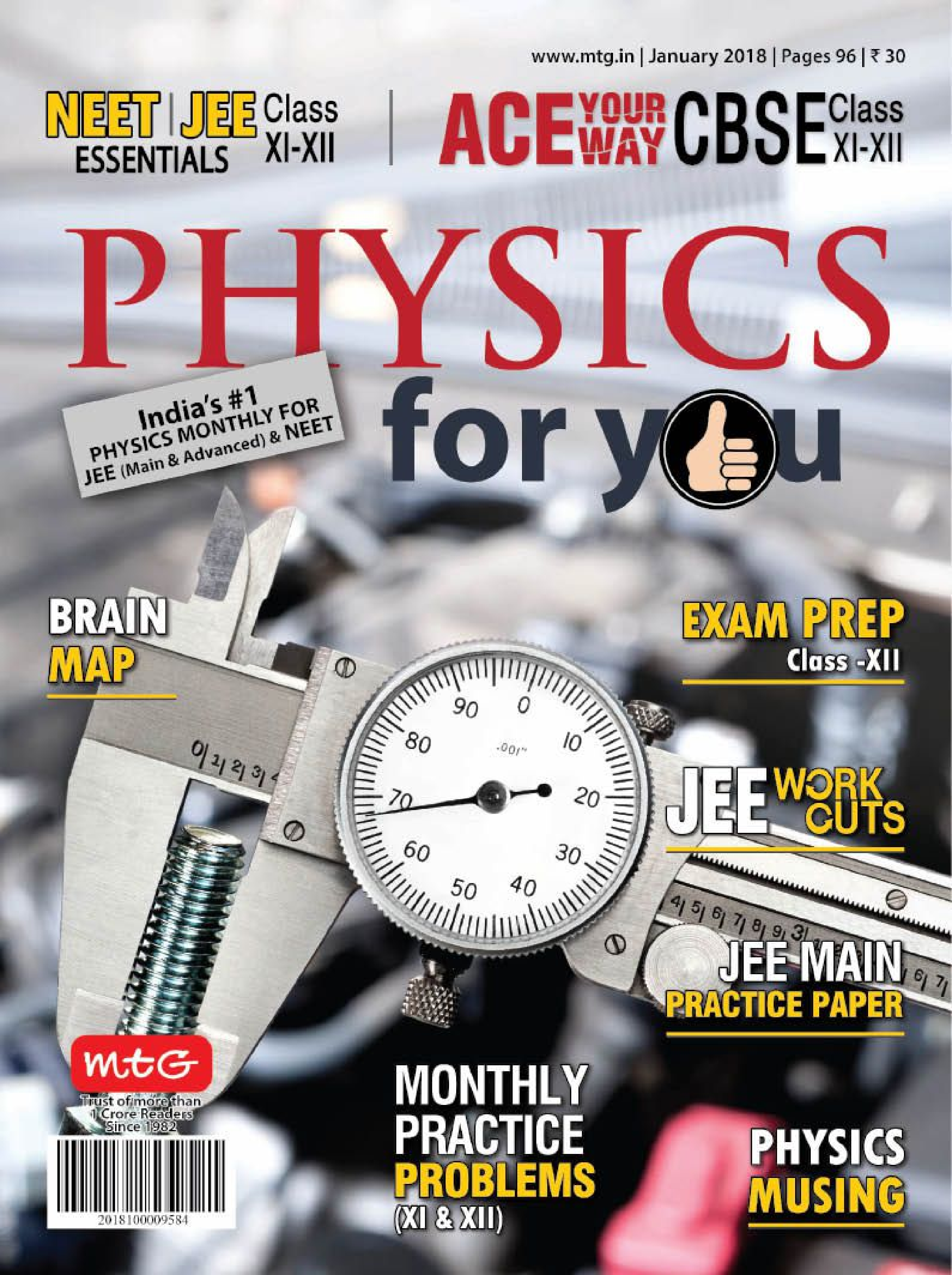

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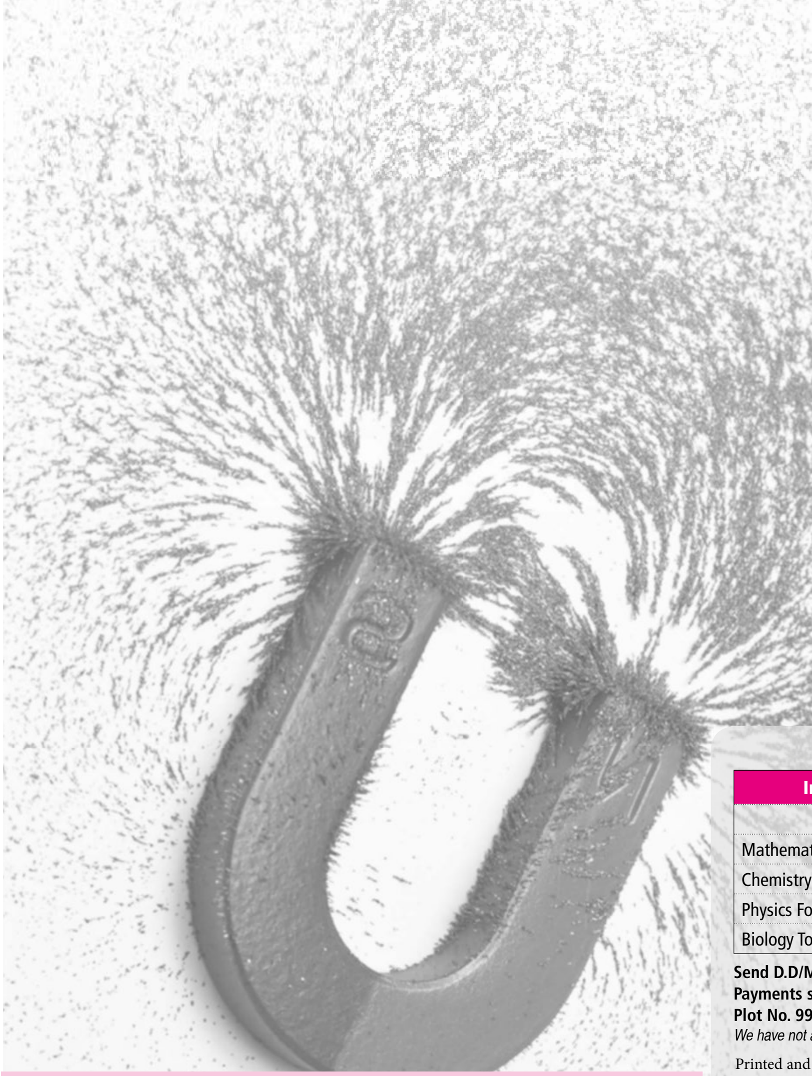

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Unit 7 THERMODYNAMICS AND KINETIC THEORY

THERMAL EQUILIBRIUM AND ZEROTH LAW

Thermal Equilibrium

It is observed that a higher temperature object which is in contact with a lower temperature object will transfer heat to the lower temperature object. The objects will approach the same temperature, and in the absence of loss to other objects, they will then maintain a constant temperature. They are then said to be in thermal equilibrium. Thermal equilibrium is the subject of the Zeroth law of thermodynamics.

Zeroth Law of Thermodynamics

It states that if two systems are in thermal equilibrium with a third system then they are in thermal equilibrium with each other. The Zeroth law leads to the concept of temperature.

FIRST LAW OF THERMODYNAMICS

- The first law of thermodynamics is represented as
  $\Delta Q = \Delta U + \Delta W$
  ΔQ is the heat exchange within a system, ΔU is the change in internal energy of a system, ΔW is the work done by the system.
- System itself can be classified as open, closed or isolated system as per the table given here:

System	Heat exchange takes place or $\Delta Q \neq 0$	Mass enters or leaves the system
Open	✓	✓
Closed	✓	×
Isolated	×	×

Sign Convention

- We will use the following thermodynamic sign convention wherein:
  ΔQ : Heat given to the system is positive, heat given by the system is negative.
  ΔW : Work done by the system is positive and work done on the system is negative.
  ΔU : It is the value of the final internal energy minus the initial internal energy.

Specific Heat Capacity

- The amount of heat absorbed or evolved by unit mass of a substance such that its temperature changes by unity, is called the specific heat capacity of the substance. Specific heat capacity is expressed as
  $Q = ms\Delta T = ms(T_f - T_i)$; $s = \dfrac{Q}{m\Delta T}$
- The amount of heat required to raise the temperature of one gram mole of a substance

through a unit degree is called the molar specific heat of the substance.

$$C = \frac{S}{n} = \frac{1}{n}\left(\frac{\Delta Q}{\Delta T}\right);$$

Here $S = \dfrac{\Delta Q}{\Delta T}$ is heat capacity.

- **Relation between specific heat at constant volume and pressure**
  - If ΔQ is absorbed at constant volume, then change in volume $\Delta V = 0$.

    $$C_V = \left(\frac{\Delta Q}{\Delta T}\right)_V = \left(\frac{\Delta U}{\Delta T}\right)_V = \frac{\Delta U}{\Delta T}$$

  - If ΔQ is the heat absorbed by the ideal gas at constant pressure, we have

    $$C_P = \left(\frac{\Delta Q}{\Delta T}\right)_P = \left(\frac{\Delta U}{\Delta T}\right)_P + P\left(\frac{\Delta V}{\Delta T}\right)_P$$

    $$= C_V + R \qquad \text{(Using } PV = RT\text{)}$$

(U depends only on temperature so subscripts P and V have no meaning for internal energy)

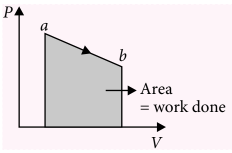
or $C_P - C_V = R$

Work done by an ideal gas

- Mathematical method : $\Delta W = P\Delta V$

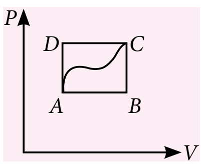
$$\Rightarrow \quad W = \int_{V_1}^{V_2} PdV$$

- Graphical method :
  - Work done = Area enclosed between P - V curve on V axis



  - Sign concept for work done :
    – If $V\uparrow \Rightarrow \Delta V = +$ ve $\Rightarrow$ expansion of gas $\Delta W = (+\text{ve}) \Rightarrow$ work done by the system.
    – If $V\downarrow \Rightarrow \Delta V = -$ ve $\Rightarrow$ compression of gas, $\Delta W = (-\text{ve}) \Rightarrow$ work done on the system.

Illustration 1 : In the indicator diagram, we have



(a) Change in internal energy along ABC is 10 J.
(b) Work done along path $AB = 20$ J
(c) $U_C = 5$ J
(d) Heat absorbed by the system along path AD is 5 J.

Calculate
(i) Change in internal energy along the path CDA
(ii) Heat given to the system along path ABC.
(iii) Value of U_A.
(iv) Change in internal energy along AD.

Soln.: (i) $U_C - U_A = 10$ J
$\therefore\ U_A - U_C = -10$ J
(ii) $\Delta Q = \Delta U + \Delta W = (U_C - U_A) + \Delta W$
or $\Delta Q = 10 + 20 = 30$ J
(iii) $U_C - U_A = 10$ J
or $U_A = U_C - 10$
or $U_A = 5 - 10 = -5$ J
(iv) $U_D - U_A = \Delta Q_{(AD)} - \Delta W_{AD} = 5 - 0 = 5$ J

Thermodynamic Processes

- **Isothermal process :** When a thermodynamic system undergoes a physical change in such a way that its temperature remains constant, then the change is known as isothermal process.
  - **Equation of state:** In this process, P and V change but T = constant, *i.e.*, change in temperature $\Delta T = 0$.
    Boyle's law is obeyed, *i.e.*, PV = constant
    $\Rightarrow \quad P_1V_1 = P_2V_2$
  - **First law in isothermal process:** From $\Delta Q = \Delta U + \Delta W$,
    As $\Delta U = 0 \Rightarrow \Delta Q = \Delta W$
    i.e., heat supplied in an isothermal change is used to do work against external surrounding.
- **Adiabatic process :** When a thermodynamic system undergoes a change in such a way that no exchange of heat takes place between system and surroundings, the process is known as adiabatic process.
  - In this process P, V and T change but $\Delta Q = 0$.
  - **First law in adiabatic process:** As $\Delta Q = 0$
    Using $\Delta Q = \Delta U + \Delta W$, we get $\Delta U = -\Delta W$
    If ΔW = positive then ΔU = negative, so temperature decreases, *i.e.*, adiabatic expansion produces cooling.
    If ΔW = negative then ΔU = positive, so temperature increases, *i.e.*, adiabatic compression produces heating.
  - **Equation of state:** In adiabatic change, ideal gases obey
    PV^γ = constant ; where $\gamma = \dfrac{C_P}{C_V}$
- **Isobaric process :** When a thermodynamic system undergoes a physical change in such a way that

its pressure remains constant, then the change is known as isobaric process.

- **In isobaric expansion (Heating)**
  - Temperature increases, so ΔU is positive.
  - Volume increases, so ΔW is positive.
  - Heat flows into the system, so ΔQ is positive.
- **In isobaric compression (Cooling)**
  - Temperature decreases, so ΔU is negative.
  - Volume decreases, so ΔW is negative.
  - Heat flows out from the system, so ΔQ is negative.

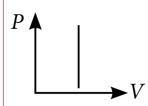
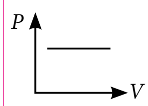
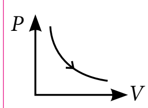
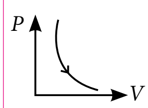
• **Isochoric or Isometric process :** When a thermodynamic process undergoes a physical change in such a way that its volume remains constant, then the change is known as isochoric process.

- **Isometric heating**
  - Pressure $\rightarrow$ increase
  - Temperature $\rightarrow$ increase
  - $\Delta Q \rightarrow$ positive
  - $\Delta U \rightarrow$ positive
- **Isometric cooling**
  - Pressure $\rightarrow$ decrease
  - Temperature $\rightarrow$ decrease
  - $\Delta Q \rightarrow$ negative
  - $\Delta U \rightarrow$ negative

• **Quasi-static process :** If the process is performed in such a way that at any instant during the process, the system is very nearly in thermodynamic equilibrium, the process is called quasi-static. This means, we can specify the parameters P, V, T uniquely at any instant during such a process.

• **Cyclic and non-cyclic process :** A cyclic process consists of a series of changes which return the system back to its initial state. In non-cyclic process, the series of changes involved do not return the system back to its initial state. In case of cyclic process as $U_f = U_i \Rightarrow \Delta U = U_f - U_i = 0$ *i.e.*, change in internal energy for cyclic process is zero and also $\Delta U \propto \Delta T \Rightarrow \Delta T = 0$, *i.e.*, temperature of system remains constant.

Essential Regarding Thermodynamical Processes

Name	Condition	Internal Energy	Work Done	Heat Exchanged	State variable relation	*PV* diagram	Specific Heat
Isochoric	$\Delta V = 0$	$nC_V\Delta T$	0	$nC_V\Delta T$	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$		$C_V = \frac{f}{2}R$
Isobaric	$\Delta P = 0$	$nC_V\Delta T$	$P\Delta V$	$nC_P\Delta T$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$		$C_P = \left(\frac{f}{2}+1\right)R$
Isothermal	$\Delta T = 0$	$nC_V\Delta T$	$nRT\ln\left(\frac{V_2}{V_1}\right)$	$nRT\ln\left(\frac{V_2}{V_1}\right)$	$P_1V_1 = P_2V_2$		$C = \frac{Q}{n\Delta T} = \frac{Q}{n \times 0} = \infty$
Adiabatic	$Q = 0$	$nC_V\Delta T$	$\frac{R\Delta T}{(\gamma - 1)}$	0	$PV^\gamma = K$ $TV^{\gamma-1} = K$ $P^{1-\gamma}T^\gamma = K$		$C = \frac{\Delta Q}{n\Delta T} = \frac{0}{n\Delta T} = 0$
Polytropic	$PV^x = K$	$nC_V\Delta T$	$\frac{P_2V_2 - P_1V_1}{1-\beta}$	$nC\Delta T$	$PV^x = K$	depends on x	$C = C_V + \frac{R}{1-x} = \frac{R}{\gamma-1} + \frac{R}{1-x}$

SECOND LAW OF THERMODYNAMICS

Kelvin-Planck Statement

- No process is possible whose sole result is the absorption of heat from a reservoir and the complete conversion of the heat into work.

Clausius Statement

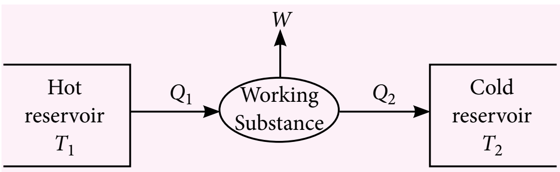
- No process is possible whose sole result is the transfer of heat from a colder object to a hotter object.

Reversible and Irreversible Processes

- **Reversible process :** A reversible process is one which can be retraced in the opposite direction to the initial state.
- A quasi-static isothermal expansion of an ideal gas in a cylinder fitted with a frictionless movable piston is an example of a reversible process.
- **Irreversible process :** An irreversible process is one which cannot be retraced back in the opposite direction to the initial state.
- All spontaneous processes of nature are irreversible processes. *e.g.* transfer of heat from a hot body to a cold body, diffusion of gases, etc. are all irreversible processes.

Heat Engine

- It is a device which converts heat energy into the mechanical energy.
- Every heat engine basically consists of three parts:
  - a hot reservoir called source
  - a working substance
  - a cold reservoir called sink
- The schematic diagram of a heat engine is shown here :



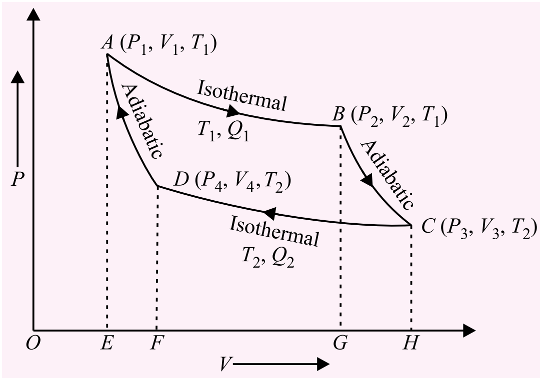
- The efficiency of a heat engine is given by

$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

Carnot Engine

Carnot engine is a reversible heat engine operating between two temperatures T_1 (source) and T_2 (sink).

- **Carnot cycle :** In order to obtain a continuous supply of work, the working substance is subjected to the following cycle of quasi-static operations known as Carnot's cycle.



  - **Isothermal expansion (AB) :**

$$Q_1 = W_1 = \int_{V_1}^{V_2} P dV = nRT_1 \log_e \frac{V_2}{V_1}$$
$$= \text{area } ABGEA$$

  - **Adiabatic expansion (BC) :**

$$W_2 = \frac{nR(T_1 - T_2)}{\gamma - 1} = \text{Area } BCHGB$$

  - **Isothermal compression (CD) :**

$$Q_2 = W_3 = -nRT_2 \log_e \frac{V_3}{V_4} = \text{Area } CHFDC$$

  - **Adiabatic compression (DA) :**

$$W_4 = \int_{V_4}^{V_1} PdV = -\frac{nR(T_1 - T_2)}{\gamma - 1} = \text{Area } DFEAD$$

  (Negative sign indicates that work is done on the working substance. Since W_2 and W_4 are equal and opposite, so they cancel each other.)

- **Efficiency of Carnot Cycle :** The efficiency of engine is defined as the ratio of work done to the heat supplied, *i.e.*,

$$\eta = \frac{\text{Work done}}{\text{Heat input}} = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

So efficiency of Carnot engine, $\eta = 1 - \frac{T_2}{T_1}$

Illustration 2 : A reversible heat engine converts one-sixth of heat, which it extracts from source, into work. When the temperature of the sink is reduced by 40°C, its efficiency is doubled. Find the temperature of source.

Soln.: Efficiency $\eta = \frac{W}{Q_1} = \frac{1}{6}$

Again $\eta = 1 - \frac{T_2}{T_1}; \frac{1}{6} = 1 - \frac{T_2}{T_1} \Rightarrow T_2 = \frac{5T_1}{6}$

Finally, efficiency $= 2\eta = \frac{2 \times 1}{6} = \frac{1}{3}$

Also, $\Delta T = 40°C = 40$ K

$$\therefore \quad \frac{1}{3} = 1 - \frac{T_2 - 40}{T_1} \text{ or } \frac{T_2 - 40}{T_1} = \left(1 - \frac{1}{3}\right) = \frac{2}{3}$$

or $\quad 2T_1 = 3T_2 - 120$

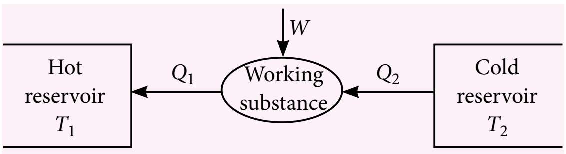
or $\quad 2T_1 = \left(3 \times \frac{5T_1}{6}\right) - 120$

or $\quad 2.5T_1 - 2T_1 = 120$ or $T_1 = 240$ K

REFRIGERATOR

A refrigerator or heat pump is basically a heat engine runs in reverse direction.

- The schematic diagram of a refrigerator or heat pump is shown.



- The coefficient of performance of a refrigerator is given by $\beta = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$
- **Relation between coefficient of performance and efficiency of refrigerator**

As $\quad \beta = \frac{Q_2}{Q_1 - Q_2} = \frac{Q_2 / Q_1}{1 - Q_2 / Q_1} \qquad \ldots\text{(i)}$

$\eta = 1 - \frac{Q_2}{Q_1}$ or $\frac{Q_2}{Q_1} = 1 - \eta \qquad \ldots\text{(ii)}$

From eqns. (i) and (ii), $\beta = \frac{1 - \eta}{\eta}$

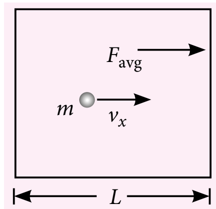
KINETIC THEORY

The kinetic theory of gases is the study of the microscopic behavior of molecules and the interactions which lead to macroscopic relationships like the ideal gas law.

- Assumptions of kinetic theory of an ideal gas :
  - The number of molecules is very large, but their separation is large compared to their molecular size.
  - Molecules move randomly with a distribution in speeds which do not change.
  - Molecules undergo elastic collisions with other molecules and the walls, but otherwise exert no forces on each other.
  - Molecules obey Newton's laws of motion.

Pressure Exerted by Gas Molecules

- Under the assumptions of kinetic theory, the average force on container walls has been determined to be



$$F_{avg} = \frac{mN\overline{v_x^2}}{L}$$

and assuming random speeds in all directions

$$\overline{v^2} = \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2} = 3\overline{v_x^2}$$

Then the pressure in a container can be expressed as

$$P = \frac{F_{avg}}{A} = \frac{mN\overline{v^2}}{3LA} = \frac{N}{3V}m\overline{v^2} = \frac{N}{3V}mv_{rms}^2$$

- The average force and pressure on a given wall depends only upon the components of velocity toward that wall. But it can be expressed in terms of the average of the entire translational kinetic energy using the assumption that the molecular motion is random.
- Expressed in terms of average molecular kinetic energy:

$$P = \frac{2N}{3V}\left[\overline{\frac{1}{2}mv^2}\right]$$

  - This leads to a concept of kinetic temperature and the ideal gas law.

Illustration 3 : The mass of molecules of a gas enclosed in a container is halved and their speed is doubled. Find the ratio of initial and final pressures.

Soln.: As $P = \frac{1}{3}\frac{M}{V}\overline{v^2} = \frac{1}{3}\frac{mn}{V}\overline{v^2}$

$$\therefore \quad \frac{P_1}{P_2} = \frac{m_1}{m_2}\left(\frac{\overline{v_1^2}}{\overline{v_2^2}}\right) = \left(\frac{2m}{m}\right)\left(\frac{\overline{v_1^2}}{4\overline{v_1^2}}\right)$$

or $\quad \frac{P_1}{P_2} = \frac{2 \times 1}{4} = \frac{1}{2}$

IDEAL GAS LAW

- An ideal gas is defined as one in which all collisions between atoms or molecules are perfectly elastic and in which there are no intermolecular attractive forces. One can visualize it as a collection of perfectly hard spheres which collide but which otherwise do not interact with each other. In such a gas, all the internal energy is in the form of kinetic energy and any change in internal energy is accompanied by a change in temperature.
- An ideal gas can be characterized by three state variables: absolute pressure (P), volume (V), and absolute temperature (T). The relationship between them is called the ideal gas law : $PV = nRT = NkT$
  n = number of moles
  R = universal gas constant = 8.3145 J mol^{-1} K
  N = number of molecules
  k = Boltzmann constant = 1.38066×10^{-23} J K^{-1}
  $k = R/N_A$
  N_A = Avogadro's number = 6.0221×10^{23} mol^{-1}

Gas Laws

- **Boyle's law :** It states that at a constant temperature, the volume of a given mass of a gas is inversely proportional to the pressure.
  $$V \propto \frac{1}{P} \quad \text{or} \quad PV = \text{constant.}$$
- **Charles' law :** It states that at a constant pressure, volume of a given mass of gas is directly proportional to its absolute temperature.
  $$V \propto T \quad \text{or} \quad V/T = \text{constant.}$$
- **Avogadro's law :** It states that at same temperature and pressure equal volumes of all the gases contain equal number of molecules.
  $N_1 = N_2$, if P, V and T are the same.
- **Graham's law of diffusion :** It states that at a constant pressure and temperature, the rate of diffusion of a gas is inversely proportional to the square root of its density.
  $$\text{Rate of diffusion} \propto \frac{1}{\sqrt{\rho}}, \quad \text{if } P \text{ and } T \text{ are constant.}$$
- **Dalton's law of partial pressure :** It states that the total pressure exerted by a mixture of non-reactive ideal gases is equal to the sum of the partial pressure which each would exert, if it alone occupies the same volume at the given temperature.
  $$P = P_1 + P_2 + P_3 + \ldots\ldots$$

Illustration 4 : An electric bulb of volume 300 cm^3 is sealed at temperature 300 K and pressure 10^{-4} mm of mercury. Find the number of air molecules in the bulb. (Given, $\sigma = 13.6 \times 10^3$ kg m^{-3} and $k = 1.38 \times 10^{-23}$ J K^{-1})

Soln.: $N = \dfrac{PV}{kT} = \dfrac{(\sigma g h)V}{kT}$

$$N = \frac{(10^{-7} \times 13.6 \times 10^3 \times 9.8) \times 300 \times 10^{-6}}{(1.38 \times 10^{-23}) \times 300}$$

$$N = 97 \times 10^{13} \approx 10^{15}$$

So, number of air molecules in the bulb = 10^{15}.

Illustration 5 : A vessel of capacity 3 litre contains 16 g of oxygen, 7 g of nitrogen and 11 g of carbon dioxide at 27°C. Calculate the pressure exerted by the mixture of gases.

Soln.: As $P = n\left(\dfrac{RT}{V}\right) = \dfrac{m}{M} \times \dfrac{RT}{V}$

and $P = P_1 + P_2 + P_3$

$$\therefore \quad P = \frac{RT}{V}\left[\frac{m_1}{M_1} + \frac{m_2}{M_2} + \frac{m_3}{M_3}\right]$$

$$P = \frac{RT}{V}\left[\frac{16}{32} + \frac{7}{28} + \frac{11}{44}\right] = \frac{RT}{V}[1]$$

$$P = \frac{RT}{V} = \frac{8.3 \times 300}{3 \times 10^{-3}} \text{ Pa} = 8.3 \text{ atm}$$

$[\because 1 \text{ litre} = 10^{-3} \text{ m}^3]$

Hence pressure = 8.3 atm

Kinetic Interpretation of Temperature

- The expression for pressure exerted by gas molecules developed from kinetic theory relates pressure and volume to the average molecular kinetic energy. Comparison with the ideal gas law leads to an expression for temperature sometimes referred to as the kinetic temperature.
  $$PV = nRT \Leftrightarrow PV = \frac{2}{3}N\left[\frac{1}{2}mv^2\right]$$
  This leads to the expression
  $$T = \frac{2}{3}\frac{N}{nR}\left[\frac{1}{2}mv^2\right] = \frac{2}{3}\frac{1}{k}\left[\frac{1}{2}mv^2\right]$$
  where N is the number of molecules, n the number of moles, R the gas constant, and k the Boltzmann constant.
- The more familiar form expresses the average molecular kinetic energy :

$$KE_{avg} = \left[\overline{\frac{1}{2}mv^2}\right] = \frac{3}{2}kT$$

It is important to note that the average kinetic energy used here is limited to the translational kinetic energy of the molecules. That is, they are treated as point masses and no account is made of internal degrees of freedom such as molecular rotation and vibration. This distinction becomes quite important when we deal the specific heats of gases. When we try to assess specific heat, you must account for all the energy possessed by the molecules, and the temperature as ordinarily measured does not account for molecular rotation and vibration. The kinetic temperature is the variable needed for subjects like heat transfer, because it is the translational kinetic energy which leads to energy transfer from a hot area (larger kinetic temperature, higher molecular speeds) to a cold area (lower molecular speeds) in direct collisional transfer.

Molecular Speeds

- From the expression for kinetic temperature

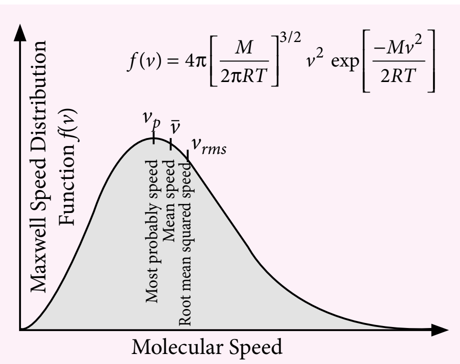
$$KE_{avg} = \left[\overline{\frac{1}{2}mv^2}\right] = \frac{3}{2}kT = \frac{1}{2}mv_{rms}^2$$

$$v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

m = mass of molecule, M = molar mass

- The speed distribution for the molecules of an ideal gas is given by

$$v_p = \sqrt{\frac{2RT}{M}}\ ;\ \bar{v} = \sqrt{\frac{8RT}{\pi M}}\ ;\ v_{rms} = \sqrt{\frac{3RT}{M}}$$



- Note that M is the molar mass and that the gas constant R is used in the expression. If the mass m of an individual molecule were used instead, the expression would be the same except that Boltzmann's constant k would be used instead of the molar gas constant R.

Illustration 5 : 0.014 kg of nitrogen is enclosed in a vessel at a temperature of 27 °C. At which temperature the rms velocity of nitrogen gas is twice its rms velocity at 27 °C?

Soln.: Using, $v_{rms} = \sqrt{\frac{3RT}{m}}$

or $\frac{(v_{rms})_1}{(v_{rms})_2} = \sqrt{\frac{T_1}{T_2}}$ ($\because$ R and m are constant.)

According to question, $(v_{rms})_2 = 2(v_{rms})_1$

$$\therefore \frac{(v_{rms})_1}{2(v_{rms})_1} = \sqrt{\frac{300}{T_2}} \Rightarrow \frac{1}{4} = \frac{300}{T_2}$$

$T_2 = 300 \times 4 = 1200$ K = 927°C

Equipartition of Energy

- The theorem of equipartition of energy states that molecules in thermal equilibrium have the same average energy associated with each independent degree of freedom of their motion and that energy is

$\frac{1}{2}kT$	k = Boltzmann's constant	$\frac{3}{2}kT$	For three translational degrees of freedom, such as in an ideal monoatomic gas.
$\frac{1}{2}RT$	R = gas constant	$\frac{3}{2}RT$	

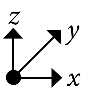
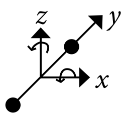
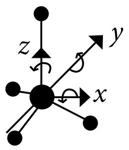
The equipartition result $KE_{avg} = \frac{3}{2}kT$ serves well in the definition of kinetic temperature since it involves just the translational degrees of freedom, but it fails to predict the specific heats of polyatomic gases because the increase in internal energy associated with heating such gases adds energy to rotational and perhaps vibrational degrees of freedom. Each vibrational mode will get $kT/2$ for kinetic energy and $kT/2$ for potential energy.

- The average translational kinetic energy possessed by free particles given by equipartition of energy is sometimes called the thermal energy per particle. It is useful in making judgements about whether the internal energy possessed by a system of particles will be sufficient to cause other phenomena. It is also useful for comparisons of other types of energy possessed by a particle to that which it possesses simply as a result of its temperature.

$$KE_{avg} = \left[\frac{1}{2}mv^2\right] = \frac{3}{2}kT$$

Degree of Freedom

- The number of independent coordinates required to specify the dynamical state of a system is called its degree of freedom.

Degree of freedom		Molar heat capacity at constant volume	Example
3		Monatomic $C_V = \frac{3}{2}R = 12.5\ \text{J mol}^{-1}\ \text{K}^{-1}$	Helium 12.5, Argon 12.6
5		Diatomic $C_V = \frac{5}{2}R = 20.8\ \text{J mol}^{-1}\ \text{K}^{-1}$	Nitrogen (N_2) 20.7, Oxygen (O_2) 20.8
6		Polyatomic $C_V = \frac{6}{2}R = 24.9\ \text{J mol}^{-1}\ \text{K}^{-1}$	Ammonia (NH_3) 29.0, Carbon dioxide (CO_2) 29.7

- The internal energy of n moles of a gas in which each molecule has f degrees of freedom is given by

$$U = nf\left(\frac{1}{2}RT\right)$$

For monatomic gas $U = \frac{3nRT}{2}$

Mixture of Non Reactive Gases

- $n = n_1 + n_2$
- $P = P_1 + P_2$
- $U = U_1 + U_2$
- $\Delta U = \Delta U_1 + \Delta U_2$
- $C_V = \frac{n_1 C_{V_1} + n_2 C_{V_2}}{n_1 + n_2}$
- $C_P = \frac{n_1 C_{P_1} + n_2 C_{P_2}}{n_1 + n_2} = C_V + R$
- $\gamma = \frac{C_P}{C_V}$ or $\frac{n}{\gamma - 1} = \frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1}$
- $M = \frac{n_1 M_1 + n_2 M_2}{n_1 + n_2}$

MEAN FREE PATH

- It is the average distance covered by a molecule between two successive collisions and is given by

$$\lambda = \frac{1}{\sqrt{2}n\pi d^2}$$

where n is the number density and d is the diameter of the molecule.

- Mean free path is related to the temperature (T) and pressure (P) as

$$\lambda = \frac{k_B T}{\sqrt{2}\pi d^2 P}$$

Illustration 6 : 1 mole of monatomic and 1 mole of diatomic gases are mixed together. What is the value of C_V for the mixture?

Soln.: For mixture of gases, $C_V = \frac{n_1 C_{V_1} + n_2 C_{V_2}}{n_1 + n_2}$

Here, $C_{V_1} = \frac{3}{2}R,\ n_1 = 1,\ C_{V_2} = \frac{5}{2}R,\ n_2 = 1$

$$\therefore \quad C_V = \frac{\left(1 \times \frac{3}{2}R\right) + \left(1 \times \frac{5}{2}R\right)}{1+1} = \frac{4}{2}R = 2R$$

SPEED PRACTICE

1. Five moles of hydrogen when heated through 20 K expand by an amount of $8.3 \times 10^{-3} m^3$ under a constant pressure of 10^5 N m^{-2}. If $C_V = 20$ J^{-1} mol^{-1} K^{-1}, find C_P in J mol^{-1}K^{-1}
(a) 28.3 (b) 17.6 (c) 15.5 (d) 20.8

2. For a gas molecule with 6 degrees of freedom the law of equipartition of energy gives the following relation between the molar specific heat (C_V) and gas constant (R)
(a) $C_V = \frac{R}{2}$ (b) $C_V = R$ (c) $C_V = 2R$ (d) $C_V = 3R$

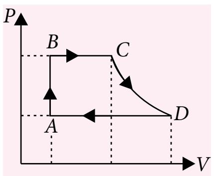
3. A tyre is pumped to a pressure of 6 atm suddenly bursts. Room temperature is 25°C. Calculate the temperature of escaping air. ($\gamma = 1.4$).
(a) –60.4°C (b) –94.4°C
(c) –70.4°C (d) –50.4°C

4. Dust particles in the suspended state in a monatomic gas are in thermal equilibrium with the gas. If the temperature of the gas is 300 K, and the mass of a certain particle is 10^{-17} kg, calculate its rms speed (in m s^{-1})($k = 1.38 \times 10^{-23}$J K^{-1}).
(a) 2.987 (b) 1.482 (c) 0.035 (d) 3.942

5. The relation between U, P and V for an ideal gas is $U = 2 + 3PV$. Find the atomicity of gas.
(a) 1 (b) 2 (c) 3 (d) 4

6. Consider a Carnot's cycle operating between T_1 = 500 K and T_2 = 300 K producing 1 kJ of mechanical energy per cycle. Find the heat absorbed from the heat reservoir.
(a) 2500 J (b) 1500 J
(c) 2000 J (d) 3000 J

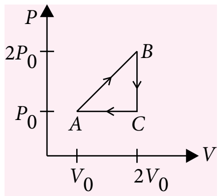
7. A cycle followed by an engine (made of one mole of an ideal gas in a cylinder with a piston) is shown in figure
AB : constant volume
BC : constant pressure
CD : adiabatic
DA : constant pressure



Which of the following relation is correct regarding, the heat exchanged by the engine with the surrounding for each section of the cycle? ($C_V = (3/2)\ R$)
(a) $Q_{AB} = \frac{3}{2}V_A(P_B - P_A)$
(b) $Q_{BC} = \frac{5}{2}P_B(V_C - V_A)$
(c) $Q_{CD} = \frac{3}{2}P_A(V_A - V_D)$
(d) both (a) and (b)

8. At what temperature will the average velocity of oxygen molecule sufficient so as to escape from the earth? Escape velocity from earth is 11.0 km s^{-1} and mass of one molecule of oxygen is 5.34×10^{-26} kg.
(a) 1.56×10^5 K (b) 7.39×10^5 K
(c) 2.35×10^5 K (d) 4.89×10^5 K

9. Find the efficiency of the thermodynamic cycle shown in figure for an ideal diatomic gas.



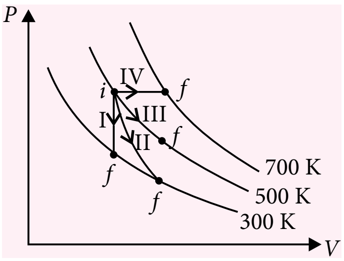
(a) 1/12 (b) 1/13
(c) 1/18 (d) 1/15

10. Two perfect gases at absolute temperatures T_1 and T_2 are mixed. There is no loss of energy. Find the temperature of the mixture if the masses of the molecules are m_1 and m_2 and the number of molecules in the gases are n_1 and n_2.
(a) $\frac{n_1T_1 + n_2T_2}{n_1 + n_2}$ (b) $\frac{n_1T_2 + n_2T_1}{n_1 + n_2}$
(c) $\frac{n_1n_2T}{n_1 + n_2}$ (d) $\frac{(n_1 + n_2)T}{n_1n_2}$

11. If the coefficient of performance of a refrigerator is 5 and operates at the room temperature 27°C, find the temperature inside the refrigerator.
(a) 100 K (b) 250 K (c) 350 K (d) 150 K

12. The collision frequency of nitrogen molecule in a cylinder at 2.0 atm pressure and temperature 17°C is (Take radius of a nitrogen molecule is 1.0 Å)
(a) 4.6×10^9 s^{-1} (b) 5.8×10^9 s^{-1}
(c) 8.9×10^9 s^{-1} (d) 7.5×10^9 s^{-1}

13. Thermodynamic processes are indicated in the following diagram.



Match the following

	Column I		Column II
P.	Process I	A.	Adiabatic
Q.	Process II	B.	Isobaric
R.	Process III	C.	Isochoric
S.	Process IV	D.	Isothermal

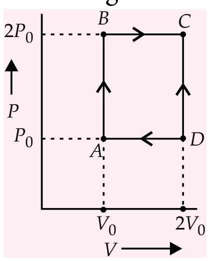
(a) P → C, Q → A, R → D, S → B
(b) P → C, Q → D, R → B, S → A
(c) P → D, Q → B, R → A, S → C
(d) P → A, Q → C, R → D, S → B **[NEET 2017]**

14. A carnot engine having an efficiency of $\frac{1}{10}$ as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is
(a) 90 J (b) 99 J (c) 100 J (d) 1 J
[NEET 2017]

15. A gas mixture consists of 2 moles of O_2 and 4 moles of Ar at temperature T. Neglecting all vibrational modes, the total internal energy of the system is
(a) 15 RT (b) 9 RT (c) 11 RT (d) 4 RT
[NEET 2017]

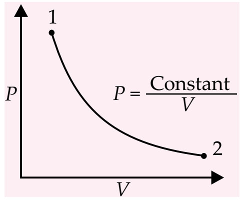
16. C_P and C_V are specific heats at constant pressure and constant volume respectively. It is observed that
$C_P - C_V = a$ for hydrogen gas
$C_P - C_V = b$ for nitrogen gas
The correct relation between a and b is
(a) $a = \frac{1}{14}b$ (b) $a = b$
(c) $a = 14b$ (d) $a = 28b$
[JEE Main Offline 2017]

17. An engine operates by taking n moles of an ideal gas through the cycle $ABCDA$ shown in figure.

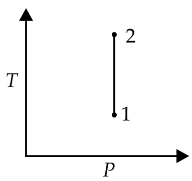


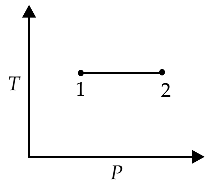
The thermal efficiency of the engine is (Take $C_V = 1.5R$, where R is gas constant)
(a) 0.15
(b) 0.32
(c) 0.24
(d) 0.08
[JEE Main Online 2017]

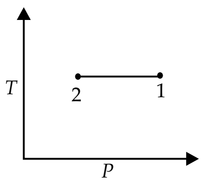
18. For the P-V diagram given for an ideal gas,

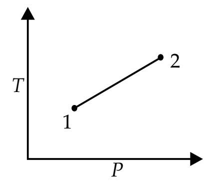


out of the following which one correctly represents the T-P diagram?

(a)


(b)


(c)


(d)


[JEE Main Online 2017]

19. An ideal gas has molecules with 5 degrees of freedom. The ratio of specific heats at constant pressure (C_P) and at constant volume (C_V) is
(a) 6 (b) $\frac{7}{2}$ (c) $\frac{5}{2}$ (d) $\frac{7}{5}$
[JEE Main Online 2017]

20. N moles of a diatomic gas in a cylinder are at a temperature T. Heat is supplied to the cylinder such that the temperature remains constant but n moles of the diatomic gas get converted into monatomic gas. What is the change in the total kinetic energy of the gas?
(a) 0 (b) $\frac{5}{2}nRT$ (c) $\frac{1}{2}nRT$ (d) $\frac{3}{2}nRT$
[JEE Main Online 2017]

MPP-9 CLASS XII ANSWER KEY

1. (a)	2. (a)	3. (b)	4. (d)	5. (c)
6. (a)	7. (a)	8. (a)	9. (a)	10. (d)
11. (b)	12. (a)	13. (c)	14. (b)	15. (c)
16. (b)	17. (c)	18. (c)	19. (b)	
20. (a,b,c,d)		21. (b,c)	22. (a,b,d)	23. (a,b)
24. (3)	25. (4)	26. (5)	27. (d)	28. (b)
29. (d)	30. (c)			

SOLUTIONS

1. (a)

2. (d): $C_V = \frac{f}{2}R$, where f is the degrees of freedom.

Here, $f = 6$ $\therefore$ $C_V = \frac{6}{2}R = 3R$

3. (b): From $P_1^{1-\gamma}T_1^{\gamma} = P_2^{1-\gamma}T_2^{\gamma}$

Here, $P_1 = 6$ atm $P_2 = 1$ atm

$T_1 = 273 + 25 = 298$ K, $\gamma = 1.4$

Now, $(6)^{(1-1.4)}(298)^{1.4} = (1)^{(1-1.4)}\ T_2^{1.4} = T_2^{1.4}$

$\therefore$ $T_2 = 178.6$ K $\Rightarrow T_2 = 178.6 - 273 = -94.4$°C.

4. (c): According to kinetic theory of gases, KE = (3/2)kT, for a particle in thermal equilibrium at temperature T.

$\therefore$ $\text{KE} = \frac{3}{2}kT = \frac{3}{2}\times 1.38\times 10^{-23}\times 300 = 6.21 \times 10^{-21}$ J

Now if m is the mass of particle and v_{rms} its rms speed,

$$\text{KE} = \frac{1}{2}mv_{rms}^2, \Rightarrow v_{rms} = \sqrt{\frac{2\,\text{KE}}{m}}$$

$$\therefore v_{rms} = \sqrt{\frac{2\times 6.21\times 10^{-21}}{10^{-17}}} = 0.035 \text{ m s}^{-1}$$

5. (c): For an adiabatic process

$dQ = 0 = dU + dW$ or $0 = dU + PdV$ ...(i)

$\because$ $U = 2 + 3\,PV$

$\therefore$ $dU = 3\,(PdV + VdP)$

$\therefore$ $0 = 3\,(PdV + VdP) + PdV$ (from eqn. (i))

or $4P\,(dV) + 3V\,(dP) = 0$ or $4\left(\frac{dV}{V}\right) = -3\left(\frac{dP}{P}\right)$

On integrating

$\ln(V^4) + \ln(P^3) = \text{constant}$; $PV^{4/3} = \text{constant}$

i.e., $\gamma = \frac{4}{3}$ *i.e.*, gas is triatomic.

6. (a): $\frac{Q_2}{Q_1} = \frac{T_2}{T_1} = \frac{3}{5}, Q_1 - Q_2 = W = 10^3\text{J}$

$$\therefore Q_1\left(1 - \frac{Q_2}{Q_1}\right) = 10^3\text{J} \Rightarrow Q_1\left(1 - \frac{3}{5}\right) = 10^3 \text{ J}$$

$$\therefore Q_1 = \frac{5}{2}\times 10^3 = 2500 \text{ J}$$

7. (d): $Q_{AB} = U_{AB} = \frac{3}{2}R(T_B - T_A) = \frac{3}{2}V_A(P_B - P_A)$

$Q_{BC} = U_{BC} + W_{BC}$

$= (3/2)\,P_B(V_C - V_B) + P_B(V_C - V_B)$

$= (5/2)P_B\,(V_C - V_A)$

$Q_{CD} = 0$ ($\because$ CD is adiabatic process)

$Q_{DA} = (5/2)\,P_A\,(V_A - V_D)$

8. (a): As $\frac{3}{2}kT = \frac{1}{2}mv^2$

For the molecule to just escape from the earth $v = v_e$

$$\therefore \quad T = \frac{mv_e^2}{3k}$$

$$= \frac{5.34\times 10^{-26}\times\left(11.0\times 10^3\right)^2}{3\times 1.38\times 10^{-23}} = 1.56\times 10^5\text{K}$$

9. (c): Let n be the number of moles of the gas and the temperature be T_0 in the state A.

Now, work done during the cycle

$$\therefore \quad W = \frac{1}{2}\times(2V_0 - V_0)(P_0) = \frac{1}{2}P_0V_0$$

For the heat (ΔQ_1) given during the process $A \to B$,

$\Delta Q_1 = \Delta W_{AB} + \Delta U_{AB}$

ΔW_{AB} = area under the straight line AB

$$= \frac{1}{2}(P_0 + 2P_0)(V_0) = \frac{3P_0V_0}{2}$$

Applying equation of state for the gas in the state A and B.

$$\frac{P_0V_0}{T_0} = \frac{(2P_0)(2V_0)}{T_B} \Rightarrow T_B = 4T_0$$

$$\therefore \quad U_{AB} = nC_V\Delta T = n\left(\frac{5R}{2}\right)(4T_0 - T_0)$$

$$= \frac{15nRT_0}{2} = \frac{15P_0V_0}{2}$$

$$\therefore \Delta Q_1 = \frac{3}{2}P_0V_0 + \frac{15}{2}P_0V_0 = 9P_0V_0$$

The processes $B \to C$ and $C \to A$ involve the abstraction of heat from the gas.

$$\eta = \frac{\text{Work done per cycle}}{\text{Total heat supplied per cycle}}$$

$$\therefore \quad \eta = \frac{P_0V_0/2}{9P_0V_0} = \frac{1}{18}$$

10. (a): According to the kinetic theory of gases, the kinetic of an ideal gas molecule at temperature T is given by KE = (3/2)kT. And as there is no force of attraction among the molecules of a perfect gas, therefore potential energy of the molecules is zero.

So the energy of molecule of perfect gas, $E = \frac{3}{2}kT$

Now if T is the temperature of the mixture, by conservation of energy, *i.e.*,

$n_1E_1 + n_2E_2 = (n_1 + n_2)E$

$$\therefore \quad n_1\left(\frac{3}{2}kT_1\right) + n_2\left(\frac{3}{2}kT_2\right) = (n_1 + n_2)\left(\frac{3}{2}kT\right)$$

i.e., $T = \frac{(n_1T_1 + n_2T_2)}{(n_1 + n_2)}$.

11. (b): $\beta = \frac{Q_2}{W} = 5, \ \therefore Q_2 = 5W$

$\because Q_1 - Q_2 = W \ \ \therefore Q_1 = 6W$

As $\frac{Q_2}{Q_1} = \frac{T_2}{T_1} \Rightarrow \frac{5}{6} = \frac{T_2}{300}$

$\Rightarrow \ T_2 = 250$ K

12. (a): Mean free path, $\lambda = \frac{kT}{\sqrt{2}\pi d^2 P}$

$$\lambda = \frac{(1.38\times10^{-23})(290)}{(1.414)(3.14)(2\times10^{-10})^2(2.026\times10^5)}$$

$= 1.1 \times 10^{-7}$ m

$$v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3\times1.38\times10^{-23}\times290}{28\times1.66\times10^{-27}}}$$

$= 5.1 \times 10^2$ m s^{-1}

$\therefore$ Collision frequency,

$$\upsilon = \frac{v_{rms}}{\lambda} = \frac{5.1\times10^2}{1.1\times10^{-7}} = 4.6\times10^9 \text{ s}^{-1}$$

13. (a): In process I, volume is constant

$\therefore$ Process I $\rightarrow$ Isochoric; P $\rightarrow$ C

As slope of curve II is more than the slope of curve III.

Process II $\rightarrow$ Adiabatic and Process III $\rightarrow$ Isothermal

$\therefore$ Q $\rightarrow$ A, R $\rightarrow$ D

In process IV, pressure is constant

Process IV $\rightarrow$ Isobaric; S $\rightarrow$ B

14. (a): Given $\eta = \frac{1}{10}, W = 10$ J

$$\beta = \frac{1-\frac{1}{10}}{\frac{1}{10}} = \frac{9}{10}.10 = 9$$

Since, $\beta = \frac{Q_2}{W}$, where Q_2 is the amount of energy absorbed from the cold reservoir.

$\therefore \ Q_2 = \beta W = 9 \times 10 = 90$ J

15. (c): The internal energy of 2 moles of O_2 atom is

$$U_{O_2} = \frac{n_1 f_1}{2}RT = 2\times\frac{5}{2}\times RT$$

$U_{O_2} = 5RT$

The internal energy of 4 moles of Ar atom is

$$U_{Ar} = \frac{n_2 f_2 RT}{2} = 4\times\frac{3}{2}\times RT = 6\,RT$$

$\therefore$ The total internal energy of the system is

$U = U_{O_2} + U_{Ar} = 5\,RT + 6\,RT = 11\,RT$

16. (c): For an ideal gas, $c_P - c_V = R$

where c_P and c_V are the molar heat capacities.

$MC_P - MC_V = R$

$(c_P = MC_P$ and $c_V = MC_V)$

Here, C_P and C_V are specific heats and M is the molar mass.

$\therefore \ C_P - C_V = \frac{R}{M}$

For hydrogen gas, $C_P - C_V = \frac{R}{2} = a$ ... (i)

For nitrogen gas, $C_P - C_V = \frac{R}{28} = b$ ... (ii)

Dividing eqn. (i) by (ii), we get

$\frac{a}{b} = 14$ or $a = 14b$

17. (a): Work done by engine = area under closed curve $= P_0V_0$

Heat given to the system, $Q = Q_{AB} + Q_{BC}$

$= nC_V\Delta T_{AB} + nC_P\Delta T_{BC}$

$= \frac{3}{2}(nRT_B - nRT_A) + \frac{5}{2}(nRT_C - nRT_B)$

$= \frac{3}{2}(2P_0V_0 - P_0V_0) + \frac{5}{2}(4P_0V_0 - 2P_0V_0)$

$= \frac{13}{2}P_0V_0$

Thermal efficiency, $\eta = \frac{W}{Q} = \frac{P_0V_0}{\frac{13}{2}P_0V_0} = \frac{2}{13} \approx 0.15$

18. (c): Here, PV = constant, so given process is isothermal *i.e.*, temperature is constant. Pressure at point 1 is higher than that at point 2. So, correct option is (c).

19. (d): An ideal gas has molecules with 5 degrees of freedom, then

$C_V = \frac{5}{2}R$ and $C_P = \frac{7}{2}R$

$\therefore \ \frac{C_P}{C_V} = \frac{(7/2)R}{(5/2)R} = \frac{7}{5}$

20. (c): Initial kinetic energy of the system

$K_i = \frac{5}{2}RTN$

Final kinetic energy of the system,

$K_f = \frac{5}{2}RT(N-n) + \frac{3}{2}RT(2n)$

$\Delta K = K_f - K_i = nRT\left(3 - \frac{5}{2}\right) = \frac{1}{2}nRT$

◈◈

ACE YOUR WAY CBSE XI

Series 7

CHAPTERWISE PRACTICE PAPER

OSCILLATIONS | WAVES

Time Allowed : 3 hours   Maximum Marks : 70

GENERAL INSTRUCTIONS

(i) All questions are compulsory.
(ii) Q. no. 1 to 5 are very short answer questions and carry 1 mark each.
(iii) Q. no. 6 to 10 are short answer questions and carry 2 marks each.
(iv) Q. no. 11 to 22 are also short answer questions and carry 3 marks each.
(v) Q. no. 23 is a value based question and carries 4 marks.
(vi) Q. no. 24 to 26 are long answer questions and carry 5 marks each.
(vii) Use log tables if necessary, use of calculators is not allowed.

SECTION - A

1. The displacement of an elastic wave is given by the function $y = 3 \sin \omega t + 4 \cos \omega t$. Where y is in cm and t is in second. Calculate the resultant amplitude.

2. Plot a graph between the time period (T) for a simple pendulum and its length (L).

3. Are $\tan \omega t$ and $\cot \omega t$ periodic functions?

4. When two waves of almost equal frequencies υ_1 and υ_2 reach at a point simultaneously, what is the time interval between successive maxima?

5. What are the two basic characteristics of a simple harmonic motion?

SECTION - B

6. Distinguish between compression and rarefaction.

7. Can a simple pendulum experiment be conducted inside a satellite?

8. A string of mass 2.50 kg is under a tension of 200 N. The length of the stretched string is 20.0 m. If the transverse jerk is struck at one end of the string, how long does the disturbance take to reach the other end?

OR

A pipe 20 cm long is open at both ends. Which harmonic mode of the pipe is resonantly excited by a source of 1650 Hz ? (velocity of sound in air = 330 m s^{-1})

9. A particle is executing S.H.M of amplitude a. At what displacement from the mean position, is the energy, half-kinetic and half-potential ?

10. Write four characteristics of wave motion.

SECTION - C

11. If c is r.m.s. speed of molecules in a gas and v is the speed of sound waves in the gas, show that c/v is constant and independent of temperature for all diatomic gases.

12. A SONAR system fixed in a submarine operates at a frequency 40.0 kHz. An enemy submarine moves towards the SONAR with a speed of 360 km h^{-1}. What is the frequency of sound reflected by the submarine? Take the speed of sound in water to be 1450 m s^{-1}.

13. The bottom of a dip on a road has a radius of curvature R. A rickshaw of mass M, left a little away from the bottom oscillates about this dip. Deduce the expression for the period of oscillation.

14. Which of the following functions of time represent:
(i) $\sin kt + \cos kt$ (ii) $2\sin^2 kt$
(iii) e^{-kt} (iv) $\log kt$.
(a) simple harmonic
(b) periodic but not simple harmonic
(c) non-periodic motion?
where k is a real positive constant.

15. A transverse harmonic wave on a string is described by $y(x, t) = 3.0 \sin(36t + 0.018x + \pi/4)$ where x and y are in cm and t in s. The positive direction of x is from left to right.
(a) Is this a travelling wave or a stationary wave? If it is travelling, what are the speed and direction of its propagation?
(b) What are its amplitude and frequency?
(c) What is the initial phase at the origin?
(d) What is the least distance between two successive crests in the wave?

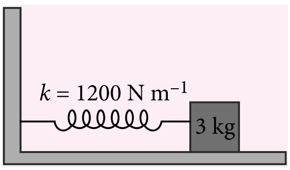
16. Explain why (or how):
(a) Bats can ascertain distances, direction, nature, and sizes of the obstacles without any eyes,
(b) A violin note and sitar note may have the same frequency, yet we can distinguish between the two notes, and
(c) Solids can support both longitudinal and transverse waves, but only longitudinal waves can propagate in gases.

17. A body describes simple harmonic motion with an amplitude of 5 cm and a period of 0.2 s. Find the acceleration and velocity of the body when the displacement is (a) 5 cm (b) 3 cm (c) 0 cm.

OR

A spring with a spring constant 1200 N m^{-1} is mounted on a horizontal smooth table as shown in figure.

A mass of 3 kg is attached to the free end of the spring. The mass is then pulled sideways to a distance of 2.0 cm and released.

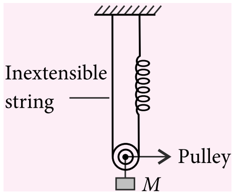


Determine (a) the frequency of oscillations
(b) maximum acceleration and
(c) the maximum speed of the mass.

18. Show that for a particle in linear S.H.M the average kinetic energy over a period of oscillation equals the average potential energy over the same period.

19. Define wave velocity. Deduce its relation with angular frequency ω and propagation constant k.

20. Find the time period of mass M when displaced from its equilibrium position and then released for the system shown in figure.



21. Discuss the various factors which affect the speed of sound in a gas.

22. A particle is vibrating in S.H.M. When the distances of the particles from the mean position are y_1 and y_2 it has velocities v_1 and v_2 respectively. Show that the time period is $T = 2\pi \times \sqrt{\frac{y_2^2 - y_1^2}{v_1^2 - v_2^2}}$

SECTION - D

23. Rajeshwer and his friends went to a hill forest for a plant collection tour. One of his friends Rajender Rana went to a different direction and entered a dense forest. He was searching a very useful and primordial plant. When he searched that plant, he loudly called his friend Rajeshwer. After a few seconds he heard the same sound as he just spoken. He afraid assuming that there was a ghost in nearby forest. He started crying. Somehow Rajeshwer heard his sound and found him. Again Rajender Rana made a loud sound, this sound was again copied by somebody. Rajender repeated that same ghost is there. Rajeshwer convinced him that it is nothing but it is reflection of sound. Now Rajender Rana became normal.
(a) What values were displayed by Rajeshwer?
(b) What is echo?
(c) If a reflector is situated at a distance of 860 m from a sound source, after how much time is echo heard? Speed of sound in air at a room temperature can be taken as 344 m s^{-1}.

SECTION - E

24. Find the expression for time period of motion of a body suspended by two springs connected in parallel and series.

OR

A cylindrical log of wood of height h and area of cross-section A floats in water. It is pressed and then released. Show that the log would execute S.H.M. with a time period

$$T = 2\pi\sqrt{\frac{m}{A\rho g}}$$

where m is mass of the body and ρ is density of the liquid.

25. (a) What are free oscillations? Give examples.

(b) A body of mass m is situated in a potential field $U(x) = U_0$ (1-cos αx) when U_0 and α are constants. Find the time period of small oscillations.

OR

Give an analytical treatment of stationary waves in a stretched string.

26. Obtain an expression for the observed frequency of the sound produced by a source when both observer and source are in motion and the medium at rest.

OR

Explain the formation of beats analytically. Prove that the beat frequency is equal to the difference in frequencies of the two superposing waves.

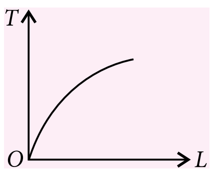
SOLUTIONS

1. Here, $y = 3\sin\omega t + 4\cos\omega t = a_1\sin\omega t + a_2\cos\omega t$

Resultant amplitude of the wave,

$$A = \sqrt{a_1^2 + a_2^2} = \sqrt{3^2 + 4^2} = 5 \text{ cm}$$

2.



3. tan ωt and cot ωt are periodic functions with the period $T = \pi/\omega$.

Since $\tan\{\omega(t + \pi/\omega)\} = \tan(\omega t + \pi) = \tan\omega t$ and $\cot\{\omega(t + \pi/\omega)\} = \cot(\omega t + \pi) = \cot\omega t$

4. Beat frequency of waves $= \upsilon_1 - \upsilon_2$

Hence, time interval between successive maxima,

$$= \frac{1}{\upsilon_1 - \upsilon_2}$$

5. Two basic characteristics of a S.H.M are

(i) Acceleration is directly proportional to the displacement.

(ii) Acceleration is directed opposite to the displacement.

6. The portion of the medium where a temporary portion in the volume (or increase in the density) takes place when a longitudinal wave passes through the medium is called a compression or a condensation. The portion of the medium where a temporary increase in the volume (or decrease in the density) takes place when a longitudinal wave passes through the medium is called a rarefaction.

7. $T = 2\pi\sqrt{\frac{l}{g}}$

Inside a statellite, the body is in a state of weightlessness so that the effective value of g is zero.

$$\therefore\ T = 2\pi\sqrt{\frac{l}{0}} = \infty$$

Thus, the pendulum does not oscillate at all and the experiment cannot be conducted inside the satellite.

8. Here, $M = 2.50$ kg, $T = 200$ N, length of the string, $l = 20$ m

Therefore, mass per unit length of the string,

$$\mu = \frac{2.5}{20} = 0.125 \text{ kg m}^{-1}$$

Now, $v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{200}{0.125}} = 40 \text{ m s}^{-1}$

Therefore, time taken by the transverse jerk to reach the other end,

$$t = \frac{l}{v} = \frac{20}{40} = 0.5 \text{ s}$$

OR

Here, $L = 20$ cm $= 0.2$ m, $\upsilon_n = 1650$ Hz, $v = 330$ m s^{-1}

Fundamental frequency of the open pipe

$$\upsilon = \frac{v}{2L} = \frac{330}{2(0.2)} = 825 \text{ Hz}$$

According to question, $\upsilon_n = n\upsilon$

$$\Rightarrow\ n = \frac{\upsilon_n}{\upsilon} = \frac{1650}{825} = 2$$

9. Kinetic energy $= \frac{1}{2}m\omega^2(a^2 - y^2)$

Potential energy $= \frac{1}{2}m\omega^2 y^2$

Since the energy is half-kinetic and half-potential, therefore,

$$\frac{1}{2}m\omega^2(a^2 - y^2) = \frac{1}{2}m\omega^2 y^2$$

or $\quad a^2 - y^2 = y^2$ or $y = \pm\frac{a}{\sqrt{2}}$

Thus, energy would be half-kinetic and half-potential at a point where displacement from the mean position is $\frac{a}{\sqrt{2}}$ on the either side.

10. (i) In a wave motion, it is the disturbance which travels in a medium due to the repeated periodic vibration of the particles about their mean positions.

(ii) There exists a definite phase relationship between any two neighbouring particles of the medium.

(iii) The energy is transferred from one place to another without any net transport of the medium.

(iv) The wave motion is possible only if the medium possesses elasticity, inertia and least possible friction between its different particles.

11. We know, $P = \frac{1}{3}\rho v_{rms}^2$

$$v_{rms} = \sqrt{\frac{3P}{\rho}} \quad \text{...(i)}$$

Speed of sound in gas, $v_a = \sqrt{\frac{\gamma P}{\rho}}$ ...(ii)

Solving, eqn. (i) and eqn. (ii)

$$\frac{v_{rms}}{v_a} = \sqrt{\frac{3P}{\rho}} \times \sqrt{\frac{\rho}{\gamma P}} = \sqrt{\frac{3}{\gamma}}$$

Here, $v_{rms} = c$ and $v_a = v$ $\therefore$ $\frac{c}{v} = \sqrt{\frac{3}{\gamma}}$

For diatomic gas, $\gamma = \frac{7}{5}$

$$\therefore \frac{c}{v} = \sqrt{\frac{3}{7/5}} = \sqrt{\frac{15}{7}} = \text{constant}$$

12. Here, frequency of SONAR (source), $\upsilon = 40.0$ kHz $= 40 \times 10^3$ Hz

Speed of sound waves, $v = 1450$ m s^{-1}

Speed of observers, $v_o = 360$ km h^{-1} $= 360 \times \frac{5}{18}$ $= 100$ m s^{-1}.

Since the source is at rest and observer moves towards the source (SONAR),

$$\therefore \upsilon' = \frac{v + v_o}{v}.\upsilon = \frac{1450+100}{1450} \times 40 \times 10^3$$

$\upsilon' = 4.276 \times 10^4$ Hz.

This frequency (υ') is reflected by the enemy submarine and is observed by the SONAR (which now acts as observer).

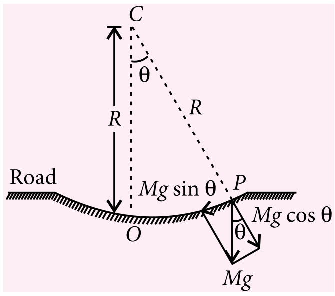
Therefore, in this case, $v_s = 360$ km h^{-1} $= 100$ m s^{-1}.

$\therefore$ Apparent frequency,

$$\upsilon'' = \frac{v}{v - v_s}\upsilon' = \frac{1450}{1450 - 100} \times 4.276 \times 10^4$$

$= 4.59 \times 10^4$ Hz $= 45.9$ kHz.

13. Let R be the radius of the dip and O be its centre. Let the rickshaw of mass M be at P at any instant. This case is similar to that of a simple pendulum. The force that produces oscillations in the rickshaw is



$F = Mg \sin\theta$. If θ is small and is measured in radians, $\sin\theta \simeq \theta$, $F = Mg\,\theta$

Displacement of the rickshaw, $OP = y = R\theta$

$\therefore$ Force constant,

$$k = \frac{\text{Force}}{\text{Displacement}} = \frac{Mg\theta}{R\theta} = \frac{Mg}{R}$$

$\therefore$ Time period,

$$T = 2\pi\sqrt{\frac{M}{k}} = 2\pi\sqrt{\frac{MR}{Mg}} = 2\pi\sqrt{\frac{R}{g}}$$

$$\therefore T = 2\pi\sqrt{\frac{R}{g}}$$

14. (i) $f(t) = \sin kt + \cos kt$

$$= \sqrt{2}\left[\frac{1}{\sqrt{2}}\sin kt + \frac{1}{\sqrt{2}}\cos kt\right]$$

$$= \sqrt{2}\sin\left(kt + \frac{\pi}{4}\right) = \sqrt{2}\cos(kt - \pi/4)$$

It represents SHM and the period of the function is $\frac{2\pi}{k}$.

(ii) $f(t) = 2\sin^2 kt = 1 - \cos 2kt$

The period of the function is $\frac{\pi}{k}$.

$f(t)$ represents a periodic function.

(iii) $f(t) = e^{-kt}$ decrease monotonically to zero as $t \to \infty$.

It is a non-periodic function.

(iv) $f(t)$ = log kt also increases monotonically with the time. It does not repeat itself and is a non-periodic function.

15. The equation of the form

$$y(x, t) = A\sin\left(\frac{2\pi}{\lambda}(vt + x) + \phi\right) \quad ...(i)$$

represents a harmonic wave of amplitude A, wavelength λ and travelling from right to left with a velocity v.

Now, the given equation for the transverse harmonic wave is

$y(x, t) = 3.0 \sin (36\,t + 0.018\,x + \pi/4)$

$$= 3.0\sin\left[0.018\left(\frac{36}{0.018}t + x\right) + \frac{\pi}{4}\right]$$

$$= 3.0 \sin [0.018 (2000\,t + x) + \pi/4] \quad ...(ii)$$

(a) Since the equation (i) and (ii) are of the same form, the given equation also represents a travelling wave propagating from right to left. Further, the coefficient of t gives the speed of the wave. Therefore, $v = 2000 \text{ cm s}^{-1} = 20 \text{ m s}^{-1}$

(b) Obviously, amplitude, A = 3.0 cm

Further, $\frac{2\pi}{\lambda} = 0.018$ or $\lambda = \frac{2\pi}{0.018}$ cm

$$\therefore \quad \upsilon = \frac{v}{\lambda} = \frac{2000}{2\pi} \times 0.018 = 5.73 \text{ s}^{-1}$$

(c) Initial phase at the origin, $\phi = \frac{\pi}{4}$ rad

(d) Least distance between two successive crests in the wave is equal to wavelength. Therefore,

$$\lambda = \frac{2\pi}{0.018} = 349 \text{ cm} = 3.49 \text{ m}$$

16. (a) Bats can produce and detect ultrasonic waves (sound waves of frequencies above 20 kHz). (i) From the interval of time between their producing the waves and receiving the echo after reflection from an object, they can estimate the distance of the object from them. (ii) From the intensity of the echo, they can estimate the nature and size of the object. (iii) Also, from the small time interval between the reception of the echo by their two ears, they can determine the direction of the object.

(b) The instruments produce different overtones (integral multiples of fundamental frequency). Hence the quality of sound produced by the two instruments of even same fundamental frequency is different.

(c) Solids have both volume and shear elasticity. So both longitudinal and transverse waves can propagate through them. On the other hand, gases have only volume elasticity and not shear elasticity. So only longitudinal waves can propagate through them.

17. Here, r = 5 cm = 0.05 m; T = 0.2 s;

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.2} = 10\pi \text{ rad s}^{-1}$$

When displacement is y, then acceleration, $a = -\omega^2 y$

velocity, $v = \omega\sqrt{r^2 - y^2}$

(a) When y = 5 cm = 0.05 m

$a = -(10\pi)^2 \times 0.05 = -5\pi^2 \text{ m s}^{-2}$

$v = 10\pi\sqrt{(0.05)^2 - (0.05)^2} = 0.$

(b) When y = 3 cm = 0.03 m

$a = -(10\pi)^2 \times 0.03 = -3\pi^2 \text{ m s}^{-2}$

$v = 10\pi\sqrt{(0.05)^2 - (0.03)^2} = 10\pi \times 0.04 = 0.4\pi \text{ m s}^{-1}$

(c) When $y = 0$, $a = -(10\pi)^2 \times 0 = 0$

$v = 10\pi\sqrt{(0.05)^2 - 0^2} = 10\pi \times 0.05 = 0.5\pi \text{ m s}^{-1}.$

OR

Here, $m = 3.0$ kg ; $k = 1200 \text{ N m}^{-1}$, A = 2 cm = 0.02 m

(a) The frequency of oscillations of the attached mass is

$$\upsilon = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2 \times 3.14}\sqrt{\frac{1200}{3}} = 3.2 \text{ Hz}$$

(b) The maximum acceleration of the mass is

$$|a_{max}| = \omega^2 A = \frac{kA}{m} \quad \left(\because \ \omega = \sqrt{\frac{k}{m}}\right)$$

$$= \frac{1200 \times 0.02}{3} = 8 \text{ m s}^{-2}$$

(c) The maximum speed of the mass is

$$v_{max} = A\omega = A\sqrt{\frac{k}{m}} = 0.02 \times \sqrt{\frac{1200}{3}} = 0.4 \text{ m s}^{-1}$$

18. Consider a particle of mass m executing S.H.M. with period T. The displacement of the particle at an instant t, when time period is noted from the mean position is given by

$y = A \sin\omega t$

$$\therefore \quad \text{Velocity, } v = \frac{dy}{dt} = A\,\omega \cos\omega t.$$

$$\text{Kinetic energy, } E_k = \frac{1}{2}mv^2 = \frac{1}{2}mA^2\omega^2\cos^2\omega t.$$

Potential energy, $E_p = \frac{1}{2}ky^2 = \frac{1}{2}mA^2\omega^2 \sin^2 \omega t$.

$(\because \; k = m\omega^2)$

$\therefore$ Average kinetic energy over one cycle

$$E_{k_{av}} = \frac{1}{T}\int_0^T E_k dt = \frac{1}{T}\int_0^T \frac{1}{2}m\,A^2\omega^2\cos^2\omega t\,dt$$

$$= \frac{1}{2T}m\,A^2\omega^2\int_0^T \frac{(1+\cos 2\omega t)}{2}dt$$

$$= \frac{1}{4T}m\,A^2\omega^2\left[t + \frac{\sin 2\omega t}{2\omega}\right]_0^T$$

$$= \frac{1}{4T}m\,A^2\omega^2(T) = \frac{1}{4}m\,A^2\omega^2 \qquad \text{...(i)}$$

Average potential energy over one cycle

$$E_{p_{av}} = \frac{1}{T}\int_0^T E_p dt = \frac{1}{T}\int_0^T \frac{1}{2}mA^2\omega^2\sin^2\omega t dt$$

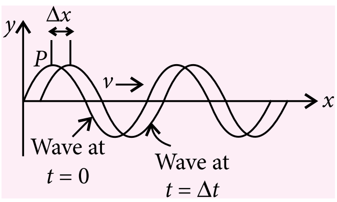
$$= \frac{1}{2T}m\,\omega^2 A^2\int_0^T \frac{(1-\cos 2\omega t)}{2}dt$$

$$= \frac{1}{4T}m\,\omega^2 A^2\left[1 - \frac{\sin 2\omega t}{2\omega}\right]_0^T$$

$$= \frac{1}{4T}m\,\omega^2 A^2[T] = \frac{1}{4}mA^2\omega^2 \qquad \text{...(ii)}$$

From eqn. (i) and (ii), $E_{k_{av}} = E_{p_{av}}$

19. The distance covered by a wave in the direction of its propagation per unit time is called the wave velocity. It represents the velocity with which a disturbance is transferred from one particle to the next with the actual motion of the particles.



The given figure shows two plots of the harmonic wave $y = A\sin(\omega t - kx)$ at two different instants of time t and $t + \Delta t$. During the small time interval Δt, the entire wave pattern moves through distance Δx in the positive x-direction. As the wave moves, each point of the moving waveform, such as point P marked on the peak retains its displacement y. This is possible only when the phase of the wave remains constant.

$\therefore \quad \omega t - kx = $ constant.

Differentiating both sides w.r.t. time t, we get

$$\omega - k\frac{dx}{dt} = 0 \quad \text{or} \quad \frac{dx}{dt} = \frac{\omega}{k}$$

But $\frac{dx}{dt} = $ wave velocity, v

$$\therefore \quad v = \frac{\omega}{k} = \frac{\lambda}{T} = \upsilon\lambda \qquad \left[\because \; \omega = \frac{2\pi}{T}, k = \frac{2\pi}{\lambda}\right]$$

20. Given situation is shown in the figure and system is in equilibrium.

So, $Mg = T + T \;\; \therefore \; Mg = 2T$

Due to hanging mass spring elongated by $2l$.

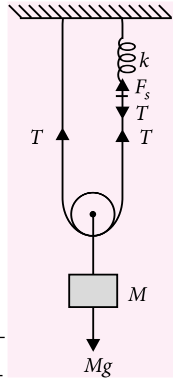
Here, l = distance moved by hanging mass.

In the spring, $T = F_s$ or $T = 2\,kl$

$\therefore \quad Mg = 2(2\,kl) = 2k(2l)$

Now, displace the mass through a distance y downwards.

Restoring force on mass M is given by



$F = Mg - 2k\,(2l + 2y)$

$\quad = Mg - (2k)\,(2l) - 4\,ky$

$\Rightarrow \quad F = Mg - Mg - 4ky = -4\,ky$

$$\text{or,}\; M\frac{d^2y}{dt^2} = -4ky$$

$$\text{or,}\; \frac{d^2y}{dt^2} = -\frac{4k}{M}y$$

Comparing it with $\frac{d^2y}{dt^2} = -\omega^2 y$

$$\therefore \; \omega = \sqrt{\frac{4k}{M}} \quad \text{or,} \quad T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{M}{4k}}$$

21. (i) The speed of sound in a gas is given by, $v = \sqrt{\frac{\gamma P}{\rho}}$

At constant temperature, PV = constant;

$\frac{Pm}{\rho}$ = constant

Since m is constant, so $\frac{P}{\rho}$ = constant *i.e.*, when pressure changes, density also changes in the same ratio so that the factor $\frac{P}{\rho}$ remains unchanged. Hence the pressure has no effect on the speed of sound in a gas for a given temperature.

(ii) We know that

$$PV = nRT \quad \text{or} \quad P = \frac{nRT}{V}$$

$$\text{Also} \; v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma nRT}{\rho V}} = \sqrt{\frac{\gamma RT}{M}}$$

where M = molecular weight of the gas

As γ, R and M are constants, so $v \propto \sqrt{T}$, *i.e.*, velocity of sound in a gas is directly proportional to the square root of its temperature, hence we conclude that the velocity of sound in air increases with increase in temperature.

(iii) As $v = \sqrt{\frac{\gamma P}{\rho}}$, *i.e.*, $v \propto \frac{1}{\sqrt{\rho}}$

The density of water vapours is less than that of dry air. Since the speed of sound is inversely proportional to the square root of density, so sound travels faster in moist air than in dry air.

22. We know, $y = a \sin \omega t$ ...(i)

$\therefore \quad \frac{dy}{dt} = a\,\omega \cos \omega t$

or $\quad v = a\,\omega \cos \omega t \quad$ or $\quad v^2 = a^2\omega^2 \cos^2 \omega t$

$v^2 = a^2\omega^2 (1 - \sin^2 \omega t) = a^2\omega^2 \left(1 - \frac{y^2}{a^2}\right)$ (From eqn (i))

$\therefore \quad v^2 = \omega^2 (a^2 - y^2)$

According to the given condition,

$v_1^2 = \omega^2 (a^2 - y_1^2)$ and $v_2^2 = \omega^2 (a^2 - y_2^2)$

$\therefore \quad (v_1^2 - v_2^2) = \omega^2 (y_2^2 - y_1^2)$

or $\quad \omega = \sqrt{\frac{(v_1^2 - v_2^2)}{(y_2^2 - y_1^2)}} = \frac{2\pi}{T}$ or $\quad T = 2\pi \times \sqrt{\frac{(y_2^2 - y_1^2)}{(v_1^2 - v_2^2)}}$

23. (a) Rajeshwer has scientific attitude, keen observer, sharp mind, creative and helping nature.

(b) Echo is the phenomenon of repetition of sound due to its reflection from the surface of a large obstacle.

(c) Total distance travelled by sound to come back $= 2 \times 860 = 1720$ m

Speed of sound is 344 m s^{-1}

$\therefore \quad \text{Time} = \frac{\text{Distance}}{\text{Speed}} = \frac{1720}{344} = 5$ s

An echo is heard 5 s after the sound produced by source.

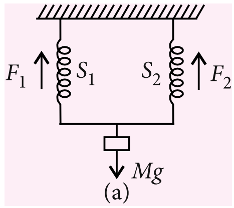
24. Consider a body of mass M suspended by two springs connected in parallel as shown in figure (a) Let k_1 and k_2 be the spring constants of two springs S_1 and S_2 respectively.

Let the body be pulled down so that each spring is stretched through a distance y. Restoring forces F_1 and F_2 will be developed in the spring S_1 and S_2 respectively.

According to Hooke's law, $F_1 = -k_1 y$

and $F_2 = -k_2 y$

Since both the forces acting in the same direction, therefore, total restoring force acting on the body is given by



(a)

$F = F_1 + F_2 = -k_1 y - k_2 y$

$= -(k_1 + k_2)\,y$

$\therefore$ Acceleration produced in the body is given by

$a = \frac{F}{M} = -\frac{(k_1 + k_2)y}{M}$

Since $\frac{(k_1 + k_2)}{M}$ is constant $\therefore a \propto -y$

Hence motion of the body is SHM.

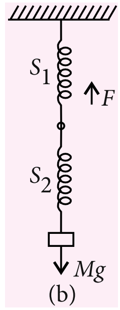
$\therefore \quad \omega^2 = \frac{k_1 + k_2}{M}$ or $\omega = \sqrt{\frac{k_1 + k_2}{M}}$

Time period of body is given by

$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{M}{k_1 + k_2}}$

If $k_1 = k_2 = k$. Then $T = 2\pi\sqrt{\frac{M}{2k}}$

Consider a body of mass M suspended by two springs S_1 and S_2 which are connected in series as shown in figure (b). Let k_1 and k_2 be the spring constants of spring S_1 and S_2 respectively.



(b)

Suppose at any instant, the displacement of the body from equilibrium position is y in the downward direction. If y_1 and y_2 be the extension produced in the spring S_1 and S_2 respectively, then

$y = y_1 + y_2$ ...(i)

Restoring forces developed in S_1 and S_2 are given by

$F_1 = -k_1 y_1$ ...(ii)

$F_2 = -k_2 y_2$ ...(iii)

Since both the springs are connected in series, so

$F_1 = F_2 = F$

$F = -k_{eff}(y_1 + y_2) = -k_1 y_1$

Using eqn. (ii) and (iii)

$-k_{eff}\left(y_1 + \frac{k_1 y_1}{k_2}\right) = -k_1 y_1$

$\therefore \quad k_{eff} = \frac{k_1 k_2}{k_1 + k_2}$ or $F = -\frac{k_1 k_2}{(k_1 + k_2)}\,y$

If a be the acceleration produced in the body of mass M, then

$a = \frac{F}{M} = -\frac{k_1 k_2 y}{(k_1 + k_2)M}$ ...(iv)

$$\therefore \quad \omega^2 = \frac{k_1k_2}{(k_1+k_2)M} \quad \text{or} \quad \omega = \sqrt{\frac{k_1k_2}{(k_1+k_2)M}}$$

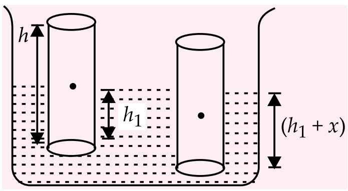
Time period of the body is given by

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{(k_1+k_2)M}{k_1k_2}} \qquad \text{[From eqn. (iv)]}$$

$$T = 2\pi\sqrt{\left(\frac{1}{k_1}+\frac{1}{k_2}\right)M}.$$

OR

Here, m = mass of cylinder
h = height of cylinder
h_1 = length of the cylinder dipping in the liquid at equilibrium position
ρ = density of liquid
A = cross-sectional area of cylinder.
At equilibrium,
mg = Buoyant force
= Weight of water displaced by the log of wood
$= \rho(Ah_1)g$ .... (i)
Now, log is pressed gently through a small distance x vertically and released.



Then the buoyant force becomes
$F_B = \rho A(h_1 + x)g$
$\therefore$ Net restoring force, F = Buoyant force – weight
$= \rho A\,(h_1 + x)g - mg$
$= \rho A(h_1 + x)g - \rho(Ah_1)g$ [using eqn (i)]
$= (A\rho g)x$
Here, F and x are in opposite direction

$$\therefore \quad F = -(A\rho g)x \quad \text{or,}\ a = \frac{-(A\rho g)}{m}x \qquad \text{...(ii)}$$

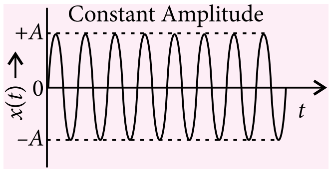
From standard SHM eqn, $a = -\omega^2 x$ ...(iii)
From eqns (ii) and (iii),

$$\omega^2 = \frac{A\rho g}{m} \Rightarrow \omega = \sqrt{\frac{A\rho g}{m}} \quad \therefore \quad T = 2\pi\sqrt{\frac{m}{A\rho g}}$$

25. If a body, capable of oscillating, is slightly displaced from its position of equilibrium and left to move itself, it starts oscillating with a frequency of its own. Such oscillations are called free oscillations. The frequency with which a body oscillates freely is called natural frequency and is given by

$$\upsilon_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Some important features of free oscillations are
(i) In the absence of dissipative forces, such a body vibrates with a constant amplitude and fixed frequency, as shown in figure. Such oscillations are also called undamped oscillations.
(ii) The amplitude of oscillation depends on the energy supplied initially to the oscillator.
(iii) The natural frequency of an oscillator depends on its mass, dimensions and restoring force *i.e.*, on its inertial and elastic properties (m and k).



Examples. (i) The vibrations of the prongs of tuning fork struck against a rubber pad.
(ii) The vibrations of the string of a sitar when pulled aside and released.
(iii) The oscillations of the bob of a pendulum when displaced from its mean position and released.
(b) Given, $U(x) = U_0(1 - \cos\alpha x)$
Differentiating both sides with respect to x

$$\frac{dU(x)}{dx} = U_0[0 + \alpha\sin\alpha x] = U_0\alpha\sin\alpha x$$

$$\therefore \quad F = -\frac{dU(x)}{dx} = -U_0\alpha\sin(\alpha x)$$

For small oscillations, $\sin\theta = \theta$.
$\Rightarrow \quad \sin\alpha x = \alpha x$
So, $F = -U_0\,\alpha(\alpha x) = -U_0\alpha^2 x$
or, $F = -(U_0\alpha^2)x$ ....(i)
Also, $F = -kx$ ....(ii)
From eqns. (i) and (ii)
$k = U_0\alpha^2$

$$\text{Thus,}\ T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{m}{U_0\alpha^2}}$$

OR

Consider a uniform string of length L stretched by a tension T along the x-axis, with its ends rigidy fixed at the end $x = 0$ and $x = L$. Suppose a transverse wave produced in the string along the string in positive x-direction and gets reflected at the fixed end $x = L$. The two waves can be represented as

$y_1 = A \sin(\omega t - kx)$ and $y_2 = -A \sin(\omega t + kx)$

The negative sign before A is due to phase reversal of the reflected wave at the fixed end. By the principle of superposition, the resultant wave is given by

$$y = y_1 + y_2 = -A[\sin(\omega t + kx) - \sin(\omega t - kx)]$$
$$= -2A \cos \omega t \sin kx$$

($\because \sin(A + B) - \sin(A - B) = 2 \cos A \sin B$)

or $y = -2A \sin kx \cos \omega t$ ...(i)

If stationary waves are formed, then the ends $x = 0$ and $x = L$ must be nodes because they are kept fixed.

So, we have the boundary conditions:

$y = 0$ at $x = 0$ for all t

and $y = 0$ at $x = L$ for all t

The first boundary condition ($y = 0$, $x = 0$) is satisfied automatically by equation (i). The second boundary condition ($y = 0$, $x = L$) will be satisfied if

$y = -2 \sin kL \cos \omega t = 0$

This will be true for all values of t only if

$\sin kL = 0$ or $kL = n\pi$, where $n = 1, 2, 3,...$

or $\frac{2\pi L}{\lambda} = n\pi$

For each value of n, there is a corresponding value of λ, so we can write

$$\frac{2\pi L}{\lambda_n} = n\pi \quad \text{or} \quad \lambda_n = \frac{2L}{n}$$

The speed of transverse wave on a string of linear mas density μ is given by $v = \sqrt{\frac{T}{\mu}}$

So the frequency of vibration of the string is

$$\upsilon_n = \frac{v}{\lambda_n} = \frac{n}{2L}\sqrt{\frac{T}{\mu}}$$

For $n = 1$, $\upsilon_1 = \frac{1}{2L}\sqrt{\frac{T}{\mu}} = \upsilon$ (say)

This is the lowest frequency with which the string can vibrate and is called fundamental frequency or first harmonic.

For $n = 2$, $\upsilon_2 = \frac{2}{2L}\sqrt{\frac{T}{\mu}} = 2\upsilon$

(First overtone or second harmonic)

For $n = 3$, $\upsilon_3 = \frac{3}{2L}\sqrt{\frac{T}{\mu}} = 3\upsilon$

(Second overtone or third harmonic)

Thus the various frequencies are in the ratio 1 : 2 : 3 : ... and hence form a harmonic series. These frequencies are called harmonics with the fundamental itself as the first harmonic. The higher harmonic are called overtones. Thus second harmonic is first overtone, third harmonic is second overtone and so on.

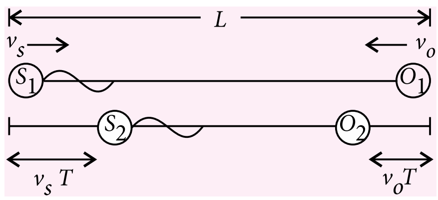
Nodes : These are the positions of zero amplitude. In the n^{th} mode of vibration, there are $(n + 1)$ nodes, which are located from one end at distances

$$x = 0, \frac{L}{n}, \frac{2L}{n}, ..., L$$

Antinodes : These are the positions of maximum amplitude. In the n^{th} mode of vibration, there are n antinodes, which are located at distances

$$x = \frac{L}{2n}, \frac{3L}{2n}, \frac{5L}{2n}, ..., \frac{(2n-1)L}{2n}.$$

26. As shown in figure consider the case when both the source and the observer are moving towards each other with speeds v_s and v_o respectively. Let the speed of a wave be v. If υ is the frequency of the source, it sends out compression pulses through the medium at regular intervals of $T = 1/\upsilon$.



At time $t = 0$, the observer is at O_1 and the source at S_1 and the distance between them is L when the source emits the first compression pulse. Since the observer is also moving towards the source, so the speed of the wave relative to the observer is $(v + v_o)$. Therefore, the observer will receive the first compression pulse at time, $t_1 = \frac{L}{v + v_o}$

At time $t = T$, both the source and observer have moved towards each other covering distances $S_1 S_2 = v_s T$ and $O_1 O_2 = v_o T$ respectively. The new distance between the source and the observer is

$S_2O_2 = L - (v_s + v_o)T$

The second compression pulse will reach the observer at time, $t_2 = T + \frac{L - (v_s + v_o)T}{v + v_o}$

The time interval between two successive compression pulses or the period of the wave as recorded by the observer is

$$T' = t_2 - t_1 = T + \frac{L-(v_s+v_o)T}{v+v_o} - \frac{L}{v+v_o}$$

$$= \left(1 - \frac{v_s+v_o}{v+v_o}\right)T = \left(\frac{v-v_s}{v+v_o}\right)T$$

Hence the apparent frequency of the sound as heard by the observer is

$$\upsilon' = \frac{1}{T'} = \frac{v+v_o}{v-v_s}\cdot\frac{1}{T} \text{ or } \upsilon' = \frac{v+v_o}{v-v_s}\upsilon \qquad \text{...(i)}$$

When the source moves towards the observer and the observer moves away from the source. In this case, the apparent frequency can be obtained by replacing v_o by $-v_o$ in eqn. (i). Thus

$$\upsilon' = \frac{v-v_o}{v-v_s}\upsilon$$

OR

Consider two harmonic waves of frequencies υ_1 and υ_2 (υ_1 being slightly greater than υ_2) and each of amplitude A travelling in a medium in the same direction. The displacements due to the two waves at a given observation point may be represented by

$$y_1 = A\sin\omega_1 t = A\sin 2\pi\upsilon_1 t$$
$$y_2 = A\sin\omega_2 t = A\sin 2\pi\upsilon_2 t$$

By the principle of superposition, the resultant displacement at the given point will be

$$y = y_1 + y_2 = A\sin 2\pi\upsilon_1 t + A\sin 2\pi\upsilon_2 t$$

$$= 2A\cos 2\pi\left(\frac{\upsilon_1-\upsilon_2}{2}\right)t\cdot\sin 2\pi\left(\frac{\upsilon_1+\upsilon_2}{2}\right)t$$

If we write

$$\upsilon_{mod} = \frac{\upsilon_1-\upsilon_2}{2} \quad\text{and}\quad \upsilon_{av} = \frac{\upsilon_1+\upsilon_2}{2}$$

then $\quad y = 2A\cos(2\pi\upsilon_{mod}t)\sin(2\pi\upsilon_{av}t)$

or $\quad y = R\sin(2\pi\upsilon_{av}t)$

where $R = 2A\cos(2\pi\upsilon_{mod}t)$ is the amplitude of the resultant wave.

The amplitude R of the resultant wave will be maximum, when

$\cos 2\pi\upsilon_{mod}t = \pm 1$

or $\quad 2\pi\upsilon_{mod}t = n\pi \quad$ where $n = 0, 1, 2, ...$

or $\quad \pi(\upsilon_1 - \upsilon_2)t = n\pi$

or $\quad t = \dfrac{n}{\upsilon_1-\upsilon_2} = 0, \dfrac{1}{\upsilon_1-\upsilon_2}, \dfrac{2}{\upsilon_1-\upsilon_2}, ...$

$\therefore$ Time interval between two successive maxima

$$= \frac{1}{\upsilon_1-\upsilon_2}$$

Similarly, the amplitude R will be minimum, when

$\cos 2\pi\upsilon_{mod}t = 0$

or $\quad 2\pi\upsilon_{mod}t = (2n+1)\pi/2 \quad$ where $n = 0, 1, 2, ...$

or $\quad \pi(\upsilon_1-\upsilon_2)t = (2n+1)\pi/2$

or $\quad t = \dfrac{(2n+1)}{2(\upsilon_1-\upsilon_2)} = \dfrac{1}{\upsilon_1-\upsilon_2}, \dfrac{3}{2(\upsilon_1-\upsilon_2)}, \dfrac{5}{(2\upsilon_1-\upsilon_2)}, ...$

$\therefore$ The time interval between successive minima

$$= \frac{1}{\upsilon_1-\upsilon_2}$$

Clearly, both maxima and minima of intensity occur alternately. Hence the time interval between two successive beats, $t_{beat} = \dfrac{1}{\upsilon_1-\upsilon_2}$

The number of beats produced per second is called beat frequency.

$$\upsilon_{beat} = \frac{1}{t_{beat}} \quad\text{or}\quad \upsilon_{beat} = \upsilon_1 - \upsilon_2$$

MPP-9 MONTHLY Practice Problems

Class XI

This specially designed column enables students to self analyse their extent of understanding of specified chapters. Give yourself four marks for correct answer and deduct one mark for wrong answer.

Self check table given at the end will help you to check your readiness.

Heat and Thermodynamics

Total Marks : 120 **Time Taken : 60 min**

NEET / AIIMS

Only One Option Correct Type

1. One end of a 2.35 m long and 2.0 cm radius aluminium rod ($K = 235$ W m^{-1}K^{-1}) is held at 20°C. The other end of the rod is in contact with a block of ice at its melting point. The rate in kg s^{-1} at which ice melts is (Take latent heat of fusion for ice as $\frac{10}{3} \times 10^5$ J kg^{-1})

(a) $48\pi \times 10^{-6}$ (b) $24\pi \times 10^{-6}$
(c) $2.4\pi \times 10^{-6}$ (d) $4.8\pi \times 10^{-6}$

2. A vessel contains a mixture consisting of $m_1 = 7$ g of nitrogen ($M_1 = 28$) and $m_2 = 11$ g of carbon dioxide ($M_2 = 44$) at temperature $T = 300$ K and pressure $P_0 = 1$ atm. Find the density of the mixture (in kg m^{-3}).

(a) 1.464 (b) 1.316 (c) 2.468 (d) 0.532

3. Two spheres A and B having radii of 3 cm and 5 cm respectively are coated with carbon black on their outer surfaces. The wavelengths of radiations corresponding to maximum intensity of emission are 300 nm and 500 nm respectively. The respective powers radiated by them are in the ratio of

(a) $\sqrt{\frac{5}{3}}$ (b) $\frac{5}{3}$ (c) $\left(\frac{5}{3}\right)^2$ (d) $\left(\frac{5}{3}\right)^4$

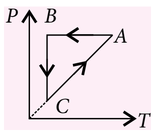
4. Find the amount of work done to increase the temperature of one mole of an ideal gas by 30°C if it is expanding under the condition, $V \propto T^{2/3}$.

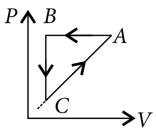
(a) 166.2 J (b) 136.2 J
(c) 126.2 J (d) None of these

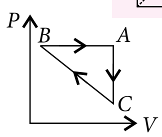
5. A liquid takes 10 minutes to cool from 80 °C to 50 °C. The temperature of the surroundings is 20 °C. Assuming that the Newton's law of cooling is obeyed, the cooling constant will be

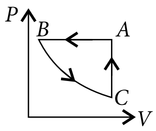
(a) 0.056 min^{-1} (b) 0.042 min^{-1}
(c) 0.081 min^{-1} (d) 0.069 min^{-1}

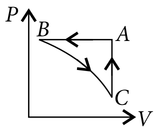
6. A cyclic process $ABCA$ is shown in P-T diagram. When presented on P-V diagram, it would



(a)


(b)


(c)


(d)


7. Oxygen is filled in a closed metal jar of volume 10^{-3} m^3 at a pressure of 1.5×10^5 Pa and temperature 400 K. The jar has a small leak in it. The atmospheric pressure is 10^5 Pa and the atmospheric temperature is 300 K. Find the mass of the gas that leaks out by the time the pressure and the temperature inside the jar equalize with the surrounding. (Molar mass of oxygen = 32 g)

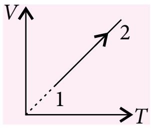
(a) 0.32 g (b) 0.16 g (c) 0.08 g (d) 0.64 g

8. Ideal gas undergoes an adiabatic change in its state from (P_1, V_1, T_1) to (P_2, V_2, T_2). The work done (W) in the process is (μ = number of moles, C_P and C_V are molar specific heats of gas)

(a) $W = \mu(T_1 - T_2)C_P$ (b) $W = \mu(T_1 - T_2)C_V$
(c) $W = \mu(T_1 + T_2)C_P$ (d) $W = \mu(T_1 + T_2)C_V$

9. Consider a sample of oxygen at 300 K. Find the average time taken by a molecule to travel a distance equal to the diameter of the earth. (Take molar mass of O_2 = 32 g)
(a) 5 h (b) 10 h (c) 24 h (d) 8 h

10. An ideal gas undergoes the process 1 → 2 as shown in figure. The heat supplied and work done in the process are ΔQ and ΔW respectively. The ratio $\Delta Q : \Delta W$ is



(a) $\gamma/(\gamma - 1)$ (b) γ
(c) $\gamma - 1$ (d) $(\gamma - 1)/\gamma$

11. A cylinder of radius R made of a material of thermal conductivity k_1 is surrounded by a cylindrical shell of inner radius R and outer radius $2R$ made of a material of thermal conductivity k_2. The two ends of the combined system are maintained at different temperatures. There is no loss of heat from the cylindrical surface and the system is in steady state. The effective thermal conductivity of the system is
(a) $k_1 + k_2$ (b) $\frac{k_1 k_2}{k_1 + k_2}$
(c) $\frac{1}{4}(k_1 + 3k_2)$ (d) $\frac{1}{4}(3k_1 + k_2)$

12. An ideal gas is found to obey an additional law P^2V = constant. The gas is initially at temperature T and volume V. When it expands to a volume $2V$, the temperature becomes
(a) T (b) $\sqrt{2}T$ (c) $2T$ (d) $2\sqrt{2}T$

Assertion & Reason Type

Directions : In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as :
(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false.
(d) If both assertion and reason are false.

13. **Assertion :** Total kinetic energy or internal energy or total energy does not determine the direction of flow of heat.
Reason : Systems are in thermal equilibrium, when their temperature are same or average kinetic energy per molecule is same.

14. **Assertion :** The specific heat of a gas in an adiabatic process is zero and in an isothermal process is infinite.
Reason : Specific heat of gas is directly proportional to change of heat in system and inversely proportional to change in temperature.

15. **Assertion :** The root mean square and most probable speeds of the molecules in a gas are the same.
Reason : The Maxwell distribution curve for the speed of the molecules in a gas is symmetrical.

JEE MAIN / JEE ADVANCED

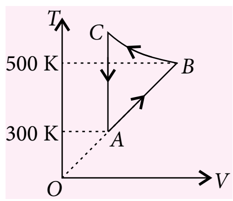
Only One Option Correct Type

16. A sphere of density ρ, specific heat s and radius r is hung by a thermally insulating thread in an enclosure which is kept at a lower temperature than the sphere. The temperature of the sphere starts to drop at a rate which depends upon the temperature difference between the sphere and the enclosure. If the temperature difference is ΔT and surrounding temperature is T_0 then rate of fall in temperature will be (Given that $\Delta T << T_0$)
(a) $\frac{4\sigma T_0^3 \Delta T}{r\rho s}$ (b) $\frac{12\sigma T_0^3 \Delta T}{r\rho s}$
(c) $\frac{12\sigma T_0^4 \Delta T}{r\rho s}$ (d) $\frac{12\sigma \Delta T}{r\rho s T_0^3}$

17. One gram mole of oxygen at 27°C and 1 atmospheric pressure is enclosed in a vessel. Assuming the molecules to be moving with v_{rms}, find the number of collisions per second which the molecules make within one square metre area of the vessel wall.
(a) 1.95×10^{24} (b) 3.95×10^{24}
(c) 1.95×10^{27} (d) 3.95×10^{27}

18. A 5 g piece of ice at –20°C is put into 10 g of water at 30°C. Assuming that heat is exchanged only between the ice and water, find the amount of ice melted.
(a) 3.125 g (b) 5.000 g (c) 4.950 g (d) 2.500 g

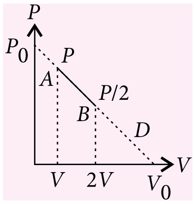
19. Consider the cyclic process $ABCA$, shown in figure is performed on a sample of 2.0 mole of an ideal gas. A total of 1200 J of heat is withdrawn from the sample in the process. The work done by the gas during the part BC is



(a) –2520 J (b) –3250 J
(c) –4520 J (d) –5520 J

More than One Options Correct Type

20. An ideal gas is taken from the state A (pressure P, volume V) to the state B (pressure $P/2$, volume $2V$) along a straight line path in the P–V diagram. Select the correct statement(s) from the following statements.



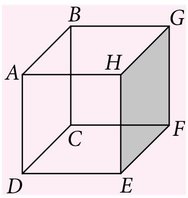
(a) The work done by the gas in process AB is greater than the work that would be done if the system were taken from A to B along the isotherm.

(b) In the T–V diagram, the path AB becomes a part of parabola.

(c) In the P–T diagram, the path AB becomes a part of hyperbola.

(d) In going from A to B, the temperature T of the gas first increases to a maximum value and then decreases.

21. $ABCDEFGH$ is a hollow cube made of an insulator (see figure). Face $EFGH$ has positive charge on it. Inside the cube, we have ionised hydrogen.



The usual kinetic theory expression for pressure

(a) will be valid.

(b) will not be valid, since the ions would experience forces other than forces due to collisions with the walls.

(c) will not be valid, since collisions with walls would not be elastic.

(d) will not be valid because isotropy is lost.

22. Two bodies A and B have thermal emissivities of 0.01 and 0.81 respectively. The outer surface areas of the two bodies are the same. The two bodies emit total radiant power at the same rate. The wavelength λ_B corresponding to maximum spectral radiancy in the radiation from B shifted from the wavelength corresponding to maximum spectral radiancy in the radiation from A, by 1.00 μm. If the temperature of A is 5802 K, then

(a) the temperature of B is 1934 K

(b) $\lambda_B = 1.5$ μm

(c) the temperature of B is 11604 K

(d) the temperature of B is 2901 K.

23. Let $\bar{v}$, v_{rms} and v_p respectively denote the mean speed, root mean square speed and most probable speed of the molecules in an ideal monatomic gas at absolute temperature T. The mass of a molecule is m. Then

(a) no molecule can have a speed greater than $\sqrt{2}\, v_{rms}$

(b) no molecule can have a speed less than $v_p/\sqrt{2}$

(c) $v_p < \bar{v} < v_{rms}$

(d) the average kinetic energy of a molecule is $\frac{3}{4} m v_p^2$.

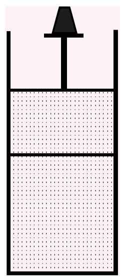
Integer Answer Type

24. A calorimeter of negligible heat capacity contains 100 cm^3 of water at 40°C. The water cools to 35°C in 5 minutes. The water is now replaced by kerosene oil of equal volume at 40°C. Find the time taken (in minutes) for the temperature to become 35°C under similar conditions. Specific heat capacities of water and kerosene oil are 4200 J kg^{-1} K^{-1} and 2100 J kg^{-1} K^{-1} respectively. Density of kerosene oil = 800 kg m^{-3}.(Assume that the rate of heat radiation is same for both the liquids)

25. A diatomic gas ($\gamma = 1.4$) does 200 J of work when it is expanded isobarically. The heat given to the gas in the process is 100 n J. Find n.

26. The temperature of water at the surface of a deep lake is 2°C. Find the temperature (in °C) expected at the bottom.

Comprehension Type



In the figure a container is shown to have a movable (without friction)piston on top. The container and the piston are all made of perfectly insulating material allowing no heat transfer between outside and inside the container. The container is divided into two compartments by a rigid partition made of a thermally conducting material that allows slow transfer of heat. The lower compartment of the container is filled with 2 moles of an ideal monatomic gas at 700 K and the upper compartment is filled with 2 moles of an ideal diatomic gas at 400 K. The heat capacities per mole of an ideal monatomic gas are

$C_V = \frac{3}{2}R,\ C_P = \frac{5}{2}R$ and those for an ideal diatomic gas are $C_V = \frac{5}{2}R,\ C_P = \frac{7}{2}R$.

27. Consider the partition to be rigidly fixed so that it does not move. When equilibrium is achieved, the final temperature of the gases will be

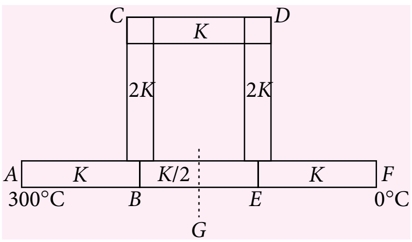
(a) 550 K (b) 525 K
(c) 513 K (d) 490 K

28. Now consider the partition to be free to move without friction so that the pressure of gases in both compartments is the same. Then total work done by the gases till the time they achieve equilibrium will be

(a) 250 R (b) 200 R
(c) 100 R (d) –100 R

Matrix Match Type

29. In given figure all the rods are of identical shape and size. Heat current passing through section AB is 250 units. Match entries in column I with column II.

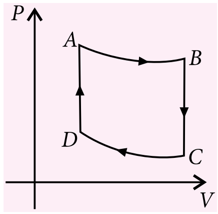


	Column I		Column II
(A)	Temperature of point G (in °C)	(P)	150
(B)	Temperature of point C (in °C)	(Q)	125
(C)	Heat current in CD	(R)	175
(D)	Temperature of point D (in °C)	(S)	100
		(T)	200

	A	B	C	D
(a)	R	T	Q	P
(b)	P	R	Q	S
(c)	P	R	Q	Q
(d)	Q	P	R	S

30. One mole of a monatomic ideal gas is taken through the cycle shown in figure.

$A \to B$: adiabatic expansion
$B \to C$: cooling at constant volume
$C \to D$: adiabatic compression
$D \to A$: heating at constant volume.



The pressure and temperature at A and B are denoted by P_A, T_A and P_B, T_B respectively. Given that T_A = 1000 K, $P_B = (2/3)P_A$ and $P_C = (1/3)P_A$. Match entries in column I with column II.

	Column I		Column II
(A)	Work done by gas in process AB (in J)	(P)	–5298
(B)	Heat lost by gas in process BC (in J)	(Q)	500
(C)	Temperature at D (in K)	(R)	1870
(D)	Temperature at B (in K)	(S)	850

	A	B	C	D
(a)	P	Q	R	S
(b)	R	P	Q	S
(c)	P	R	Q	S
(d)	R	P	S	Q

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SELF CHECK

No. of questions attempted ……
No. of questions correct ……
Marks scored in percentage ……

Check your score! If your score is

> 90%	EXCELLENT WORK !	You are well prepared to take the challenge of final exam.
90-75%	GOOD WORK !	You can score good in the final exam.
74-60%	SATISFACTORY !	You need to score more next time.
< 60%	NOT SATISFACTORY!	Revise thoroughly and strengthen your concepts.

BRAIN MAP
CLASS XI

MOTION OF A RIGID BODY

GEOMETRICAL OPTICS

BRAIN MAP
CLASS XII

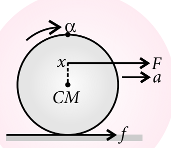
Snapshot of Rolling Motion

For rigid bodies : solid cylinder, hollow cylinder, solid sphere and hollow sphere,

- *Order of acceleration*
  $a_{\text{solid sphere}} > a_{\text{solid cylinder}} > a_{\text{hollow sphere}} > a_{\text{hollow cylinder}}$
- *Order of required friction force for pure rolling*
  $f_{\text{hollow cylinder}} > f_{\text{hollow sphere}} > f_{\text{solid cylinder}} > f_{\text{solid sphere}}$
- *Order of required minimum friction coefficient for pure rolling*
  $\mu_{\text{hollow cylinder}} > \mu_{\text{hollow sphere}} > \mu_{\text{solid cylinder}} > \mu_{\text{solid sphere}}$

- A force F is applied at a distance x above the centre of a rigid body of radius R, mass M and moment of inertia CMR^2 about an axis passing through the centre of mass

$a = \dfrac{F(R+x)}{MR(C+1)}$, $f = \dfrac{F(x-RC)}{R(C+1)}$ $\left\{ f \text{ must be } \le \mu_s mg \right.$



When a force acts on a body

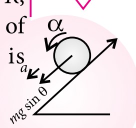
PURE ROLLING MOTION

- For a body rolling without slipping, velocity of centre of mass, $v_{CM} = R\omega$
  Kinetic energy, $K = K_{\text{trans.}} + K_{\text{rot.}}$
  $= \dfrac{1}{2}mv_{CM}^2(1+C)$

On an Inclined Plane

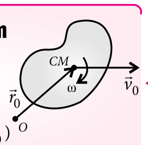
- A rigid body of radius R, mass M and moment of inertia, $I = CMR^2$ is released at rest.

$a = \dfrac{g\sin\theta}{1+C}$ $\left\{ C\,(=k^2/R^2) \text{ is a constant varies for different bodies} \right.$



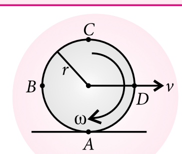
Angular momentum of a rigid body in combined motion

$\vec{L} = \vec{L}_{CM} + M(\vec{r}_0 \times \vec{v}_0)$



COMBINED TRANSLATIONAL AND ROTATIONAL MOTION

- If all points in the body rotates about an axis of rotation and the axis of rotation moves with respect to the ground.



- The speed of a point on the circumference at any instant t is $2r\omega\sin(\omega t/2)$
- x and y coordinates of the bottommost point at any time t, $(x, y) \equiv (vt - r\sin\omega t, r - r\cos\omega t)$

- Velocity of any point of the rigid body in combined motion is the vector sum of $\vec{v}$ and $\vec{r} \times \vec{\omega}$.

RIGID BODY MOTION

PURE TRANSLATIONAL MOTION

- During such motion, all the particles have same displacement (s), velocity (v) and acceleration (a) during any interval and at any instant.

- For a system of particles
  - Position, $\vec{r}_{CM} = \dfrac{m_1\vec{r}_1 + m_2\vec{r}_2 + ...}{m_1 + m_2 + ...}$
  - Velocity, $\vec{v}_{CM} = \dfrac{m_1\vec{v}_1 + m_2\vec{v}_2 + ...}{m_1 + m_2 + ...}$

- Acceleration, $\vec{a}_{CM} = \dfrac{m_1\vec{a}_1 + m_2\vec{a}_2 + ...}{m_1 + m_2 + ...}$
- If $\vec{F}_{\text{ext.}} = 0$, then $\vec{v}_{CM}$ = constant.

PURE ROTATIONAL MOTION

Kinematics of Rotational Motion

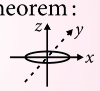
- Angular displacement, $\theta = \dfrac{s}{r}$
- Angular velocity, $\omega = \dfrac{d\theta}{dt}$
- Angular acceleration, $\alpha = \dfrac{d\omega}{dt}$
- Equations of rotational motion
  - $\omega = \omega_0 + \alpha t$
  - $\theta = \omega_0 t + \dfrac{1}{2}\alpha t^2$
  - $\omega^2 = \omega_0^2 + 2\alpha\theta$

- Every point of the body moves in a circle whose centre lies on the axis of rotation and every point moves through same angle.

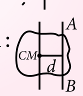
Rotational Analogue of Mass

Moment of Inertia

- For a rigid body, $I = \sum_{i=1}^{n} m_i r_i^2$
- Perpendicular axes theorem : $I_z = I_x + I_y$ (Object is in x-y plane)



- Parallel axes theorem : $I_{AB} = I_{CM} + Md^2$



Dynamics of Rotational Motion

Angular Momentum

- Of a particle about a point $\vec{L} = \vec{r} \times \vec{p}$; $L = r\,p\sin\theta$
- Of a rigid body rotating about a fixed axis $\vec{L} = \sum_i m_i(\vec{r}_i \times \vec{v}_i)$; $L = I\omega$

- From Newton's 2nd law $\vec{\tau}_{\text{net}} = \dfrac{d\vec{L}}{dt}$
- Torque about the axis of rotation $\vec{\tau} = \vec{r} \times \vec{F}$; $\tau = rF\sin\theta = I\alpha$
- Work done by torque, $W = \tau d\theta$
- Power, $P = \tau\omega$

Conservation of Angular Momentum

If $\vec{\tau}_{\text{net}} = 0$, then $\dfrac{d\vec{L}}{dt} = 0$, so that
$L = I\omega$ = constant

GEOMETRICAL OPTICS

Deals with light propagation in the form of rays.

REFLECTION OF LIGHT

The bouncing back of a light ray to other side of normal in a same medium. According to the law of reflection, $\angle i = \angle r$

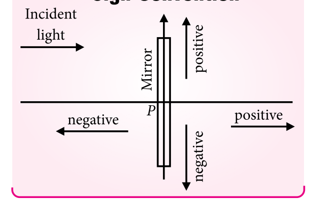
Through Spherical Mirrors

Velocity of the Image of a Moving Object

Object is approaching the focus of a concave mirror from infinite with speed v_{obj},

$v_{\text{image}} = \dfrac{dv}{dt} = -\dfrac{f^2}{(u-f)^2}\dfrac{du}{dt} = -m^2 v_{\text{obj}}$

Sign-Convention

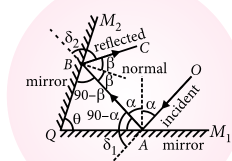


Newton's Formula

If object distance (x_1) and image distance (x_2) are measured from focus, $f^2 = x_1 x_2$

- **Mirror formula,** $\dfrac{1}{u} + \dfrac{1}{v} = \dfrac{1}{f} = \dfrac{2}{R}$
- **Magnification,** $m = -v/u$
  - Longitudinal magnification : $m_L = -\dfrac{dv}{du} = \left[\dfrac{v}{u}\right]^2 = m^2$
  - Superficial magnification : $m_s = \dfrac{\text{area of image}}{\text{area of object}} = m^2$

Through Plane Mirrors



Deviation produced by the combination of two plane mirrors,
$\delta = 360 - 2(\alpha + \beta)$
$\delta = 360 - 2\theta$

For two plane mirrors inclined at an angle θ, the number of images of a point object formed are
- $n = 360/\theta - 1$ [If 360/θ is even]
- $n = 360/\theta$ [If 360/θ is odd]

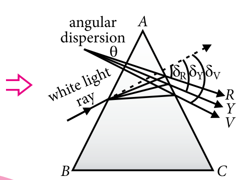
Minimum length (L_m) of a mirror to see complete Image of
- A person in the mirror $L_m = 1/2 \times$ (height of person)
- A wall behind a person in the mirror $L_m = 1/3 \times$ (height of wall)

REFRACTION OF LIGHT

Snell's law : When light travels from medium a to medium b, ${}^a\mu_b = \dfrac{\mu_b}{\mu_a} = \dfrac{\sin i}{\sin r}$

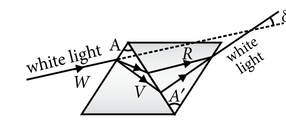
Refractive index, $\mu = \dfrac{c}{v}$

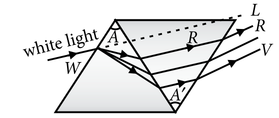
Through Prism



Combination of Prism

- Deviation without dispersion
  $(\theta = 0)$ $A' = -\dfrac{(\mu_V - \mu_R)A}{\mu'_V - \mu'_R}$
  $\delta_{\text{net}} = (\mu - 1)A + (\mu' - 1)A'$





- Dispersion without deviation
  $(\delta = 0)$ $A' = -\dfrac{(\mu - 1)A}{\mu' - 1}$
  $\theta_{\text{net}} = (\mu_V - \mu_R)A + (\mu'_V - \mu'_R)A'$

Angular dispersion, $\theta = (\mu_V - \mu_R)A$
Dispersive power, $\omega = \dfrac{\mu_V - \mu_R}{\mu_Y - 1}$

Relation between μ and δ_m

$\mu = \dfrac{\sin\dfrac{A + \delta_m}{2}}{\sin\dfrac{A}{2}}$ where, δ_m = angle of minimum deviation, A = angle of prism

or $\delta_m = (\mu - 1)A$ (Prism of small angle)

Through Spherical Lenses

General relation for spherical surfaces

$\dfrac{\mu_{\text{denser}}}{v} - \dfrac{\mu_{\text{rarer}}}{u} = \dfrac{\mu_{\text{denser}} - \mu_{\text{rarer}}}{R}$

Lens maker's formula

$\dfrac{1}{f} = (\mu - 1)\left[\dfrac{1}{R_1} - \dfrac{1}{R_2}\right]$

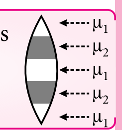
Thin Spherical Lens

Thin lens formula : $\dfrac{1}{v} - \dfrac{1}{u} = \dfrac{1}{f}$

Magnification : $m = \dfrac{v}{u} = \dfrac{h_i}{h_o}$

Special Cases

- If half portion of lens is covered by black paper then only intensity of image will be reduced.
- If a lens is made of number of layers of different R.I. for a given λ number of images = number of R.I.



- If lens is cut into two equal parts by a vertical plane, focal length of each part $f' = 2 \times$ focal length of original lens (f)

Through Different Medium

Apparent Depth (d_{ap}) and Normal Shift (x)

- **Object in denser medium is observed from rarer :** $d_{ap} = \dfrac{d_{ac}}{\mu}$; $x = d_{ac}\left[1 - \dfrac{1}{\mu}\right]$
- **Object in rarer medium is observed from denser :** $\dfrac{d_{ac}}{d_{ap}} = \dfrac{1}{\mu}(<1)$; $x = [\mu - 1]d_{ac}$
- **Lateral shift :** $d = \dfrac{t}{\cos r}\sin(i - r)$

NEET | JEE ESSENTIALS

Class XII

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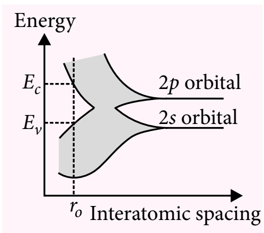
Unit 7 SEMICONDUCTOR DEVICES AND COMMUNICATION SYSTEM

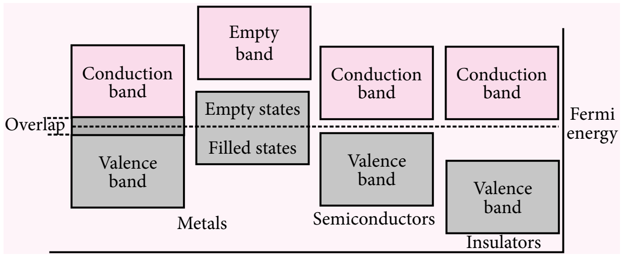
BAND THEORY OF SOLIDS

Inside the crystal each electron has a unique position and no two electrons see exactly the same pattern of surrounding charges. Because of this, each electron will have a different energy level. These different energy levels with continuous energy variation form what are called energy bands.

- Electrons occupy energy states in atomic orbitals
- When several atoms are brought close to each other in a solid these energy states split into a series of energy states (molecular orbitals).

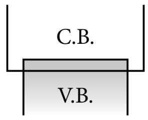
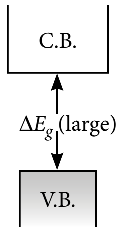
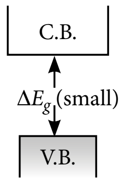


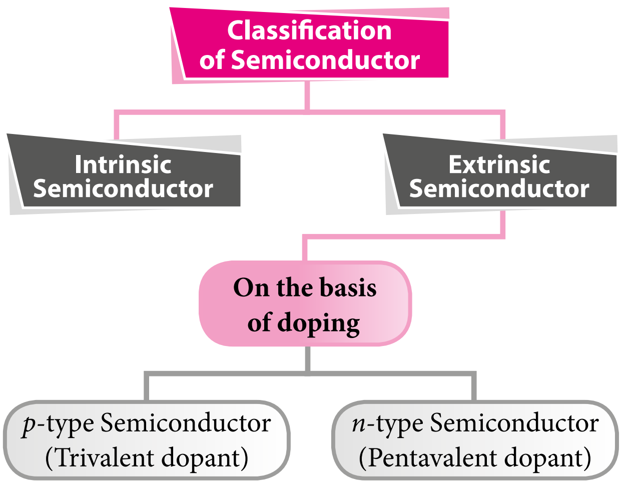
- The spacing between these states are so small that they overlap to form an energy band.
- The furthest band from the nucleus is filled with valence electrons and is called the valence band.
- The empty band is called the conduction band.
- The energy of the highest filled state is called Fermi energy.
- There is a certain energy gap, called forbidden energy bandgap (ΔE_g), between valence and conduction bands.
- Primarily four types of band structure exist in solids.



- In metals the valence band is either partially filled (Cu) or the valence and conduction bands overlap (Mg).
- Insulators and semiconductors have completely filled valence band and empty conduction band.
- It is the magnitude of bandgap which separates metals, semiconductors and insulators in terms of their electrical conductivity.
  - Energy gap between conduction band and valence band $\Delta E_g = (\text{C.B.})_{min} - (\text{V.B.})_{max}$
  - No free electron is present in forbidden energy gap.
  - Width of forbidden energy gap depends upon the nature of substance.
  - As temperature increase, forbidden energy gap decreases very slightly.
- The bandgap is relatively smaller in semiconductors while it is very large in insulators.

CLASSIFICATION OF SOLIDS ON VARIOUS PROPERTIES

Properties	Conductors	Insulators	Semiconductors
Electrical conductivity	10^2 to 10^8 mho m^{-1}	10^{-11} to 10^{-19} mho m^{-1}	10^5 to 10^{-6} mho m^{-1}
Resistivity	10^{-2} to 10^{-8} Ω m (negligible)	10^{11} to 10^{19} Ω m	10^{-5} to 10^6 Ω m
Band structure			
Energy gap (E_g)	Zero or very small	Very large; for diamond it is 6 eV	Less than 3 eV
Current carriers	Free electons	—	Electrons and holes
Condition of V.B. and C.B. at ordinary temperature	V.B. and C.B. are completely filled or C.B. is somewhat empty	V.B. – completely filled C.B. – completely unfilled	V.B. – somewhat empty C.B. – somewhat filled
Temperature co-efficient of resistance (ideally)	Positive	Zero	Negative
Effect of temperature on conductivity	Decreases	Remains unchanged	Increases
Electron density	10^{29} m^{-3}	—	Ge ~ 10^{19} m^{-3} Si ~ 10^{16} m^{-3}
Examples	Cu, Ag, Au, Na, Pt, Hg, etc.	Wood, plastic, mica, diamond, glass, etc.	Ge, Si, GaAs, etc.



Intrinsic Semiconductor

- A pure semiconductor is called intrinsic semiconductor. It has thermally generated current carriers.
- They have four electrons in the outermost orbit of atom and atoms are held together by covalent bonds.
- Electrons and holes both are charge carriers and n_e (in C.B.) = n_h (in V.B.)

Extrinsic Semiconductor

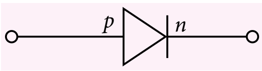
- An impure semiconductor is called extrinsic semiconductor.
- When pure semiconductor material is doped with small amounts of certain specific impurities with valency different from that of the parent material, the number of mobile electrons/holes drastically changes. The process of addition of impurity is called doping.
- In extrinsic semiconductors $n_e \neq n_h$.
- Electrical conductivity of extrinsic semiconductor is given by $\sigma = 1/\rho = e(n_e\mu_e + n_h\mu_h)$
  Where ρ is resistivity, μ_e and μ_h are mobility of electrons and holes respectively.

- ***n*-type semiconductor :** Extrinsic semiconductor doped with pentavalent impurity like As, Sb, Bi, etc. in which negatively charged electrons work as charge carriers, is called *n*-type semiconductor. Every pentavalent impurity atom donate one electron in the crystal, therefore it is called a donor atom.
- ***p*-type semiconductor :** Extrinsic semiconductor doped with trivalent impurity like Al, B, etc. in which positively charged holes work as charge carriers, is called *p*-type semiconductor. Every trivalent impurity atom has a tendency to accept one electron, therefore it is called an acceptor atom.

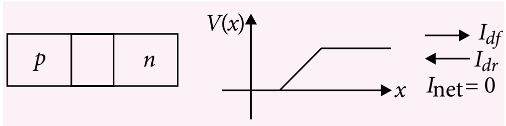
VARIOUS SEMICONDUCTOR DEVICES

p-n Junction Diode

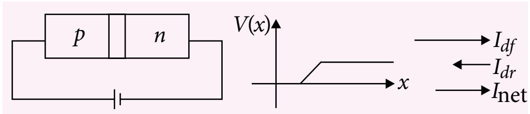
- When donor impurities are introduced into one side and acceptors into the other side of a single crystal of an intrinsic semiconductor, a *p-n* junction is formed. It is also known as junction diode. It is symbolically represented by



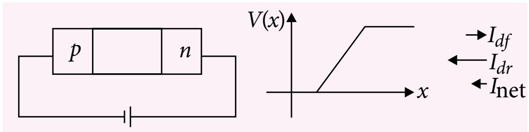
- The most important characteristic of a *p-n* junction is its ability to conduct current in one direction only. In the other (reverse) direction, it offers very high resistance.
- The current in the junction diode is given by
  $I = I_0\,(e^{eV/nkT} - 1)$
  where k = Boltzmann constant, I_0 = reverse saturation current,
  $$n = \text{constant} = \begin{cases} 1 & \text{for Ge} \\ 2 & \text{for Si} \end{cases}$$
  - In forward biasing, V is positive and low,
    $e^{eV/nkT} >> 1$, then forward current,
    $I_f = I_0\,(e^{eV/nkT})$
  - In reverse biasing, V is negative and high
    $e^{eV/nkT} << 1$, then reverse current,
    $I_r = -I_0$
- **Depletion region :** When a hole diffuses from $p \rightarrow n$ due to concentration gradient, it leaves behind an ionised acceptor which is immobile. As the process continues, a layer of negative charge on the *p*-side of the junction is developed. Similarly electron diffusion creates a layer of positive charge on *n*-side. This region containing the uncompensated acceptor and donor ions is known as depletion region.
- **Biasing of *p-n* junction**
  - Unbiased



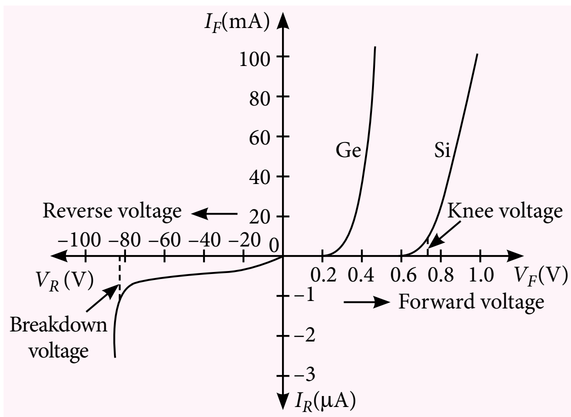
  - Forward-biased



    – Effective barrier potential decreases.
    – Depletion width decreases.
    – Low resistance offered at junction.
    – High current flows through the circuit.
  - Reverse-biased



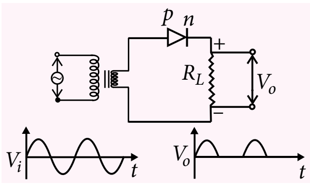
    – Effective barrier potential increases.
    – Depletion width increases.
    – High resistance offered at junction.
    – Low current flows through the circuit.
- ***I-V* characteristic of a *p-n* junction :** The *I-V* characteristics of a *p-n* junction do not obey Ohm's law. The *I-V* characteristics of a *p-n* junction are as shown in the figure.



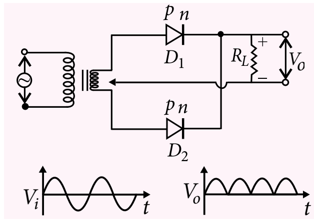
Applications of *p-n* junction diode as rectifier

- Rectifier is a device which is used for converting alternating current into direct current. There are two types of rectifiers.

- Half wave rectifier
  - Peak current,
    $$I_{max} = \frac{\varepsilon_{max}}{(r_f + R_L)}$$
  - Output *dc* current,
    $$I_{dc} = \frac{I_{max}}{\pi}$$
  - Efficiency $= \frac{P_{dc}}{P_{ac}} = 40.6\%$
  - Output frequency = Input frequency



- Full wave rectifier
  - Peak current,
    $$I_{max} = \frac{\varepsilon_{max}}{(r_f + R_L)}$$
  - Output *dc* current,
    $$I_{dc} = \frac{2I_{max}}{\pi}$$
  - Efficiency $= \frac{P_{dc}}{P_{ac}} = 81.2\%$
  - Output frequency = 2 × Input frequency



Special Types of Diode

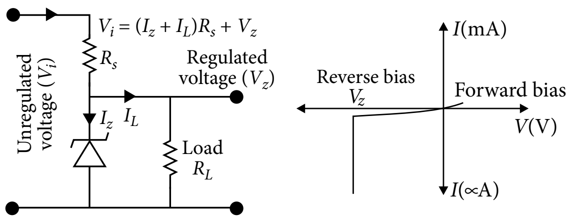
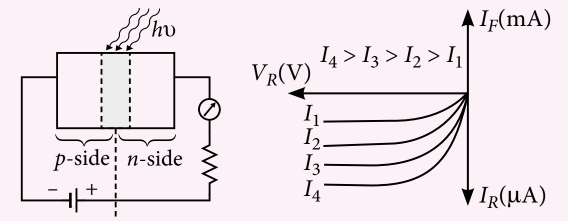
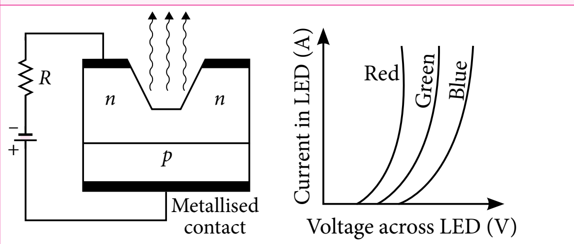
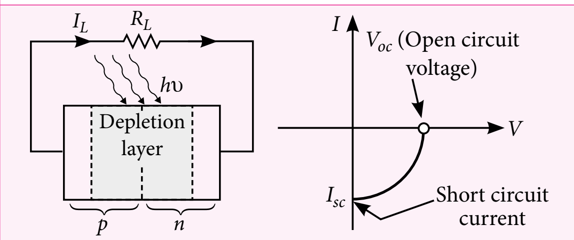
Types of diode	Circuit Diagram and *I-V* characteristics	Working
Zener diode : It is heavily doped *p-n* junction and operated in reverse bias which is used as voltage regulator.		• Any increase (decrease) in the input voltage results in increase (decrease) of voltage drop across R_s without any change in voltage across the zener diode.
Photodiode : It is fabricated with a transparent window to allow light to fall on the diode to detect the light signals.		• It is operated under reverse bias. • If $h\upsilon > E_g$, electron hole pairs are generated in near depletion region so reverse current I_R increases.
LED : It is a heavily doped *p-n* junction which emits spontaneous radiation under forward bias.		• It converts electrical energy into light energy. • The semiconductor used for fabrication of visible LEDs must have minimum band gap of 1.8 eV.
Solar cell : It is basically a *p-n* junction which generates emf when solar radiation falls on the *p-n* junction. It converts solar energy into electrical energy.		• It works on the same principle (photovoltaic effect) as the photodiode, except that no external bias is applied and the junction area is kept large.

Illustration 1 : An alternating voltage of 350 V, 60 Hz is applied on a full wave rectifier. The internal resistance of each diode is 200 Ω. If R_L = 5 kΩ, then find
(i) the peak value of output current.
(ii) the value of output direct current.
(iii) the output dc power.
(iv) the rms value of output current.

Soln.: (i) $I_{max} = \frac{V_{rms} \times \sqrt{2}}{(R_L + r_f)} = \frac{350 \times \sqrt{2}}{(5000 + 200)} = 0.095$ A

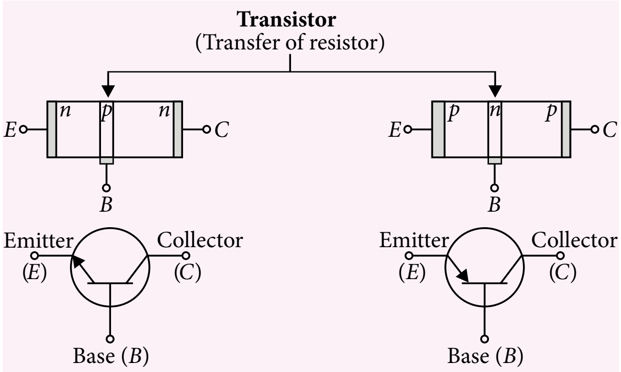
(ii) $I_{dc} = \frac{2I_{max}}{\pi} = \frac{2 \times 0.095}{3.14} = 0.061$ A

(iii) $P_{dc} = I_{dc}^2 \times R_L = (0.061)^2 \times (5000) \simeq 18.6$ W

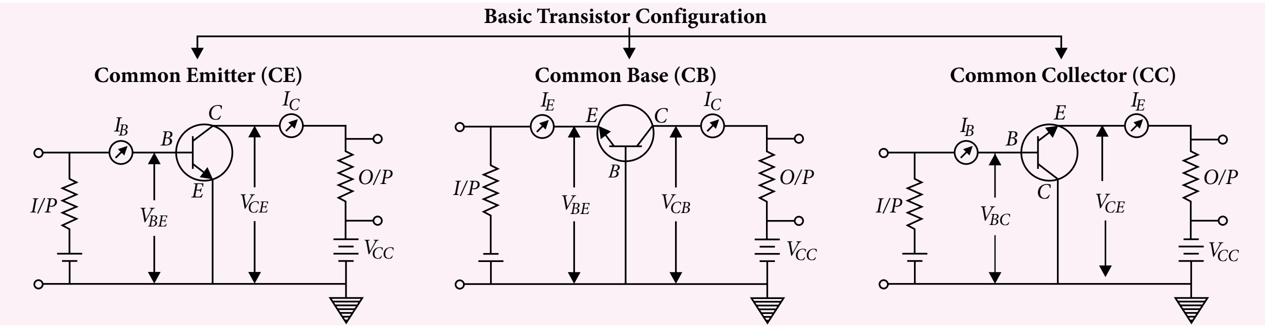
(iv) $I_{rms} = \frac{I_{max}}{\sqrt{2}} = \frac{0.095}{1.41} = 0.067$ A

Transistors

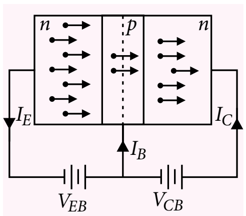
- The name of this electronic device is derived from it's fundamental action *i.e.*, transfer of resistor.
- Transistor is basically silicon or germanium crystal containing three main regions :
  - **Emitter (*E*) :** It provides majority charge carriers by which current flows in the transistor. Therefore the emitter semiconductor is heavily doped.
  - **Base (*B*) :** The base region is lightly doped and thin.
  - **Collector (*C*) :** The collector region is larger than the other two regions and is moderately doped.
- A transistor has two junctions and thus have two depletion regions.
- Transistor in general is known as bipolar junction transistor.
- Transistor is a current operated device.
- There are two types of transistor.



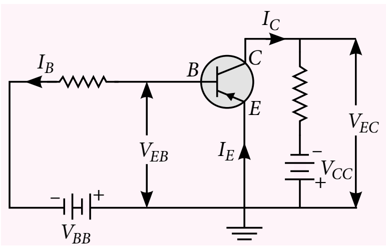
- **Configuration of transistor :**



- **Action of *n-p-n* transistor :** The forward bias of the emitter-base circuit repels the electrons of emitter towards the base, setting up emitter current I_E. As the base is very thin and lightly doped, a very few electrons (≈ 5%) from the emitter combine with the holes of base, giving rise to base current I_B and remaining electrons (≈ 95%) are pulled by collector which is at high positive potential. The electrons are finally collected by the positive terminal of battery V_{CB}, giving rise to collector current I_C. $I_E = I_B + I_C$

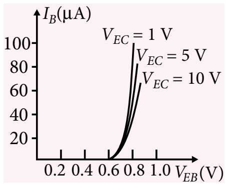


- **For a common-emitter *p-n-p* transistor**



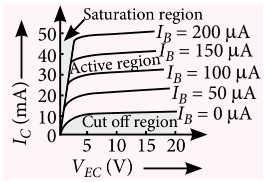
- **Input characteristics :**
  Dynamic input resistance

$$R_i = \left(\frac{\Delta V_{EB}}{\Delta I_B}\right)_{V_{EC}}$$



- **Output characteristics :**
  Dynamic output resistance

$$R_0 = \left(\frac{\Delta V_{EC}}{\Delta I_C}\right)_{I_B}$$



- There are four possible ways of biasing the two *p-n* junctions of a transistor.
  - Active mode : Also known as linear mode operation.
  - Saturation mode : Maximum collector current flows and transistor acts as a closed switch from collector to emitter terminals.
  - Cut-off mode : Denotes operation like an open switch where only leakage current flows.
  - Inverse mode : The emitter and collector are interchanged.

Applications of transistor :

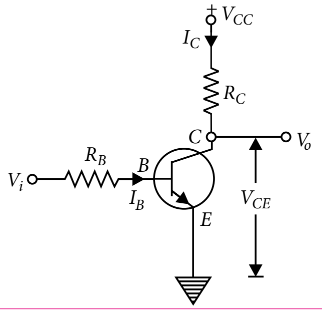
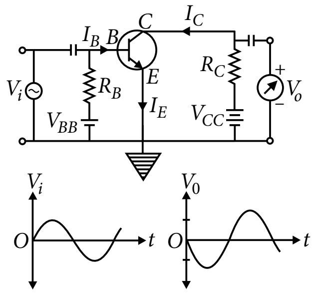
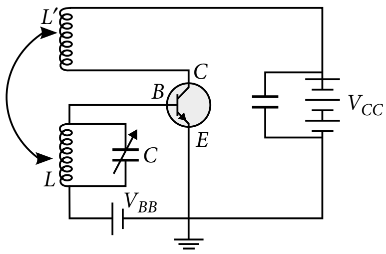
Transistor as a switch	Transistor as an amplifier	Transistor as an oscillator
		
• Operated in cut off region or saturation region. • $V_{BB} = I_BR_B + V_{BE}$ $V_{CE} = V_{CC} - I_CR_C$ • When $V_i = 0$ or < 0.7 V, $I_B = 0$ Hence $I_C = 0$ $\therefore \quad V_{CE} = V_{CC}$ (open circuit (switch)) • When $V_i > 0.7$ V, then this is similar to a closed circuit (switch).	• Net collector voltage, $V_{CE} = V_{CC} - I_CR_C$ • Input and output signals are 180° out of phase. • ac current amplification factor $\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right)$ • dc current amplification factor $\beta_{dc} = \frac{I_C}{I_B}$; $\alpha = \frac{\beta}{1+\beta} = \frac{I_C}{I_E}$ • Voltage gain, $A_v = \frac{\Delta V_o}{\Delta V_i} = -\beta_{ac}\left(\frac{R_C}{R_B}\right)$	• An oscillator produces a continuing, repeated waveform without input other than perhaps a trigger. • The essentials of a transistor as an oscillator are ➢ Tank circuit : It is a parallel combination of L and C. This network resonates at a frequency $\upsilon_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$. ➢ Amplifier : The amplifier increases the strength of oscillations.

Illustration 2 : The current gain of a transistor in common emitter configuration is 70. If emitter current is 8.8 mA, then find

(i) base current. (ii) collector current.

(iii) the current gain in common base configuration.

Soln.: Current gain, $\beta = \frac{I_C}{I_B}$, $I_E = I_B + I_C$,

(i) $I_C = \beta I_B$ or $I_C = 70I_B$

Since $I_E = I_B + I_C$ or $I_E = I_B + 70I_B$

or $I_E = 71I_B \quad \therefore \; I_B = \frac{I_E}{71} = \frac{8.8}{71} = 0.124$ mA

(ii) Collector current = I_C

$I_C = 70I_B$ or $I_C = 70 \times 0.124 = 8.68$ mA

(iii) Current gain in common base configuration

$\alpha = \frac{\beta}{1+\beta}$ or $\alpha = \frac{70}{71} = 0.986$

DIGITAL ELECTRONICS AND LOGIC GATES

Digital electronic circuit uses discrete signals. A digital circuit operates in a binary manner only in two states designated as 0 (off) and 1(on) using different logic gates.

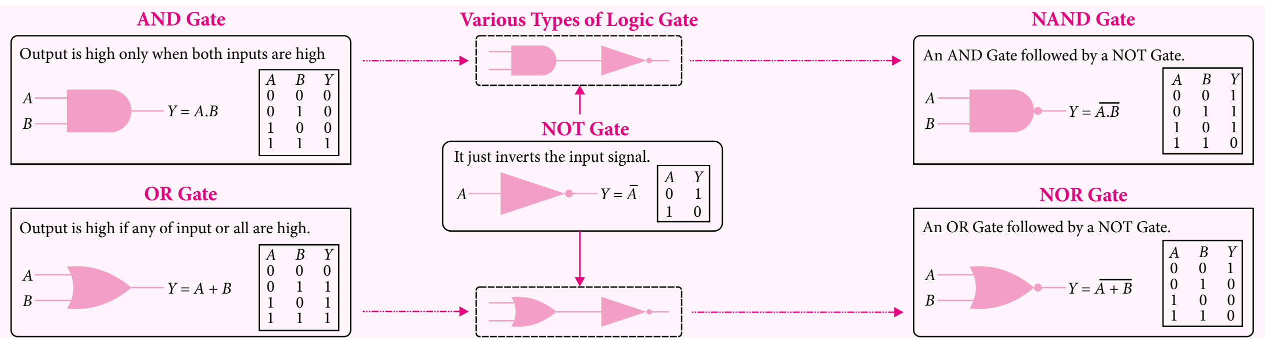
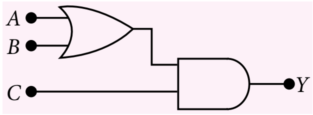


Illustration 3 : What must be the input to get an output $Y = 1$ from the circuit shown in figure?

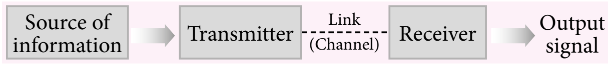


Soln.: It is a combination of OR and AND gate. There can be three schemes for getting output = 1.

A	B	C
1	0	1
0	1	1
1	1	1

BASIC COMMUNICATION SYSTEM

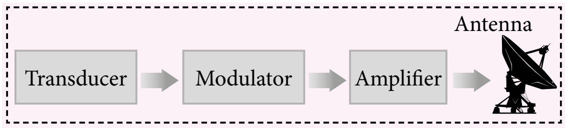
A basic communication system consists of an information source, a transmitter, a link and a receiver.



Transmitter

In radio transmission, the transmitter consists of a transducer, modulator, amplifier and transmitting antenna.

- **Transducer :** Converts sound signals into electric signal.
- **Modulator :** Mixing of audio electric signal with high frequency radio wave.
- **Amplifier :** Boosting the power of modulated signal.
- **Antenna :** Signal is radiated in the space with the aid of an antenna.



Transmitter

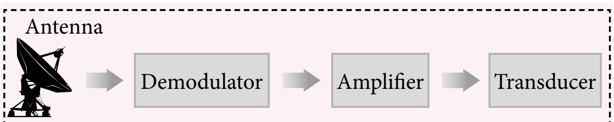
Communication Channel

The function of communication channel is to carry the modulated signal from transmitter to receiver. The communication channel is also called transmission medium or link.

Receiver

The receiver consists of antenna, demodulator, amplifier and transducer.

- **Pickup antenna :** To pick the signal
- **Demodulator :** To separate out the audio signal from the modulated signal
- **Amplifier :** To boost up the weak audio signal
- **Transducer :** Converts electrical signal into audio signal.



Receiver

MODULATION

- The process of superposition of a low frequency (LF) signal over the high frequency (HF) signal is known as modulation.

Need for Modulation

- Digital and analog signals to be transmitted are usually of low frequency and hence cannot be transmitted to long distances.
  - **Height of antenna :** For efficient radiation and reception, the height of transmitting and receiving antennas should be comparable to a quarter of wavelength of the frequency used.

Amplitude Modulation (AM)

- The process of changing the amplitude of a carrier wave in accordance with the amplitude of the audio frequency (AF) signal is known as amplitude modulation (AM).
- **Modulation index :** The ratio of amplitude of modulated wave to the amplitude of carrier wave is called the modulation factor or degree of modulation or modulation index (m).

$$m = \frac{\text{Change in amplitude of modulated wave}}{\text{Amplitude of carrier wave}} = \frac{E_m}{E_c}$$

- **Voltage equation for AM wave :** Suppose voltage equations for carrier wave and modulating wave are
  $c(t) = E_c \sin \omega_c t$ and $m(t) = E_m \sin \omega_m t$
  $c_m(t) = E \sin \omega_c t = (E_c + E_m \sin \omega_m t) \sin \omega_c t$
  $$= E_c \sin \omega_c t + \frac{mE_c}{2} \cos(\omega_c - \omega_m)t - \frac{mE_c}{2} \cos(\omega_c + \omega_m)t$$
  The above AM wave indicated that the AM wave is equivalent to summation of three sinusoidal wave, one having amplitude E_c and the other two having amplitude $\frac{mE_c}{2}$.

DEMODULATION

- The process of extracting the audio signal from the modulated wave is known as demodulation or detection.

Simple Demodulator Circuit

- A diode can be used to detect or demodulate an amplitude modulated (AM) wave. A diode basically acts as a rectifier *i.e.*, it reduces the modulated carrier wave into positive envelop only.

- In the actual circuit the value of RC is chosen such that $\frac{1}{\upsilon_c} << RC$; where υ_c = frequency of carrier signal.

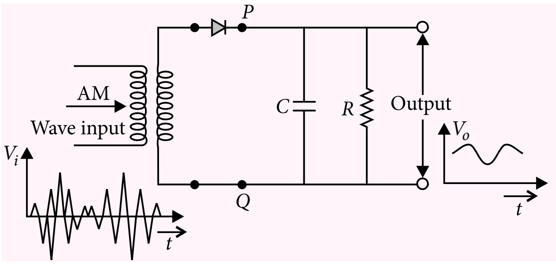
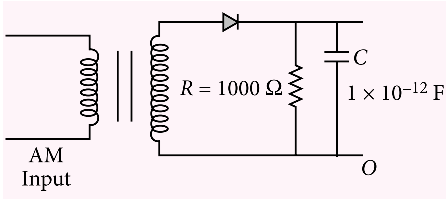


Illustration 4 : In the given detector circuit, determine the suitable value of carrier frequency.



Soln.: Using $\frac{1}{\upsilon_{carrier}} << RC$

We get time constant, $RC = 1000 \times 10^{-12}\ \text{s} = 10^{-9}\ \text{s}$

Now $\upsilon = \frac{1}{T} = \frac{1}{10^{-9}} = 10^9$ Hz

Thus the value of carrier frequency should be much less than 10^9 Hz, say 100 kHz.

SPACE COMMUNICATION

Ground Wave Propagation

- In ground wave propagation, radio waves travel along the surface of the earth (following the curvature of earth).
- These waves induce currents in the ground as they propagate due to which some energy is lost.
- The decrease in the value of energy (*i.e.*, attenuation) increases with the increase in the frequency of radio wave.

Sky Wave Propagation

- These are the waves which are reflected back to the earth by ionosphere. Ionosphere is a layer of atmosphere having charged particles, ions and electrons and extended above 80 km – 300 km from the earth's surface.
- **Critical frequency (υ_c) :** It is defined as the highest frequency of radio wave, which gets reflected to earth by the ionosphere after having been sent straight to it. If maximum electron density of the ionosphere is N_{max} m^{-3}, then $\upsilon_c \approx 9(N_{max})^{1/2}$. Above υ_c, a wave will penetrate the ionosphere and will not be reflected by it.

Space Wave Propagation

- The space waves are the radio waves of very high frequency (30 MHz to 300 MHz) ultra-high frequency (300 MHz to 3000 MHz) and microwave (more than 3000 MHz). At such high frequencies, the sky wave as well as ground wave both fails.
- The space wave propagation is also called as line of sight propagation. The line of sight distance is the distance between transmitting antenna and receiving antenna at which they can see each other. Maximum line of sight distance, $d_M = \sqrt{2h_T R} + \sqrt{2h_R R}$
- Space wave propagation can be utilised for transmitting high frequency TV and FM signals.

Illustration 5 : The electron density of E, F_1, F_2 layers of ionosphere is 2×10^{11}, 5×10^{11} and 8×10^{11} m^{-3} respectively. What is the ratio of critical frequency for reflection of radio waves?

Soln.: $\upsilon_c \propto (N_{max})^{1/2}$

$\Rightarrow\ (\upsilon_c)_E : (\upsilon_c)_{F_1} : (\upsilon_c)_{F_2}$

$= (2 \times 10^{11})^{1/2} : (5 \times 10^{11})^{1/2} : (8 \times 10^{11})^{1/2} = 2 : \sqrt{10} : 4$

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- ZS Associates

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LIST OF MAJORS

- Aerospace
- Automobile
- Biotechnology
- Chemical
- Civil
- Computer Science
- Electronics and Communication
- Electrical and Electronics
- Mechanical
- Mechatronics Engineering
- Nanotechnology

LIST OF MINORS

- English
- Management
- Entrepreneurship and Innovation
- Economics
- Finance
- Journalism
- Psychology and Patent Rights

Students can pursue any of the mentioned Engineering Majors as a Minor. Non-Engineering Minors include as mentioned above.

LIST OF SPECIALIZATIONS

- IoT (Internet of Things)
- Bioinformatics
- Cyber Security
- Robotics
- Artificial Intelligence and Machine Learning
- Wireless Communication
- Mechatronics
- Nanotechnology
- Genetics
- IT
- Software Engineering

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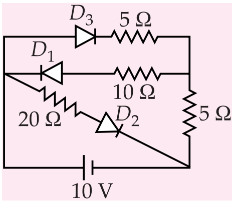
* for SRM Institute of Science and Technology, Kattankulathur

SPEED PRACTICE

1. In the given circuit the current through the battery is (Assume all diodes are ideal)
(a) 0.5 A
(b) 1 A
(c) 1.5 A
(d) 2 A



2. If $V_c = 20\sin 10^5\pi t$ and $V_m = 10\sin 400\pi t$ are carrier and modulating signals, the modulation index is
(a) 56% (b) 30%
(c) 50% (d) 48%

3. A light emitting diode (LED) has a voltage drop of 2 V across it and a current of 10 mA passes when it operates with a 6 V battery through a limiting resistor R. The value of R is
(a) 40 kΩ (b) 4 kΩ
(c) 200 Ω (d) 400 Ω

4. A diode AM detector with the output circuit consisting of $R = 1$ kΩ and $C = 1$ μF would be more suitable for detecting a carrier signal of
(a) 0.1 kHz (b) 0.5 kHz
(c) 10 kHz (d) 0.75 kHz

5. If β, R_L and r are the ac current gain, load resistance and the input resistance of a transistor respectively in CE configuration, the voltage and the power gains respectively are
(a) $\beta\frac{R_L}{r}$ and $\beta^2\frac{R_L}{r}$ (b) $\beta\frac{r}{R_L}$ and $\beta^2\frac{r}{R_L}$
(c) $\beta\frac{R_L}{r}$ and $\beta\left(\frac{R_L}{r}\right)^2$ (d) $\beta\frac{r}{R_L}$ and $\beta\left(\frac{r}{R_L}\right)^2$

6. The ionospheric layer acts as a reflector for the frequency range
(a) 1 kHz to 10 kHz (b) 3 MHz to 30 MHz
(c) 3 kHz to 30 kHz (d) 100 kHz to 1 MHz

7. To get an OR gate from a NAND gate, we need
(a) only two NAND gates.
(b) two NOT gates obtained from NAND gates and one NAND gate.
(c) four NAND gates and two AND gates obtained from NAND gates.
(d) None of these

8. The peak voltage in the output of a half-wave diode rectifier fed with a sinusoidal signal without filter is 10 V. The dc component of the output voltage is
(a) $10\sqrt{2}$ V (b) $10/\pi$ V (c) 10 V (d) $20/\pi$ V

9. In an n-p-n transistor 10^8 electrons enter the emitter in 10^{-8} s. If 1·5% of the electrons are lost in the base of transistor, then the current transfer ratio and current amplification factor respectively are
(a) 0·95, 19 (b) 0·96, 24
(c) 0·975, 39 (d) 0·985, 65·7

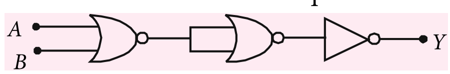
10. A TV tower has a height of 100 m. How much population is covered by the TV broadcast if the average population density around the tower is 1000 km^{-2}.
(Radius of the earth = 6.37×10^6 m)
(a) 4 lakh (b) 4 billion
(c) 40,000 (d) 40 lakh

11. A diode having potential difference 0.5 V across its junction which does not depend on current is connected in series with resistance of 20 Ω across a source. If 0.1 A passes through resistance, then what is the voltage of the source?
(a) 1.5 V (b) 2.0 V (c) 2.5 V (d) 5 V

12. The electron mobility in N-type Germanium is 3900 cm^2 V^{-1}s^{-1} and its conductivity is 6.24 mho cm^{-1}. Then impurity concentration will be
(a) 10^{15} cm^{-3} (b) 10^{13} cm^{-3}
(c) 10^{12} cm^{-3} (d) 10^{16} cm^{-3}

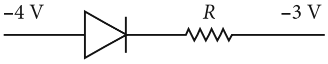
13. In a common emitter transistor amplifier the audio signal voltage across the collector is 3 V. The resistance of collector is 3 kΩ. If current gain is 100 and the base resistance is 2 kΩ, the voltage and power gain of the amplifier is
(a) 15 and 200 (b) 150 and 15000
(c) 20 and 2000 (d) 200 and 1000
[NEET 2017]

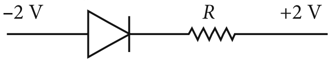
14. The given electrical network is equivalent to

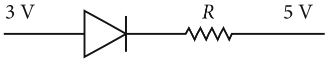


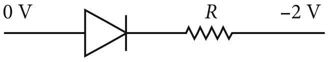
(a) OR gate (b) NOR gate
(c) NOT gate (d) AND gate
[NEET 2017]

15. Which one of the following represents forward bias diode?

(a) 

(b) 

(c) 

(d) 

[NEET 2017]

16. In amplitude modulation, sinusoidal carrier frequency used is denoted by ω_c and the signal frequency is denoted by ω_m. The bandwidth $(\Delta\omega_m)$ of the signal is such that $\Delta\omega_m << \omega_c$. Which of the following frequencies is not contained in the modulated wave?

(a) ω_m (b) ω_c
(c) $\omega_m + \omega_c$ (d) $\omega_c - \omega_m$

[JEE Main Offline 2017]

17. In a common emitter amplifier circuit using an *n-p-n* transistor, the phase difference between the input and the output voltages will be

(a) 45° (b) 90°
(c) 135° (d) 180°

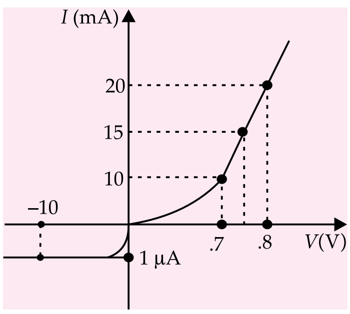
[JEE Main Offline 2017]

18. A signal of frequency 20 kHz and peak voltage of 5 V is used to modulate a carrier wave of frequency 1.2 MHz and peak voltage 25 V. Choose the correct statement.

(a) Modulation index = 5, side frequency bands are at 1400 kHz and 1000 kHz
(b) Modulation index = 0.2, side frequency bands are at 1220 kHz and 1180 kHz
(c) Modulation index = 0.8, side frequency bands are at 1180 kHz and 1220 kHz
(d) Modulation index = 5, side frequency bands are at 21.2 kHz and 18.8 kHz

[JEE Main Online 2017]

19. The *V-I* characteristic of a diode is shown in the figure. The ratio of forward to reverse bias resistance is



(a) 100 (b) 10^6
(c) 10 (d) 10^{-6}

[JEE Main Online 2017]

20. A signal is to be transmitted through a wave of wavelength λ, using a linear antenna. The length *l* of the antenna and effective power radiated P_{eff} will be given respectively as
(*K* is a constant of proportionality)

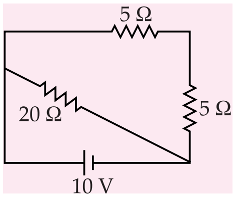
(a) $\frac{\lambda}{5}, P_{eff} = K\left(\frac{l}{\lambda}\right)^{1/2}$ (b) $\lambda, P_{eff} = K\left(\frac{l}{\lambda}\right)^2$

(c) $\frac{\lambda}{16}, P_{eff} = K\left(\frac{l}{\lambda}\right)^3$ (d) $\frac{\lambda}{8}, P_{eff} = K\left(\frac{l}{\lambda}\right)$

[JEE Main Online 2017]

SOLUTIONS

1. **(c) :** In the given circuit, diode D_1 is reverse biased, so it will not conduct. The corresponding equivalent circuit is as shown in the figure. The equivalent resistance of the circuit is



$$R_{eq} = \frac{(5\,\Omega + 5\,\Omega)\times 20\,\Omega}{(5\,\Omega + 5\,\Omega) + 20\,\Omega} = \frac{20}{3}\,\Omega$$

The current through the battery is $I = \dfrac{10\text{ V}}{\frac{20}{3}\,\Omega} = 1.5\text{ A}$

2. **(c) :** Modulation index, $\mu = \dfrac{10}{20} = 0.5 = 50\,\%$

3. **(d):** As LED is connected to a battery through a resistance *R* in series, hence the current flowing is 10 mA(which is the same).
The voltage drop across LED = 2 V
As the battery has 6 V, the potential difference across *R* = 6 V – 2 V = 4 V

$$\therefore \quad IR = 4\text{ V} \;\text{ or }\; R = \frac{4\text{ V}}{I} = \frac{4\text{ V}}{10\times 10^{-3}\text{ A}} = 400\,\Omega$$

4. **(c) :** For demodulation, $\dfrac{1}{\upsilon_C} << RC$
where υ_C is the frequency of the carrier signal.
Here, *R* = 1 kΩ, *C* = 1 μF

$\therefore \quad RC = 1\times 10^3\,\Omega \times 1\times 10^{-6}\text{ F} = 10^{-3}\text{ s}$

$$\frac{1}{\upsilon_C} = \frac{1}{10\times 10^3} = 0.1\times 10^{-3}\text{ s}$$

or $\upsilon_C = 10^4$ Hz = 10 kHz

5. (a) : Voltage gain = current gain × resistance gain

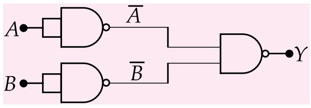
$$= \beta \times \frac{\text{output resistance}}{\text{input resistance}} = \beta \times \frac{R_L}{r}$$

Power gain = voltage gain × current gain

$$= \beta \frac{R_L}{r} \times \beta = \beta^2 \frac{R_L}{r}$$

6. (b) : The ionospheric layer acts as a reflector for a certain range of frequencies (3 to 30 MHz). Electromagnetic waves of frequencies higher than 30 MHz penetrate the ionosphere and escape.

7. (b) : To obtain an OR gate from NAND gates, we need two NOT gates obtained from NAND gates and one NAND gate as shown in figure.



The Boolean expression is

$$Y = \overline{\overline{A} \cdot \overline{B}} = \overline{\overline{A}} + \overline{\overline{B}} = A + B$$

8. (b) : In half-wave rectifier, $V_{dc} = \frac{V_0}{\pi} = \frac{10}{\pi}$

9. (d) : Emitter current,

$$I_E = \frac{\text{charge}}{\text{time}} = \frac{10^8 \times (1.6 \times 10^{-19})}{10^{-8}} A = 1.6 \text{ mA}$$

Base current, $I_B = 1.5\%$ of $I_E = \frac{1.5}{100} \times 1.6 = 0.024$ mA

Collector current, $I_C = I_E - I_B = 1.6 - 0.024$
$= 1.576$ mA

Current transfer ratio, $\alpha = \frac{I_C}{I_E} = \frac{1.576}{1.6} = 0.985$

Current amplification factor, $\beta = \frac{I_C}{I_E} = \frac{1.576}{0.024} = 65.7$

10. (d) : Maximum distance of communication to TV tower, $d = \sqrt{2hR}$

Population covered = πd^2 × population density

$$= \frac{22}{7} \times 2 \times 100 \times 6.37 \times 10^6 \times 1000 \times 10^{-6}$$

$= 44 \times 0.91 \times 10^5 = 40 \times 10^5 = 40$ lakh.

11. (c) : $V' = V + IR = 0.5 + (0.1 \times 20) = 2.5$ V

12. (d) : Given, $\mu_e = 3900$ cm^2 V^{-1} s^{-1}

$\sigma = 6.24$ mho cm^{-1}, $e = 1.6 \times 10^{-19}$ C

Since, $\sigma = e n_e \mu_e$

$$n_e = \frac{\sigma}{e\mu_e} = \frac{6.24}{1.6 \times 10^{-19} \times 3900} = 10^{16} \text{cm}^{-3}$$

13. (b) : Given: $V_i = 3$ V, $R_C = 3$ kΩ, $R_B = 2$ kΩ, $\beta = 100$

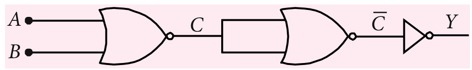
Voltage gain of the CE amplifier,

$$A_V = -\beta_{ac}\left(\frac{R_C}{R_B}\right) = -100\left(\frac{3}{2}\right) = -150$$

Power gain, $A_P = \beta \times A_V = 100 \times (-150) = -15000$

Negative sign represents that output voltage is in opposite phase with the input voltage.

14. (b) :



A	B	C	$\overline{C}$	Output (Y)
0	0	1	0	1
0	1	0	1	0
1	0	0	1	0
1	1	0	1	0

At output, the truth table corresponds to NOR gate.

15. (d) : A diode is said to be forward biased if p-side is at higher potential than n-side of p-n junction.

16. (a)

17. (d)

18. (b) : Modulation index, $\mu = \frac{V_m}{V_c} = \frac{5}{25} = 0.2$

Frequency of carrier wave,

$\upsilon_c = 1.2 \times 10^3$ kHz = 1200 kHz

Frequency of modulate wave = 20 kHz

$\upsilon_1 = \upsilon_c - \upsilon_m = 1200 - 20 = 1180$ kHz

$\upsilon_2 = \upsilon_c + \upsilon_m = 1200 + 20 = 1220$ kHz

19. (d) : Forward bias resistance,

$$R_1 = \frac{\Delta V}{\Delta I} = \frac{0.8 - 0.7}{(20 - 10) \times 10^{-3}} = \frac{0.1}{10 \times 10^{-3}} = 10$$

Reverse bias resistance, $R_2 = \frac{10}{1 \times 10^{-6}} = 10^7$

Then, the ratio of forward to reverse bias resistance,

$$\frac{R_1}{R_2} = \frac{10}{10^7} = 10^{-6}$$

20. (b) : For transmitting a signal, the size of antenna should be comparable to the wavelength of the signal (λ). A linear antenna of length (l) radiates power which is proportional to $\left(\frac{l}{\lambda}\right)^2$ *i.e.* $P_{eff} = K\left(\frac{l}{\lambda}\right)^2$.

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EXAM PREP 2018

CLASS XII

Useful for Medical/Engg. Entrance Exams

CHAPTERWISE MCQS FOR PRACTICE

ATOMS

1. When an electron in hydrogen atom revolves in stationary orbit, it
(a) does not radiate energy and its velocity changes.
(b) does not radiate energy and its velocity remains unchanged.
(c) radiates energy but its velocity is unchanged.
(d) radiates energy with the change of velocity.

2. In Rutherford's scattering experiment when a projectile of charge z_1 and mass M_1 approaches a target nucleus of charge z_2 and mass M_2, the distance of closest approach is r_0. The energy of the projectile is
(a) directly proportional to $z_1 z_2$
(b) inversely proportional to z_1
(c) directly proportional to mass M_1
(d) directly proportional to $M_1 \times M_2$

3. If an electron in hydrogen atom jumps from an orbit of level n = 3 to an orbit of level n = 2, the emitted radiation has a frequency
(R = Rydberg constant, c = velocity of light)
(a) $\frac{Rc}{25}$ (b) $\frac{5Rc}{36}$ (c) $\frac{3Rc}{27}$ (d) $\frac{8Rc}{9}$

4. The ionization energy of hydrogen is 13.6 eV. The energy of the photon released when an electron jumps from the first excited state (n = 2) to the ground state of a hydrogen atom is
(a) 3.4 eV (b) 4.53 eV
(c) 10.2 eV (d) 13.6 eV

5. υ_1 is the frequency of the series limit of Lyman series, υ_2 is the frequency of the first line of Lyman series and υ_3 is the frequency of the series limit of the Balmer series. Then
(a) $\upsilon_1 - \upsilon_2 = \upsilon_3$ (b) $\upsilon_1 = \upsilon_2 - \upsilon_3$
(c) $\frac{1}{\upsilon_2} = \frac{1}{\upsilon_1} + \frac{1}{\upsilon_3}$ (d) $\frac{1}{\upsilon_1} = \frac{1}{\upsilon_2} + \frac{1}{\upsilon_3}$

6. In hydrogen atom, electron excites from ground state to higher energy state and its orbital velocity is reduced to $\left(\frac{1}{3}\right)^{\text{rd}}$ of its initial value. The radius of the orbit in the ground state is R. The radius of the orbit in that higher energy state is
(a) $2R$ (b) $3R$ (c) $27R$ (d) $9R$

7. Hydrogen atom from excited state comes to the ground state by emitting a photon of wavelength λ. If R is the Rydberg constant, the principal quantum number n of the excited state is
(a) $\sqrt{\frac{\lambda R}{\lambda R - 1}}$ (b) $\sqrt{\frac{\lambda}{\lambda R - 1}}$
(c) $\sqrt{\frac{\lambda R^2}{\lambda R - 1}}$ (d) $\sqrt{\frac{\lambda R}{\lambda - 1}}$

8. Two H-atoms in the ground state collide inelastically. The maximum amount by which their combined kinetic energy is reduced is
(a) 10.2 eV (b) 20.4 eV (c) 13.6 eV (d) 27.2 eV

9. The transition from the state n = 4 to n = 3 in a hydrogen-like atom results in ultraviolet radiation. Infrared radiation will be obtained in the transition
(a) $2 \rightarrow 1$ (b) $3 \rightarrow 2$
(c) $4 \rightarrow 2$ (d) $5 \rightarrow 4$

10. In accordance with the Bohr's model, find the quantum number that characterises the earth's revolution around the sun in an orbit of radius 1.5×10^{11} m with orbital speed 3×10^4 m s^{-1}.
(Mass of earth = 6.0×10^{24} kg)

(a) 3.21×10^{64} (b) 1.26×10^{75}
(c) 4.52×10^{30} (d) 2.57×10^{74}

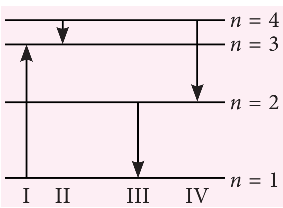
11. A hydrogen atom initially in the ground level absorbs a photon, which excites it to the $n = 4$ level. Determine the wavelength of photon when it again fall back to ground level.
(a) 632.8 Å (b) 453.2 Å
(c) 970.5 Å (d) 512.6 Å

12. Taking the Bohr radius as $a_0 = 53$ pm, the radius of Li^{++} ion in its ground state, on the basis of Bohr's model, will be about
(a) 53 pm (b) 27 pm
(c) 18 pm (d) 13 pm

13. Positronium is just like a H-atom with the proton replaced by the positively charged antiparticle of the electron (called the positron which is as massive as the electron). What would be the ground state energy of positronium?
(a) –6.8 eV (b) –13.4 eV
(c) 26.8 eV (d) 4.4 eV

14. A diatomic molecule is made of two masses m_1 and m_2 which are separated by a distance r. If we calculate its rotational energy by applying Bohr's rule of angular momentum quantization, its energy will be given by (n is an integer)
(a) $\frac{n^2\hbar^2}{2(m_1+m_2)r^2}$ (b) $\frac{2n^2\hbar^2}{(m_1+m_2)r^2}$
(c) $\frac{(m_1+m_2)n^2\hbar^2}{2m_1m_2r^2}$ (d) $\frac{(m_1+m_2)^2n^2\hbar^2}{2m_1^2m_2^2r^2}$

15. The diagram shows the energy levels for an electron in a certain atom. Which transition shown represents the emission of a photon with the highest energy?



(a) I (b) II (c) III (d) IV

NUCLEI

16. There is a stream of neutrons with a kinetic energy of 0.0327 eV. If the half-life of neutrons is 700, what fraction of neutrons will decay before they travel a distance of 10 m?
(a) 4.6×10^{-5} (b) 3.9×10^{-6}
(c) 9.2×10^{-5} (d) 7.8×10^{-6}

17. In a nuclear fusion reaction, two nuclei, A and B fuse to produce a nucleus C, releasing an amount of energy ΔE in the process. If the mass defects of the three nuclei are ΔM_A, ΔM_B and ΔM_C respectively, then which of the following relations holds? Here, c is the speed of light.
(a) $\Delta M_A + \Delta M_B = \Delta M_C - \Delta E/c^2$
(b) $\Delta M_A + \Delta M_B = \Delta M_C + \Delta E/c^2$
(c) $\Delta M_A - \Delta M_B = \Delta M_C - \Delta E/c^2$
(d) $\Delta M_A - \Delta M_B = \Delta M_C + \Delta E/c^2$

18. The energy released by the fission of one Uranium atom is 200 MeV. The number of fissions per second required to produce 3.2 W of power is (Take 1 eV = 1.6×10^{-19} J)
(a) 10^7 (b) 10^{10} (c) 10^{15} (d) 10^{11}

19. The ionizing power and penetration range of radioactive radiations increase in the order
(a) γ, β, α and γ, β, α respectively
(b) γ, β, α and α, β, γ respectively
(c) α, β, γ and α, β, γ respectively
(d) α, β, γ and γ, β, α respectively

20. The activity of a sample of radioactive material is A_1 at time t_1 and A_2 at time $t_2(t_2 > t_1)$. If its mean life is T, then
(a) $A_1t_1 = A_2t_2$ (b) $A_1 - A_2 = t_2 - t_1$
(c) $A_2 = A_1e^{(t_1-t_2)/T}$ (d) $A_2 = A_1e^{(t_1/t_2)T}$

21. Two radioactive substances A and B have decay constants 5λ and λ respectively. At $t = 0$, they have the same number of nuclei. The ratio of number of nuclei of A to those of B will be $(1/e^2)$ after a time
(a) 4λ (b) 2λ (c) $\frac{1}{2\lambda}$ (d) $\frac{1}{4\lambda}$

22. A radioactive nucleus is being produced at a constant rate α per second. Its decay constant is λ. If N_0 are the number of nuclei at time $t = 0$, then the maximum number of nuclei possible are
(a) $N_0 + \frac{\alpha}{\lambda}$ (b) N_0
(c) $\frac{\lambda}{\alpha} + N_0$ (d) $\frac{\alpha}{\lambda}$

23. The masses of two radioactive substances are same and their half-lives are 1 year and 2 years respectively. The ratio of their activities after 6 years will be
(a) 1 : 3 (b) 1 : 6 (c) 1 : 4 (d) 1 : 2

24. The mass of a ${}^7_3Li$ nucleus is 0.042 u less than the sum of the masses of all its nucleons. The binding energy per nucleon of ${}^7_3Li$ nucleus is nearly
(a) 46 MeV (b) 5.6 MeV
(c) 3.9 MeV (d) 23 MeV

25. Using the following data : Mass of hydrogen nucleus = 1.00783 u, mass of neutron = 1.00867 u and mass of nitrogen atom ($^{14}_{7}N$) = 14.00307 u, the calculated value of the binding energy of the nucleus of the nitrogen atom ($^{14}_{7}N$) is close to
(a) 56 MeV (b) 98 MeV
(c) 104 MeV (d) 112 MeV

26. Which of the following statements is correct ?
(a) The rest mass of a stable nucleus is less than the sum of the rest masses of its separated nucleons.
(b) The rest mass of a stable nucleus is greater than the sum of the rest masses of its separated nucleons.
(c) In nuclear fission, energy is released by fusion of two nuclei of medium mass (approximately 100 amu)
(d) In nuclear fission, energy is released by fragmentation of a very low nucleus.

27. Two protons are kept at a separation of 40 Å. F_n is the nuclear force and F_e is the electrostatic force between them. Then
(a) $F_n << F_e$ (b) $F_n \approx F_e$
(c) $F_n >> F_e$ (d) $F_n = F_e$

28. A radioactive element has rate of disintegration 10,000 disintegrations per minute at a particular instant. After four minutes, it becomes 2500 disintegrations per minute. The decay constant per minute is
(a) $0.2 \log_e 2$ (b) $0.5 \log_e 2$
(c) $0.6 \log_e 2$ (d) $0.8 \log_e 2$

29. The half-life of radioactive nucleus is 100 years. The time interval between 20% and 80% decay of the parent nucleus is
(a) 100 years (b) 200 years
(c) 300 years (d) 400 years

30. Two nuclei have their mass numbers in the ratio of 1 : 3. The ratio of their nuclear densities would be
(a) $(3)^{1/3} : 1$ (b) 1 : 1
(c) 1 : 3 (d) 3 : 1

SOLUTIONS

1. **(a) :** Electrons can revolve around the nucleus in stationary orbits only which are non-radiating. Energy is radiated only when an electron jumps from an outer stationary orbit to inner stationary orbit. Velocity of electron changes while revolving in stationary orbits but energy remains constant.

2. **(a) :** Energy of the projectile is the potential energy at closest approach, $= \frac{1}{4\pi\varepsilon_0}\frac{z_1 z_2}{r_0}$

Therefore energy $\propto z_1 z_2$.

3. **(b):** When an electron jumps from higher level n_1 to lower energy level n_2, the frequency of the emitted radiation is

$$\upsilon = Rc\left[\frac{1}{n_2^2} - \frac{1}{n_1^2}\right]$$

$\therefore$ For $n = 3$ to $n = 2$,

$$\upsilon = Rc\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = Rc\left[\frac{1}{4} - \frac{1}{9}\right] = Rc\left[\frac{9-4}{36}\right] = \frac{5Rc}{36}$$

4. **(c) :** Energy of the electron in n^{th} state of hydrogen atom is $E_n = -\frac{13.6}{n^2}$ eV

For ground state ($n = 1$) $E_1 = -\frac{13.6}{1^2}$ eV

For first excited state ($n = 2$) $E_2 = -\frac{13.6}{2^2}$ eV

The energy of the photon emitted for the electron transition from $n = 2$ to $n = 1$ is

$$\Delta E = E_2 - E_1 = (-13.6 \text{ eV})\left(\frac{1}{2^2} - \frac{1}{1^2}\right) = 10.2 \text{ eV}$$

5. **(a) :** For Lyman series

$$\upsilon = Rc\left[\frac{1}{1^2} - \frac{1}{n^2}\right], \text{ where } n = 2, 3, 4, \ldots\ldots.$$

For the series limit of Lyman series, $n = \infty$

$$\therefore \upsilon_1 = Rc\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right] = Rc \quad \ldots(i)$$

For the first line of Lyman series, $n = 2$

$$\therefore \upsilon_2 = Rc\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = \frac{3}{4}Rc \quad \ldots(ii)$$

For Balmer series

$$\upsilon = Rc\left[\frac{1}{2^2} - \frac{1}{n^2}\right], \text{ where } n = 3, 4, 5\ldots.$$

For the series limit of Balmer series, $n = \infty$

$$\therefore \upsilon_3 = Rc\left[\frac{1}{2^2} - \frac{1}{\infty^2}\right] = \frac{Rc}{4} \quad \ldots(iii)$$

From eqns. (i), (ii) and (iii), we get

$$\upsilon_1 = \upsilon_2 + \upsilon_3 \text{ or } \upsilon_1 - \upsilon_2 = \upsilon_3$$

6. **(d):** As per question, $\frac{v_h}{v_g} = \frac{1}{3}$ ..(i)

where subscripts h and g denotes higher energy state and ground state.
Orbital velocity of electron in the n^{th} orbit is

$$v_n = \frac{e^2}{2\varepsilon_0 nh} \quad \text{or} \quad v_n \propto \frac{1}{n}$$

For ground state, $n = 1$, $\frac{v_h}{v_g} = \frac{1}{n}$ ...(ii)

Equating eqns. (i) and (ii), we get $n = 3$

Radius of n^{th} orbit is $r_n = \frac{n^2 h^2 \varepsilon_0}{\pi e^2 m^2}$ or $r_n \propto n^2$

$$\therefore \frac{r_3}{r_1} = \frac{(3)^2}{(1)^2} = 9$$

$$r_3 = 9r_1 = 9R \qquad (\because r_1 = R\text{(Given)})$$

7. **(a) :** According to Rydberg's formula

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

Here, $n_f = 1$, $n_i = n$

$$\therefore \frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right) \Rightarrow \frac{1}{\lambda} = R\left(1 - \frac{1}{n^2}\right) \quad \text{... (i)}$$

Multiplying eqn. (i) by λ on both sides,

$$1 = \lambda R\left(1 - \frac{1}{n^2}\right) \text{ or } n = \sqrt{\frac{\lambda R}{\lambda R - 1}}$$

8. **(a) :** In inelastic collision kinetic energy is not conserved so some part of K.E. is lost.

$\therefore$ Reduction in K.E. =

K.E. before collision – K.E. after collision

Now, since initial K.E. of each of two hydrogen atoms in ground state = 13.6 eV

$\therefore$ Total K.E. of both hydrogen atom before collision = 2 × 13.6 = 27.2 eV.

If one H atom goes over to first excited state (n_1 = 2) and other remains in ground state (n_2 = 1) then their combined K.E. after collision is

$$= \frac{13.6}{(2)^2} + \frac{13.6}{(1)^2} = 3.4 + 13.6 = 17 \text{ eV}$$

Hence, reduction in K.E. = 27.2 – 17 = 10.2 eV.

9. **(d):** In hydrogen like atoms:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

Transition of electron occurs from n_2 to n_1.

$\frac{1}{\lambda}$ is proportional to energy.

From $n = 4$ to $n = 3$, ultraviolet radiation is obtained.

$$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{4^2}\right) = \frac{7R}{144} = 0.048\,R$$

(a) $\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = \frac{3R}{4} = 0.75\,R$

(b) $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5R}{36} = 0.14\,R$

(c) $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{4^2}\right) = \frac{3R}{16} = 0.2\,R$

(d) $\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{5^2}\right) = \frac{9R}{400} = 0.02\,R$

λ is smaller than ultraviolet in (a), (b) and (c).

λ is greater than ultraviolet in (d).

Greater the λ, less the energy of radiation.

Infrared radiation has less energy and greater λ as compared to ultraviolet radiation.

Hence option (d) is correct.

10. **(d):** According to Bohr's quantization condition of angular momentum,

Angular momentum of the earth around the sun,

$$mvr = \frac{nh}{2\pi}; \therefore n = \frac{2\pi mvr}{h}$$

$$= \frac{2 \times 3.14 \times 6.0 \times 10^{24} \times 1.5 \times 10^{11} \times 3 \times 10^4}{6.6 \times 10^{-34}}$$

$= 2.57 \times 10^{74}$

11. **(c) :** Energy of an electron in the n^{th} orbit of H-atom,

$$E_n = -\frac{13.6}{n^2} \text{ eV}$$

Energy in the ground (n = 1) level, E_1 = –13.6 eV

Energy in the fourth (n = 4) level, E_4 = –0.85 eV

Energy radiated during emission

$$\Delta E = E_4 - E_1 = -0.85 - (-13.6) = 12.75 \text{ eV}$$

As $\Delta E = \frac{hc}{\lambda}$

$$\therefore \text{Wavelength, } \lambda = \frac{hc}{\Delta E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{12.75 \times 1.6 \times 10^{-19}}$$

$$= 0.9705 \times 10^{-7} \text{ m} = 970.5 \text{ Å}$$

12. **(c) :** Here, a_0 = 53 pm, n = 1 for ground state.

For Li^{++} ion, $z = 3$

Radius of n^{th} orbit, $r = \frac{n^2 h^2}{4\pi^2 mKze^2} = \frac{a_0 n^2}{z}$

$$\therefore r = \frac{53 \times (1)^2}{3} \quad \left[\because a_0 = \frac{h^2}{4\pi^2 mKe^2} = 53 \text{ pm}\right]$$

$= 17.66 \approx 18$ pm

13. **(a) :** According to Bohr's formula,

$$E_n = \frac{-me^4}{8\varepsilon_0^2 n^2 h^2}$$, m is called reduced mass.

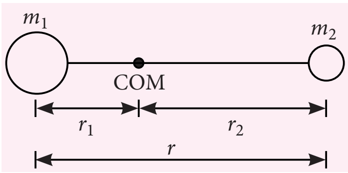
In case of hydrogen, $m = m_e$ = mass of electron.
For positronium,

$$m = \frac{m_e \times m_e}{m_e + m_e} = \frac{m_e}{2}$$

Since for H-atom, $E_1 = \frac{-m_e e^4}{8\varepsilon_0^2 n^2 h^2} = -13.6 \text{ eV}$

So, for positronium $E_1' = \frac{-13.6}{2} = -6.8 \text{ eV}.$

14. (c) : A diatomic molecule consists of two atoms of masses m_1 and m_2 at a distance r apart. Let r_1 and r_2 be the distances of the atoms from the centre of mass.



The moment of inertia of this molecule about an axis passing through its centre of mass and perpendicular to a line joining the atoms is
$I = m_1 r_1^2 + m_2 r_2^2$

As $m_1 r_1 = m_2 r_2$ or $r_1 = \frac{m_2}{m_1} r_2$

$\therefore \quad r_1 = \frac{m_2}{m_1}(r - r_1)$; $r_1 = \frac{m_2 r}{m_1 + m_2}$

Similarly, $r_2 = \frac{m_1 r}{m_1 + m_2}$

Therefore, the moment of inertia can be written as

$$I = m_1\left(\frac{m_2 r}{m_1 + m_2}\right)^2 + m_2\left(\frac{m_1 r}{m_1 + m_2}\right)^2$$

$$= \frac{m_1 m_2}{m_1 + m_2} r^2 \quad \text{...(i)}$$

According to Bohr's quantisation condition

$$L = \frac{nh}{2\pi} \quad \text{or} \quad L^2 = \frac{n^2 h^2}{4\pi^2} \quad \text{...(ii)}$$

Rotational energy, $E = \frac{L^2}{2I}$

$$E = \frac{n^2 h^2}{8\pi^2 I} = \frac{n^2 \hbar^2 (m_1 + m_2)}{2 m_1 m_2 r^2} \quad \text{(Using (i) and (ii))}$$

15. (c) : Transition I is showing absorption photon. From rest of three, transition III have maximum energy as $\Delta E \propto \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$.

16. (b): Kinetic energy of neutron = 0.0327 eV

or $K = 0.0327 \times 1.6 \times 10^{-19}$ J

or $\frac{1}{2} m v^2 = 0.0327 \times 1.6 \times 10^{-19}$

or $v^2 = \frac{2 \times 0.0327 \times 1.6 \times 10^{-19}}{1.675 \times 10^{-27}}$

or $v^2 = 0.0625 \times 10^8$; $v = 0.25 \times 10^4$ m s^{-1}

$\therefore$ Time taken $= \frac{\text{distance}}{\text{velocity}} = \frac{10}{0.25 \times 10^4}$

or $t = 4 \times 10^{-3}$ s

$\therefore$ Fraction that decays $= \frac{N}{N_0} = (1 - e^{-\lambda t})$

$$= 1 - \left\{ e^{-\left(\frac{0.693}{700} \times 4 \times 10^{-3}\right)} \right\} = 3.9 \times 10^{-6}$$

17. (a): Binding energy of $A = \Delta M_A c^2$
Binding energy of $B = \Delta M_B c^2$
Binding energy of $C = \Delta M_C c^2$
The nuclear reaction is given by

$$A + B \rightarrow C$$

Energy released ,

ΔE = BE of C – (BE of A + BE of B)

$= \Delta M_C c^2 - (\Delta M_A c^2 + \Delta M_B c^2)$

$$\frac{\Delta E}{c^2} = \Delta M_C - (\Delta M_A + \Delta M_B)$$

$$\Delta M_A + \Delta M_B = \Delta M_C - \frac{\Delta E}{c^2}$$

18. (d): Energy released per fission is

$E = 200 \text{ MeV} = 200 \times 10^6 \times 1.6 \times 10^{-19}$ J
$= 3.2 \times 10^{-11}$ J

Power, $P = 3.2$ W

Number of fissions per second $= \frac{P}{E}$

$$= \frac{3.2}{3.2 \times 10^{-11}} = \frac{3.2}{3.2 \times 10^{-11}} = 10^{11}$$

19. (b)

20. (c) : $A_1 = \left(\frac{dN}{dt}\right)_1 = \lambda N_1 = \lambda N_0 e^{-\lambda t_1}$

$$A_2 = \left(\frac{dN}{dt}\right)_2 = \lambda N_2 = \lambda N_0 e^{-\lambda t_2}$$

$$\therefore \quad \frac{A_2}{A_1} = \frac{e^{-\lambda t_2}}{e^{-\lambda t_1}} = e^{(t_1 - t_2)\lambda}$$

$$\frac{A_2}{A_1} = e^{(t_1 - t_2)/T} \quad \text{or} \quad A_2 = A_1 e^{(t_1 - t_2)/T}$$

21. (c) : At $t = 0$, $N = N_0$ for both the substances A and B

$\therefore \quad N_A = N_0 e^{-\lambda_A t}$ and $N_B = N_0 e^{-\lambda_B t}$

$$\frac{N_A}{N_B} = \frac{e^{-\lambda_A t}}{e^{-\lambda_B t}} = e^{(\lambda_B - \lambda_A)t} = e^{(\lambda - 5\lambda)t} = \left(\frac{1}{e}\right)^{4\lambda t}$$

As $\dfrac{N_A}{N_B} = \left(\dfrac{1}{e}\right)^2$

$\therefore \quad 4\lambda t = 2$ or $t = \dfrac{2}{4\lambda} = \dfrac{1}{2\lambda}$

22. (d): Maximum number of nuclei will be present, When rate of decay = rate of formation

$\lambda . N = \alpha, \; N = \dfrac{\alpha}{\lambda}$

23. (c) : Let us assume that the initial total number of radioactive substances are the same.
Sample -1 : Half life $T_{1/2}$ = 1 year.
Sample - 2 : Half life $T_{1/2}$ = 2 years.

		1 yr	2 yr	3 yr	4 yr	5 yr	6 yr
Sample-1	N	$N_0/2$	$N_0/4$	$N_0/8$	$N_0/16$	$N_0/32$	$N_0/64$
Sample-2	N		$N_0/2$		$N_0/4$		$N_0/8$

$$\frac{dN_1}{dt} = -\lambda_1 \cdot \frac{N_0}{64} \Rightarrow \frac{dN_1}{dt} = -\frac{0.693}{1\text{ yr}} \cdot \frac{N_0}{64}$$

$$\frac{dN_2}{dt} = -\lambda_2 \cdot \frac{N_0}{8} \Rightarrow \frac{dN_2}{dt} = -\frac{0.693}{2\text{ yr}} \cdot \frac{N_0}{8}$$

$\therefore$ Ratio of their activities $= \dfrac{2 \times 8}{1 \times 64} = \dfrac{1}{4}$

24. (b): For ${}^7_3\text{Li}$ nucleus,

Mass defect, $\Delta M = 0.042$ u

$\because \quad 1 \text{ u} = 931.5 \text{ MeV}/c^2$

$\therefore \quad \Delta M = 0.042 \times 931.5 \text{ MeV}/c^2 = 39.1 \text{ MeV}/c^2$

Binding energy, $E_b = \Delta M c^2$

$$= \left(39.1 \frac{\text{MeV}}{c^2}\right) c^2 = 39.1 \text{ MeV}$$

Binding energy per nucleon, $E_{bn} = \dfrac{E_b}{A} = \dfrac{39.1 \text{ MeV}}{7}$

≈ 5.6 MeV

25. (c) : Binding energy of ${}^{14}_7\text{N}$,

B.E. = $(7 \times 1.00783 + 7 \times 1.00867 - 14.00307)\text{u}c^2$

B.E. = 0.11243×931.5 MeV = 104.7 MeV

26. (a)

27. (a) : Nuclear force is much stronger than the electrostatic force inside the nucleus *i.e.*, at distances of the order of fermi. At 40 Å, nuclear force is ineffective and only electrostatic force of repulsion is present. This is very high at this distance because nuclear force is not acting now and the gravitational force is very feeble. $F_{\text{nuclear}} << F_{\text{electrostatic}}$ in this case.

28. (b): The number of nuclei in the radioactive element is

$N = N_0 e^{-\lambda t}$

$$\frac{N}{N_0} = e^{-\lambda t}; \; \frac{2500}{10000} = e^{-\lambda t}; \; = \frac{1}{4} = e^{-4\lambda}$$

or $e^{4\lambda} = 4 = 2; \lambda = 0.5 \ln 2 = 0.5 \log_e 2$

29. (b): Let the radioactive nucleus decay 20% in time t_1 and 80% in time t_2. Then in time t_1, 80% of the nucleus left undecayed and in time t_2, 20% of the nucleus left undecayed.

As $\dfrac{N}{N_0} = \left(\dfrac{1}{2}\right)^{t/T_{1/2}}$

$$\therefore \quad \frac{80}{100} = \left(\frac{1}{2}\right)^{t_1/T_{1/2}} \text{ or } \frac{4}{5} = \left(\frac{1}{2}\right)^{t_1/T_{1/2}} \quad \text{...(i)}$$

$$\text{and} \quad \frac{20}{100} = \left(\frac{1}{2}\right)^{t_2/T_{1/2}} \text{ or } \frac{1}{5} = \left(\frac{1}{2}\right)^{t_2/T_{1/2}} \quad \text{...(ii)}$$

Dividing eqn. (ii) by eqn. (i), we get

$$\text{or} \quad \left(\frac{1}{2}\right)^2 = \left(\frac{1}{2}\right)^{\frac{t_2 - t_1}{T_{1/2}}} \text{ or } \frac{t_2 - t_1}{T_{1/2}} = 2$$

or $t_2 - t_1 = 2(T_{1/2}) = 2(100 \text{ years}) = 200$ years

30. (b): $A_1 : A_2 = 1 : 3$

Their radii will be in the ratio

$R_0 A_1^{1/3} : R_0 A_2^{1/3} = 1 : 3^{1/3}$

Density $= \dfrac{A}{\frac{4}{3}\pi R^3}$

$$\therefore \quad \rho_{A_1} : \rho_{A_2} = \frac{A_1}{\frac{4}{3}\pi R_0^3 A_1} : \frac{\frac{4}{3}\pi R_0^3 A_2}{A_2}$$

Their nuclear densities will be the same.

◈◈

MPP-9 CLASS XI ANSWER KEY

1. (c)	2. (a)	3. (c)	4. (a)	5. (d)
6. (c)	7. (b)	8. (b)	9. (d)	10. (a)
11. (c)	12. (b)	13. (b)	14. (a)	15. (d)
16. (b)	17. (c)	18. (a)	19. (c)	20. (a,b,d)
21. (b,d)	22. (a,b)	23. (c,d)	24. (2)	25. (7)
26. (4)	27. (d)	28. (d)	29. (c)	30. (b)

ACE YOUR WAY CBSE XII

PRACTICE PAPER 2018

Time Allowed : 3 hours | Maximum Marks : 70

GENERAL INSTRUCTIONS

(i) All questions are compulsory.
(ii) Q. no. 1 to 5 are very short answer questions and carry 1 mark each.
(iii) Q. no. 6 to 10 are short answer questions and carry 2 marks each.
(iv) Q. no. 11 to 22 are also short answer questions and carry 3 marks each.
(v) Q. no. 23 is a value based question and carries 4 marks.
(vi) Q. no. 24 to 26 are long answer questions and carry 5 marks each.
(vii) Use log tables if necessary, use of calculators is not allowed.

SECTION - A

1. A solenoid is connected to a battery so that a steady current flows through it. If an iron core is inserted into the solenoid, will the current increase or decrease? Explain.

2. Two wires of equal lengths are bent in the form of two loops. One of the loops is square shaped whereas the other loop is circular. They are suspended in a uniform magnetic field and the same current is passed through them. Which loop will experience greater torque? Give reasons.

3. A variable frequency a.c. source is connected to a capacitor. How will the displacement current change with decrease in frequency?

4. Can a charged body attract another uncharged body? Explain.

5. An air capacitor is given a charge of 2 μC raising its potential to 200 V. If on inserting a dielectric medium, its potential falls to 50 V, what is the dielectric constant of the medium?

SECTION - B

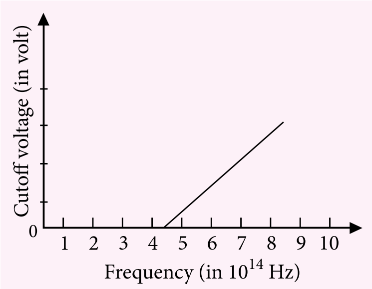
6. An object is placed 18 cm in front of a mirror. If the image is formed at 4 cm to the other side of the mirror, calculate its focal length. Is the mirror convex or concave? What is the nature of the image? What is the radius of curvature of the mirror?

7. A transmitting antenna at the top of a tower has a height of 36 m and the height of the receiving antenna is 49 m. What is maximum distance between them, for satisfactory communication in the LOS mode? (Radius of earth = 6400 km)

8. Why is the wave nature of matter not more apparent to our daily observations?

OR

For photoelectric effect in sodium, the figure shows the plot of cut off voltage versus frequency of incident radiation. Find
(i) the threshold frequency
(ii) the work function for sodium.



9. A change of 8.0 mA in the emitter current brings a change of 7.6 mA in the collector current. How much change in the base current is required to have the same change (= 7.6 mA) in collector current. Find the value of α and β.

10. Two wires of equal length, one of aluminium and the other of copper have the same resistance. Which of the two wires is lighter? Hence explain why aluminium wire preferred for overhead power cables. ($\rho_{Al} = 2.63 \times 10^{-8}\ \Omega$ m, $\rho_{Cu} = 1.72 \times 10^{-8}\ \Omega$ m, relative density of Al = 2.7, of Cu = 8.9)

SECTION - C

11. Write the order of frequency range and one use of each of the following electromagnetic radiations.
(i) Microwaves (ii) Ultraviolet rays
(iii) Gamma rays

12. A circular coil is placed in a uniform magnetic field of strength 0.10 T normal to the plane of the coil. If the current in the coil is 5.0 A, find : (i) total torque on the coil, (ii) total force on the coil, (iii) average force on each electron in the coil due to the magnetic field (the coil is made of copper wire of cross-sectional area 10^{-5} m^2 and the free electron density in copper is 10^{29}m^{-3}).

13. Define mean life of a radioactive sample. Deduce its relation with decay constant and half-life.

14. Deduce an expression for the de Broglie wavelength of an electron accelerated through a potential difference V. Is it possible to detect matter wave associated with electron with the help of electron diffraction experiment?

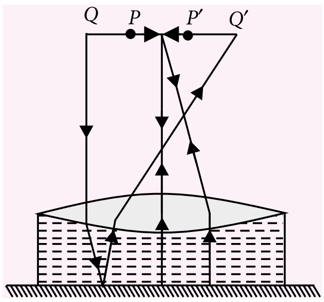
15. A short bar magnet placed with its axis inclined at 30° with an external magnetic field of 800 G acting horizontally experiences a torque of 0.016 N m. Calculate (i) the magnetic moment of the magnet, (ii) the work done by an external force in moving it from most stable to most unstable position, (iii) the work done by the force due to the external magnetic field in the process mentioned in (ii)?

OR

(a) If χ stands for the magnetic susceptibility of a given material, identify the class of materials for which:
(i) $-1 \geq \chi < 0$
(ii) $0 < \chi < \varepsilon$ (ε stands for a small positive number).
(b) Write the range of relative permeability of these materials.
(c) Draw the pattern of the magnetic field lines when these materials are placed in an external magnetic field.

16. An electric dipole with moment $\vec{p}$ is placed in a uniform electric field of intensity $\vec{E}$. Write the expression for the torque $\vec{\tau}$ experienced by the dipole. Identify two pairs of perpendicular vectors in the expression. Show diagrammatically the orientation of the dipole in the field for which the torque is (i) maximum, (ii) half the maximum value, (iii) zero.

17. Figure shows an equiconvex lens of refractive index 1.5 in contact with a liquid layer on top of a plane mirror. A small needle with its tip on the principal axis is moved along the axis until its inverted image is found at the position of the needle. The distance of needle from the lens is measured to be 45 cm. The liquid is removed and experiment is repeated. The new distance is measured to be 30 cm. What is the refractive index of the liquid?



18. Write two basic modes of communication. Explain the process of amplitude modulation. Draw a schematic sketch showing how amplitude modulated signal is obtained by superposing a modulating signal over a sinusoidal carrier wave.

19. What is induced emf? Write Faraday's law of electromagnetic induction. Express it mathematically. A conducting rod of length l, with one end pivoted, is rotated with a uniform angular speed ω in vertical plane, normal to uniform magnetic field *B*. Deduce an expression for the emf induced in this rod.

20. Calculate the longest and shortest wavelength in the Balmer series of hydrogen atom. Given : Rydberg constant = $1.0987 \times 10^7\ m^{-1}$.

21. Give reasons for the following :
(i) Longitudinal waves cannot be polarised.
(ii) Two identical but independent monochromatic sources of light cannot be coherent.
(iii) The value of the Brewster angle for a transparent medium is different for lights of different colours.

22. (i) A charge $+Q$ is placed on a large spherical conducting shell of radius *R*. Another small conducting sphere of radius *r* carrying charge *q* is introduced inside the large shell and is placed at its centre. Find the potential difference between two points, one lying on the sphere and the other on the shell.
(ii) How would the charge between the two spheres flow if they are connected by a conducting wire?

SECTION - D

23. Anuj's mother was having a constant headache and was diagnosed with tumor. She was avoiding treatment because of financial constraints. When Anuj learnt about it, he cancelled his plans to go abroad and decided to use that money for the treatment and care of his mother. Answer the following questions :
(i) What, according to you are the values displayed by Anuj?
(ii) Which type of radiation do you think could be used for the treatment?
(iii) Why are γ-rays emitted by a nucleus ?

SECTION - E

24. State Kirchhoff's laws. Derive the condition for obtaining balance in a wheatstone bridge.

OR

Explain the working and principle of a potentiometer. How will you find the value of emf of a cell using a potentiometer?

25. (i) What is wavefront? Explain different types of wavefronts.
(ii) Derive Snell's law of refraction using Huygens' principle.

OR

(i) What are coherent sources of light?
(ii) Derive a mathematical expression for the width of interference fringes obtained in Young's double slit experiment with the help of a suitable diagram.

26. Derive an expression for the phase angle of an a.c. with an inductor *L*, a capacitor *C* and a resistor *R* in series. Draw the phase diagram. Obtain an expression for the resonant frequency of the circuit.

OR

Explain briefly, with the help of a labelled diagram, the basic principle of the working of an a.c. generator. In an a.c. generator, coil of *N* turns and area *A* is rotated at υ revolutions per second in a uniform magnetic field *B*. Write the expression for the emf produced.
A 100-turn coil of area 0.1 m^2 rotates at half a revolution per second. It is placed in a magnetic field 0.01 T perpendicular to the axis of rotation of the coil. Calculate the maximum voltage generated in the coil.

SOLUTIONS

1. When an iron core is inserted into it, magnetic flux increases, an induced emf is set up in the coil which opposes current according to Lenz's law and hence current in solenoid decreases.

2. For a wire of given length, the circular loop has greater area than the square loop. So the circular loop will experience greater torque in the magnetic field, because torque ∝ area of the loop.

3. On decreasing the frequency, reactance $X_C = \frac{1}{\omega C}$ will increase and it leads to decrease in conduction current. In this case displacement current is equal to conduction current; hence displacement current will decrease.

4. Yes, a charged body can attract another uncharged body. When the charged body is placed near the uncharged body, the induced charges of opposite kind are produced on the uncharged body and thus uncharged body is attracted by the charged body.

5. When dielectric is introduced, the potential difference between the plates of capacitor decreases by a factor *K*, the dielectric constant.

Thus, $K = \frac{V}{V'} = \frac{200}{50} = 4$

6. Here, $u = -18$ cm

$v = 4$ cm

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

or $\frac{1}{f} = \frac{1}{4} - \frac{1}{18} = \frac{9-2}{36} = \frac{7}{36}$

$f = \frac{36}{7} = 5.14 \text{ cm}$

As focal length is positive, the mirror must be convex. The image is virtual, erect and smaller in size.

Radius of curvature, $R = 2f = 2 \times 5.14$ cm

$= 10.28$ cm

7. Here $h_T = 36$ m, $h_R = 49$ m

and $R = 6400$ km $= 6400000 = 64 \times 10^5$ m

∴ Maximum line-of-sight (LOS) distance d_M between the two antennae is

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

$$d_M = \sqrt{2 \times 64 \times 10^5 \times 36} + \sqrt{2 \times 64 \times 10^5 \times 49}$$

$$d_M = \left(8 \times 6 \times 10^2 \times \sqrt{2 \times 10}\right) + \left(8 \times 7 \times 10^2 \times \sqrt{2 \times 10}\right)$$

$$= \left(48 \times 10^2 \times \sqrt{20}\right) + \left(56 \times 10^2 \times \sqrt{20}\right)$$

$$= 104 \times 10^2 \times \sqrt{20} = 104 \times 10^2 \times 2\sqrt{5}$$

$$= 208 \times \sqrt{5} \times 10^2$$

$= 208 \times 2.236 \times 100 = 46.51$ km

8. According to de Broglie wave equation,

$$\lambda = \frac{h}{mv}$$

where the letters have their usual meanings. Since the value of h (*i.e.*, 6.63×10^{-34} J s) is exceedingly small and the objects in our daily observations have got large masses, λ is almost negligible. Let us calculate the de Broglie wavelength of a car whose mass is 1500 kg and speed is 36 km h^{-1} (= 10 m s^{-1}).

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{(1500) \times (10)} \approx 4 \times 10^{-38} \text{ m}$$

This wavelength is so small relative to the dimensions of the car, so, we do not expect wave aspect in its behaviour.

OR

From Einstein's photoelectric equation,

$$V_0 = \left(\frac{h}{e}\right)\upsilon - \frac{\phi_0}{e}$$

When $V_0 = 0$

(i) $\upsilon_0 = 4.5 \times 10^{14}$ Hz

(ii) $\phi_0 = h\upsilon_0$

$$= \frac{6.6 \times 10^{-34} \times 4.5 \times 10^{14}}{1.6 \times 10^{-19}} \text{ eV} = 1.86 \text{ eV}$$

9. Given, $\Delta I_E = 8.0$ mA, $\Delta I_C = 7.6$ mA

As $\Delta I_E = \Delta I_B + \Delta I_C$

or $\Delta I_B = \Delta I_E - \Delta I_C = 8.0 - 7.6 = 0.4$ mA

$$\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{7.6}{8.0} = 0.95$$

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{7.6}{0.4} = 19$$

10. Two wires have same length and resistance. As the areas are different,

For Cu wire, $R_{Cu} = \rho_{Cu} \frac{l}{A_{Cu}}$

For aluminium wire, $R_{Al} = \rho_{Al} \frac{l}{A_{Al}}$

As resistances are equal,

so, $\rho_{Cu} \frac{l}{A_{Cu}} = \rho_{Al} \frac{l}{A_{Al}}$

$$\frac{A_{Al}}{A_{Cu}} = \frac{\rho_{Al}}{\rho_{Cu}} = \frac{2.63 \times 10^{-8}}{1.72 \times 10^{-8}} = \frac{263}{172}$$

Ratio of masses, $\frac{M_{Al}}{M_{Cu}} = \frac{\rho_{Al} l A_{Al}}{\rho_{Cu} l A_{Cu}} = \frac{2.7 \times 263}{8.9 \times 172} = 0.46$

∴ $M_{Al} < M_{Cu}$

Thus the aluminium wire of the same resistance is lighter than copper wire and that is why aluminium wires are preferred for overhead power cables.

11. (i) Microwaves : Order of frequency range 10^9 Hz to 10^{12} Hz.

Use : Microwaves are used for radar systems in aircraft navigation.

(ii) Ultra-violet rays : Order of frequency range 10^{14} Hz to 10^{17} Hz.

Use : Ultra-violet rays are used to destroy the bacteria and for sterilizing the surgical instruments.

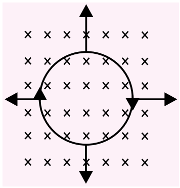
(iii) Gamma rays : Order of frequency range 10^{18} Hz to 10^{22} Hz.

Use : Gamma rays are used in the treatment of cancer and tumors.

12. (i) Total torque $\tau = NIAB \sin\theta$

As $\theta = 0°$

$\Rightarrow \tau = 0$



(ii) $F_{net} = 0$ as force on each side is balanced by force on corresponding side.

(iii) Force on each electron $F_e = ev_dB$

$I = Anev_d$

$$v_d = \frac{I}{Ane}$$

$$\therefore \quad F_e = e\frac{I}{Ane}B = \frac{1.6\times10^{-19}\times5\times0.10}{10^{-5}\times10^{29}\times1.6\times10^{-19}}$$

$= 5 \times 10^{-25}$ N

13. Mean life : The average time for which the nuclei of a radioactive sample exist is called mean life or average life of that sample. It is equal to the ratio of the combined age of all the nuclei to the total number of nuclei present in the given sample. It is denoted by τ.

$$\text{Mean life} = \frac{\text{Sum of the lives of all the nuclei}}{\text{Total number of nuclei}}$$

Relation between mean life and decay constant: Suppose a radioactive sample contains N_0 nuclei at time $t = 0$. After time t, this number reduces to N. Furthermore, suppose dN nuclei disintegrate in time t to $t + dt$. As dt is small, so the life of each of dN nuclei can be approximately taken equal to t.

$\therefore$ Total life of all dN nuclei $= t\,dN$

$$\text{Total life of all the } N_0 \text{ nuclei} = \int_0^{N_0} t\,dN$$

$$\text{Mean life} = \frac{\text{Total life of all the } N_0 \text{ nuclei}}{N_0}$$

$$\text{or} \quad \tau = \frac{1}{N_0}\int_0^{N_0} t\,dN$$

As $N = N_0 e^{-\lambda t}$

$\therefore \quad dN = -\lambda N_0 e^{-\lambda t}\,dt$

When $N = N_0$, $t = 0$ and when $N = 0$, $t = \infty$.

Changing the limits of integration in terms of time, we get

$$\tau = \frac{1}{N_0}\int_0^{\infty} t\lambda N_0 e^{-\lambda t}\,dt$$

Here we have ignored the negative sign which just tells that N decreases with the passage of time t.

Thus

$$\tau = \lambda\int_0^{\infty} t\,e^{-\lambda t}\,dt = \lambda\left[\left\{\frac{te^{-\lambda t}}{-\lambda}\right\}_0^{\infty} - \int_0^{\infty}\frac{e^{-\lambda t}}{-\lambda}dt\right]$$

$$= 0 + \frac{\lambda}{\lambda}\int_0^{\infty} e^{-\lambda t}dt = \int_0^{\infty} e^{-\lambda t}\,dt = \left[\frac{e^{-\lambda t}}{-\lambda}\right]_0^{\infty}$$

$$= -\frac{1}{\lambda}[e^{-\infty} - e^0] = -\frac{1}{\lambda}[0-1] \text{ or } \tau = \frac{1}{\lambda}$$

$$\text{Also } T_{1/2} = \frac{0.693}{\lambda} = 0.693\,\tau$$

$$\text{or} \quad \tau = \frac{T_{1/2}}{0.693} = 1.44\,T_{1/2}$$

14. de Broglie wavelength of an electron : Consider an electron of mass m and charge e. Let v be the final velocity attained by the electron when it is accelerated from rest through a potential difference V. Then kinetic energy gained by the electron equals the work done on the electron by the electric field.

K.E. gained by the electron,

$$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

Work done on the electron $= eV$

$$\therefore \quad K = \frac{p^2}{2m} = eV$$

$$\text{or} \quad p = \sqrt{2mK} = \sqrt{2meV}$$

Hence, the de Broglie wavelength of the electron is

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$$

Now, $h = 6.63 \times 10^{-34}$ J s,

$m = 9.1 \times 10^{-31}$ kg,

$e = 1.6 \times 10^{-19}$ C

$$\therefore \quad \lambda = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}V}}$$

$$= \frac{12.3\times10^{-10}}{\sqrt{V}}\text{ m} = \frac{12.3}{\sqrt{V}}\text{ Å}$$

For an accelerating potential of 120 V, we find $\lambda = 0.112$ nm. This wavelength is of the same order as the spacing between the atomic planes in crystals. This suggests that matter waves associated with electrons could be detected by electron diffraction experiments.

15. (i) Since, $\tau = mB\sin\theta$

$\therefore \quad m = \dfrac{\tau}{B\sin\theta}$

or $\quad m = \dfrac{0.016}{800 \times 10^{-4} \times \sin 30°} \qquad [\because 1\ \text{G} = 10^{-4}\ \text{T}]$

or $\quad m = 0.40\ \text{A m}^2$

(ii) $W = -mB(\cos\theta_2 - \cos\theta_1)$

$W = -mB(\cos 180° - \cos 0°)$

$= -mB(-1-1) = 2\,mB$

or $\quad W = 2 \times 0.40 \times 800 \times 10^{-4} = 0.064\ \text{J}$

(iii) The displacement and the torque due to the magnetic field are in opposite direction. So work done by the force due to the external magnetic field is $W_B = -0.064$ J.

OR

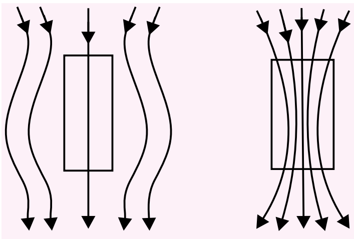
(a) (i) For $-1 \geq \chi < 0$, material is diamagnetic.

(ii) For $0 < \chi < \varepsilon$, material is paramagnetic.

(b) Range of relative magnetic permeability of diamagnetic material is $0 \leq \mu_r < 1$.

Range of relative magnetic permeability of paramagnetic material is $1 < \mu_r < 1 + \varepsilon$.

(c) Pattern of magnetic field lines when diamagnetic and paramagnetic material is placed in an external field, is as shown in given figures (i) and (ii) respectively.



16. Expression for torque on dipole in uniform electric field is

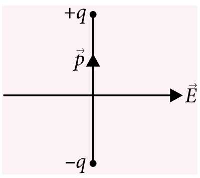
$\tau = pE\sin\theta \quad \text{or} \quad \vec{\tau} = \vec{p} \times \vec{E}$

So, two pairs of perpendicular vectors are :

(a) torque $\vec{\tau}$ and electric dipole moment $\vec{p}$

(b) torque $\vec{\tau}$ and electric field intensity $\vec{E}$.

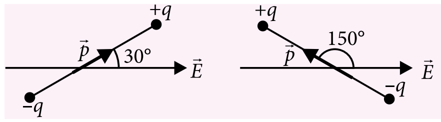
(i) Torque is maximum, when $\theta = 90°$ between $\vec{p}$ and $\vec{E}$ *i.e.*, when electric dipole is perpendicular to direction of field $\tau_{max} = pE$



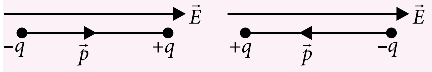
(ii) $\tau = \dfrac{1}{2}\tau_{max} \quad \text{or} \quad pE\sin\theta = \dfrac{1}{2}pE$

$\sin\theta = \dfrac{1}{2} \quad \text{or} \quad \theta = 30° \text{ or } 150°$

So, torque is half the maximum value for $\theta = 30°$ or $150°$ between $\vec{p}$ and $\vec{E}$.

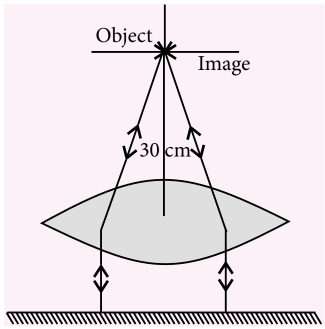


(iii) Torque is zero, when $\theta = 0°$ or $180°$ between $\vec{p}$ and $\vec{E}$ *i.e.*, when dipole is placed parallel or antiparallel to direction of electric field.



17. Let us first consider the situation when there is no liquid between lens and plane mirror and the image is formed at 30 cm *i.e.*, at the position of object.

As the image is formed on the object position itself, the object must be placed at focus of biconvex lens.



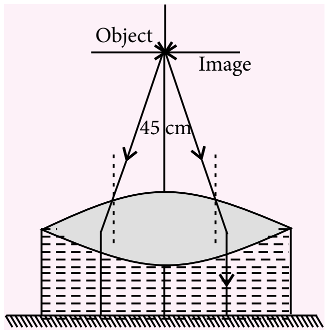
$\therefore \quad f = 30$ cm

Radius of curvature of convex lens can be calculated

$$\frac{1}{f} = ({}^a\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \text{or } \frac{1}{30} = \left(\frac{3}{2} - 1\right)\left(\frac{1}{R} - \frac{1}{-R}\right)$$

or $\quad \dfrac{1}{30} = \dfrac{1}{2}\left(\dfrac{2}{R}\right) \Rightarrow R = 30$ cm

Now a liquid is filled between lens and plane mirror and the image is formed at position of object at 45 cm. The image is formed on the position of object itself, the object must be placed at focus of equivalent lens of biconvex of glass and plano convex lens of liquid



$$\frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2} \quad \text{...(i)}$$

Equivalent total length f_{eq} = 45 cm

Focal length of biconvex lens f_1 = 30 cm

Focal length of plano convex lens

$$\frac{1}{f_2} = (\mu - 1)\left(\frac{1}{-R} - \frac{1}{\infty}\right)$$

or $$\frac{1}{f_2} = (\mu - 1)\left(\frac{-1}{30}\right)$$

$$f_2 = \frac{-30}{\mu - 1}$$

Now equation (i),

$$\frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow \frac{1}{45} = \frac{1}{30} - \left(\frac{\mu - 1}{30}\right)$$

$$\frac{\mu - 1}{30} = \frac{1}{90} \quad \text{or} \quad \mu - 1 = \frac{1}{3},$$

$$\mu = \frac{1}{3} + 1 = \frac{4}{3}$$

18. The two basic modes of communication are

(i) point-to-point communication

(ii) broadcast communication

Amplitude modulation : Amplitude modulation is produced by varying the amplitude of the carrier waves in accordance with the modulating wave.

Let the carrier wave be $c(t) = A_c \sin\omega_c t$

and the modulating signal be $m(t) = A_m \sin\omega_m t$,

where $\omega_m = 2\pi\upsilon_m$ is the angular frequency of the message signal.

Modulated signal $c_m(t)$ is

$$c_m(t) = (A_c + A_m \sin \omega_m t)\sin\omega_c t$$

$$= A_c\left(1 + \frac{A_m}{A_c}\sin\omega_m t\right)\sin\omega_c t$$

$$\therefore \quad c_m(t) = A_c \sin\omega_c t + \mu A_c \sin\omega_m t \sin\omega_c t$$

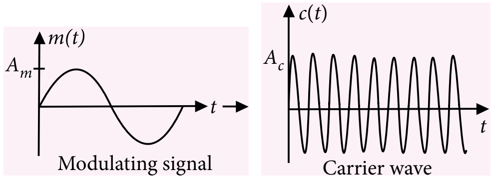
where $\mu = \dfrac{A_m}{A_c}$ is the modulation index.

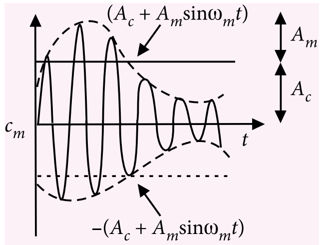
$$c_m(t) = A_c \sin \omega_c t + \frac{\mu A_c}{2}\cos(\omega_c - \omega_m)t - \frac{\mu A_c}{2}\cos(\omega_c + \omega_m)t$$

$\omega_c - \omega_m$ and $\omega_c + \omega_m$ are the lower side band and upper side band, respectively.

Production of amplitude modulated wave :

Amplitude modulated signal is obtained by superposing a modulating signal over a sinusoidal carrier wave is shown in the figure given below :





Amplitude-modulated wave

19. Whenever the magnetic flux linked with a closed circuit changes, an emf is set up across it which lasts only so long as the change in flux is taking place. This emf is called induced emf.

According to Faraday's law of electromagnetic induction, the magnitude of induced emf is equal to the rate of change of magnetic flux linked with the closed circuit (or coil).

Mathematically,

$$\varepsilon = -N\frac{d\phi_B}{dt}$$

where N is the number of turns in the circuit and ϕ_B is the magnetic flux linked with each turn.

Here, negative sign indicates the direction of induced emf.

Let the conducting rod of length l completes one revolution in time T. Then

Change in flux in time $T = B \times$ Area swept $= B \times \pi l^2$

$$\text{Induced emf} = \frac{\text{Change in flux}}{\text{Time}}$$

$$\varepsilon = \frac{B \times \pi l^2}{T}$$

But $T = \dfrac{2\pi}{\omega}$

$$\therefore \quad \varepsilon = \frac{B \times \pi l^2}{2\pi/\omega} = \frac{1}{2}Bl^2\omega$$

20. The wavelength (λ) of different spectral lines of Balmer series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right] \quad \text{where } n = 3, 4, 5, 6, \ldots\ldots$$

For longest wavelength, $n = 3$

$$\therefore \quad \frac{1}{\lambda} = 1.097 \times 10^7 \left[\frac{1}{2^2} - \frac{1}{3^2}\right] = 1.097 \times 10^7 \times \frac{5}{36}$$

$$\lambda = \frac{36}{5 \times 1.097 \times 10^7} \text{ m} \quad = \frac{36 \times 10^{10}}{5 \times 1.097 \times 10^7} \text{ Å}$$

$\lambda = 6563$ Å

For shortest wavelength, $n = \infty$

$$\frac{1}{\lambda} = 1.097 \times 10^7 \left[\frac{1}{2^2} - \frac{1}{\infty^2}\right] = \frac{1.097 \times 10^7}{4}$$

$$\therefore \quad \lambda = \frac{4}{1.097 \times 10^7} \text{ m} = \frac{4 \times 10^{10} \text{ Å}}{1.097 \times 10^7} = 3646 \text{ Å}$$

21. (i) In polarisation, vibrations perpendicular to the direction of propagation are restricted to just one direction. This is possible in transverse waves which have such vibrations. In longitudinal waves, vibrations occur along the direction of propagation. So their polarisation is not possible.

(ii) The phase difference between two independent light sources changes 10^8 times in one second. Such rapid changes cannot be detected by our eyes.

(iii) According to Brewster law, $\mu = \tan i_p$. As refractive index μ of a transparent medium is different for light of different colours, so Brewster angle i_p is different for light of different colours.

22. (i) Electric potential on the shell A is

$$V_A = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{R} + \frac{q}{R}\right) \quad \ldots\text{(i)}$$

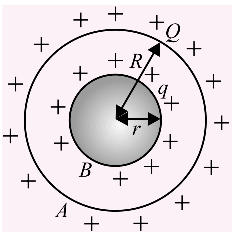
Whereas electric potential on sphere B is

$$V_B = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{R} + \frac{q}{r}\right) \quad \ldots\text{(ii)}$$

So, the potential difference between the sphere and shell is

$$V_B - V_A = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{R} + \frac{q}{r} - \frac{Q}{R} - \frac{q}{R}\right)$$

$$\text{or} \quad V_B - V_A = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{r} - \frac{1}{R}\right)$$



(ii) If they are connected by wire, then whole charge of inner sphere will flow to outershell.

23. (i) Anuj is caring, sacrificing and concerning

(ii) X-rays, gamma rays and charged particle are type of radiation used for treatment of tumor. Radiations are given to the brain to shrink tumors formed by cancer cells.

(iii) γ-rays are emitted by nucleus for coming down to a lower energy level.

24. Refer to point 2.5 (1, 2, 4), page no. 99 (MTG Excel in Physics).

OR

Refer to point 2.5 (7), page no. 101 (MTG Excel in Physics).

25. (i) Refer to point 6.10 (6), page no. 443 (MTG Excel in Physics).

(ii) Refer to point 6.11 (5), page no. 445 (MTG Excel in Physics).

OR

(i) Refer to point 6.13 (3), page no. 446 (MTG Excel in Physics).

(ii) Refer to point 6.13 (7), page no. 448 (MTG Excel in Physics).

26. Refer to point 4.6 (6,7), page no. 269 (MTG Excel in Physics).

OR

Refer to point 4.8 (2), page no. 275 (MTG Excel in Physics).

$N = 100$, $A = 0.1\text{m}^2$, $\upsilon = \frac{1}{2}\ \text{s}^{-1}$ $B = 0.01\text{T}$

Maximum voltage generated in the coil is

$\varepsilon_0 = NBA\omega = NBA \times 2\pi\upsilon$

or $\varepsilon_0 = 100 \times 0.01 \times 0.1 \times 2 \times 3.14 \times \frac{1}{2}$

or $\varepsilon_0 = 0.314$ V.

MPP-9 MONTHLY Practice Problems

This specially designed column enables students to self analyse their extent of understanding of specified chapters. Give yourself four marks for correct answer and deduct one mark for wrong answer. Self check table given at the end will help you to check your readiness.

Atoms and Nuclei

Total Marks : 120 **Time Taken : 60 min**

NEET / AIIMS

Only One Option Correct Type

1. Which one of the following statements is true, if half-life of a radioactive substance is 1 month?

(a) $\frac{7}{8}$th part of the substance will disintegrate in 3 months.

(b) $\frac{1}{8}$th part of the substance will remain undecayed at the end of 4 months.

(c) The substance will disintegrate completely in 4 months.

(d) $\frac{1}{16}$th part of the substance will remain undecayed at the end of 3 months.

2. The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons. This is because

(a) of the electrons not being subject to a central force.

(b) of the electrons colliding with each other.

(c) of screening effects.

(d) the force between the nucleus and an electron will no longer be given by Coulomb's law.

3. If doubly ionized lithium atom is hydrogen like with atomic number 3, the wavelength of radiation required to excite the electron in Li^{++} from the first to the third Bohr orbit and the number of different spectral lines observed in the emission spectrum of the above excited system are

(a) 296 Å, 6 (b) 114 Å, 3
(c) 1026 Å, 6 (d) 8208 Å, 3

4. Fission of nuclei is possible because the binding energy per nucleon in them

(a) increases with mass number at low mass numbers

(b) decreases with mass number at low mass numbers

(c) increases with mass number at high mass numbers

(d) decreases with mass number at high mass numbers.

5. The wavelength limit present in the Pfund series is ($R = 1.097 \times 10^7\ m^{-1}$)

(a) 1572 nm (b) 1898 nm
(c) 2278 nm (d) 2535 nm

6. For scattering by an inverse square field (such as that produced by a charged nucleus in Rutherford's model) the relation between impact parameter b and the scattering angle θ is given by, $b = (Ze^2\cot(\theta/2))/(2\pi\varepsilon_0 mv^2)$. The scattering angle for $b = 0$ is

(a) 180° (b) 90°
(c) 45° (d) 120°

7. The count rate of a radioactive sample falls from $4.0 \times 10^6\ s^{-1}$ to $1.0 \times 10^6\ s^{-1}$ in 20 h. What will be the count rate after 100 h from beginning?

(a) $3.91 \times 10^3\ s^{-1}$ (b) $3.91 \times 10^2\ s^{-1}$
(c) $3.91 \times 10^4\ s^{-1}$ (d) $3.91 \times 10^6\ s^{-1}$

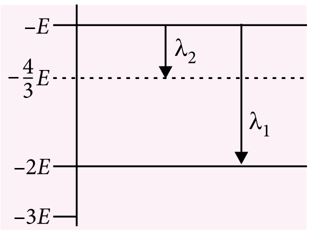
8. Two stable isotopes ${}^6_3Li$ and ${}^7_3Li$ have respective abundances of 7.5% and 92.5%. These isotopes have masses 6.01512 u and 7.01600 u respectively. The atomic weight of lithium is

(a) 6.941 u (b) 3.321 u
(c) 2.561 u (d) 0.621 u

9. The temperature at which protons in proton gas would have enough energy to overcome Coulomb barrier of 4.14×10^{-14} J is

(Boltzmann constant = 1.38×10^{-23} J K^{-1})
(a) 2×10^9 K (b) 10^9 K
(c) 6×10^9 K (d) 3×10^9 K

10. Some energy levels of a molecule are shown in the figure. The ratio of the wavelengths $r = \frac{\lambda_1}{\lambda_2}$ is given by



(a) $r = \frac{4}{3}$ (b) $r = \frac{2}{3}$ (c) $r = \frac{3}{4}$ (d) $r = \frac{1}{3}$

11. Let $E_n = \frac{-me^4}{8\varepsilon_0^2 n^2 h^2}$ be the energy of the n^{th} level of H-atom. If all the H-atoms are in the ground state and radiation of frequency $(E_2 - E_1)/h$ falls on it, then
(a) it will not be absorbed at all.
(b) some of atoms will move to the first excited state.
(c) all atoms will be excited to the $n = 2$ state.
(d) all atoms will make a transition to the $n = 3$ state.

12. The fission properties of $^{239}_{94}$Pu are very similar to those of $^{235}_{92}$U. The average energy released per fission is 180 MeV. If all the atoms in 1 kg of pure $^{239}_{94}$Pu undergo fission, then the total energy released in MeV is
(a) 4.53×10^{26} MeV (b) 2.21×10^{14} MeV
(c) 1×10^{13} MeV (d) 6.33×10^{24} MeV

Assertion & Reason Type

Directions : In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as :
(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false.
(d) If both assertion and reason are false.

13. Assertion : Most of the mass of the atom is concentrated in its nucleus.
Reason : All alpha particles striking a gold sheet are scattered in different directions.

14. Assertion : If the accelerating potential in an X-ray tube is increased, the wavelengths of the characteristic X-rays do not change.
Reason : When an electron beam strikes the target in an X-ray tube, part of the kinetic energy is converted into X-ray energy.

15. Assertion : Isotopes of an element can be separated by using a mass spectrometer.
Reason : Separation of isotopes is possible because of difference in electron number of isotopes.

JEE MAIN / JEE ADVANCED

Only One Option Correct Type

16. A nucleus with $Z = 92$ emits the following in a sequence :
$\alpha, \beta^-, \beta^-\ \alpha, \alpha, \alpha, \alpha, \alpha, \beta^-, \beta^-, \alpha, \beta^+, \beta^+, \alpha$
Then Z of the resulting nucleus is
(a) 76 (b) 78
(c) 82 (d) 74

17. The half-life of a radioactive substance is 20 min. The approximate time interval between the time t_2 when $\frac{2}{3}$ of it has decayed and time t_1 when $\frac{1}{3}$ of it had decayed is

(a) 7 min (b) 14 min (c) 20 min (d) 28 min

18. The inverse square law in electrostatics is $|\vec{F}| = \frac{e^2}{(4\pi\varepsilon_0)\cdot r^2}$ for the force between an electron and a proton. The $\left(\frac{1}{r}\right)$ dependence of $|\vec{F}|$ can be understood in quantum theory as being due to the fact that the particle of light (photon) is massless. If photons had a mass m_p, force would be modified to $|\vec{F}| = \frac{e^2}{(4\pi\varepsilon_0)r^2}\left[\frac{1}{r^2} + \frac{\lambda}{r}\right].\exp(-\lambda r)$ where $\lambda = m_p c/\hbar$ and $\hbar = \frac{h}{2\pi}$. The change in the ground state energy (eV) of a H-atom if m_p were 10^{-6} times the mass of an electron is (r_B = Bohr's radius)

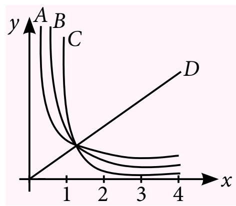
(a) $18.6\ \lambda r_B$ (b) -27.2
(c) $27.2\ \lambda r_B$ (d) $-\lambda r_B$

19. An electron and a proton are separated by a large distance. The electron starts approaching the proton with energy 2 eV. The proton captures the electron and forms a hydrogen atom in first excited state. The resulting photon is incident on a photosensitive metal of threshold wavelength 4600 Å. The maximum kinetic energy of the emitted photoelectron is (Take hc = 12420 eV Å)

(a) 2.4 eV (b) 2.7 eV
(c) 2.9 eV (d) 5.4 eV

More than One Options Correct Type

20. A class XII student draws graph A, B, C and D to show relationships of principal quantum number n and different physical quantities related to H-atom.



x-axis : principal quantum number
y-axis : different physical quantities
Then, mark the correct options.

(a) Magnetic field produced due to Bohr's electron at centre of atom is given by graph marked (C).
(b) Magnetic dipole moment of electron of H-atom is represented by graph marked (D).
(c) Frequency of rotation of electron is represented by graph (B).
(d) Energy of electron is represented by graph (A).

21. 10 g of a radioactive element is kept in a container. The element is β-active. Then after one half-life (molar mass of the substance is 100 g, Avogadro's number = 6×10^{23} per mole).

(a) The weight of the substance left in the container will be 5 g.
(b) The weight of the substance left in the container will be nearly 10 g.
(c) If all β-particles leave the container then the charge of the substance left is 4800 C.
(d) If all β-particles leave the container then the charge of the substance left is 9600 C.

22. If stability of a nucleus depends on even and odd number of protons and neutrons. Then,

(a) nucleus with even N and even Z are most stable.
(b) an even N, odd Z or odd N even N nucleus is somewhat lesser stable than even-even nucleus.
(c) an odd N, odd Z nucleus is least stable.
(d) there are few odd N, odd Z nuclides which are stable.

23. Consider aiming a beam of free electrons towards free protons. When they scatter, an electron and a proton cannot combine to produce a H-atom,

(a) because of energy conservation.
(b) without simultaneously releasing energy in the form of radiation.
(c) because of momentum conservation.
(d) because of angular momentum conservation.

Integer Answer Type

24. In hydrogen like atom an electron is orbiting in an orbit having quantum number n. Its frequency of revolution is found to be 13.2×10^{15} Hz. Energy required to free the electron from the atom from the above orbit is 54.4 eV. In time 7 ns the electron jumps back to orbit having quantum number $\frac{n}{2}$. τ be the average torque acted on the electron during the above process, then find $0.2\tau \times 10^{27}$ in N m. (Given : $\frac{h}{\pi} = 2.1 \times 10^{-34}$ J s, frequency of revolution of electron in the ground state of H-atom $\upsilon_0 = 6.6 \times 10^{15}$ Hz and ionization energy of H-atom, E_0 = 13.6 eV).

25. A sample of hydrogen gas is excited by means of a monochromatic radiation. In the subsequent emission spectrum, 10 different wavelengths are obtained, all of which have energies greater than or equal to the energy of the absorbed radiation. Find the initial quantum number of the state (before absorbing radiation).

26. When a slow moving neutron collides with Uranium 235 atom ($^{235}_{92}U$), following reaction occurs.

$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{236}_{92}U^* \longrightarrow ^{99}_{40}Zr + ^{134}_{52}Te + 3^{1}_{0}n$

If kinetic energy of neutrons is neglected (as it is very small), then the Q of reaction is $37 \times K$ MeV. Find the value of K. Use following data.

$m(U^{235}) = 235.0439$ u, $m(n) = 1.0087$ u,
$m(Zr^{99}) = 98.9165$ u, $m(Te^{134}) = 133.9115$ u.

Comprehension Type

The key feature of Bohr's theory of spectrum of hydrogen atom is the quantization of angular momentum when an electron is revolving around a proton. We will extend this to a general rotational motion to find quantized rotational energy of a diatomic molecule assuming it to be rigid. The rule to be applied is Bohr's quantization condition.

27. A diatomic molecule has moment of inertia I. By Bohr's quantization condition, its rotational energy in the n^{th} level ($n = 0$ is not allowed) is

(a) $\frac{1}{n^2}\left(\frac{h^2}{8\pi^2 I}\right)$ (b) $\frac{1}{n}\left(\frac{h^2}{8\pi^2 I}\right)$

(c) $n\left(\frac{h^2}{8\pi^2 I}\right)$ (d) $n^2\left(\frac{h^2}{8\pi^2 I}\right)$

28. It is found that the excitation frequency from ground to the first excited state of rotation for the CO molecule is close to $\frac{4}{\pi}\times 10^{11}$ Hz. Then the moment of inertia of CO molecule about its center of mass is close to (Take $h = 2\pi \times 10^{-34}$ J s)

(a) 2.76×10^{-46} kg m^2
(b) 1.87×10^{-46} kg m^2
(c) 4.67×10^{-47} kg m^2
(d) 1.17×10^{-47} kg m^2

Matrix Match Type

29. Using Bohr's formula for energy quantisation, match the entries in column I with column II.

Column I	Column II
(A) Excitation energy of $n = 3$ level of He^+ atom (in eV)	(P) 0.85
(B) Energy required to excite electron in Li^{++} from $n = 1$ to $n = 3$ (in eV)	(Q) 48.1
(C) Energy of electron in fourth excited state of H-atom (in eV)	(R) 12.09
(D) Second excitation potential of H-atom (in V)	(S) 108.8

	A	B	C	D
(a)	Q	R	P	S
(b)	P	R	S	Q
(c)	P	S	Q	R
(d)	Q	S	P	R

30. Match column I of the nuclear processes with column II containing parent nucleus and one of the end products of each process and then select the correct answer using the codes given below.

Column I	Column II
(A) Alpha decay	(P) $^{15}_{8}O \rightarrow ^{15}_{7}N + ...$
(B) β^+ decay	(Q) $^{238}_{92}U \rightarrow ^{234}_{94}Th + ...$
(C) Fission	(R) $^{185}_{83}Bi \rightarrow ^{184}_{82}Pb + ...$
(D) Proton emission	(S) $^{239}_{94}Pu \rightarrow ^{140}_{47}La + ...$

	A	B	C	D
(a)	S	Q	P	R
(b)	P	R	Q	S
(c)	Q	P	S	R
(d)	R	S	Q	P

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Keys are published in this issue. Search now! ☺

SELF CHECK

No. of questions attempted ……
No. of questions correct ……
Marks scored in percentage ……

Check your score! If your score is

> 90%	EXCELLENT WORK !	You are well prepared to take the challenge of final exam.
90-75%	GOOD WORK !	You can score good in the final exam.
74-60%	SATISFACTORY !	You need to score more next time.
< 60%	NOT SATISFACTORY!	Revise thoroughly and strengthen your concepts.

PHYSICS MUSING

Physics Musing was started in August 2013 issue of Physics For You. The aim of Physics Musing is to augment the chances of bright students preparing for JEE (Main and Advanced) / NEET / AIIMS / JIPMER with additional study material.
In every issue of Physics For You, 10 challenging problems are proposed in various topics of JEE (Main and Advanced) / NEET. The detailed solutions of these problems will be published in next issue of Physics For You.
The readers who have solved five or more problems may send their detailed solutions with their names and complete address. The names of those who send atleast five correct solutions will be published in the next issue.
We hope that our readers will enrich their problem solving skills through "Physics Musing" and stand in better stead while facing the competitive exams.

PROBLEM Set 54

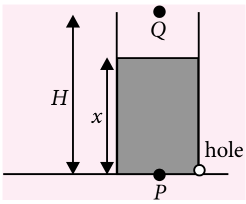
SINGLE OPTION CORRECT TYPE

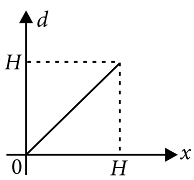
1. The half lives of radioisotopes ^{32}P and ^{33}P are 20 days and 30 days respectively. These radioisotopes are mixed in the ratio of 4 : 1 of their atoms. If the initial activity of the mixed sample is 7 mCi, then the activity of the mixed sample after 60 days.

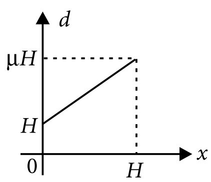
(a) 2.5 mCi (b) 1 mCi
(c) 3.2 mCi (d) 3 mCi

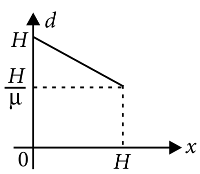
2. Liquid of refractive index μ is filled in a vessel of height *H*. At the bottom of the vessel is a spot *P* and a hole from which liquid is coming out.

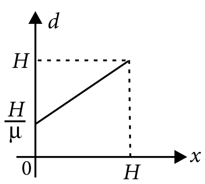
Let *d* be the distance of image of *P* from an eye at point *Q* at height *H* from bottom at an instant when level of liquid in the vessel is *x*. If we plot a graph between *d* and *x*, it will be like



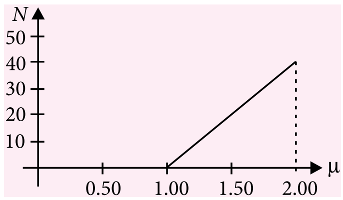
(a)


(b)


(c)


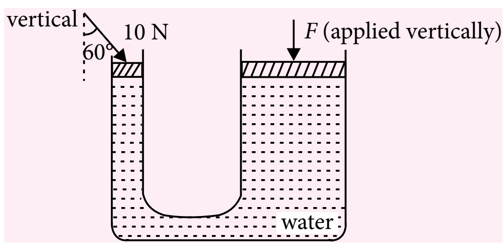
(d)


3. The slits in double-slit interference experiment are illuminated by orange light (λ = 600 nm). A thin transparent plastic of thickness *t* is placed in front of one of the slits. The number of fringes (*N*) shifting on screen is plotted versus the refractive index μ of the plastic in graph shown. The value of *t* is



(a) 4.8 mm (b) 48 μm
(c) 2. 4 μm (d) 24 μm

4. The area of cross-section of the two vertical arms of a hydraulic press are 1 cm^2 and 10 cm^2 respectively. A force of 10 N applied, as shown in the figure, to a tight fitting light piston in the thinner arm balances a force *F* applied to the corresponding piston in the thicker arm. Assuming that the levels of water in both the arms are the same, we can conclude



(a) *F* = 100 N
(b) *F* = 50 N
(c) *F* = 25 N
(d) *F*, as applied, cannot balance the effect of the force on the first piston.

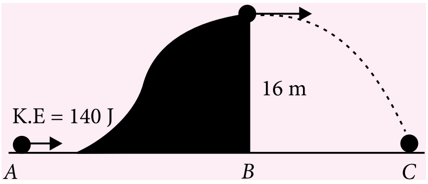
By Akhil Tewari, Author Foundation of Physics for JEE Main & Advanced, Professor, IITians PACE, Mumbai.

5. An ideal gas obey the law PV^x = constant. The value of x for which it has non positive molar specific heat at normal temperature, is (C_V for the gas is $2.5R$)
(a) −0.5 (b) 1.45 (c) 1.4 (d) −1.4

COMPREHENSION TYPE

For questions 6 and 7 :

A solid spherical ball of mass 0.5 kg and radius 10 cm rolls to the top of a hill, as shown in figure. Kinetic energy of the ball at the bottom of hill is 140 J. As the ball moves up the hill, it rolls without slipping. Height of the hill is 16 m. As the ball reaches the top of the hill, it is moving horizontally. From the top of hill, it will move into air and fall freely under gravity. Assuming that no work is done against friction as the ball rolls and neglecting air resistance. (g = 10 m s^{-2})



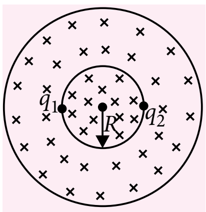
6. Rotational kinetic energy of the ball at the top of the hill is nearly
(a) 22.5 J (c) 37 J (c) 23 J (d) 17 J

7. In the figure, when the ball strikes the ground at C, its distance from the foot of the hill, *i.e.*, BC is nearly
(a) 23 m (b) 36 m (c) 14 m (d) 42 m

For questions 8 and 9

Figure shows a region containing uniform magnetic field B which is increasing at the rate $\frac{dB}{dt}$.

The region is gravity free. A disc of mass m and radius R is kept in this magnetic field. Two charged particles having charges q_1 and q_2 and each having mass m are embedded to this non conducting disc on circumference at diametrically opposite points. The disc is free to translate as well as rotate.



Region of magnetic field

8. If $q_1 = q_2 = q$, then the initial acceleration of q_1 will be

(a) $\frac{5qR}{5m}\frac{dB}{dt}$ (b) $\frac{4qR}{5m}\frac{dB}{dt}$

(c) $\frac{3qR}{5m}\frac{dB}{dt}$ (d) $\frac{2qR}{5m}\frac{dB}{dt}$

9. If $q_1 = q$, $q_2 = -q$, then the initial acceleration of q_2 will be

(a) $\frac{qR}{6m}\frac{dB}{dt}$ (b) $\frac{qR}{3m}\frac{dB}{dt}$

(c) $\frac{qR}{12m}\frac{dB}{dt}$ (d) $\frac{qR}{24m}\frac{dB}{dt}$

MATRIX MATCH

10. The equation for the displacement of a stretched string is given by $y = 8\sin^2 \pi\left[\frac{t}{0.02} - \frac{x}{100}\right]$ where y and x are in cm and t in s. Match the column I with column II.

	Column-I		Column-II
(A)	Amplitude of wave (in cm)	(P)	50
(B)	Frequency of wave (in Hz)	(Q)	4
(C)	Velocity of wave (in m s^{-1})	(R)	4π
(D)	Maximum particle velocity (in cm s^{-1})	(S)	400π

	A	B	C	D
(a)	Q	P	P	S
(b)	R	P	P	S
(c)	Q	P	S	P
(d)	R	P	S	P

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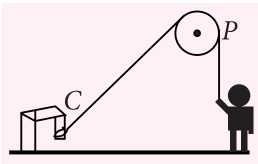
PRACTICE PAPER 2018
JEE MAIN

Exam Dates
OFFLINE : 8th April
ONLINE : 15th & 16th April

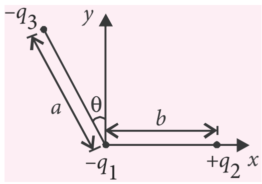
1. One end of a massless rope, which passes over a massless and frictionless pulley P is tied to a hook C while the other end is free. Maximum tension that the rope can bear is 960 N. With what value of maximum safe acceleration can a man of 60 kg climb on the rope? (Take $g = 10 \text{ m s}^{-2}$)



(a) 16 m s^{-2} (b) 6 m s^{-2}
(c) 4 m s^{-2} (d) 8 m s^{-2}

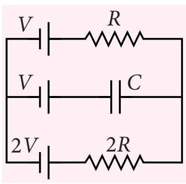
2. A ball is released from the top of a tower of height h. It takes time T to reach the ground. What is the position of the ball in time $T/3$?
(a) $h/9$ from the ground
(b) $7h/9$ from the ground
(c) $8h/9$ from the ground
(d) $17h/18$ from the ground.

3. Three charges $-q_1$, $+q_2$ and $-q_3$ are placed as shown in the figure. The x-component of the force on $-q_1$ is proportional to



(a) $\frac{q_2}{b^2} - \frac{q_3}{a^2}\cos\theta$ (b) $\frac{q_2}{b^2} + \frac{q_3}{a^2}\sin\theta$
(c) $\frac{q_2}{b^2} + \frac{q_3}{a^2}\cos\theta$ (d) $\frac{q_2}{b^2} - \frac{q_3}{a^2}\sin\theta$

4. In the given circuit, with steady current, the potential drop across the capacitor must be

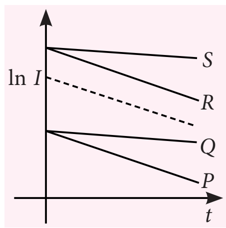


(a) V
(b) $V/2$
(c) $V/3$
(d) $2V/3$

5. The refractive index of glass is 1.520 for red light and 1.525 for blue light. Let δ_1 and δ_2 be angles of minimum deviation for red and blue light respectively in a prism of this glass. Then
(a) $\delta_1 > \delta_2$ (b) $\delta_1 < \delta_2$
(c) $\delta_1 = \delta_2$
(d) δ_1 can be less than or greater than depending upon the angle of prism.

6. The binding energy per nucleon of deuteron $\left({}^2_1\text{H}\right)$ and helium nucleus $\left({}^4_2\text{He}\right)$ is 1.1 MeV and 7 MeV respectively. If two deuteron nuclei react to form a single helium nucleus, then the energy released is
(a) 13.9 MeV (b) 26.9 MeV
(c) 23.6 MeV (d) 19.2 MeV.

7. A capacitor is charged using an external battery with a resistance x in series. The dashed line shows the variation of $\ln I$ with respect to time. If the resistance is changed to $2x$ the new graph will be

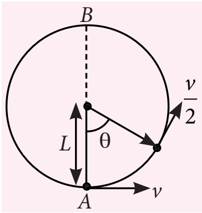


(a) P (b) Q (c) R (d) S.

8. The upper half of an inclined plane with inclination ϕ is perfectly smooth while the lower half is rough. A body starting from rest at the top will again come to rest at the bottom if the coefficient of friction for the lower half is given by
(a) $2\tan\phi$ (b) $\tan\phi$ (c) $2\sin\phi$ (d) $2\cos\phi$

9. A wave travelling along the x-axis is described by the equation $y(x, t) = 0.005 \cos(\alpha x - \beta t)$. If the wavelength and the time period of the wave are 0.08 m and 2.0 s, respectively, then α and β in appropriate units are
(a) $\alpha = 12.50\pi,\ \beta = \frac{\pi}{2.0}$
(b) $\alpha = 25.00\pi,\ \beta = \pi$
(c) $\alpha = \frac{0.08}{\pi},\ \beta = \frac{2.0}{\pi}$
(d) $\alpha = \frac{0.04}{\pi},\ \beta = \frac{1.0}{\pi}$

10. A bob of mass M is suspended by a massless string of length L. The horizontal velocity v at position A is just sufficient to make it reach the point B. The angle θ at which the speed of the bob is half of that at A, satisfies



(a) $\theta = \frac{\pi}{4}$ (b) $\frac{\pi}{4} < \theta < \frac{\pi}{2}$

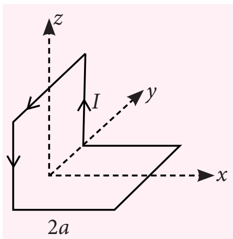
(c) $\frac{\pi}{2} < \theta < \frac{3\pi}{4}$ (d) $\frac{3\pi}{4} < \theta < \pi$

11. In a series resonant LCR circuit, the voltage across R is 100 V and R = 1 kΩ with C = 2 μF. The resonant frequency ω is 200 rad s^{-1}. At resonance the voltage across L is

(a) 4×10^{-3} V (b) 2.5×10^{-2} V

(c) 40 V (d) 250 V

12. A non-planar loop of conducting wire carrying a current I is placed as shown in the figure. Each of the straight sections of the loop is of length $2a$. The magnetic field due to this loop at the point $P(a, 0, a)$ points in the direction



(a) $\frac{1}{\sqrt{2}}(-\hat{j} + \hat{k})$ (b) $\frac{1}{\sqrt{3}}(-\hat{j} + \hat{k} + \hat{i})$

(c) $\frac{1}{\sqrt{3}}(\hat{i} + \hat{j} + \hat{k})$ (d) $\frac{1}{\sqrt{2}}(\hat{i} + \hat{k})$

13. A thin uniform rod of length l and mass m is swinging freely about a horizontal axis passing through its end. Its maximum angular speed is ω. Its centre of mass rises to a maximum height of

(a) $\frac{1}{3}\frac{l^2\omega^2}{g}$ (b) $\frac{1}{12}\frac{l^2\omega^2}{g}$

(c) $\frac{1}{2}\frac{l^2\omega^2}{g}$ (d) $\frac{1}{6}\frac{l^2\omega^2}{g}$

14. The electrical conductivity of a semiconductor increases when electromagnetic radiation of wavelength shorter than 2480 nm is incident on it. The band gap (in eV) for the semiconductor is

(a) 0.9 (b) 0.7 (c) 0.5 (d) 1.1

15. Suppose the gravitational force varies inversely as the n^{th} power of distance. Then the time period of a planet in circular orbit of radius R around the sun will be proportional to

(a) $R^{\left(\frac{n+1}{2}\right)}$ (b) $R^{\left(\frac{n-1}{2}\right)}$

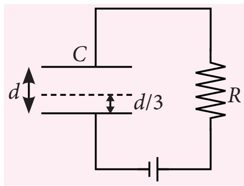
(c) R^n (d) $R^{\left(\frac{n-2}{2}\right)}$

16. According to Newton's law of cooling, the rate of cooling of a body is proportional to $(\Delta T)^n$, where ΔT is the difference of the temperature of the body and the surroundings, and n is equal to

(a) two (b) three

(c) four (d) one.

17. A parallel plate capacitor C with plates of unit area and separation d is filled with a liquid of dielectric constant K = 2. The level of liquid is $d/3$ initially. Suppose the liquid level decreases at a constant speed v, the time constant as a function of time t is



(a) $\frac{6\varepsilon_0 R}{5d + 3vt}$ (b) $\frac{(15d + 9vt)\varepsilon_0 R}{2d^2 - 3dvt - 9v^2t^2}$

(c) $\frac{6\varepsilon_0 R}{5d - 3vt}$ (d) $\frac{(15d - 9vt)\varepsilon_0 R}{2d^2 + 3dvt - 9v^2t^2}$

18. A spherical solid ball of volume V is made of a material of density ρ_1. It is falling through a liquid of density ρ_2 ($\rho_2 < \rho_1$). Assume that the liquid applies a viscous force on the ball that is proportional to the square of its speed v, *i.e.*, $F_{\text{viscous}} = -kv^2$ ($k > 0$). The terminal speed of the ball is

(a) $\frac{Vg(\rho_1 - \rho_2)}{k}$ (b) $\sqrt{\frac{Vg(\rho_1 - \rho_2)}{k}}$

(c) $\frac{Vg\rho_1}{k}$ (d) $\sqrt{\frac{Vg\rho_1}{k}}$

19. Spherical balls of radius R are falling in a viscous fluid of viscosity η with a velocity v. The retarding viscous force acting on the spherical ball is

(a) directly proportional to R but inversely proportional to v

(b) directly proportional to both radius R and velocity v

(c) inversely proportional to both radius R and velocity v

(d) inversely proportional to R but directly proportional to velocity v.

20. The difference in the variation of resistance with temperature in a metal and a semiconductor arises essentially due to the difference in the

(a) crystal structure
(b) variation of the number of charge carriers with temperature
(c) type of bonding
(d) variation of scattering mechanism with temperature.

21. The K_α X-ray emission line of tungsten occurs at $\lambda = 0.021$ nm. The energy difference between K and L levels in this atom is about
(a) 0.51 MeV (b) 1.2 MeV
(c) 59 keV (d) 13.6 eV.

22. A mass M, attached to a horizontal spring, executes S.H.M. with a amplitude A_1. When the mass M passes through its mean position then a smaller mass m is placed over it and both of them move together with amplitude A_2. The ratio of $\left(\frac{A_1}{A_2}\right)$ is
(a) $\frac{M}{M+m}$ (b) $\frac{M+m}{M}$
(c) $\left(\frac{M}{M+m}\right)^{1/2}$ (d) $\left(\frac{M+m}{M}\right)^{1/2}$

23. The energy of radiation emitted by LED is
(a) greater than the band gap of the semiconductor used
(b) always less than the band gap of the semiconductor used
(c) always equal to the band gap of the semiconductor used
(d) equal to or less than the band gap of the semiconductor used.

24. In Young's double slit experiment, 12 fringes are observed to be formed in a certain segment of the screen when light of wavelength 600 nm is used. If the wavelength of light is changed to 400 nm, number of fringes observed in the same segment of the screen is given by
(a) 12 (b) 18 (c) 24 (d) 30

25. If S is stress and Y is Young's modulus of material of a wire, the energy stored in the wire per unit volume is
(a) $2Y/S$ (b) $S/2Y$ (c) $2S^2Y$ (d) $\frac{S^2}{2Y}$

26. Consider the spectral line resulting from the transition $n = 2 \rightarrow n = 1$ in the atoms and ions given below. The shortest wavelength is produced by
(a) hydrogen atom (b) deuterium atom
(c) singly ionized helium
(d) doubly ionised lithium

27. Three rods of identical cross-sectional area and made from the same metal form the sides of an isosceles triangle ABC, right-angled at B. The points A and B are maintained at temperatures T and $\sqrt{2}\,T$ respectively. In the steady state, the temperature of the point C is T_C. Assuming that only heat conduction takes place, T_C/T is
(a) $\frac{1}{2(\sqrt{2}-1)}$ (b) $\frac{3}{\sqrt{2}+1}$
(c) $\frac{1}{\sqrt{3}(\sqrt{2}-1)}$ (d) $\frac{1}{\sqrt{2}+1}$

28. A convex lens is in contact with concave lens. The magnitude of the ratio of their focal lengths is 2/3. Their equivalent focal length is 30 cm. What are their individual focal lengths?
(a) – 15, 10 (b) – 10, 15
(c) 75, 50 (d) – 75, 50.

29. The magnitude of electric field $\vec{E}$ in the annular region of a charged cylindrical capacitor
(a) is same throughout
(b) is higher near the outer cylinder than near the inner cylinder
(c) varies as $1/r$, where r is the distance from axis
(d) varies as $1/r^2$, where r is the distance from axis.

30. A monoatomic ideal gas, initially at temperature T_1, is enclosed in a cylinder fitted with a frictionless piston. The gas is allowed to expand adiabatically to a temperature T_2 by releasing the piston suddenly. If L_1 and L_2 are the lengths of the gas column before and after expansion respectively, then T_1/T_2 is given by
(a) $\left(\frac{L_1}{L_2}\right)^{2/3}$ (b) $\frac{L_1}{L_2}$
(c) $\frac{L_2}{L_1}$ (d) $\left(\frac{L_2}{L_1}\right)^{2/3}$

SOLUTIONS

1. **(b) :** $T - 60g = 60a$ or $960 - (60 \times 10) = 60a$
or $60a = 360$ or $a = 6\text{ m s}^{-2}$.

2. **(c):** Equation of motion : $s = ut + \frac{1}{2}gt^2$
$\therefore\quad h = 0 + \frac{1}{2}gT^2$ or $2h = gT^2$ ..... (i)
After $T/3$,

$$s = 0 + \frac{1}{2} \times g\left(\frac{T}{3}\right)^2 = \frac{gT^2}{18}$$

or $18\,s = gT^2$ ..... (ii)

From (i) and (ii), $18\,s = 2h$

or $s = \frac{h}{9}$ from top.

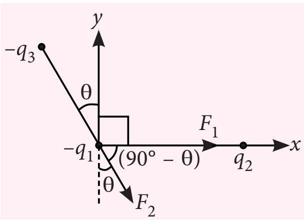
$\therefore$ Height from ground $= h - \frac{h}{9} = \frac{8h}{9}$.

3. (b) : Force on $(-q_1)$ due to $q_2 = \frac{-q_1q_2}{4\pi\varepsilon_0 b^2}$

$\therefore$ $F_1 = \frac{q_1q_2}{4\pi\varepsilon_0 b^2}$ along (q_1q_2)

Force on $(-q_1)$ due to $(-q_3) = \frac{(-q_1)(-q_3)}{4\pi\varepsilon_0 a^2}$

$F_2 = \frac{q_1q_3}{4\pi\varepsilon_0 a^2}$ as shown



F_2 makes an angle of $(90° - \theta)$ with (q_1q_2)

Resolved part of F_2 along q_1q_2

$= F_2 \cos(90° - \theta)$

$= \frac{q_1q_3 \sin\theta}{4\pi\varepsilon_0 a^2}$ along (q_1q_2)

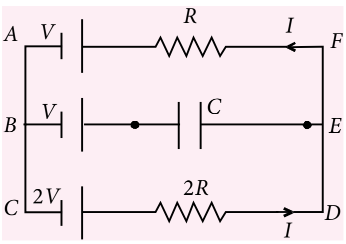
$\therefore$ Total force on $(-q_1)$

$$= \left[\frac{q_1q_2}{4\pi\varepsilon_0 b^2} + \frac{q_1q_3 \sin\theta}{4\pi\varepsilon_0 a^2}\right] \text{ along } x\text{-axis}$$

$\therefore$ x-component of force $\propto \left[\frac{q_2}{b^2} + \frac{q_3}{a^2}\sin\theta\right]$.

4. (c): In the steady state condition, no current flows through the capacitor C along the branch BE.

Apply Kirchhoff's law to the closed mesh $ACDFA$,



$2V - I(2R) - I(R) - V = 0$ or $V = 3\,IR$

or $I = \frac{V}{3R}$ .....(i)

Apply Kirchhoff's law to the mesh $ABEFA$,

$V + V_C - IR - V = 0$ or $V_C = IR = \left(\frac{V}{3R}\right)R = \frac{V}{3}$

$\therefore$ Potential difference across capacitor $V_C = \frac{V}{3}$

5. (b) : Angle of minimum deviation $\delta = A(\mu - 1)$

$$\frac{\delta_1 \text{ for red}}{\delta_2 \text{ for blue}} = \frac{\mu_R - 1}{\mu_B - 1}$$

Since $\mu_B > \mu_R$,

$\therefore$ $\frac{\delta_1}{\delta_2} < 1$ $\therefore$ $\delta_1 < \delta_2$.

6. (c): Total binding energy for (each deuteron)

$= 2 \times 1.1 = 2.2$ MeV

Total binding energy for helium $= 4 \times 7 = 28$ MeV

$\therefore$ Energy released $= 28 - (2 \times 2.2)$

$= 28 - 4.4 = 23.6$ MeV.

7. (b) : Charging current $I = \frac{E}{x}e^{-tx/C}$

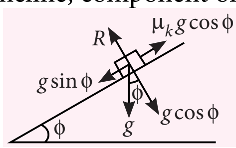
or $\ln I = \ln\left(\frac{E}{x}\right) - \frac{t}{xC}$

Slope of $\ln I$ versus t curve $= -\frac{1}{xC}$

When x is changed to $2x$, the slope of the curve increases and maximum current decreases. Obviously the new graph is Q.

8. (a) : For upper half smooth incline, component of g down the incline $= g\sin\phi$

$\therefore$ $v^2 = 2(g\sin\phi)\frac{l}{2}$



For lower half rough incline, frictional retardation $= \mu_k g\cos\phi$

$\therefore$ Resultant acceleration $= g\sin\phi - \mu_k g\cos\phi$

$\therefore$ $0 = v^2 + 2(g\sin\phi - \mu_k g\cos\phi)\frac{l}{2}$

or $0 = 2(g\sin\phi)\frac{l}{2} + 2g(\sin\phi - \mu_k\cos\phi)\frac{l}{2}$

or $0 = \sin\phi + \sin\phi - \mu_k\cos\phi$

or $\mu_k\cos\phi = 2\sin\phi$ or $\mu_k = 2\tan\phi$.

9. (b) : The wave travelling along the x-axis is given by $y(x, t) = 0.005\cos(\alpha x - \beta t)$.

Therefore $\alpha = k = \frac{2\pi}{\lambda}$. As $\lambda = 0.08$ m.

$\therefore$ $\alpha = \frac{2\pi}{0.08} = \frac{\pi}{0.04} = 25.00\,\pi$.

and $\beta = \omega = \frac{2\pi}{T} = \frac{2\pi}{2} = \pi$

$\therefore$ $\alpha = 25.00\,\pi$, $\beta = \pi$

10. (d) : Energy conservation gives

$v^2 = u^2 - 2g(L - L\cos\theta)$

or $\frac{5gL}{4} = 5gL - 2gL(1 - \cos\theta)$

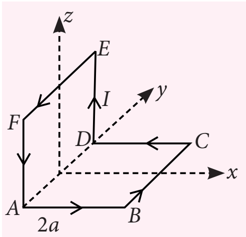
or $5 = 20 - 8 + 8\cos\theta$

or $\cos\theta = -\frac{7}{8}$

$\Rightarrow \frac{3\pi}{4} < \theta < \pi$

11. (d)

12. (d) : Imagine a wire AD added to form a closed loop $DEFAD$. Current flows along AD.



Imagine that a wire DA is added to form a closed loop $ABCDA$. Current flows along DA.

Effectively there is no current in DA or AB.

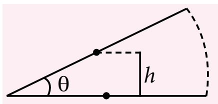
The point $(a, 0, a)$ lies in the x-z plane.

The magnetic field due to current in $ABCDA$ will be in positive z-direction.

Similarly the magnetic field due to current in $ADEFA$ will be in positive x-direction. Magnitudes of the two fields will be equal.

The direction of resultant magnetic field at P will be $\frac{1}{\sqrt{2}}(\hat{i}+\hat{k})$.

13. (d) : The uniform rod of length l and mass m is swinging about an axis passing through the end.



When the centre of mass is raised through h, the increase in potential energy is mgh.

This is equal to the kinetic energy $\left(=\frac{1}{2}I\omega^2\right)$.

$$\Rightarrow \quad mgh = \frac{1}{2}\left(m\frac{l^2}{3}\right)\omega^2.$$

$$\therefore \quad h = \frac{l^2\omega^2}{6g}.$$

14. (c): Energy (in eV) = $\frac{12375}{\lambda\ (\text{in Å})}$

$$\therefore \quad \Delta E = \frac{12375}{24800}\ \text{eV} \qquad (\because 2480\ \text{nm} = 24800\ \text{Å})$$

or $\Delta E = 0.5$ eV $\quad\therefore\quad$ Band gap = 0.5 eV.

15. (a) : For motion of a planet in circular orbit,

Centripetal force = Gravitational force

$$\therefore \quad mR\omega^2 = \frac{GMm}{R^n} \quad \text{or} \quad \omega = \sqrt{\frac{GM}{R^{n+1}}}$$

$$\therefore \quad T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{R^{n+1}}{GM}} = \frac{2\pi}{\sqrt{GM}}R^{\left(\frac{n+1}{2}\right)}$$

$\therefore \quad T$ is proportional to $R^{\left(\frac{n+1}{2}\right)}$.

16. (d) : According to Newton's law of cooling, rate of cooling is proportional to ΔT.

$\therefore \quad (\Delta T)^n = (\Delta T)$ or $n = 1$.

17. (a) : Time constant $\tau = RC$.

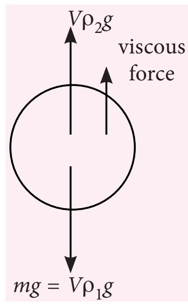
$$\text{Now } C = \frac{C_1C_2}{C_1+C_2} = \frac{\left(\frac{A\varepsilon_0}{d-x}\right)\left(\frac{KA\varepsilon_0}{x}\right)}{\frac{A\varepsilon_0}{d-x}+\frac{KA\varepsilon_0}{x}} = \frac{KA\varepsilon_0}{x+K(d-x)}.$$

$$\text{Since } x = \frac{d}{3} - vt,\ \tau = \frac{RKA\varepsilon_0}{\frac{d}{3} - vt + K\left(d - \frac{d}{3} + vt\right)}$$

Substituting $A = 1$ and $K = 2$ in the above equation

$$\tau = \frac{3\times 2R\varepsilon_0}{d - 3vt + 6d - 2d + 6vT} = \frac{6R\varepsilon_0}{5d+3vt}.$$

18. (b) : The forces acting on the solid ball when it is falling through a liquid are mg downwards, thrust by Archimedes principle upwards and the force due to the friction (viscous) also acting upwards. The viscous force rapidly increases with velocity,



attaining a maximum when the ball reaches the terminal velocity. Then the acceleration is zero.

$mg - V\rho_2 g - kv^2 = ma$

where V is volume of ball, v is the terminal velocity.

When the ball is moving with terminal velocity $a = 0$. Therefore $V\rho_1 g - V\rho_2 g - kv^2 = 0$.

$$\Rightarrow \quad v = \sqrt{\frac{Vg(\rho_1 - \rho_2)}{k}}.$$

19. (b) : Retarding viscous force = $6\pi\eta Rv$

obviously option (b) holds goods.

20. (b) : Variation of number of charge carriers with temperature is responsible for variation of resistance in a metal and a semiconductor.

21. (c): Consider the transition of an electron from L-shell to K-shell

$E_L - E_K = \frac{12375}{\lambda}$ where E is in eV and λ is in Å.

or $\quad \Delta E = \frac{12375}{0.21} = 58928$ eV $\quad$ or $\quad \Delta E \approx 59$ keV

22. (d) : $T_1 = 2\pi\sqrt{\frac{M}{k}}$ ...(i)

When a mass m is placed on mass M, the new system is of mass = $(M + m)$ attached to the spring. New time period of oscillation

$$T_2 = 2\pi\sqrt{\frac{(m+M)}{k}} \quad ...(ii)$$

Consider v_1 is the velocity of mass M passing through mean position and v_2 velocity of mass $(m + M)$ passing through mean position.

Using, law of conservation of linear momentum

$Mv_1 = (m + M)v_2$

$M(A_1\omega_1) = (m + M)(A_2\omega_2)$

$(v_1 = A_1\omega_1$ and $v_2 = A_2\omega_2)$

or $\frac{A_1}{A_2} = \frac{(m+M)}{M}\frac{\omega_2}{\omega_1} = \left(\frac{m+M}{M}\right)\times\frac{T_1}{T_2}$

$\left(\because \omega_1 = \frac{2\pi}{T_1} \text{ and } \omega_2 = \frac{2\pi}{T_2}\right)$

$\frac{A_1}{A_2} = \sqrt{\frac{m+M}{M}}$ (Using (i) and (ii))

23. (d)

24. (b) : Fringe width $\beta = \frac{\lambda D}{d}$

12 fringes of λ_1, occupy a segment of screen.

Let N fringes of λ_2 occupy the same segment.

$\therefore \quad N\left(\frac{\lambda_2 D}{d}\right) = 12\left(\frac{\lambda_1 D}{d}\right)$

$N = \frac{12 \times 600 \times 10^{-9}}{400 \times 10^{-9}}$ or $N = 18$

25. (d) : Energy stored per unit volume

$= \frac{1}{2}\times \text{stress} \times \text{strain} = \frac{\text{Stress}\times\text{stress}}{2Y} = \frac{S^2}{2Y}$

26. (d) : $\frac{1}{\lambda} = RZ^2\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right) \quad \therefore \frac{1}{\lambda} \propto Z^2$

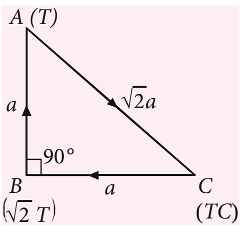
λ is shortest if Z is largest. Z is largest for doubly ionised lithium atom (Z = 3) among the given elements.

Hence wavelength for doubly ionised lithium will be the least.

27. (b) : For heat conduction,

$\frac{\Delta Q}{\Delta t} = KA\left(\frac{\Delta T}{l}\right)$

Since B is at higher temperature than A, heat flows from B to A, A to C and then C to B, for steady state.



For AC, $\frac{\Delta Q}{\Delta t} = KA\left(\frac{T - T_C}{\sqrt{2}a}\right)$

For CB, $\frac{\Delta Q}{\Delta t} = KA\left(\frac{T_C - \sqrt{2}T}{a}\right)$

Equate the two equations for steady state.

$\therefore \quad KA\left(\frac{T - T_C}{\sqrt{2}a}\right) = KA\left(\frac{T_C - \sqrt{2}\,T}{a}\right)$

or $\quad T - T_C = \sqrt{2}T_C - 2T$

or $\quad 3T = T_C(\sqrt{2}+1)$ or $\frac{T_C}{T} = \frac{3}{(\sqrt{2}+1)}$

28. (a) : Let focal length of convex lens = f_1 = f (suppose)

f_2 = focal length of concave lens = $\frac{-3f}{2}$

Equivalent focal length = 30 cm

$\therefore \quad \frac{1}{30} = \frac{1}{f} - \frac{2}{3f} \quad \left(\because \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}\right)$

or $\quad \frac{1}{30} = \frac{1}{3f}$

or $\quad f = 10$ cm = Focal length of convex lens.

$\therefore$ Focal length of concave lens $= \frac{-3}{2}\times 10 = -15$ cm

$\therefore$ Focal lengths are – 15 cm (concave lens) and 10 cm (convex lens).

29. (c): Let λ = charge per unit length of cylinder

$\therefore \quad E = \frac{\lambda}{2\pi\varepsilon_0 r}$ where r = distance from axis of cylinder.

$\therefore \quad E$ varies as $\frac{1}{r}$. Option (c) represents the correct answer.

30. (d) : For an adiabatic process, $TV^{\gamma-1}$ = constant

$V_1 = AL_1$, $V_2 = AL_2$

where A denotes area of cross-section of the gas-cylinder.

$\therefore \quad \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\frac{5}{3}-1}$, as $\gamma = \frac{5}{3}$ for monoatomic gas.

or $\quad \frac{T_1}{T_2} = \left(\frac{L_2}{L_1}\right)^{2/3}$

SRM University AP - Amaravati announces the setting up of School of Liberal Arts and Basic Sciences (SLABS)

B.A., B.B.A, B.Com. & B.Sc. courses will be offered from 2018 in 12 subjects

President of SRM University, Dr. P. Sathyanarayanan, announced the setting up of School of Liberal Arts and Basic Sciences (SLABS) at its University in Amaravati in the presence of the Honorary Pro Chancellor of SRM University, AP - Amaravati, Prof. Nicholas Dirks (Chancellor Emeritus, University of California, Berkley), and Dr. D Narayana Rao, Pro Vice Chancellor of SRM University, AP – Amaravati. SLABS will be SRM Amaravati's home for fundamental research, where free, open, and critical inquiry is pursued across disciplines, finding answers and solutions to world's most challenging problems and daunting issues. SLABS will have its first intake of students in 2018 and will offer B.A., B.B.A., B.Com and B.Sc. programs across 12 departments –Economics, English, History, Journalism, Psychology, Business Studies, Commerce, Physics, Chemistry, Mathematics, Biology and Computer Science.

"Today, we face increasingly complex issues and challenges, and tackling these, calls for multi-dimensional thought processes and problem solving skills. Education needs to focus on this and much more. We aim to help students develop such skills through the liberal arts and basic sciences education offered at SRM SLABS. For this, we are looking at hands-on guidance from Prof. Nicholas Dirks, given his background as a renowned anthropologist, and his rich experience in Liberal Arts. SRM SLABS also has a strong faculty base of international caliber who will bring a global perspective to liberal arts education." They will assist in creating a holistic approach to education, which will become, we hope, the calling card for SRM Amarvati's SLABS", says Dr. P Sathyanarayanan, President SRM Amaravati.

"I am very pleased to be involved with SRM Amaravati as it establishes its School of Liberal Arts and Basic Sciences. In our program, students will learn the skills of critical thinking and knowledge creation in a range of fields in the humanities, social sciences, and sciences. They will have an innovative multi-disciplinary education, in close proximity as well to breaking new teaching and research in areas ranging from machine learning and data science to public policy and social analysis", says Prof. Nicholas Dirks, Honorary Pro Chancellor, SRM Amaravati.

"SRM is committed to offering a distinctive form of learning empowering young students and thinkers with historical and cultural perspectives, as well as language, critical thinking, and communication skills— ideal traits to survive the modern world. The multi-disciplinary focus of SLABS will ensure that the students would have both breadth as well as depth of knowledge about a wide range of subjects", says Dr. D Narayana Rao, Pro. Vice Chancellor, SRM Amaravati.

About SRM University, AP-Amaravati

SRM University, AP – Amaravati, is envisaged to be a multi-disciplinary institution starting off with programs in engineering, followed by liberal arts and later on in fields of management, law, medical sciences, and pure sciences. SRM envisions to emerge as a world-class university in creating and disseminating knowledge and providing students a

unique learning experience in their chosen field of scholarship that would best serve the society. The focus is on developing into an inter-disciplinary institution combining academic rigour, excitement of discovery, creativity and entrepreneurship that delivers cutting-edge research based education, creating new knowledge and innovations.

The School of Engineering and Applied Sciences is already functional with the first batch of engineering students having commenced their courses in August 2017.

For more information, please visit: www.srmap.edu.in

FACT SHEET:

School of Liberal Arts and Basic Sciences (SLABS), at SRM University, AP-Amaravati

Beginning from	2018 session
Courses Offered	B.A., BBA, B. Com., B. Sc.
Program Duration	3 years + 1 Additional year (Optional) resulting in a Diploma / Certificate
Disciplines	Physical and Natural Sciences, Arts, Humanities, Social Sciences, Business Studies, Commerce
Subjects	Economics, English, History, Journalism, Psychology, Business Studies, Commerce, Physics, Chemistry, Mathematics, Biology and Computer Science.
Admission Criterion	Merit, based on Std. XII Exam Results
Faculty Profile	Top in the category from India and Abroad. 100% PhDs 75% have international Exposure in Research/Teaching 15% Foreign nationals Visiting faculty comprising of local and global experts/ academics
SLABS Approach	Multi-disciplinary. No restriction on courses across disciplines In class discussions, Field Trips Presentations / Movies / Hands on Assignments

JEE WORK OUTS

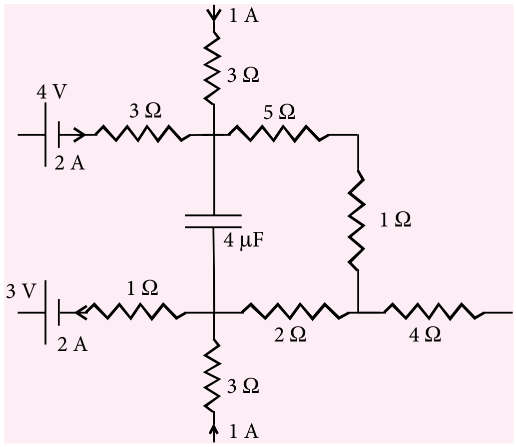
1. A small ball of mass 2×10^{-3} kg having a charge of 1 μC is suspended by a string of length 0.8 m. Another identical ball having the same charge is kept at the point of suspension. Determine the minimum horizontal velocity which should be imparted to the lower ball so that it can make complete revolution.

2. Three particles, each of mass m, are situated at the vertices of an equilateral triangle of side length a. The only forces acting on the particles are their mutual gravitational forces. It is desired that each particle moves in a circle while maintaining the original mutual separation a. Find the initial velocity that should be given to each particle and also the time period of the circular motion.

3. A large open container of negligible mass and uniform cross-sectional area A has a small hole of cross-sectional area $A/100$ in its side wall near the bottom. The container is kept on a smooth horizontal floor and contains a liquid of density δ and mass m_0. Assuming that the liquid starts flowing out horizontally through the hole at $t = 0$, Calculate
   (i) the acceleration of the container, and
   (ii) velocity of efflux when 75% of the liquid has drained out.

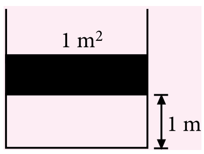
4. A metallic rod of length 1m is rigidly clamped at its mid point. Longitudinal stationary waves are set up in the rod in such a way that there are two nodes on either side of the mid-point. The amplitude of an antinode is 2×10^{-6} m. Write the equation of motion at a point 2 cm from the mid-point and those of the constituent waves in the rod. (Young's Modulus of the material of the rod $= 2 \times 10^{11}$ N m^{-2}, density = 8000 kg m^{-3}).

5. A part of circuit in a steady state along with the currents flowing in the branches, the values of resistances etc., is shown in the figure.



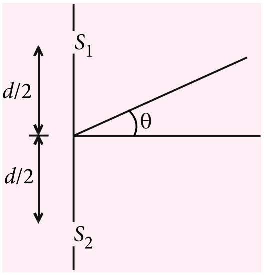
Calculate the energy stored in the capacitor C(4 μF).

6. A diatomic gas is enclosed in a vessel fitted with massless movable piston. Area of cross section of vessel is 1 m^2. Initial height of the piston is 1 m as shown in the figure. The initial temperature of the gas is 300 K. The temperature of the gas is increased to 400 K, keeping pressure constant. Calculate the new height of the piston. The piston is brought to its initial position with no heat exchange. Calculate the final temperature of the gas. You can leave answer in fraction.



7. In an interference arrangement similar to Young's double-slit experiment, the slits S_1 and S_2 are illuminated with coherent microwave sources, each of frequency 10^9 Hz. The sources are synchronized to

have zero phase difference. The slits are separated by a distance $d = 150.0$ mm. The intensity $I(\theta)$ is measured as a function of θ, where θ is defined as shown. If I_0 is the maximum intensity, then find $I(\theta)$ for $0 \le \theta \le 90°$.



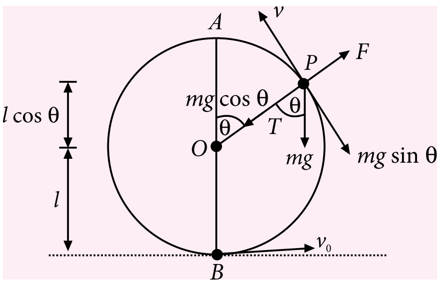
8. A cart is moving along x-direction with a velocity of 4 m s^{-1}. A person on the cart, throws a stone with a velocity of 6 m s^{-1}, relative to himself. In the frame of reference of the cart, the stone is thrown in y-z plane making an angle of 30° with vertical z-axis. At the highest point of its trajectory, the stone hits an object of equal mass, hung vertically from branch of a tree, by means of a string of length L. A completely inelastic collision occurs in which the stone gets embedded in the object. Determine :

(i) the speed of the combined mass immediately after the collision with respect to an observer on the ground.

(ii) the length L of the string such that tension in the string becomes zero when the string becomes horizontal during the subsequent motion of the combined mass.

SOLUTIONS

1. Two balls, each of mass 2×10^{-3} kg and similar charge of 1 μC are separated by a string of length 0.8 m. Force of repulsion occurs between the two similar charges.



Let us consider the vertical circular motion of the lower ball. The three forces acting on the ball are:

(i) Weight of ball = mg

(ii) Electrostatic force of repulsion

$$F = \frac{9 \times 10^9 \times 10^{-12}}{(0.8)^2}$$

(iii) Tension of string = T

$$\text{Centripetal force} = \frac{mv^2}{l}$$

$$\text{or} \quad T + mg\cos\theta - F = \frac{mv^2}{l} \quad \text{...(i)}$$

Energy is conserved.

$$\therefore \quad E_B = \frac{1}{2}mv_0^2$$

$$E_P = \frac{1}{2}mv^2 + mg(l + l\cos\theta)$$

$$\therefore \quad \frac{1}{2}mv_0^2 = \frac{1}{2}mv^2 + mg\, l(1 + \cos\theta) \quad \text{...(ii)}$$

For reaching the top of circle at A,

$T = 0, \theta = 0$

From (i), we get

$$mg - F = \frac{mv^2}{l} \quad \text{...(iii)}$$

$$\text{and} \quad \frac{1}{2}mv_0^2 = \frac{1}{2}mv^2 + mg\, l(1+1),$$

$$\text{or} \quad v_0^2 = v^2 + 4gl \quad \text{...(iv)}$$

From eqns. (iii) and (iv),

$$\therefore \quad mg - F = \frac{m}{l}\left(v_0^2 - 4gl\right)$$

$$\text{or} \quad lg - \frac{lF}{m} = v_0^2 - 4gl \quad \text{or} \quad v_0^2 = 5lg - \frac{lF}{m}$$

$$v_0^2 = (5 \times 0.8 \times 10) - \left(\frac{0.8}{0.002}\right) \times \left(\frac{9 \times 10^{-3}}{0.64}\right)$$

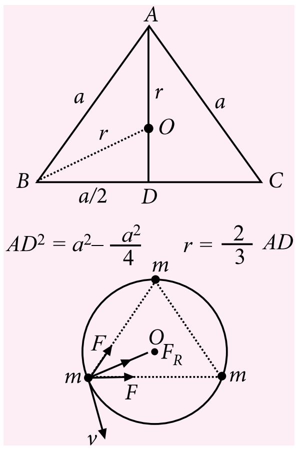
$$\text{or} \quad v_0^2 = 40 - \frac{45}{8} = 34.38 \text{ or } v_0 = 5.86 \text{ m s}^{-1}.$$

2. Side of equilateral triangle = a

Let r = radius of the circle

$$\therefore \quad r = \frac{2}{3} \times \sqrt{a^2 - \frac{a^2}{4}}$$

$$\text{or} \quad r = \frac{a}{\sqrt{3}} \quad \text{...(i)}$$



Let v = initial velocity given to each particle. For circular motion, centripetal force must be provided by net gravitational force

Gravitational force between two masses is given by

$$\therefore \quad F = G.\frac{m \times m}{a^2} = \frac{Gm^2}{a^2} \qquad \text{...(ii)}$$

Resultant force = Centripetal force

$$\text{or} \quad F_R = \frac{mv^2}{r} \quad \text{or} \quad \sqrt{F^2 + F^2 + 2F^2 \cos 60°} = \frac{mv^2}{r}$$

$$\text{or} \quad \sqrt{3}\, F = \frac{mv^2}{r}$$

$$\text{or} \quad v^2 = \frac{\sqrt{3}\, Fr}{m} = \frac{\sqrt{3}}{m} \times \left(\frac{Gm^2}{a^2}\right)\left(\frac{a}{\sqrt{3}}\right) = \frac{Gm}{a}$$

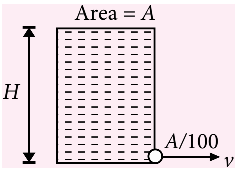
$$\therefore \quad v = \sqrt{\frac{Gm}{a}}$$

Time period of circular motion

$$T = \frac{2\pi r}{v} = 2\pi \times \left(\frac{a}{\sqrt{3}}\right) \times \sqrt{\frac{a}{Gm}} = 2\pi\sqrt{\frac{a^3}{3Gm}}$$

3. (i) Mass of water = volume × density

$$\therefore \quad m_0 = (AH)\rho \quad \text{or} \quad H = \frac{m_0}{A\rho}$$



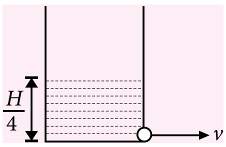
$\therefore$ velocity of efflux = v

$$\therefore \quad v = \sqrt{2gH} = \sqrt{2g \times \frac{m_0}{A\rho}}$$

$$\text{or} \quad v = \sqrt{\frac{2m_0 g}{A\rho}}$$

When the liquid flows out of the container horizontally, a force is exerted on the container.

Force $F = \rho \times$ (area of hole) $\times v^2$



$$\text{or} \quad F = \rho \times \frac{A}{100} \times v^2$$

$$\text{or} \quad F = \frac{\rho A}{100} \times \frac{2m_0 g}{A\rho}$$

$$\text{or} \quad m_0 a = \frac{m_0 g}{50} \quad \text{or} \quad a = \frac{g}{50}$$

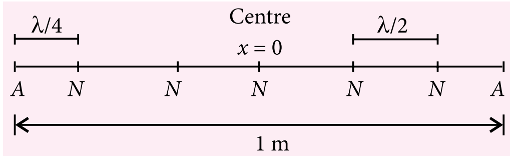
(ii) When 75% of liquid has drained out then, $h = H/4$

$$\therefore \quad v = \sqrt{2gh} \quad \text{or} \quad v = \sqrt{2g\frac{H}{4}}$$

$$\text{or} \quad v = \sqrt{\frac{g \times m_0}{2A\rho}} = \sqrt{\frac{m_0 g}{2A\rho}}.$$

4. For a longitudinal wave,

$$\text{Velocity, } v = \sqrt{\frac{Y}{\rho}} = \sqrt{\frac{2 \times 10^{11}}{8000}} = 5000 \text{ m s}^{-1}$$



Let A = Amplitude of constituent wave

$\therefore$ Amplitude at antinode = $2A = 2 \times 10^{-6}$ m

$$\text{Length of rod} = \frac{5\lambda}{2} \quad \text{or} \quad 1 = \frac{5\lambda}{2} \quad \text{or} \quad \lambda = 0.4 \text{ m}$$

$\therefore$ Let equation of stationary wave = $A \sin kx \sin \omega t$

or $y = A \sin kx \sin \omega t$

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.4} = 5\pi$$

$$\omega = 2\pi\upsilon = 2\pi\left(\frac{v}{\lambda}\right) \quad \text{or} \quad \omega = 2\pi \times \frac{5000}{0.4}$$

or $\omega = 25000\pi$

$\therefore \quad y = (10^{-6}) \sin (5\pi x) \sin (25000\, \pi t)$

At $x = 2$ cm $= 2 \times 10^{-2}$ m,

or $y = 10^{-6} \sin(5\pi \times 2 \times 10^{-2}) \sin(25000\, \pi t)$

or $y = 10^{-6} \sin(0.1\pi) \sin (25000\, \pi t)$

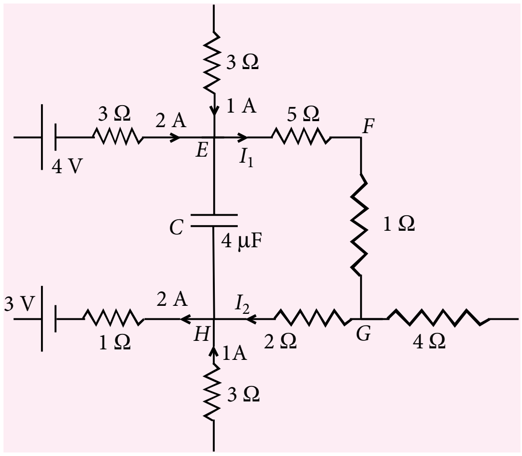
Constituent waves : The two waves are

$y_1 = A \sin(\omega t - kx)$ and $y_2 = A \sin(\omega t + kx)$

$\therefore \quad y_1 = 10^{-6} \sin(25000\, \pi t - 5\pi x)$ and

$y_2 = 10^{-6} \sin (25000\pi t + 5\pi x)$

5.



At steady state, no current flows through capacitor C.

According to Kirchhoff's law,

(i) at junction E, $I_1 = 3$A (ii) at junction H, $I_2 = 1$A

(iii) Potential difference across capacitor,

$V_E - V_H = 6I_1 + 2I_2$

or $V = (6 \times 3) + (2 \times 1) = 18 + 2 = 20$ V

$$\therefore \quad \text{Energy} = \frac{1}{2}CV^2$$

$$\text{or} \quad U = \frac{1}{2} \times (4 \times 10^{-6}) \times (20)^2 = 8 \times 10^{-4} \text{ J}$$

6. When pressure is kept constant, $\frac{T_1}{V_1} = \frac{T_2}{V_2}$

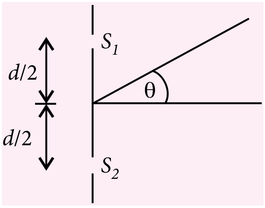
Volume = Area × height = Ah

$$\therefore \quad \frac{T_1}{Ah_1} = \frac{T_2}{Ah_2} \quad \text{or} \quad h_2 = \frac{T_2 h_1}{T_1} = \frac{400 \times 1}{300} = \frac{4}{3}\,\text{m}$$

The process is adiabatic. When the gas is compressed without exchange of heat.

$$\therefore \quad \frac{T'}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} \quad \therefore \quad T' = 400\left(\frac{4}{3}\right)^{2/5} K$$

7. The intensity $I(\theta)$ is measured as a function of θ. I_0 denotes the maximum intensity. θ varies from 0° to 90°.



$$\because \quad I(\theta) = I_o \cos^2\left(\frac{\delta}{2}\right)$$

$$\text{Where} \quad \delta = \frac{2\pi}{\lambda} d \sin\theta$$

$$\therefore \quad I(\theta) = I_o \cos^2\left(\frac{\pi d \sin\theta}{\lambda}\right)$$

$$\text{where } \lambda = \frac{3 \times 10^8}{10^9} = 0.30\text{ m}$$

$$\text{or} \quad I(\theta) = I_o \cos^2\left(\frac{\pi \times 0.15 \times \sin\theta}{0.30}\right)$$

$$= I_o \cos^2\left(\frac{\pi \sin\theta}{2}\right)$$

8. (i) The cart is moving in x - y plane.

The stone, thrown from cart, travels in y - z plane while z-axis is vertical axis. The stone makes an angle of 30° with z-axis. Its path is parabolic. At the highest point of its trajectory, the vertical velocity of the stone will be zero. The velocity of the stone is thus confined to (x, y) plane at the highest point.

Velocity of cart is along x-axis

$$\therefore \quad \vec{v}_c = 4\hat{i}$$

Velocity of stone with respect to cart

$$\vec{v}_{sc} = (6 \sin 30°)\,\hat{j} + (6 \cos 30°)\,\hat{k}$$

$$= 3\hat{j} + 3\sqrt{3}\,\hat{k} = 3(\hat{j} + \sqrt{3}\,\hat{k})$$

$\therefore$ Velocity of stone = $\vec{v}_s$

$$\therefore \quad \vec{v}_s = \vec{v}_{sc} + \vec{v}_c$$

or $\vec{v}_s = 4\hat{i} + 3\hat{j} + 3\sqrt{3}\,\hat{k}$ = absolute velocity of stone

At the highest point, z-component of velocity is zero

$$\therefore \quad v = (4\hat{i} + 3\hat{j})$$

$\therefore$ Speed at the highest point $(v) = \sqrt{4^2 + 3^2} = 5\text{ m s}^{-1}$.

Momentum is conserved so

$mv = (2m)v_0$

where v_0 = velocity of combined mass

$$\text{or} \quad v_0 = \frac{v}{2} = \frac{5}{2} = 2.5\text{ m s}^{-1}$$

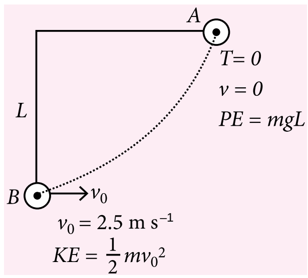
(ii) It is given that the tension in the string becomes zero at horizontal position. The combined mass therefore is at rest in this position. During the subsequent motion of the combined mass, the energy is conserved.

$P.E.$ at A = $K.E.$ at B

$$mgL = \frac{1}{2}mv_0^2$$

$$\text{or} \quad L = \frac{v_0^2}{2g} = \frac{(2.5)^2}{2 \times 10}$$

$$= \frac{6.25}{20} = 0.32\text{ m}$$



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PHYSICS FOR YOU 2017 AT A GLANCE

MONTHS	SOLVED PAPERS (2017)	PRACTICE PAPERS (2017-18)	BRAIN MAP		NEET | JEE ESSENTIALS		OTHERS
			XI	XII	XI	XII	
JANUARY		JEE Main 2017, ACE Your Way CBSE XII 2017, CBSE XI Series-7 MPP-7 (XI-XII)	Gravitation	Alternating Current and Electromagnetic Waves	Heat and Thermodynamics	Electronic Devices and Communication Systems	Physics Musing Problem Set 42, Solution Set 41, Key Concept, You Ask We Answer, Crossword, At a Glance 2016
FEBRUARY		JEE Main 2017, NEET 2017, ACE Your Way CBSE XII 2017 CBSE XI 2017 MPP-8 (XI-XII) BITSAT 2017	Mechanical Properties of Solids and Fluids	Ray Optics and Optical Instruments	Waves and Oscillations		Physics Musing Problem Set 43, Solution Set 42, Crossword, Key Concept
MARCH		NEET 2017, JEE Main 2017, JEE Advanced 2017, AIIMS 2017 BITSAT 2017 MPP (XI-XII) Ace Your Way CBSE XII 2017	Thermal Properties of Matter	Wave Optics			Physics Musing Problem Set 44, Solution Set 43, Key Concept
APRIL	CBSE Board 2017	NEET 2017, JEE Advanced 2017, AIIMS 2017, BITSAT 2017 AMU 2017 MPP (XI-XII)	Thermodynamics	Dual Nature of Radiation and Matter			Physics Musing Problem Set 45, Solution Set 44, Crossword, Key Concept
MAY	JEE Main 2017	JEE Advanced 2017, BITSAT Full Length 2017, AIIMS 2017, MPP-1 (XI-XII)	Kinetic Theory	Atoms and Nuclei			Physics Musing Problem Set 46, Solution Set 45, Crossword, Key Concept
JUNE	NEET 2017, Karnataka CET 2017, Kerala PET 2017, WB JEE 2017	ACE Your Way CBSE XII Series-1 MPP-2 (XI-XII)	Oscillations	Semiconductor Electronics			Physics Musing Problem Set 47, Solution Set 46, Exam Prep 2018, Olympiad Problems,
JULY	JEE Advanced 2017	ACE Your Way CBSE XII Series-2, CBSE XI Series - 1 MPP-3 (XI-XII)	Waves	Communication systems	Mathematical Tools and Measurements	Electrostatics	Physics Musing Problem Set 48, Solution Set 47, Cracking the JEE Advanced Exam, Exam Prep 2018 (XI)
AUGUST		ACE Your Way CBSE XII Series-3, CBSE XI Series-2 MPP-4 (XI-XII)	Projectile Motion	Electric flux and Gauss's law	Kinematics	Current Electricity	Physics Musing Problem Set 49, Solution Set 48, Live Physics, Exam Prep 2018 (XI-XII), Success Story, Key Concept
SEPTEMBER		ACE Your Way CBSE XII Series-4, CBSE XI Series-3 MPP-5 (XI-XII)	Circular Motion	Capacitor and Capacitance	Laws of Motion, Work, Energy and Power	Magnetic Effect of Current and Magnetism	Physics Musing Problem Set 50, Solution Set 49, Exam Prep 2018 (XI-XII), Key Concept
OCTOBER		ACE Your Way CBSE XII Series-5, CBSE XI Series - 4 MPP-6 (XI-XII)	Newton's Laws of Motion	Ohm's law and Kirchhoff's rule	System of Particles and Rotational Motion	Electromagnetic Induction, Alternating Current and Electromagnetic Waves	Physics Musing Problem Set 51, Solution Set 50, Exam Prep 2018 (XI-XII), Olympiad Problems, JEE Work Outs
NOVEMBER		ACE Your Way CBSE XII Series-6, CBSE XI Series - 5 MPP-7 (XI-XII)	Work and Energy	Biot-savart Law	Gravitation	Optics	Physics Musing Problem Set 52, Solution Set 51, You Ask We Answer, Exam Prep 2018 (XI-XII), JEE Work Outs
DECEMBER		ACE Your Way CBSE XII Series-7, CBSE XI Series - 6 MPP-8 (XI-XII)	Collision	AC Circuits	Properties of Bulk Matter	Modern Physics	Physics Musing Problem Set 53, Solution Set 52, Olympiad Problems, JEE Workouts, Exam Prep 2018 (XI-XII)

PHYSICS MUSING

SOLUTION SET-53

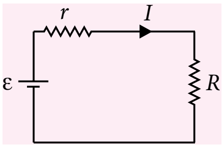
1. (c): $V = IR = \frac{I\rho l}{A} \Rightarrow \frac{V}{l}A = I\rho \Rightarrow EA = I\rho$

Apply Gauss's law,

$\frac{q_{in}}{\varepsilon_0}$ = (outgoing flux – incoming flux)

$\Rightarrow \frac{q_{in}}{\varepsilon_0} = I|\rho_1 - \rho_2| \Rightarrow q_{in} = I\varepsilon_0|\rho_1 - \rho_2|$

2. (a) : Any such black box can be replaced by an effective emf ε and an effective resistor r connected in series as shown.



$\therefore\ \varepsilon = I(R + r)$

Case (i) : $\varepsilon = 1\,(10 + r)$.

Case (ii) : $\varepsilon = 0.6\,(18 + r)$

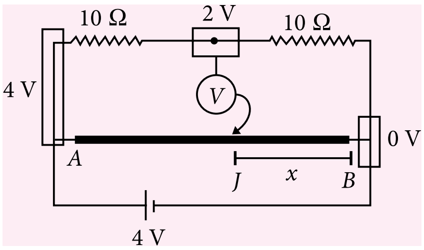
$\therefore\ \varepsilon = 12$ V and $r = 2\ \Omega$.

For $I = 0.1$ A, $12 = 0.1\,(R + 2)$

$\Rightarrow R = 118\ \Omega$

3. (d) : Let us assume that the terminal B is at 0 V and hence the terminal A is at potential 4 V. Current through wire AB,

$$I_{AB} = \frac{4\text{ V}}{0.4 \times 50\ \Omega} = 0.2\text{ A}$$



Potential difference across voltmeter,

$V = I_{AB}r - 2 \Rightarrow 2\sin\pi t = 0.2 \times 50x - 2$

Differentiating the equation

$2\pi\cos\pi t = 10\,v$

$v = 0.2\,\pi\cos\pi t$ m s^{-1}

$v = 20\pi\,(\cos\pi t)$ cm s^{-1}

4. (a, c): For $a < r < b$

$$I = \frac{dV}{dR} = \frac{Edr}{\frac{dr}{\sigma 4\pi r^2}} = E\sigma(4\pi r^2) = kE^2\,4\pi r^2$$

$$E^2 = \frac{I}{4\pi k r^2} \quad \text{or} \quad \left(\frac{dV}{dr}\right)^2 = \frac{I}{4\pi k r^2}$$

$$\Rightarrow dV = \sqrt{\frac{I}{4\pi k}}\frac{1}{r}dr;\ V = \sqrt{\frac{I}{4\pi k}}\int_a^b \frac{dr}{r}$$

$$\therefore\ V = \sqrt{\frac{I}{4\pi k}}\ln\left(\frac{b}{a}\right)$$

5. (a, c, d) : Equivalent resistance across AB,

$$R_{eq} = \frac{RR'}{R + R'}$$

Current drawn from battery, $I = \dfrac{V}{r + \frac{RR'}{R + R'}}$

If $R' >> R$,

$\frac{R'R}{R + R'} < R$ so, $I > \frac{V}{R + r}$

Since R' is always much greater than R

$\therefore I > \frac{V}{r + R}$

Potential drop across resistance r,

$$V_r = Ir = \frac{Vr}{r + \frac{RR'}{R + R'}}$$

$$V_{AB} = V - V_r = V\left[1 - \frac{r}{r + \frac{RR'}{R + R'}}\right] = V\frac{\left[\frac{RR'}{R + R'}\right]}{r + \frac{RR'}{R + R'}}$$

As $R' >> R$, $V_{AB} = \frac{VR}{r + R}$

Current through R', $I_1 = \frac{V_{AB}}{R'} = \frac{VR}{r\,(R + R') + RR'}$

As $R' >> R$

$\therefore I_1 \approx \frac{VR}{(r + R)R'}$

Since I_1 depends on R' hence current through resistance R' is not constant as R' varies.

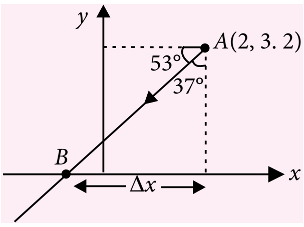
But potential drop across AB will remain nearly constant.

Solution Senders of Physics Musing

SET-52

1. Sudhakar, Latur (Maharashtra)
2. Laxmi Trupti, Calicult (W.B.)
3. Harshdeep Kaur, Chandigarh

6. (2) :



Electric field on particle,

$$\vec{E} = -\hat{i}\frac{\partial V}{dx} - \hat{j}\frac{\partial V}{\partial y} = -3\hat{i} - 4\hat{j}$$

The particle released, will move along $\vec{E}$.

Direction of electric field with x axis,

$$\tan\theta = \frac{(-4)}{(-3)} = \frac{4}{3} \quad \text{or } \theta = 53°$$

$$\therefore \quad \frac{\Delta x}{3.2} = \frac{3}{4} \Rightarrow \Delta x = 2.4 \text{ m}$$

If charge particle starts at A, it crosses the x-axis at B.

x-coordinates of B,

$x_B = -(2.4 - 2) = -0.4$

$V_A = (3 \times 2) + (4 \times 3.2) = 18.8$ V

$V_B = (3 \times (-0.4)) + (4 \times 0) = -1.2$ V

Using work energy theorem,

$$\frac{1}{2} \times 10 \times v^2 = 10^{-6}(18.8 - (-1.2))$$

$\Rightarrow v = 2 \times 10^{-3}$ m s^{-1} $\Rightarrow v = 2$ mm s^{-1}

7. (5) : Here $p = \pi^2 \times 10^{-30}$ C m, $I = 2 \times 10^{-48}$ kg m^2, $E = 2 \times 10^6$ N C^{-1}

Using energy conservation,

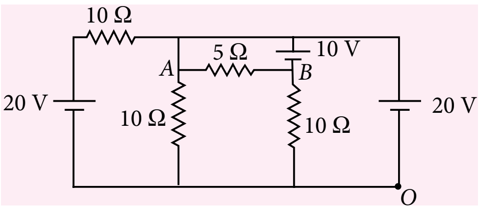
$$\omega^2 = \frac{pE}{I} = \frac{\pi^2 \times 10^{-30} \times 2 \times 10^6}{2 \times 10^{-48}} = \pi^2 \times 10^{24}$$

Since $\omega = 2\pi\upsilon$

$$\Rightarrow 4\pi^2\upsilon^2 = \pi^2 \times 10^{24} \quad \text{or} \quad \upsilon^2 = \frac{10^{24}}{4}$$

$\therefore \upsilon = 5 \times 10^{11}$ Hz

8. (2) :



Let potential of point O is 0 volt.

Therefore $V_A = 20$ V and $V_B = (20 - 10)$ V = 10 V

Current through 5 Ω resistance,

$$I = \frac{V_A - V_B}{R} = \frac{20 - 10}{5} = 2 \text{ A}$$

9. (5) : Equivalent resistance of heater $= \frac{R_1 R_2}{R_1 + R_2}$

$$= \frac{60 \times 30}{60 + 30} = 20\ \Omega$$

Emf of battery, $\varepsilon = IR = (20 \times 3) = 60$ V

Current in 60 Ω resistance, $I_1 = 1$ A

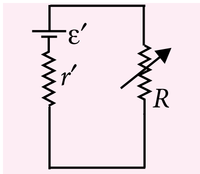
$\therefore Q = I_1^2 R_1 t = (1)^2 \times 60 \times 7 \times 60$ J

$\therefore ms\Delta T = 25200$ J

$$\text{or } \Delta T = \frac{25200}{0.240 \times 4200} \Rightarrow \Delta T = 25°\text{C} = 5x$$

$\therefore x = 5$

10. (3) : Using Thevenin's theorem, the given circuit can be simplified to the equivalent circuit shown in figure, where ε' is the potential drop across terminal of R and $\frac{1}{r'} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r}$ or $r' = \frac{r}{3}$



equivalent circuit

For power losses in R to be maximum

R = Equivalent resistance of remaining circuit (r')

$$R = \frac{r}{3} = \frac{9}{3} = 3\Omega$$

EXAM CORNER 2018

Exam	Date
VITEEE	4th April to 15th April
JEE Main	8th April (Offline), 15th & 16th April (Online)
SRMJEEE	16th April to 30th April
Karnataka CET	18th April & 19th April
WBJEE	22nd April
Kerala PET	23rd April & 24th April
AMU (Engg.)	29th April
COMEDK (Engg.)	13th May
BITSAT	16th May to 31st May
JEE Advanced	20th May
AIIMS	27th May

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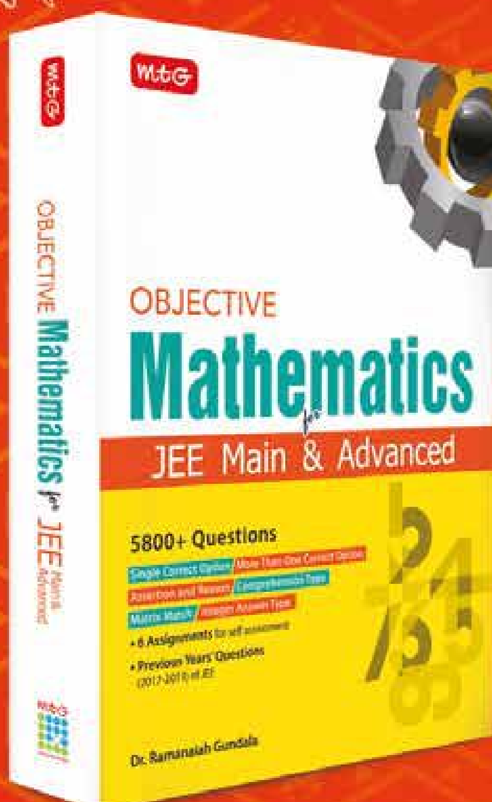

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