrac{V_2}{V_1}$	(iv) Adiabatic	(d) 

4A. Which of the following options is the only correct representation of a process, where $\Delta U = \Delta Q - p\Delta V$?

[P] $\rightarrow$ (ii) (iv) (c) [Q] $\rightarrow$ (ii) (iii) (a)

[R] $\rightarrow$ (ii) (iii) (d) [S] $\rightarrow$ (iii) (iii) (a)

4B. Which one of the following options is the correct combination?

[P] $\rightarrow$ (iii) (ii) (d) [Q] $\rightarrow$ (ii) (iv) (c)

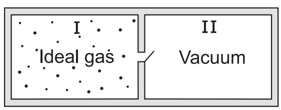
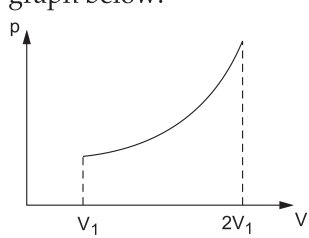
[R] $\rightarrow$ (ii) (iv) (a) [S] $\rightarrow$ (iv) (ii) (d)

4C. Which one of the following options correctly represents a thermodynamic process that is used as a correction in the determination of the speed of sound in an ideal gas?

[P] $\rightarrow$ (iii) (iv) (c) [Q] $\rightarrow$ (i) (ii) (b)

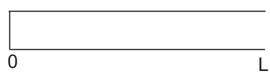
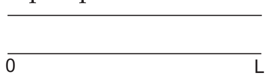
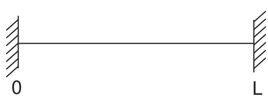
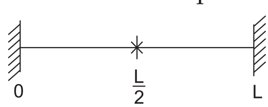
[R] $\rightarrow$ (iv) (ii) (c) [S] $\rightarrow$ (i) (iv) (b)

5. Column A contains a list of processes involving expansion of an ideal gas. Match these with the thermodynamic changes during the processes as described in Column B.

Column A	***Column B***
(i) An insulated container has two chambers separated by a valve as shown in the figure below. Chamber I contains an ideal gas and chamber II has vacuum. The valve is opened.  	(a) The temperature of the gas decreases.
(ii) An ideal monatomic gas expands to twice its original volume such that its pressure $p \propto \frac{1}{V^2}$, where V is the volume of the gas.	(b) The temperature of the gas increases or remains constant.
(iii) An ideal monatomic gas expands to twice its original volume such that its pressure $p \propto \frac{1}{V^{4/3}}$, where V is its volume.	(c) The gas loses heat.
(iv) An ideal monatomic gas expands such that its pressure p and volume V follows the behaviour as shown in the graph below.  	(d) The gas gains heat.

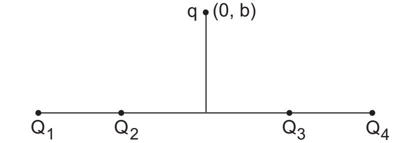
4.3 Sound Waves

1. Column A shows four systems, each with the same length L, for producing standing waves. The lowest possible natural frequency is called its fundamental frequency, whose wavelength is denoted as λ_f. Match each system of Column A with statements given in Column B describing the nature and wavelength of the standing waves.

<table>
<tr><th>Column A</th><th>Column B</th></tr>
<tr><td>(i) Pipe closed at one end

</td><td>(a) Longitudinal waves</td></tr>
<tr><td>(ii) Pipe open at both ends

</td><td>(b) Transverse waves</td></tr>
<tr><td>(iii) Stretched wire clamped at both ends

</td><td>(c) $\lambda_f = L$</td></tr>
<tr><td>(iv) Stretched wire clamped at both ends and at midpoint

</td><td>(d) $\lambda_f = 2L$</td></tr>
<tr><td></td><td>(e) $\lambda_f = 4L$</td></tr>
</table>

4.4 Electrostatics

1. Four charges Q_1, Q_2, Q_3 and Q_4 of the same magnitude are fixed along the x-axis at $x = -2a$, $-a$, $+a$ and $+2a$ respectively. A positive charge q is placed



on the positive y-axis at a distance $b > 0$. Four options of the signs of these charges are given in Column A. The direction of the forces on the charge q is given in Column B. Match Column A with Column B and select the correct answer using the codes given below the columns.

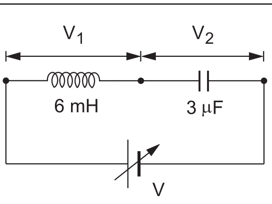
Column A	*Column B*
(i) Q_1, Q_2, Q_3, Q_4 all positive	(a) $+x$
(ii) Q_1, Q_2 positive; Q_3, Q_4 negative	(b) $-x$
(iii) Q_1, Q_4 positive; Q_2, Q_3 negative	(c) $+y$
(iv) Q_1, Q_3 positive; Q_2, Q_4 negative	(d) $-y$

Codes:

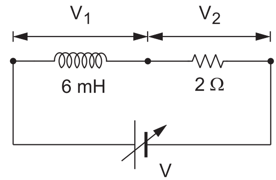
P $\rightarrow$	(i) – (c)	(ii) – (a)	(iii) – (d)	(iv) – (b)
Q $\rightarrow$	(i) – (d)	(ii) – (b)	(iii) – (c)	(iv) – (a)
R $\rightarrow$	(i) – (c)	(ii) – (a)	(iii) – (b)	(iv) – (d)
S $\rightarrow$	(i) – (d)	(ii) – (b)	(iii) – (a)	(iv) – (c)

4.5 Current Electricity and Magnetism

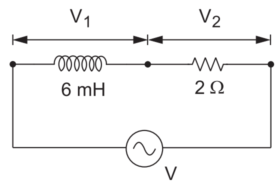
1. You are given many resistors, capacitors and inductors. These are connected to a variable DC voltage source (the first two circuits) or an AC voltage source of 50 Hz frequency (the next three circuits) in different ways as shown in Column B. When a current I (steady state for DC or rms for AC) flows through the circuit, the corresponding voltage V_1 and V_2 (indicated in circuits) are related as shown in Column A. Match the two.

Column A	*Column B*
(i) $I \neq 0$, V_1 is proportional to I	(a) 

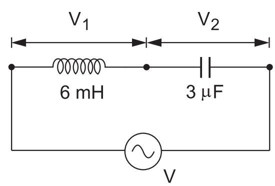
(ii) $I \neq 0$, $V_2 > V_1$

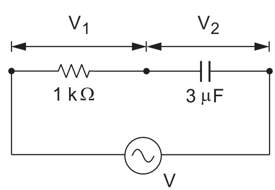
(b) 

(iii) $V_1 = 0$, $V_2 = V$

(c) 

(iv) $I \neq 0$, V_2 is proportional to I

(d) 

(e) 

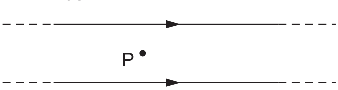
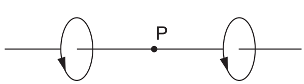
2. Match Column A with Column B.

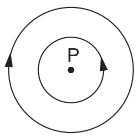
Column A	*Column B*
(i) A uniformly charged dielectric ring	(a) A time-independent electrostatic field directed out of the system
(ii) A uniformly charged dielectric ring rotating with an angular velocity ω	(b) A magnetic field
(iii) A ring carrying a constant current i_0	(c) An induced electric field
(iv) $i = i_0 \cos \omega t$	(d) A magnetic moment

3. Column A gives certain situations in which a straight metallic wire of resistance R is used and Column B gives some resulting effects. Match the statements in Column A with the statements in Column B.

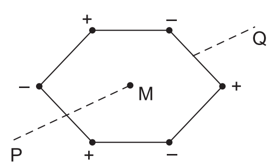
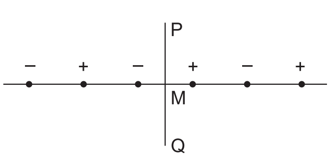
Column A	***Column B***
(i) A charged capacitor is connected to the ends of the wire.	(a) A constant current flows through the wire.
(ii) The wire is moved perpendicular to its length with a constant velocity in a uniform magnetic field perpendicular to the plane of its motion.	(b) Thermal energy is generated in the wire.
(iii) The wire is placed in a constant electric field that has its direction along the length of the wire.	(c) A constant potential difference develops between the ends of the wire.
(iv) A battery of constant emf is connected to the ends of the wire.	(d) Charges of constant magnitude appear at the ends of the wire.

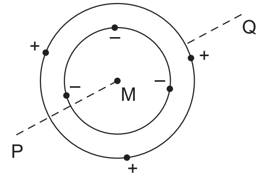
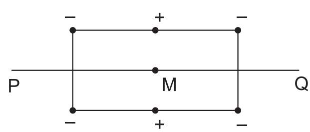
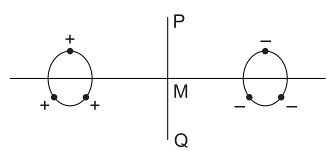
4. Two wires, each carrying a steady current I, are shown in four configurations in Column A. Some of the resulting effects are described in Column B. Match the statements in the two columns.

Column A	***Column B***
(i) P is situated between the wires. 	(a) The magnetic field (B) at P due to the currents in the wires are in the same directions.
(ii) P is situated at the midpoint of the line joining the centres of the circular wires, which have the same radii. 	(b) The magnetic fields at P due to the currents in the wires are in opposite directions.

(iii) P is situated at the midpoint of the line joining the centres of the circular wires, which have the same radii. 	(c) There is no magnetic field at P.
(iv) P is situated at the common centre of the wires. 	(d) The wires repel each other.

5. Six point charges, each of the same magnitude q, are arranged in different manners as shown in Column B. Let E be the electric field and V be the electric potential at M (potential at infinity is zero) due to the given charge distribution when it is at rest. The whole system is set into rotation with a constant angular velocity about the line PQ. Let B be the magnetic field at M and μ be the magnetic moment of the system in this condition. Assume each rotating charge to be equivalent to a steady current.

Column A	*Column B*
(i) $E = 0$	(a) The charges are at the corners of a regular hexagon. M is at the centre of the hexagon. PQ is perpendicular to the plane of the hexagon. 
(ii) $V \neq 0$	(b) The charges are on a line perpendicular to PQ, at equal intervals. M is the midpoint between the two innermost charges. 

(iii) $B = 0$	(c) The charges are placed on two coplanar insulating rings at equal intervals. M is the common centre of the rings. PQ is perpendicular to the plane of the rings. 
(iv) $\mu \neq 0$	(d) The charges are placed at the corners of a rectangle of side a and $2a$ and at the midpoints of the large sides. M is at the centre of the rectangle. PQ is parallel to the longer sides. 
	(e) The charges are placed on two coplanar identical insulating rings at equal intervals. M is the midpoint between the centres of the rings. PQ is perpendicular to the line joining the centres and coplanar with the rings. 

6. A charged particle (electron or proton) is introduced at the origin ($x = 0$, $y = 0$, $z = 0$) with a given initial velocity $\vec{v}$. A uniform electric field $\vec{E}$ and a uniform magnetic field $\vec{B}$ exist everywhere. The velocity $\vec{v}$, electric field $\vec{E}$ and magnetic field $\vec{B}$ are given in Columns A, B and C respectively. The quantities $\vec{E}_0$ and $\vec{B}_0$ are positive in magnitude.

Column A	*Column B*	*Column C*
(i) Electron with $\vec{v} = \dfrac{2E_0}{B_0}\hat{x}$	(i) $\vec{E} = E_0\hat{z}$	(a) $\vec{B} = -B_0\hat{x}$
(ii) Electron with $\vec{v} = \dfrac{E_0}{B_0}\hat{y}$	(ii) $\vec{E} = -E_0\hat{y}$	(b) $\vec{B} = B_0\hat{x}$
(iii) Proton with $\vec{v} = 0$	(iii) $\vec{E} = -E_0\hat{x}$	(c) $\vec{B} = B_0\hat{y}$
(iv) Proton with $\vec{v} = 2\dfrac{E_0}{B_0}\hat{x}$	(iv) $\vec{E} = E_0\hat{x}$	(d) $B = B_0\hat{z}$

6A. In which case will the particle move in a straight line with a constant velocity?

[P] $\rightarrow$ (ii) (iii) (d) [Q] $\rightarrow$ (iv) (i) (d)
[R] $\rightarrow$ (iii) (ii) (c) [S] $\rightarrow$ (iii) (iii) (a)

6B. In which case will the particle describe a helical path with axis along the positive z-direction?

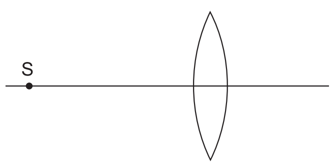
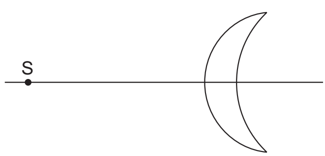
[P] $\rightarrow$ (ii) (iii) (c) [Q] $\rightarrow$ (iv) (ii) (c)
[R] $\rightarrow$ (iv) (i) (d) [S] $\rightarrow$ (iii) (iii) (a)

6C. In which case would the particle move in a straight line along the negative direction of the y-axis (i.e., move along $-\hat{y}$)?

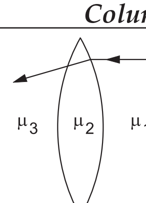
[P] $\rightarrow$ (iv) (ii) (d) [Q] $\rightarrow$ (iii) (ii) (a)
[R] $\rightarrow$ (ii) (iii) (b) [S] $\rightarrow$ (iii) (ii) (c)

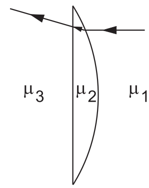
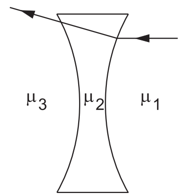
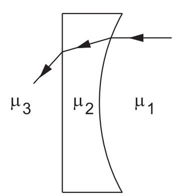
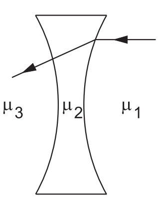
4.6 Ray Optics and Wave Optics

1. An optical component and an object S placed along its optic axis are given in Column A. The distance between the object and the component can be varied. The properties (nature) of images are given in Column B. Match all the properties of the images from Column B with the appropriate components given in Column A.

Column A	***Column B***
(i)  Concave mirror	(a) Real image
(ii)  Convex mirror	(b) Virtual image
(iii)  Convex lens	(c) Magnified image
(iv)  Concavo-convex lens	(d) Image at infinity

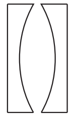
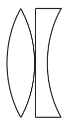
2. Two transparent media of refractive indices μ_1 and μ_3 have a solid lens-shaped transparent material of refractive index μ_2 between them as shown in the figures in Column B. A ray traversing these media is also shown in the figures. In Column A different relationships between μ_1, μ_2 and μ_3 are given. Match them to the ray diagrams shown in Column B.

Column A	***Column B***
(i) $\mu_1 < \mu_2$	(a) 

(ii) $\mu_1 > \mu_2$	(b) 
(iii) $\mu_2 = \mu_3$	(c) 
(iv) $\mu_2 > \mu_3$	(d) 
	(e) 

3. Four combinations of two thin lenses are given in Column A. The radius of curvature of each curved surface is r and the refractive index of each lens is 1.5. Match the lens combination in Column A with the focal length in Column B. Select the correct answer using the codes given below the columns.

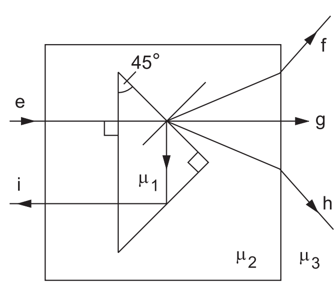
Column A	*Column B*
(i) 	(a) $2r$

(ii) 	(b) $\frac{r}{2}$
(iii) 	(c) $-r$
(iv) 	(d) r

Codes:

P →	(i) – (a)	(ii) – (b)	(iii) – (c)	(iv) – (d)
Q →	(i) – (b)	(ii) – (d)	(iii) – (c)	(iv) – (a)
R →	(i) – (d)	(ii) – (a)	(iii) – (b)	(iv) – (c)
S →	(i) – (b)	(ii) – (a)	(iii) – (c)	(iv) – (d)

4. A right-angled prism of refractive index μ_1 is placed in a rectangular block of refractive index μ_2, which is surrounded by a medium of refractive index μ_3, as shown in the figure. A ray of light *e* enters the rectangular block at normal incidence. Depending upon the relationships between μ_1, μ_2 and μ_3 it takes one of the four possible paths *ef*, *eh*, *eg* or *ei*.



Match the paths in Column A with the conditions of refractive indices in Column B and select the correct answer using the codes given below the columns.

Column A	*Column B*
(i) $e \to f$	(a) $\mu_1 > \sqrt{2}\mu_2$
(ii) $e \to g$	(b) $\mu_2 > \mu_1$ and $\mu_2 > \mu_3$
(iii) $e \to h$	(c) $\mu_1 = \mu_2$
(iv) $e \to i$	(d) $\mu_2 < \mu_1 < \sqrt{2}\mu_2$ and $\mu_2 > \mu_3$

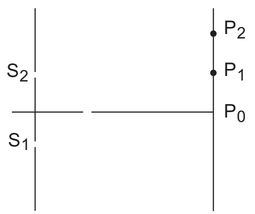
Codes:

	(i)	(ii)	(iii)	(iv)
P →	(b)	(c)	(a)	(d)
Q →	(a)	(b)	(d)	(c)
R →	(d)	(a)	(b)	(c)
S →	(b)	(c)	(d)	(a)

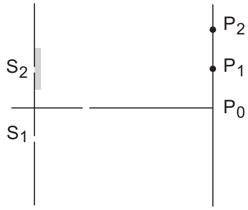
5. A simple telescope used to view distant objects has eyepiece and objective lens of focal lengths f_e and f_o respectively. Match the columns A and B.

Column A	*Column B*
(i) Intensity of light received by the lens	(a) Radius of aperture (R)
(ii) Angular magnification	(b) Dispersion of lens
(iii) Length of telescope	(c) Focal length f_o, f_e
(iv) Sharpness of image	(d) Spherical aberration

6. The figures in Column A relate to Young's double-slit arrangement with the screen placed far away from the slits S_1 and S_2. In each of these cases, $S_1P_0 = S_2P_0$, $S_1P_1 - S_2P_1 = \frac{\lambda}{4}$ and $S_1P_2 - S_2P_2 = \frac{\lambda}{3}$, where λ is the wavelength of the light used. In (ii), (iii) and (iv), a transparent sheet of refractive index n and thickness t is pasted on the slit S_2. The thickness of the sheets are different in different cases. The phase difference between the light waves reaching a point P on the screen from the two slits is denoted by $\delta(P)$ and the intensity by $I(P)$. Match the columns A and B.

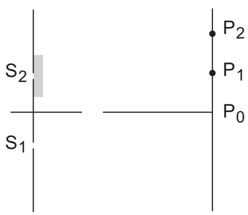
Column A	*Column B*
(i) 	(a) $\delta(P_0) = 0$

(ii) $(n-1)t = \lambda/4$



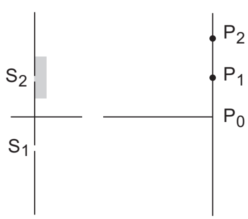
(b) $\delta(P_1) = 0$

(iii) $(n-1)t = \lambda/2$



(c) $I(P_1) = 0$

(iv) $(n-1)t = 3\frac{\lambda}{4}$



(d) $I(P_0) > I(P_1)$

(e) $I(P_2) > I(P_1)$

4.7 Modern Physics

1. Match Column A showing the nuclear processes with Column B containing the parent nucleus and one of the end products of each process, and then select the correct answer using the codes given below the columns.

Column A	*Column B*
(i) Alpha decay	(a) ${}^{15}_{8}O \rightarrow {}^{15}_{7}N + \ldots$
(ii) β^+ decay	(b) ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + \ldots$

(iii) Fission	(c) $^{185}_{83}\text{Bi} \rightarrow {}^{184}_{82}\text{Pb} +$
(iv) Proton emission	(d) $^{239}_{94}\text{Pu} \rightarrow {}^{140}_{57}\text{La} + ...$

Codes:

	(i)	(ii)	(iii)	(iv)
P →	(d)	(b)	(a)	(c)
Q →	(a)	(c)	(b)	(d)
R →	(b)	(a)	(d)	(c)
S →	(d)	(c)	(b)	(a)

2. Match the nuclear processes given in Column A with the appropriate option(s) in Column B.

Column A	*Column B*
(i) Nuclear fusion	(a) Absorption of thermal neutrons by $^{235}_{92}\text{U}$
(ii) Fission in a nuclear reactor	(b) $^{60}_{27}\text{Co}$ nucleus
(iii) β-Decay	(c) Energy production starts via the conversion of hydrogen into helium
(iv) γ-Ray emission	(d) Heavy water
	(e) Neutrino emission

3. Match the following.

Column A	*Column B*
(i) The transition of a hydrogen atom from one energy level to another	(a) Characteristic X-rays
(ii) Electron emission from a material	(b) Photoelectric effect
(iii) Moseley's law	(c) Hydrogen spectrum
(iv) Change of photon energy into the kinetic energy of electrons	(d) β-Decay

4. Column B gives certain systems, each undergoing a process. Column A suggests changes in some of the parameters related to the systems. Match the statements in Column A with the appropriate process(es) in Column B.

Column A	*Column B*
(i) The energy of the system is increased.	(a) System: A capacitor initially uncharged Process: Connected to a battery
(ii) Mechanical energy provided to the system is converted into energy of random motion of its parts.	(b) System: A gas in an adiabatic container fitted with an adiabatic piston Process: The gas is compressed by pushing the piston
(iii) Internal energy of the system is converted into mechanical energy.	(c) System: A gas in a rigid container Process: The gas getting cooled due to colder atmosphere surrounding it
(iv) Mass of the system is decreased	(d) System: A heavy nucleus, initially at rest Process: Nuclear fission—two fragments of nearly equal masses and some neutrons emitted
	(e) System: A resistance-wire loop Process: The loop placed in a time-varying magnetic field perpendicular to its plane

Answers

4.1 General Physics

1.

	a	b	c	d
(i)	●	●	○	○
(ii)	○	○	●	●
(iii)	○	○	●	●
(iv)	○	○	●	●

2.

	a	b	c	d
(i)	●	○	○	●
(ii)	○	●	○	●
(iii)	○	○	○	●
(iv)	○	●	○	○

3.

	a	b	c	d
(i)	○	○	○	●
(ii)	○	●	○	○
(iii)	●	○	○	○
(iv)	○	○	●	○

Code: R

4.

	a	b	c	d
(i)	●	○	○	○
(ii)	●	○	○	○
(iii)	●	○	○	○
(iv)	○	○	○	●

Code: R

5.

	a	b	c	d
(i)	○	●	○	○
(ii)	○	●	○	○
(iii)	○	○	●	○
(iv)	○	○	●	○

Code: S

6.

	a	b	c	d	e
(i)	●	●	●	○	●
(ii)	○	●	○	●	○
(iii)	●	●	●	●	○
(iv)	●	○	●	○	●

7.

	a	b	c	d
(i)	●	○	○	○
(ii)	○	●	●	○
(iii)	○	●	○	○
(iv)	○	●	●	○

8.

	a	b	c	d	e
(i)	●	○	○	○	●
(ii)	○	●	○	●	●
(iii)	●	○	●	○	●
(iv)	○	●	○	○	○

4.2 Heat and Thermodynamics

1.

	a	b	c	d	e
(i)	●	○	●	○	●
(ii)	●	○	●	○	○
(iii)	○	●	○	●	○
(iv)	○	○	●	○	●

2.

	a	b	c	d
(i)	○	○	○	●
(ii)	○	○	●	○
(iii)	○	●	○	○
(iv)	●	○	○	○

Code: P

3.

	a	b	c	d
(i)	○	●	○	○
(ii)	●	○	○	●
(iii)	○	○	○	●
(iv)	○	●	●	○

4A. Q **4B.** P **4C.** S

5.

	a	b	c	d
(i)	○	●	○	○
(ii)	●	○	●	○
(iii)	●	○	○	●
(iv)	○	●	○	●

4.3 Sound Waves

1.

	a	b	c	d	e
(i)	●	○	○	○	●
(ii)	●	○	○	●	○
(iii)	○	●	○	●	○
(iv)	○	●	●	○	○

4.4 Electrostatics

1.

	a	b	c	d
(i)	○	○	●	○
(ii)	●	○	○	○
(iii)	○	○	○	●
(iv)	○	●	○	○

Code: P

4.5 Current Electricity and Magnetism

1.

	a	b	c	d	e
(i)	○	○	●	●	●
(ii)	○	●	●	●	●
(iii)	●	●	○	○	○
(iv)	○	●	●	●	●

2.

	a	b	c	d
(i)	●	○	○	○
(ii)	○	●	○	●
(iii)	○	●	○	●
(iv)	○	●	●	●

3.

	a	b	c	d
(i)	○	●	○	○
(ii)	○	○	●	●
(iii)	○	○	●	●
(iv)	●	●	●	○

4.

	a	b	c	d
(i)	○	●	●	○
(ii)	●	○	○	○
(iii)	○	●	●	○
(iv)	○	●	○	○

5.

	a	b	c	d	e
(i)	●	○	●	●	○
(ii)	○	○	●	●	○
(iii)	●	●	○	○	●
(iv)	○	○	●	●	○

6A. R **6B.** R **6C.** S

4.6 Ray Optics and Wave Optics

1.

	a	b	c	d
(i)	●	●	●	●
(ii)	○	●	○	○
(iii)	●	●	●	●
(iv)	●	●	●	●

2.

	a	b	c	d	e
(i)	●	○	●	○	○
(ii)	○	●	○	●	●
(iii)	●	○	●	○	●
(iv)	○	●	○	●	○

3.

	a	b	c	d
(i)	○	●	○	○
(ii)	○	○	○	●
(iii)	○	○	●	○
(iv)	●	○	○	○

Code: Q

4.

	a	b	c	d
(i)	○	●	○	○
(ii)	○	○	●	○
(iii)	○	○	○	●
(iv)	●	○	○	○

Code: S

5.

	a	b	c	d
(i)	●	○	○	○
(ii)	○	○	●	○
(iii)	○	○	●	○
(iv)	●	●	○	●

6.

	a	b	c	d	e
(i)	●	○	○	●	○
(ii)	○	●	○	○	○
(iii)	○	○	○	○	●
(iv)	○	○	●	●	●

4.7 Modern Physics

1.

	a	b	c	d
(i)	○	●	○	○
(ii)	●	○	○	○
(iii)	○	○	○	●
(iv)	○	○	●	○

Code: R

2.

	a	b	c	d	e
(i)	○	○	●	○	●
(ii)	●	○	○	●	○
(iii)	○	●	○	○	●
(iv)	○	○	●	○	○

3.

	a	b	c	d
(i)	●	○	●	○
(ii)	○	●	○	●
(iii)	●	○	○	○
(iv)	○	●	○	○

4.

	a	b	c	d	e
(i)	●	●	○	○	●
(ii)	○	●	○	○	○
(iii)	○	○	○	●	○
(iv)	○	○	○	●	○

Hints and Solutions

4.1 General Physics

1. (i) → (a), (b) : $GM_eM_s = Fr^2 = \text{kg m}^3\text{ s}^{-2}$.

$$\text{V C m} = \text{J m} = \text{N m m} = \text{kg m}^3\text{ s}^{-2}.$$

(ii) → (c), (d) : $\dfrac{3RT}{M} = C_{\text{rms}}^2 \to (\text{m s}^{-1})^2 = \text{m}^2\text{ s}^{-2}$.

$$\begin{aligned}\text{F V}^2\text{ kg}^{-1} &= \text{C V kg}^{-1} = \text{J kg}^{-1}\\ &= \text{kgm}^2\text{ s}^{-2}\text{ kg}^{-1}\\ &= \text{m}^2\text{ s}^{-2}.\end{aligned}$$

(iii) → (c), (d) : $\dfrac{F^2}{q^2B^2} = \dfrac{(IlB)^2}{(qB)^2} = (\text{s}^{-1}\text{ m})^2 = \text{m}^2\text{ s}^{-2} = \text{FV}^2\text{ kg}^{-1}$.

(iv) → (c), (d) : $\dfrac{GM_e}{R_e} = \dfrac{\text{force} \times \text{distance}}{\text{mass}}$

$$= \frac{\text{N m}}{\text{kg}} = \frac{\text{kg m s}^{-2}\cdot\text{m}}{\text{kg}} = \text{m}^2\text{ s}^{-2}.$$

2. (i) → (a), (d) : $U = \dfrac{1}{2}kx^2$ represents a parabola.

(ii) → (b), (d) : With zero acceleration, motion is uniform and slope of $(x–t)$ is constant. Hence (b). With constant acceleration $\left(x = \dfrac{1}{2}at^2\right)$, the slope increases with time, hence (d).

(iii) → (d) : Range $R = u^2\dfrac{\sin 2\theta}{g}$, $R \propto u^2$.

This represents a parabola passing through the origin.

(iv) → (b) : $T^2 = \left(\dfrac{4\pi^2}{g}\right)l = kl$.

3. (i) : Energy $= \dfrac{3}{2}kT \equiv \text{ML}^2\text{T}^{-2}$

$$\Rightarrow [k] = \frac{\text{ML}^2\text{ T}^{-2}}{\text{Temperature}} = \text{ML}^2\text{T}^{-2}\text{K}^{-1}.$$

(ii) : $F = 6\pi\eta rv \Rightarrow \eta = \text{ML}^{-1}\text{T}^{-1}$.

(iii) : Energy $= h\nu \Rightarrow h = \text{ML}^2\text{ T}^{-1}$.

(iv) : $Q = K\dfrac{\Delta\theta}{\Delta x}At \Rightarrow [K] = \text{MLT}^{-3}\text{K}^{-1}$.

Thus, (i) → (d), (ii) → (b), (iii) → (a), (iv) → (c) [Code R].

4. In column A, in situations (i), (ii) and (iii), no horizontal velocity is imparted to the falling water, so d remains the same.

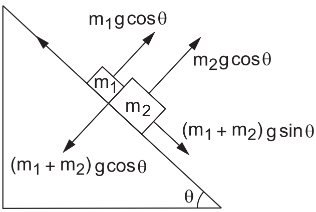
Hence, (i) → (a), (ii) → (a), (iii) → (a).

For free fall in situation (iv), effective value of g is zero, so no water leaks out of the jar. So, (iv) → (d).

∴ code (R) is correct.

5. Condition for not sliding,

$$f_{max} > (m_1 + m_2)g\sin\theta$$
$$\Rightarrow \quad \mu N > (m_1 + m_2)g\sin\theta$$
$$\Rightarrow \quad 0.3\,\text{m}_2\text{g}\cos\theta \geq 30\sin\theta$$
$$\Rightarrow \quad 6 \geq 30\tan\theta$$
$$\Rightarrow \quad \tan\theta \leq 0.2,\ \theta = 11°.$$



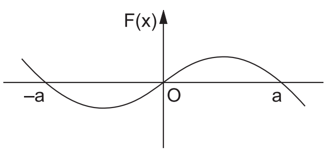
∴ for (i) and (ii), $f = (m_1 + m_2)g\sin\theta$.

For (iii) and (iv), $F = f_{max} = \mu m_2 g\cos\theta$.

Thus, (i) → (b), (ii) → (b), (iii) → (c), (iv) → (c).

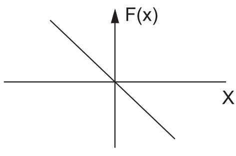
Combining all, code (S) is correct.

6. (i) $$F_x = -\frac{dU}{dx} = -\frac{d}{dx}\left[\frac{U_0}{2}\left(1 - \frac{x^2}{a^2}\right)^2\right]$$
$$= -\frac{U_0}{2}2\left(1 - \frac{x^2}{a^2}\right)\left(-\frac{2}{a^2}x\right)$$
$$= \frac{2U_0}{a^4}(x - a)x(x + a).$$



The variation of $F(x)$ with (x) is shown in the graph. The correct options are (a), (b), (c) and (e).

(ii) $$F_x = -\frac{dU}{dx} = -\frac{d}{dx}\left[\frac{U_0}{2}\frac{x^2}{a^2}\right] = -\frac{U_0}{a^2}x.$$

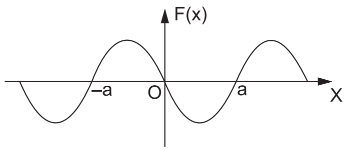


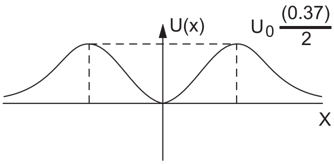
The plot $F(x)$–x is shown here.

The correct options are (b) and (d).

(iii) $$Fx = -\frac{dU}{dx} = -\frac{d}{dx}\left[\frac{U_0}{2}\left(\frac{x}{a}\right)^2\exp\left(-\frac{x^2}{a^2}\right)\right]$$
$$= U_0\,e^{-x^2/a^2}\cdot\frac{1}{a^4}(x + a)x(x - a).$$

This variation is given by the following graphs.



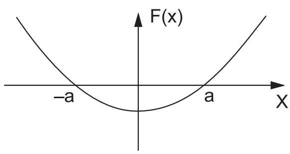


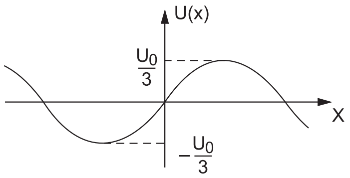
The correct options are (a), (b), (c) and (d).

(iv) $F_x = -\dfrac{dU}{dx} = -\dfrac{d}{dx}\left[\dfrac{U_0}{2}\left\{\dfrac{x}{a} - \dfrac{1}{3}\left(\dfrac{x}{a}\right)^3\right\}\right]$

$= -\dfrac{U_0}{2a^3}\,[(x-a)(x+a)].$

The variation of F_x and $U(x)$ are shown below.





Correct options are (a), (c) and (e).

7. (i) → (a) : In SHM, $v = \omega\sqrt{A^2 - x^2} \equiv C_1\sqrt{C_2 - x^2}$.
The object executes SHM.

(ii) → (b), (c) : $v = -kx = \dfrac{dx}{dt} \Rightarrow x = e^{-kt}$.
$\therefore\ v = -ke^{-kt}$.
The object keeps on moving on the x-axis [option (b)] and its kinetic energy decreases exponentially [(option (c)].

(iii) → (b) : $T = 2\pi\sqrt{\dfrac{m}{k}}$, the oscillation is independent of the frame and depends only on spring constant k.

(iv) → (b), (c) : Since the speed of projection is greater than the escape speed $(v_e = \sqrt{GM_e/R_e})$, the kinetic energy keeps on decreasing [option (c)], and the object does not change its direction [option (b)].

8. (i) → (a), (e) : For uniform motion,
$Mg\sin\theta = f = \mu\, Mg\cos\theta \ \Rightarrow\ \mu = \tan\theta.$

Net force on the block Y by the incline X is

$$\sqrt{f^2+N^2} = \sqrt{M^2g^2\sin^2\theta + M^2g^2\cos^2\theta}$$
$$= Mg \text{ [option (a)].}$$

Weight $(Mg) = F_{\text{viscous}} + F_{\text{buoyancy}}$ [option (e)].

(ii) $\rightarrow$ (b), (d), (e) : Lift moves up, gravitational potential energy of X goes on increasing [option (b)]. Similarly for options (d) and (e).

(iii) $\rightarrow$ (a), (c), (e) : Block Y moves down, gravitational potential energy of the system $(X + Y)$ goes on decreasing [option (a)]. Same is true for options (c) and (e).

(iv) $\rightarrow$ (b) : Weight of Y passes through P, its torque about P is zero [option (b)].

4.2 Heat and Thermodynamics

1. (i) Process $A \rightarrow B$: Isobaric compression [options (a), (c), (e)].

(ii) Process $B \rightarrow C$: Isochoric decrease in pressure [options (a), (c)].

(iii) Process $C \rightarrow D$: Isobaric expansion [options (b), (d)].

(iv) Process $D \rightarrow A$: Polytropic compression with $T_A = T_D$ [options (c), (e)].

2. Let the temperature at E be T_0.

Process E $\rightarrow$ F is isochoric, so the temperature at F is $32T_0$. Process F $\rightarrow$ G is isothermal, so the temperature at G is also $32T_0$. Process F $\rightarrow$ H is adiabatic, so $(32\,p_0)V_0^{5/3} = p_0\,(V_H)^{5/3}$, since $\gamma = \frac{5}{3}$ for a monoatomic gas. Hence $V_H = 8V_0$. Since the work done is given by the area under the p–V graph, the magnitudes of work done during the processes are

(i) $G \rightarrow E$: $p_0(V_G - V_E) = p_0(32V_0 - V_0) = 31p_0V_0$.

(ii) $G \rightarrow H$: $p_0(V_G - V_H) = p_0\,(32V_0 - 8V_0) = 24p_0V_0$.

(iii) $F \rightarrow H$: $\dfrac{1}{\gamma-1}(p_FV_F - p_HV_H) = \dfrac{3}{2}(32p_0V_0 - 8p_0V_0) = 36p_0V_0$.

(iv) $F \rightarrow G$: $RT\ln(V_G/V_F) = p_FV_F\ln\dfrac{V_G}{V_F} = p_FV_F\ln\dfrac{p_F}{p_G}$

$$= (32p_0)V_0\ln\left(\frac{32\,p_0}{p_0}\right) = 32\,p_0V_0(5\ln 2)$$
$$= 160p_0V_0\ln 2.$$

Hence, the code (P) is correct.

3. (i) → (b) : AB is an isochoric process, $\Delta W = 0$ and heat is expelled.

(ii) → (a), (d) : BC is an isobaric expansion, work is done by the gas ($\Delta W > 0$). Heat is absorbed ($\Delta Q > 0$).

(iii) → (d) : CD is an isochoric process with increase in pressure ($p \propto T$); temperature increases, heat is absorbed, so $\Delta Q > 0$.

(iv) → (b), (c) : DA represents compression, so $\Delta W < 0$.

$$T_{\mathrm{D}} = \frac{p_{\mathrm{D}} V_{\mathrm{D}}}{nR} = \frac{(20)(20)}{nR} = \frac{400}{nR}.$$

$$T_{\mathrm{A}} = \frac{p_{\mathrm{A}} V_{\mathrm{A}}}{nR} = \frac{(30)(10)}{nR} = \frac{300}{nR}.$$

Since $T_{\mathrm{A}} < T_{\mathrm{D}}$, heat is expelled, $\Delta Q < 0$.

4A. In the isobaric process (iii), $W_{1\to 2} = pV_1 - pV_2$. ...(ii)
Pressure remains constant, (a). Hence code Q.

4B. $W_{1\to 2} = 0$, (iii), is applicable for isochoric process [(ii) and (d)]: hence code P.

4C. Expression for the work done during adiabatic expansion:
$W_{1\to 2} = \dfrac{1}{\gamma - 1}(p_2V_2 - p_1V_1)$, corresponds to options (i) and (iv) respectively and also represented by (b). Thus code S.

5. (i) → (b) : Opening of the valve causes free expansion under adiabatic condition for which $\Delta Q = 0$, $\Delta W = 0$, $\Delta U = 0$, so the temperature of the gas remains constant.

(ii) → (a), (c) : Given $p = \dfrac{k}{V^2}$. And $pV = nRT$

$$\Rightarrow V = \frac{k}{nRT} \Rightarrow VT = \text{constant}.$$

when $V \to 2V$, $T \to \dfrac{T}{2}$.

Further, change in internal energy,

$$\Delta U = nC_{\mathrm{V}}\Delta T = n\left(\frac{3}{2}R\right)\left(-\frac{T}{2}\right) = n\left(\frac{3}{2}R\right)\left(-\frac{k}{2nRV}\right) = -\frac{3}{4}\left(\frac{k}{V}\right).$$

Work done by the gas,

$$\Delta W = \int p\,dV = \int_V^{2V} \frac{k}{V^2}\,dV = \frac{k}{2V}.$$

From the first law, $\Delta Q = \Delta U + \Delta W = \dfrac{-k}{4}$.

Heat is expelled.

(iii) $\rightarrow$ (a), (d) : Given $p = \dfrac{k}{V^{4/3}}$. And $p = \dfrac{nRT}{V}$

$$\Rightarrow \frac{k}{V^{1/3}} = nRT.$$

During expansion, $V \rightarrow 2V$, $T \rightarrow \dfrac{T}{2^{1/3}} < T$.

Hence T decreases [option (a)].

Further, change in internal energy,

$$\Delta U = nC_V\Delta T = n\left(\frac{3}{2}R\right)T\left(\frac{1}{2^{1/3}} - 1\right) = \frac{3k}{2V^{1/3}}\left(\frac{1}{2^{1/3}} - 1\right).$$

Work done during expansion,

$$\Delta W = \int p dV = k\int_V^{2V} \frac{dV}{V^{4/3}} = \frac{3K}{V^{1/3}}\left(1 - \frac{1}{2^{1/3}}\right).$$

$$\Rightarrow \Delta Q = \Delta U + \Delta W = \frac{3k}{2V^{1/3}}\left(\frac{1}{2^{1/3}} - 1\right) + \frac{3k}{V^{1/3}}\left(1 - \frac{1}{2^{1/3}}\right)$$

$$= \frac{3k}{2V^{1/3}}\left(1 - \frac{1}{2^{2/3}}\right).$$

$\therefore$ $\Delta Q > 0$ [option (d)].

(iv) $\rightarrow$ (b), (d) : $p_1V_1 = nRT_1$; $p_2(2V_1) = nRT_2$.

$$\therefore \frac{T_2}{T_1} = \frac{2p_2}{p_1} \Rightarrow T_2 > T_1.$$

Now, $\Delta U = nC_V\Delta T = nC_V(T_2 - T_1) > 0$;

ΔW = area under p–V diagram is positive during expansion, so $\Delta W > 0$.

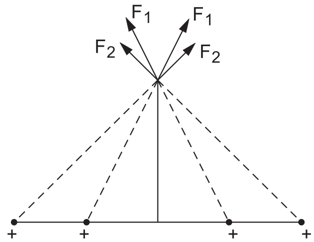
Heat $\Delta Q > 0$ (absorption).

4.3 Sound Waves

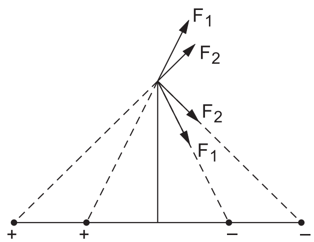
1. (i) $\rightarrow$ (a), (e) : Closed organ pipe: longitudinal wave; $\lambda_f = 4L$
   (ii) $\rightarrow$ (a), (d) : Open organ pipe: longitudinal wave; $\lambda_f = 2L$
   (iii) $\rightarrow$ (b), (d) : Stretched string clamped at both ends: transverse wave; $\lambda_f = 2L$
   (iv) $\rightarrow$ (b), (c) : String clamped at both ends and at midpoint; transverse wave; $\lambda_f = L$

4.4 Electrostatics

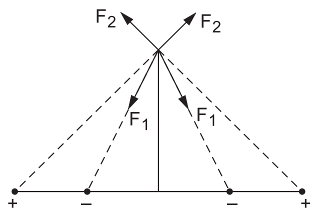
1. (i) → (c) : The x-components of the forces will cancel out and the net force will act along the $+y$-axis.



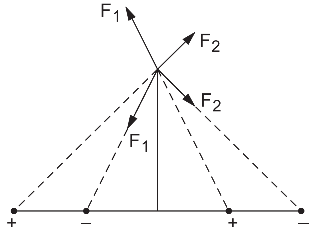
(ii) → (a) : The y-components of the forces will cancel out and the net force will act along the $+x$-axis.



(iii) → (d) : The x-components of the forces cancel out and the net force will act along the $-y$-axis.



(iv) → (b) : The y-components of the forces will cancel out and the net force will be along the $-x$-axis.



Combining all, code P is correct.

4.5 Current Electricity and Magnetism

1. (i) → (c), (d), (e) : Current I is zero in case (a) in steady state but $I \neq 0$ for cases (b) to (e).

In case (b), across the inductor V_1 is not proportional to I, so (c), (d) and (e) are correct options.

(ii) $\rightarrow$ (b), (c), (d), (e) : $V_1 = 0$, $V_2 = V$. $\therefore V_2 > V_1$ ... case (b).

$X_L = \omega L \approx 1.88\ \Omega < R = 2\ \Omega$

$\Rightarrow V_2 > V_1$ ... case (c).

$$X_C = \frac{1}{\omega C} = \frac{1}{100\pi(3 \times 10^{-6}\ \text{F})} = 1061\ \Omega > X_L$$

$\Rightarrow V_L > V_1$ ... case (d).

(iii) $\rightarrow$ (a), (b) : In DC, L acts as a short circuit in steady state ($V_1 = 0$) and $V_2 = V$.

(iv) $\rightarrow$ (b), (c), (d), (e) : As explained above, $I \neq 0$ and the voltage drop across the circuit elements is proportional to I.

2. (i) $\rightarrow$ (a) : $\vec{E} = \dfrac{1}{4\pi\varepsilon_0} \dfrac{Qx}{(R^2 + x^2)^{3/2}}$.

Time-independent electrostatic field at an axial point.

(ii) $\rightarrow$ (b), (d) : A charged ring rotating uniformly is equivalent to a current $I = \dfrac{Q}{T} = \dfrac{Q\omega}{2\pi}$, which produced a magnetic field

$$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}}.$$

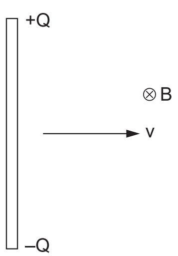
Its magnetic moment $\vec{m} = I\vec{A}$.

(iii) $\rightarrow$ (b), (d) : Constant current I_0 in ring is the same case as in (ii), hence (b) and (d) are correct options.

(iv) $\rightarrow$ (b), (c), (d) : Time-varying magnetic field is produced by time-varying current [option (b)]. The time-varying magnetic flux creates induced emf, hence induced electric field [option (c)]; finally, $\vec{m} = I\vec{A}$ [option (d)].

3. (i) $\rightarrow$ (b) : Energy of the charged capacitor $\left(U = \dfrac{Q^2}{2C}\right)$ appear as heat in the connecting wire.

(ii) $\rightarrow$ (c), (d) : Motional emf ($\mathcal{E} = Blv$) is induced in the wire. As shown in the figure, charges of constant magnitude, $\pm Q$, appear at the ends of the wire.



(iii) $\to$ (c), (d) : Free electrons in the conducting wire experience electric force $F = eE$, thus charges with opposite sign accumulate at the ends. This in turn develops potential difference across the ends.

(iv) $\to$ (a), (b), (c) : Connecting a wire of resistance R across a battery causes a constant current I (= $\mathcal{E}/R$) through the wire. Heat (I^2RT) is developed in the wire. The terminal voltage V (= $\mathcal{E} - Ir$) is developed between the ends of the wire.

4. (i) $\to$ (b), (c) : Magnetic field is at P due to two straight currents which are in opposite directions [option (b)]; if P is at the midpoint, $B = 0$ [option (c)].

(ii) $\to$ (a) : Magnetic moment ($\vec{m} = I\vec{A}$) due to both the coils is towards the right, so magnetic field at P is in the same direction.

(iii) $\to$ (b), (c) : Magnetic fields at P are due to two coils which are in opposite direction [option (b)]. For symmetrical position of P, $B = 0$ [option (c)].

(iv) $\to$ (b) : Magnetic fields at P are due to two concentric circular coils which are in opposite directions and unequal in magnitude.

5. (i) $\to$ (a), (c), (d) : Field $E = 0$ for charge distribution.

(ii) $\to$ (c), (d) : Potential is nonzero.

(iii) $\to$ (a), (b), (e) : Magnetic field is produced by a current loop. Net current during rotation in each of (a), (b) and (e) is zero, so $B = 0$.

(iv) $\to$ (c), (d) : Magnetic moment $\vec{m} = I\vec{A}$ will be nonzero if $\vec{m} \neq 0$, so $I \neq 0$, which is true for (c) and (d) only.

6A. For a constant velocity, $\vec{F} = \vec{F_E} + \vec{F_B} = 0$ (so net force $\vec{F}$ must be zero).

$q\vec{E} + q(\vec{v} \times \vec{B}) = 0, \vec{E} = -(\vec{v} \times \vec{B})$. Hence code R.

6B. $\vec{v} = 2\dfrac{E_0}{B_0}\hat{x}, \vec{E} = E_0\hat{z}, \vec{B} = B_0\hat{z}$.

Since velocity is along the x-direction, magnetic field will rotate it about the z-axis and electric field will provide the helical path. Hence code R.

6C. Magnetic force is always zero and electric field will move it along the $-y$ direction. Hence code S.

4.6 Ray Optics and Wave Optics

1. (i) → (a), (b), (c), (d) : For a concave mirror, with $f \le u \le \infty$, the image is real; magnified for $f \le u \le 2f$; virtual for $u < f$; at infinity for $u = f$.

(ii) → (b) : Image formed by a convex mirror is always virtual and diminished.

(iii) → (a), (b), (c), (d) : Image formed by a convex lens is real for $u > f$; virtual for $u < f$; magnified for $f < u < 2f$ and formed at infinity for $u = f$.

(iv) → (a), (b), (c), (d) : Image formed by a concavo-convex lens may be real, virtual, magnified and at infinity.

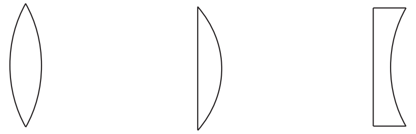
2. (i) → (a), (c) : The ray bends towards the normal while passing from optically denser to rarer ($\mu_1 < \mu_2$) medium.

(ii) → (b), (d), (e) : The ray bends away from the normal while passing from optically denser to rarer ($\mu_1 > \mu_2$) medium.

(iii) → (a), (c), (e) : Path of the ray remains unchanged when refractive indices of the two media are same ($\mu_2 = \mu_3$).

(iv) → (b), (d) : The ray bends away from the normal while passing from denser to rarer ($\mu_2 > \mu_3$) medium.

3. From $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$, the focal lengths of the three component lenses are



f = R f = 2R f = –2R

For lens combination $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$, so

for (i) : $\frac{1}{f_{eq}} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$, $f_{eq} = \frac{R}{2} \to$ (b)

for (ii) : $\frac{1}{f_{eq}} = \frac{1}{2R} + \frac{1}{2R} = \frac{1}{R}$, $f_{eq} = R \to$ (d)

for (iii) : $\frac{1}{f_{eq}} = \frac{1}{-2R} + \frac{1}{-2R} = -\frac{1}{R}$, $f_{eq} = -R \to$ (c)

for (iv) : $\frac{1}{f_{eq}} = \frac{1}{R} + \frac{1}{-2R} = \frac{1}{2R}$, $f_{eq} = 2R \to$ (a)

4. (i) → (b) : $\mu_2 > \mu_1$ ... (towards the normal);
$\mu_2 > \mu_3$ ... (away from the normal).

(ii) → (c) : $\mu_1 = \mu_2$ ... (no change in path);

(iii) → (d) : $\mu_1 > \mu_2$ ... (away from the normal);
$\mu_2 > \mu_3$ ... (away from the normal);

$$\mu_1 \times \frac{1}{\sqrt{2}} = \mu_2 \sin r \Rightarrow \sin r = \frac{\mu_1}{\sqrt{2}\,\mu_2}.$$

Since $\sin r < 1$, so $\mu_1 < \sqrt{2}\mu_2$.

(iv) → (a) : For total reflection, $45° > \theta_c$.
So, $\sin 45° > \sin \theta_c$,

$$\Rightarrow \frac{1}{\sqrt{2}} > \frac{\mu_2}{\mu_1} \quad \Rightarrow \mu_1 > \sqrt{2}\,\mu_2.$$

Hence, code S is the correct answer.

5. (i) → (a) : Intensity $\propto$ aperture (R)

(ii) → (c) : Angular magnification $= f_o/f_e$

(iii) → (c) : Length of telescope $= f_o \pm f_e$

(iv) → (a), (b), (d) : Sharpness of image depends on aperture [option (a)], dispersion [option (b)] and spherical aberration [option (d)].

6. (i) → (a), (d) : Path difference, $\Delta = S_1P_0 - S_2P_0 = 0$, so phase difference

$$\delta(P_0) = \frac{2\pi}{\lambda} \cdot \Delta = 0.$$

$I(P_0) = 4I_0$, where I_0 = intensity due to each source.

$$I(P_1) = 2I_0\,(1 + \cos\phi) = 4I_0\cos^2\frac{\phi}{2}$$

$\Rightarrow I(P_0) > I(P_1)$.

(ii) → (b) : Path difference at P_1 is $\Delta = S_1P_1 - [S_2P_1 + (n-1)t]$

$$= (S_1P_1 - S_2P_1) - \frac{\lambda}{4} = \frac{\lambda}{4} - \frac{\lambda}{4} = 0.$$

$\therefore \delta(P_1) = 0.$

(iii) → (e) : Path difference at P_1 is $S_1P_1 - [S_2P_1 + (n-1)t]$

$$= \frac{\lambda}{4} - \frac{\lambda}{2} = -\frac{\lambda}{4}, \quad \text{so } \phi = -\frac{\pi}{2}.$$

$\therefore$ intensity $I(P_1) = 2I_0$.

Similarly, for point P_2, $\Delta = S_1P_2 - [S_2P_2 + (n-1)t]$

$$= \frac{\lambda}{3} - \frac{\lambda}{2} = -\frac{\lambda}{6}.$$

The corresponding phase difference,

$$\phi = \frac{2\pi}{\lambda}\left(-\frac{\lambda}{6}\right) = -\frac{\pi}{3}.$$

$\therefore\ I(P_2) = I_0 + I_0 + 2I_0 \cos\left(-\frac{\pi}{3}\right) = 3I_0 < 2I_0.$

$\Rightarrow\ I(P_2) < I(P_1).$

(iv) $\rightarrow$ (c), (d), (e) : Path difference at P_1,

$$S_1P_1 - [S_2P_1 + (n-1)t] = \frac{\lambda}{4} - \frac{3\lambda}{4} = -\frac{\lambda}{2}, \quad \text{so } \phi = -\pi.$$

$\therefore\ I(P_1) = 2I_0\,(1 + \cos\phi) = 2I_0 \times 0 = 0.$

For P_0, path difference

$$\Delta = S_2P_0 + (n-1)t - S_1P_0$$

$$= \frac{3\lambda}{4}, \text{ so phase difference } \phi = \frac{3}{2}\pi.$$

$\therefore\ I(P_0) = 2I_0\left(1 + \cos\frac{3\pi}{2}\right) = 2I_0$

$\Rightarrow\ I(P_0) > I(P_1).$

Finally at P_2,

$$\Delta = S_1P_2 - [S_2P_2 + (n-1)t] = \frac{\lambda}{3} - \frac{3\lambda}{4} = -\frac{5\lambda}{12}.$$

$\therefore$ phase difference $\phi = -\frac{5\pi}{6}$; $\cos\phi = \frac{-\sqrt{3}}{2}.$

$\therefore\ I(P_2) = 2I_0(1 + \cos\phi) = 2I_0\left(1 - \frac{\sqrt{3}}{2}\right)$

$\Rightarrow\ I(P_2) > I(P_1).$

4.7 Modern Physics

1. (i) $\rightarrow$ (b) : In α-decay, ${}^{A}_{Z}\text{X} \rightarrow {}^{A-4}_{Z-2}\text{Y} + \ldots$

(ii) $\rightarrow$ (a) : In β^+-decay, charge number reduces by 1 and mass number remains unchanged.

(iii) $\rightarrow$ (d) : In a fission reaction, the heavy nucleus splits into two lighter nuclei as in ${}^{239}_{94}\text{U} \rightarrow {}^{140}_{57}\text{La} + \ldots$

(iv) $\rightarrow$ (c) : In proton (${}^{1}_{1}\text{H}$) emission, charge number and mass number both reduce by 1 as in ${}^{185}_{83}\text{Bi} \rightarrow {}^{184}_{82}\text{Po} + \ldots$

2. (i) $\rightarrow$ (c), (e) : In a fusion reaction, the lighter nuclei fuse to form heavier nuclei with neutrino emission.

(ii) → (a), (d) : Absorption of thermal neutrons $({}_0^1n)$ by ${}_{92}^{235}U$ produces fission. Heavy water is used to slow down the fast-moving neutrons.

(iii) → (b), (e) : Unstable ${}_{27}^{60}Co$ nucleus disintegrates with emission of β-particle and neutrino.

(iv) → (c) : During a fusion reaction, γ-rays are emitted.

3. (i) → (a), (c) : Transition between two energy levels occurs in hydrogen spectrum and when characteristic X-rays are produced.

(ii) → (b), (d) : β-decay is electron emission; photoelectric effect also occurs with electron emission.

(iii) → (a) : Moseley's law relates wavelength of characteristic X-rays.

(iv) → (b) : From Einstein's equation $h\nu = \phi_0 + \frac{1}{2}mv_{max}^2$.

4. (i) → (a), (b), (e) : Energy of a charged capacitor = $Q^2/2C$.

Adiabatic compression increases the internal energy.

Time-varying magnetic field induces electric field and the induced current dissipates heat.

(ii) → (b) : Same as in case (i).

(iii) → (d) : During fission, energy is released due to loss in mass.

(iv) → (d) : Same as in case (iii).

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