

## PART I : PHYSICS

### SECTION 1 (Maximum Marks: 21)

- This section contains **SEVEN** questions
- Each question has **FOUR** options [A], [B], [C] and [D]. **ONLY ONE** of these four options is correct
- For each question, darken the bubble corresponding to the correct option in the ORS
- For each question, marks will be awarded in one of the following categories:

*Full Marks* : +3 If only the bubble corresponding to the correct option is darkened

*Zero Marks* : 0 If none of the bubbles is darkened

*Negative Marks*: -1 In all other cases

Q.1 A photoelectric material having work-function  $\phi_0$  is illuminated with light of wavelength  $\lambda$  ( $\lambda < \frac{hc}{\phi_0}$ ). The fastest photoelectron has a de Broglie wavelength  $\lambda_d$ . A change in wavelength of the incident light by  $\Delta\lambda$  results in a change  $\Delta\lambda_d$  in  $\lambda_d$ . Then the ratio  $\Delta\lambda_d/\Delta\lambda$  is proportional to

[A]  $\lambda_d^3/\lambda^2$

[B]  $\lambda_d^2/\lambda^2$

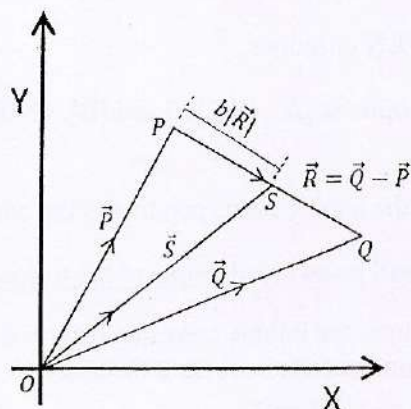
[C]  $\lambda_d/\lambda$

[D]  $\lambda_d^3/\lambda$

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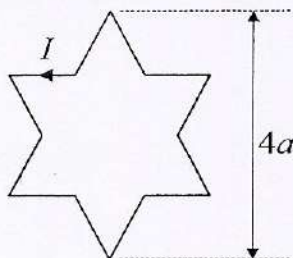
Space for rough work

- Q.2 Three vectors  $\vec{P}$ ,  $\vec{Q}$  and  $\vec{R}$  are shown in the figure. Let  $S$  be any point on the vector  $\vec{R}$ . The distance between the points  $P$  and  $S$  is  $b|\vec{R}|$ . The general relation among vectors  $\vec{P}$ ,  $\vec{Q}$  and  $\vec{S}$  is



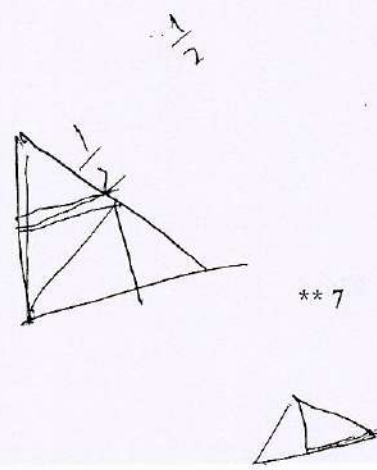
- [A]  $\vec{S} = (1 - b)\vec{P} + b^2\vec{Q}$                       [B]  $\vec{S} = (1 - b^2)\vec{P} + b\vec{Q}$   
 [C]  $\vec{S} = (1 - b)\vec{P} + b\vec{Q}$                        [D]  $\vec{S} = (b - 1)\vec{P} + b\vec{Q}$

- Q.3 A symmetric star shaped conducting wire loop is carrying a steady state current  $I$  as shown in the figure. The distance between the diametrically opposite vertices of the star is  $4a$ . The magnitude of the magnetic field at the center of the loop is

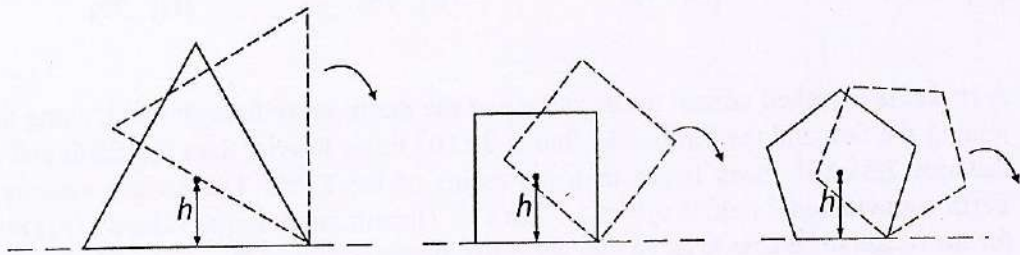


- [A]  $\frac{\mu_0 I}{4\pi a} 6[\sqrt{3} - 1]$                       [B]  $\frac{\mu_0 I}{4\pi a} 3[\sqrt{3} - 1]$   
 [C]  $\frac{\mu_0 I}{4\pi a} 6[\sqrt{3} + 1]$                       [D]  $\frac{\mu_0 I}{4\pi a} 3[2 - \sqrt{3}]$

Space for rough work



Q.4 Consider regular polygons with number of sides  $n = 3, 4, 5, \dots$  as shown in the figure. The center of mass of all the polygons is at height  $h$  from the ground. They roll on a horizontal surface about the leading vertex without slipping and sliding as depicted. The maximum increase in height of the locus of the center of mass for each polygon is  $\Delta$ . Then  $\Delta$  depends on  $n$  and  $h$  as



[A]  $\Delta = h \sin\left(\frac{2\pi}{n}\right)$

[B]  $\Delta = h \sin^2\left(\frac{\pi}{n}\right)$

[C]  $\Delta = h \tan^2\left(\frac{\pi}{2n}\right)$

[D]  $\Delta = h \left( \frac{1}{\cos\left(\frac{\pi}{n}\right)} - 1 \right)$

Q.5 Consider an expanding sphere of instantaneous radius  $R$  whose total mass remains constant. The expansion is such that the *instantaneous* density  $\rho$  remains uniform throughout the volume. The rate of fractional change in density  $\left(\frac{1}{\rho} \frac{d\rho}{dt}\right)$  is constant. The velocity  $v$  of any point on the surface of the expanding sphere is proportional to

[A]  $R^{2/3}$

[B]  $R$

[C]  $R^3$

[D]  $\frac{1}{R}$

Space for rough work

Handwritten rough work for Q.4 and Q.5. The work includes various mathematical derivations and calculations. For Q.4, it shows the geometry of a regular polygon with side length  $a$  and height  $h$ . It derives the relationship between  $a$  and  $h$  for different values of  $n$  (3, 4, 5). For Q.5, it shows the derivation of the velocity  $v$  of a point on the surface of an expanding sphere, leading to the conclusion that  $v$  is proportional to  $R$ .

Q.6 A person measures the depth of a well by measuring the time interval between dropping a stone and receiving the sound of impact with the bottom of the well. The error in his measurement of time is  $\delta T = 0.01$  seconds and he measures the depth of the well to be  $L = 20$  meters. Take the acceleration due to gravity  $g = 10 \text{ ms}^{-2}$  and the velocity of sound is  $300 \text{ ms}^{-1}$ . Then the fractional error in the measurement,  $\delta L/L$ , is closest to

- [A] 0.2%                      [B] 5%                      [C] 1%                      [D] 3%

Q.7 A rocket is launched normal to the surface of the Earth, away from the Sun, along the line joining the Sun and the Earth. The Sun is  $3 \times 10^5$  times heavier than the Earth and is at a distance  $2.5 \times 10^4$  times larger than the radius of the Earth. The escape velocity from Earth's gravitational field is  $v_e = 11.2 \text{ km s}^{-1}$ . The minimum initial velocity ( $v_s$ ) required for the rocket to be able to leave the Sun-Earth system is closest to (Ignore the rotation and revolution of the Earth and the presence of any other planet)

- [A]  $v_s = 62 \text{ km s}^{-1}$                       [B]  $v_s = 42 \text{ km s}^{-1}$   
 [C]  $v_s = 72 \text{ km s}^{-1}$                       [D]  $v_s = 22 \text{ km s}^{-1}$

Space for rough work

$$\frac{GM}{R^2} = \frac{GM_{\text{Sun}}}{R^2} - \frac{GM_{\text{Earth}}}{R^2}$$

$$\frac{3 \times 10^5 GM_{\text{Earth}}}{2.5 \times 10^4 R^2} - \frac{GM_{\text{Earth}}}{R^2}$$

$$L = \frac{v^2}{2a} \Rightarrow \sqrt{2aL} = t$$

$$0.01 \text{ s} = \sqrt{2 \times 10 \times L}$$

$$\log t = \frac{1}{2} (2 + \log a + \log L)$$

$$\frac{dt}{t} = \frac{1}{2} \left( \frac{da}{a} + \frac{dL}{L} \right)$$

$$\frac{0.01}{0.07} = \frac{1}{2} \left( \frac{\delta L}{L} + \frac{\delta a}{a} \right)$$

$$\frac{0.02}{0.07} = \frac{1}{2} \left( \frac{\delta L}{20} + \frac{10}{300} \right)$$

$$0.066 \text{ sec} \quad **7$$

$$0.07 \text{ sec.}$$

5  
 15  
 25  
 35

**SECTION 2 (Maximum Marks: 28)**

- This section contains **SEVEN** questions
- Each question has **FOUR** options [A], [B], [C] and [D]. **ONE OR MORE THAN ONE** of these four options is(are) correct
- For each question, darken the bubble(s) corresponding to all the correct option(s) in the ORS
- For each question, marks will be awarded in one of the following categories:

*Full Marks* : +4 If only the bubble(s) corresponding to all the correct option(s) is(are) darkened

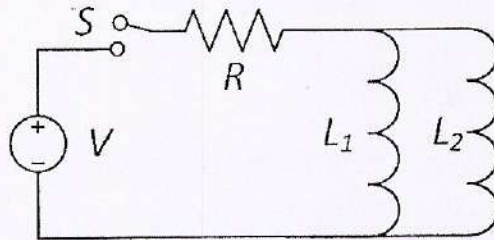
*Partial Marks* : +1 For darkening a bubble corresponding to **each correct option**, provided **NO** incorrect option is darkened

*Zero Marks* : 0 If none of the bubbles is darkened

*Negative Marks* : -2 In all other cases

- For example, if [A], [C] and [D] are all the correct options for a question, darkening all these three will get +4 marks; darkening only [A] and [D] will get +2 marks; and darkening [A] and [B] will get -2 marks, as a wrong option is also darkened

- Q.8 A source of constant voltage  $V$  is connected to a resistance  $R$  and two ideal inductors  $L_1$  and  $L_2$  through a switch  $S$  as shown. There is no mutual inductance between the two inductors. The switch  $S$  is initially open. At  $t = 0$ , the switch is closed and current begins to flow. Which of the following options is/are correct?



[A] At  $t = 0$ , the current through the resistance  $R$  is  $\frac{V}{R}$

~~[B]~~ After a long time, the current through  $L_2$  will be  $\frac{V}{R} \frac{L_1}{L_1 + L_2}$

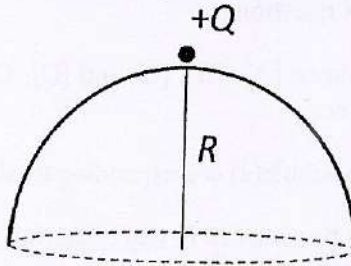
~~[C]~~ After a long time, the current through  $L_1$  will be  $\frac{V}{R} \frac{L_2}{L_1 + L_2}$

[D] The ratio of the currents through  $L_1$  and  $L_2$  is fixed at all times ( $t > 0$ )

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Space for rough work

- Q.9 A point charge  $+Q$  is placed just outside an imaginary hemispherical surface of radius  $R$  as shown in the figure. Which of the following statements is/are correct?

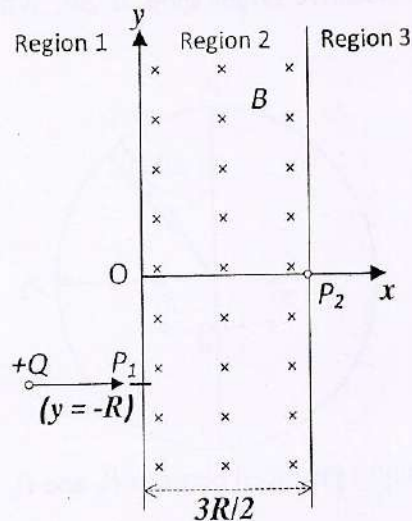


- [A] The electric flux passing through the *curved* surface of the hemisphere is  $-\frac{Q}{2\epsilon_0} \left(1 - \frac{1}{\sqrt{2}}\right)$
- [B] The component of the electric field normal to the flat surface is constant over the surface
- [C] Total flux through the curved and the flat surfaces is  $\frac{Q}{\epsilon_0}$
- [D] The circumference of the flat surface is an equipotential

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Space for rough work

- Q.10 A uniform magnetic field  $B$  exists in the region between  $x = 0$  and  $x = \frac{3R}{2}$  (region 2 in the figure) pointing normally into the plane of the paper. A particle with charge  $+Q$  and momentum  $p$  directed along  $x$ -axis enters region 2 from region 1 at point  $P_1$  ( $y = -R$ ). Which of the following option(s) is/are correct?

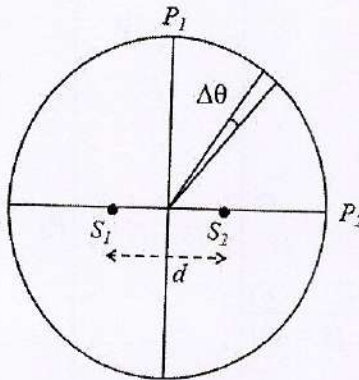


- [A] For  $B = \frac{8}{13} \frac{p}{QR}$ , the particle will enter region 3 through the point  $P_2$  on  $x$ -axis
- [B] For  $B > \frac{2}{3} \frac{p}{QR}$ , the particle will re-enter region 1
- [C] For a fixed  $B$ , particles of same charge  $Q$  and same velocity  $v$ , the distance between the point  $P_1$  and the point of re-entry into region 1 is inversely proportional to the mass of the particle
- [D] When the particle re-enters region 1 through the longest possible path in region 2, the magnitude of the change in its linear momentum between point  $P_1$  and the farthest point from  $y$ -axis is  $p/\sqrt{2}$

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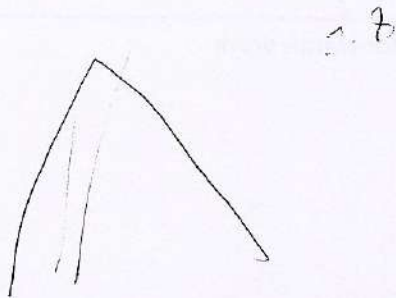
Space for rough work

Q.11 Two coherent monochromatic point sources  $S_1$  and  $S_2$  of wavelength  $\lambda = 600 \text{ nm}$  are placed symmetrically on either side of the center of the circle as shown. The sources are separated by a distance  $d = 1.8 \text{ mm}$ . This arrangement produces interference fringes visible as alternate bright and dark spots on the circumference of the circle. The angular separation between two consecutive bright spots is  $\Delta\theta$ . Which of the following options is/are correct?



- [A] The total number of fringes produced between  $P_1$  and  $P_2$  in the first quadrant is close to 3000
- [B] A dark spot will be formed at the point  $P_2$
- [C] At  $P_2$  the order of the fringe will be maximum
- [D] The angular separation between two consecutive bright spots decreases as we move from  $P_1$  to  $P_2$  along the first quadrant

Space for rough work





Q.12 The instantaneous voltages at three terminals marked  $X$ ,  $Y$  and  $Z$  are given by

$$V_X = V_0 \sin \omega t,$$

$$V_Y = V_0 \sin \left( \omega t + \frac{2\pi}{3} \right) \text{ and}$$

$$V_Z = V_0 \sin \left( \omega t + \frac{4\pi}{3} \right).$$

An ideal voltmeter is configured to read *rms* value of the potential difference between its terminals. It is connected between points  $X$  and  $Y$  and then between  $Y$  and  $Z$ . The reading(s) of the voltmeter will be

[A]  $V_{YZ}^{rms} = V_0 \sqrt{\frac{1}{2}}$

[B]  $V_{XY}^{rms} = V_0 \sqrt{\frac{3}{2}}$

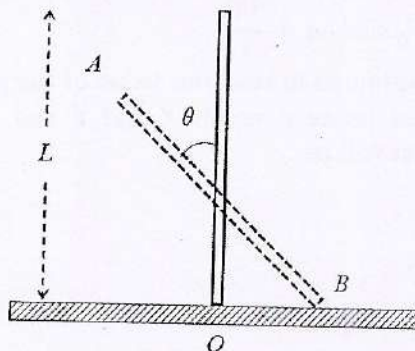
[C]  $V_{XY}^{rms} = V_0$

[D] independent of the choice of the two terminals

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Space for rough work

Q.13 A rigid uniform bar AB of length  $L$  is slipping from its vertical position on a frictionless floor (as shown in the figure). At some instant of time, the angle made by the bar with the vertical is  $\theta$ . Which of the following statements about its motion is/are correct?



- [A] The trajectory of the point  $A$  is a parabola
- [B] Instantaneous torque about the point in contact with the floor is proportional to  $\sin \theta$
- [C] The midpoint of the bar will fall vertically downward
- [D] When the bar makes an angle  $\theta$  with the vertical, the displacement of its midpoint from the initial position is proportional to  $(1 - \cos \theta)$

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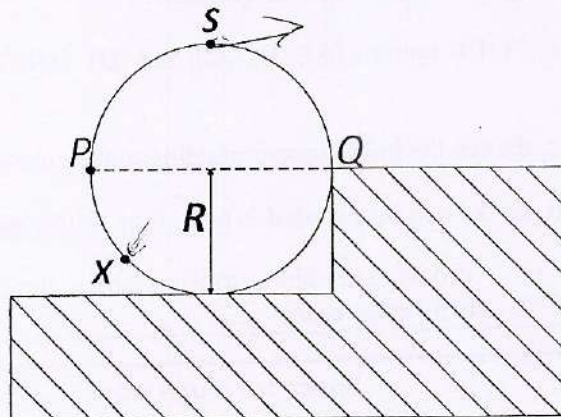
Space for rough work

M

O

I

Q.14 A wheel of radius  $R$  and mass  $M$  is placed at the bottom of a fixed step of height  $R$  as shown in the figure. A constant force is continuously applied on the surface of the wheel so that it just climbs the step without slipping. Consider the torque  $\tau$  about an axis normal to the plane of the paper passing through the point  $Q$ . Which of the following options is/are correct?



- [A] If the force is applied tangentially at point  $S$  then  $\tau \neq 0$  but the wheel never climbs the step
- [B] If the force is applied normal to the circumference at point  $P$  then  $\tau$  is zero
- [C] If the force is applied normal to the circumference at point  $X$  then  $\tau$  is constant
- [D] If the force is applied at point  $P$  tangentially then  $\tau$  decreases continuously as the wheel climbs

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Space for rough work

**SECTION 3 (Maximum Marks: 12)**

- This section contains **TWO** paragraphs
- Based on each paragraph, there are **TWO** questions
- Each question has **FOUR** options [A], [B], [C], and [D]. **ONLY ONE** of these four options is correct
- For each question, darken the bubble corresponding to the correct option in the ORS
- For each question, marks will be awarded in one of the following categories:

*Full Marks* : +3 If only the bubble corresponding to the correct option is darkened  
*Zero Marks* : 0 In all other cases

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Space for rough work

PARAGRAPH 1

Consider a simple RC circuit as shown in Figure 1.

Process 1: In the circuit the switch  $S$  is closed at  $t = 0$  and the capacitor is fully charged to voltage  $V_0$  (i.e., charging continues for time  $T \gg RC$ ). In the process some dissipation ( $E_D$ ) occurs across the resistance  $R$ . The amount of energy finally stored in the fully charged capacitor is  $E_C$ .

Process 2: In a different process the voltage is first set to  $\frac{V_0}{3}$  and maintained for a charging time  $T \gg RC$ . Then the voltage is raised to  $\frac{2V_0}{3}$  without discharging the capacitor and again maintained for a time  $T \gg RC$ . The process is repeated one more time by raising the voltage to  $V_0$  and the capacitor is charged to the same final voltage  $V_0$  as in Process 1.

These two processes are depicted in Figure 2.

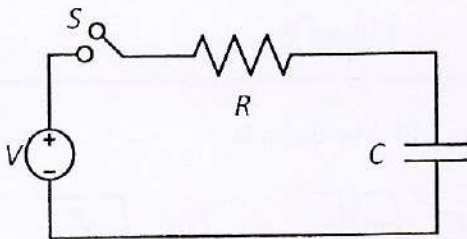


Figure 1

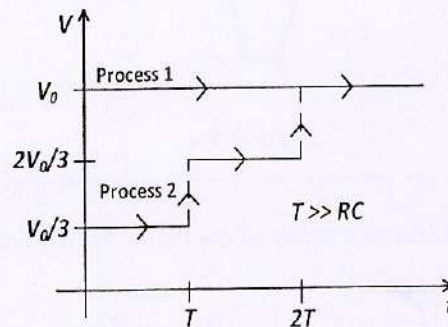


Figure 2

Q.15 In Process 2, total energy dissipated across the resistance  $E_D$  is:

[A]  $E_D = 3 \left( \frac{1}{2} CV_0^2 \right)$

[B]  $E_D = \frac{1}{2} CV_0^2$

[C]  $E_D = 3 CV_0^2$

[D]  $E_D = \frac{1}{3} \left( \frac{1}{2} CV_0^2 \right)$

Q.16 In Process 1, the energy stored in the capacitor  $E_C$  and heat dissipated across resistance  $E_D$  are related by:

[A]  $E_C = \frac{1}{2} E_D$

[B]  $E_C = 2E_D$

[C]  $E_C = E_D$

[D]  $E_C = E_D \ln 2$

Space for rough work

Handwritten notes:  $\frac{1}{2} CV^2 = I^2 R^2$ ,  $\frac{1}{2} CV^2 = \frac{Q^2}{2C}$ ,  $C = \frac{Q}{V}$ ,  $\frac{2}{IR}$

PARAGRAPH 2

One twirls a circular ring (of mass  $M$  and radius  $R$ ) near the tip of one's finger as shown in Figure 1. In the process the finger never loses contact with the inner rim of the ring. The finger traces out the surface of a cone, shown by the dotted line. The radius of the path traced out by the point where the ring and the finger is in contact is  $r$ . The finger rotates with an angular velocity  $\omega_0$ . The rotating ring rolls without slipping on the outside of a smaller circle described by the point where the ring and the finger is in contact (Figure 2). The coefficient of friction between the ring and the finger is  $\mu$  and the acceleration due to gravity is  $g$ .

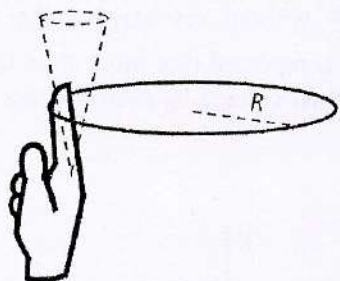


Figure 1

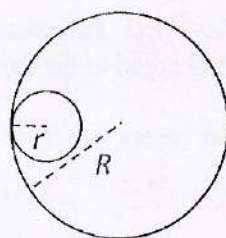


Figure 2

Q.17 The minimum value of  $\omega_0$  below which the ring will drop down is

[A]  $\sqrt{\frac{2g}{\mu(R-r)}}$

[B]  $\sqrt{\frac{g}{\mu(R-r)}}$

[C]  $\sqrt{\frac{3g}{2\mu(R-r)}}$

[D]  $\sqrt{\frac{g}{2\mu(R-r)}}$

Q.18 The total kinetic energy of the ring is

[A]  $\frac{3}{2} M \omega_0^2 (R-r)^2$

[B]  $\frac{1}{2} M \omega_0^2 (R-r)^2$

[C]  $M \omega_0^2 (R-r)^2$

[D]  $M \omega_0^2 R^2$

END OF PART I: PHYSICS

Space for rough work

Handwritten rough work showing calculations for Q.17 and Q.18. It includes expressions like  $\sqrt{2ag}$ ,  $\omega^2$ ,  $r\omega$ ,  $\frac{v^2}{r}$ ,  $\omega^2(R-r)$ , and  $\frac{\omega^2(R-r)}{R}$ .

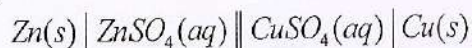
## PART II : CHEMISTRY

### SECTION 1 (Maximum Marks: 21)

- This section contains SEVEN questions
- Each question has FOUR options [A], [B], [C] and [D]. ONLY ONE of these four options is correct
- For each question, darken the bubble corresponding to the correct option in the ORS
- For each question, marks will be awarded in one of the following categories:

*Full Marks* : +3 If only the bubble corresponding to the correct option is darkened  
*Zero Marks* : 0 If none of the bubbles is darkened  
*Negative Marks*: -1 In all other cases

Q.19 For the following cell,



when the concentration of  $\text{Zn}^{2+}$  is 10 times the concentration of  $\text{Cu}^{2+}$ , the expression for  $\Delta G$  (in  $\text{J mol}^{-1}$ ) is

[F is Faraday constant; R is gas constant; T is temperature;  $E^\circ(\text{cell}) = 1.1 \text{ V}$ ]

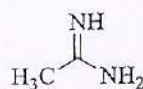
[A]  $2.303RT - 2.2F$

[B]  $2.303RT + 1.1F$

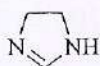
[C]  $1.1F$

[D]  $-2.2F$

Q.20 The order of basicity among the following compounds is



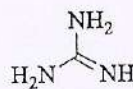
I



II



III



IV

[A] I > IV > III > II

[B] II > I > IV > III

[C] IV > I > II > III

[D] IV > II > III > I

Space for rough work

Q.21 The standard state Gibbs free energies of formation of C(graphite) and C(diamond) at T = 298 K are

$$\Delta_f G^\circ[\text{C}(\text{graphite})] = 0 \text{ kJ mol}^{-1}$$

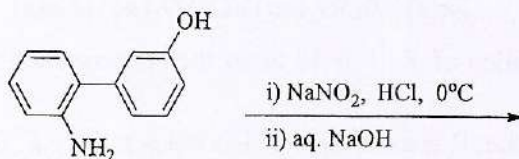
$$\Delta_f G^\circ[\text{C}(\text{diamond})] = 2.9 \text{ kJ mol}^{-1}$$

The standard state means that the pressure should be 1 bar, and substance should be pure at a given temperature. The conversion of graphite [C(graphite)] to diamond [C(diamond)] reduces its volume by  $2 \times 10^{-6} \text{ m}^3 \text{ mol}^{-1}$ . If C(graphite) is converted to C(diamond) isothermally at T = 298 K, the pressure at which C(graphite) is in equilibrium with C(diamond), is

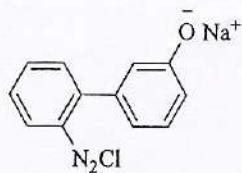
[Useful information:  $1 \text{ J} = 1 \text{ kg m}^2 \text{ s}^{-2}$ ;  $1 \text{ Pa} = 1 \text{ kg m}^{-1} \text{ s}^{-2}$ ;  $1 \text{ bar} = 10^5 \text{ Pa}$ ]

- [A] 14501 bar      [B] 29001 bar      [C] 1450 bar      [D] 58001 bar

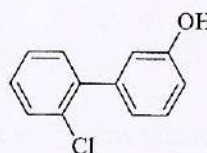
Q.22 The major product of the following reaction is



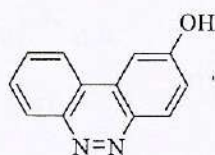
[A]



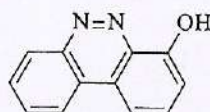
[B]



[C]



[D]



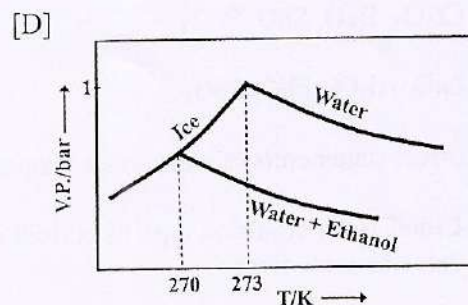
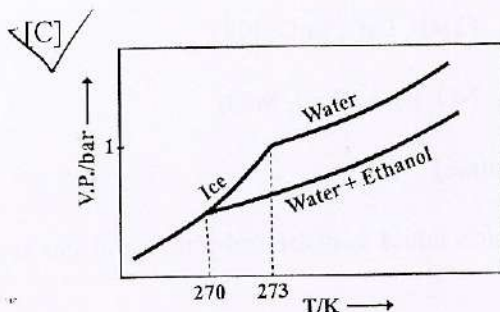
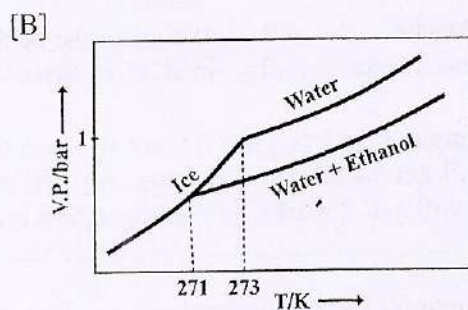
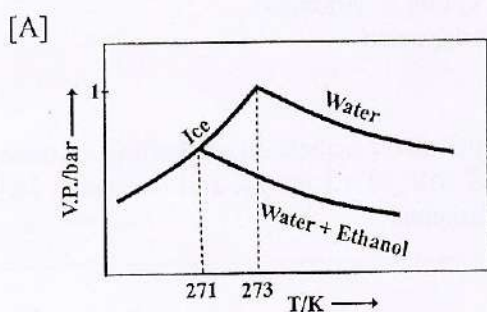
Space for rough work



Q.23 The order of the oxidation state of the phosphorus atom in  $\overset{2}{\text{H}_3\text{PO}_2}$ ,  $\overset{4}{\text{H}_3\text{PO}_4}$ ,  $\overset{3}{\text{H}_3\text{PO}_3}$ , and  $\text{H}_4\text{P}_2\text{O}_6$  is

- [A]  $\text{H}_3\text{PO}_4 > \text{H}_3\text{PO}_2 > \text{H}_3\text{PO}_3 > \text{H}_4\text{P}_2\text{O}_6$       [B]  $\text{H}_3\text{PO}_3 > \text{H}_3\text{PO}_2 > \text{H}_3\text{PO}_4 > \text{H}_4\text{P}_2\text{O}_6$   
 [C]  $\text{H}_3\text{PO}_2 > \text{H}_3\text{PO}_3 > \text{H}_4\text{P}_2\text{O}_6 > \text{H}_3\text{PO}_4$       [D]  $\text{H}_3\text{PO}_4 > \text{H}_4\text{P}_2\text{O}_6 > \text{H}_3\text{PO}_3 > \text{H}_3\text{PO}_2$

Q.24 Pure water freezes at 273 K and 1 bar. The addition of 34.5 g of ethanol to 500 g of water changes the freezing point of the solution. Use the freezing point depression constant of water as  $2 \text{ K kg mol}^{-1}$ . The figures shown below represent plots of vapour pressure (V.P.) versus temperature (T). [molecular weight of ethanol is  $46 \text{ g mol}^{-1}$ ]  
 Among the following, the option representing change in the freezing point is

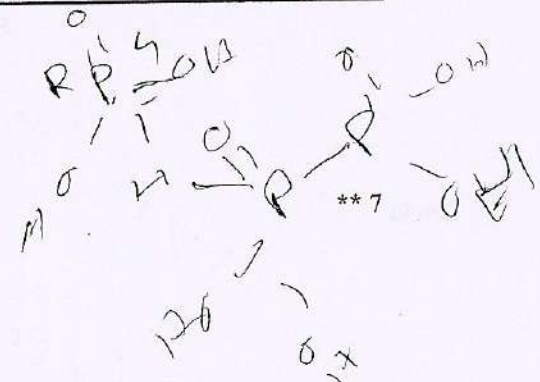
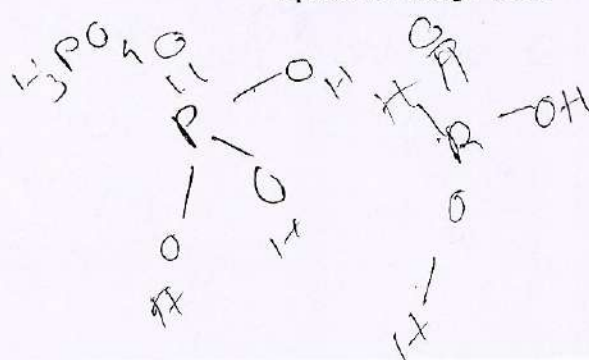
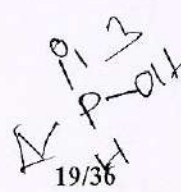


$\text{C}_2\text{H}_5\text{OH}$   
 $16 + 6 + 12 + 12$   
 $46$   
 $22$   
 $30$   
 $46$   
 $6^\circ$   
 $1.5$

Q.25 Which of the following combination will produce  $\text{H}_2$  gas?

- [A] Au metal and  $\text{NaCN}(\text{aq})$  in the presence of air  
 [B] Cu metal and conc.  $\text{HNO}_3$   
 [C] Fe metal and conc.  $\text{HNO}_3$   
 [D] Zn metal and  $\text{NaOH}(\text{aq})$

Space for rough work



**SECTION 2 (Maximum Marks: 28)**

- This section contains **SEVEN** questions
- Each question has **FOUR** options [A], [B], [C] and [D]. **ONE OR MORE THAN ONE** of these four options is(are) correct
- For each question, darken the bubble(s) corresponding to all the correct option(s) in the ORS
- For each question, marks will be awarded in one of the following categories:

*Full Marks* : +4 If only the bubble(s) corresponding to all the correct option(s) is(are) darkened

*Partial Marks* : +1 For darkening a bubble corresponding to **each correct option**, provided **NO** incorrect option is darkened

*Zero Marks* : 0 If none of the bubbles is darkened

*Negative Marks* : -2 In all other cases

- For example, if [A], [C] and [D] are all the correct options for a question, darkening all these three will get +4 marks; darkening only [A] and [D] will get +2 marks; and darkening [A] and [B] will get -2 marks, as a wrong option is also darkened

Q.26 The option(s) with only amphoteric oxides is(are)

[A]  $\text{Cr}_2\text{O}_3$ , BeO, SnO,  $\text{SnO}_2$

[B]  $\text{Cr}_2\text{O}_3$ , CrO, SnO, PbO

[C] ZnO,  $\text{Al}_2\text{O}_3$ , PbO,  $\text{PbO}_2$

[D] NO,  $\text{B}_2\text{O}_3$ , PbO,  $\text{SnO}_2$

Q.27 The correct statement(s) about surface properties is(are)

[A] Cloud is an emulsion type of colloid in which liquid is dispersed phase and gas is dispersion medium

[B] Adsorption is accompanied by decrease in enthalpy and decrease in entropy of the system

[C] The critical temperatures of ethane and nitrogen are 563 K and 126 K, respectively. The adsorption of ethane will be more than that of nitrogen on same amount of activated charcoal at a given temperature

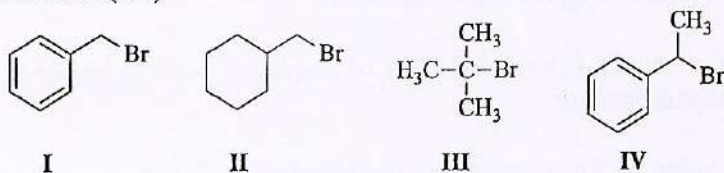
[D] Brownian motion of colloidal particles does not depend on the size of the particles but depends on viscosity of the solution

Space for rough work

Handwritten notes and chemical symbols:

$\text{Zn}$      $\text{Al}$      $\text{Be}$      $\text{Cr}$      $\text{Sn}$      $\text{Pb}$      $\text{Ag}$      $\text{Sn}$      $\text{Pb}$   
 $\text{Al}$      $\text{Be}$      $\text{Cr}$      $\text{Sn}$      $\text{Pb}$      $\text{Ag}$      $\text{Sn}$      $\text{Pb}$   
 $\text{Ag}$      $\text{Sn}$      $\text{Pb}$      $\text{Ag}$      $\text{Sn}$      $\text{Pb}$      $\text{Ag}$      $\text{Sn}$      $\text{Pb}$

Q.28 For the following compounds, the correct statement(s) with respect to nucleophilic substitution reactions is(are)



- [A] **I** and **III** follow  $S_N1$  mechanism
- [B] Compound **IV** undergoes inversion of configuration
- [C] **I** and **II** follow  $S_N2$  mechanism
- [D] The order of reactivity for **I**, **III** and **IV** is: **IV** > **I** > **III**

Q.29 Among the following, the correct statement(s) is(are)

- [A]  $BH_3$  has the three-centre two-electron bonds in its dimeric structure
- [B]  $Al(CH_3)_3$  has the three-centre two-electron bonds in its dimeric structure
- [C]  $AlCl_3$  has the three-centre two-electron bonds in its dimeric structure
- [D] The Lewis acidity of  $BCl_3$  is greater than that of  $AlCl_3$

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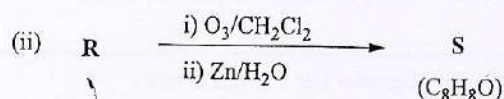
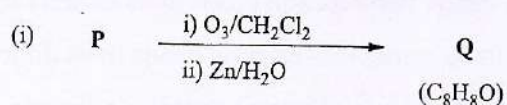
Space for rough work



Q.30 In a bimolecular reaction, the steric factor  $P$  was experimentally determined to be 4.5. The correct option(s) among the following is(are)

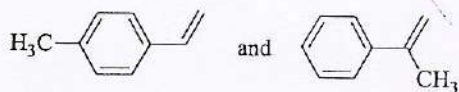
- [A] Experimentally determined value of frequency factor is higher than that predicted by Arrhenius equation
- [B] The value of frequency factor predicted by Arrhenius equation is higher than that determined experimentally
- [C] The activation energy of the reaction is unaffected by the value of the steric factor
- [D] Since  $P = 4.5$ , the reaction will not proceed unless an effective catalyst is used

Q.31 Compounds  $P$  and  $R$  upon ozonolysis produce  $Q$  and  $S$ , respectively. The molecular formula of  $Q$  and  $S$  is  $C_8H_8O$ .  $Q$  undergoes Cannizzaro reaction but not haloform reaction, whereas  $S$  undergoes haloform reaction but not Cannizzaro reaction.

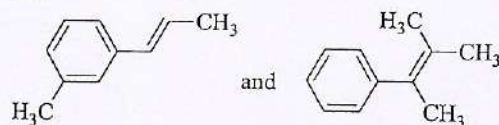


The option(s) with suitable combination of  $P$  and  $R$ , respectively, is(are)

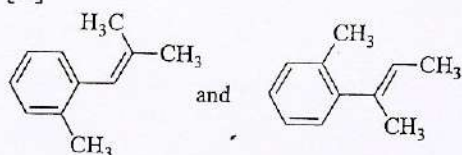
[A]



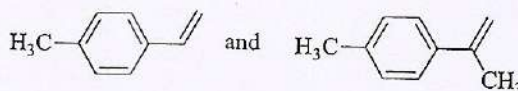
[B]



[C]



[D]



Space for rough work

Q.32 For a reaction taking place in a container in equilibrium with its surroundings, the effect of temperature on its equilibrium constant  $K$  in terms of change in entropy is described by

[A] With increase in temperature, the value of  $K$  for exothermic reaction decreases because the entropy change of the system is positive

[B] With increase in temperature, the value of  $K$  for endothermic reaction increases because unfavourable change in entropy of the surroundings decreases

[C] With increase in temperature, the value of  $K$  for endothermic reaction increases because the entropy change of the system is negative

[D] With increase in temperature, the value of  $K$  for exothermic reaction decreases because favourable change in entropy of the surroundings decreases

---

Space for rough work

**SECTION 3 (Maximum Marks: 12)**

- This section contains **TWO** paragraphs
- Based on each paragraph, there are **TWO** questions
- Each question has **FOUR** options [A], [B], [C], and [D]. **ONLY ONE** of these four options is correct
- For each question, darken the bubble corresponding to the correct option in the ORS
- For each question, marks will be awarded in one of the following categories:

*Full Marks* : +3 If only the bubble corresponding to the correct option is darkened  
*Zero Marks* : 0 In all other cases

**PARAGRAPH 1**

Upon heating  $\text{KClO}_3$  in the presence of catalytic amount of  $\text{MnO}_2$ , a gas **W** is formed. Excess amount of **W** reacts with white phosphorus to give **X**. The reaction of **X** with pure  $\text{HNO}_3$  gives **Y** and **Z**.

Q.33 **W** and **X** are, respectively

[A]  $\text{O}_2$  and  $\text{P}_4\text{O}_{10}$

[B]  $\text{O}_2$  and  $\text{P}_4\text{O}_6$

[C]  $\text{O}_3$  and  $\text{P}_4\text{O}_6$

[D]  $\text{O}_3$  and  $\text{P}_4\text{O}_{10}$

Q.34 **Y** and **Z** are, respectively

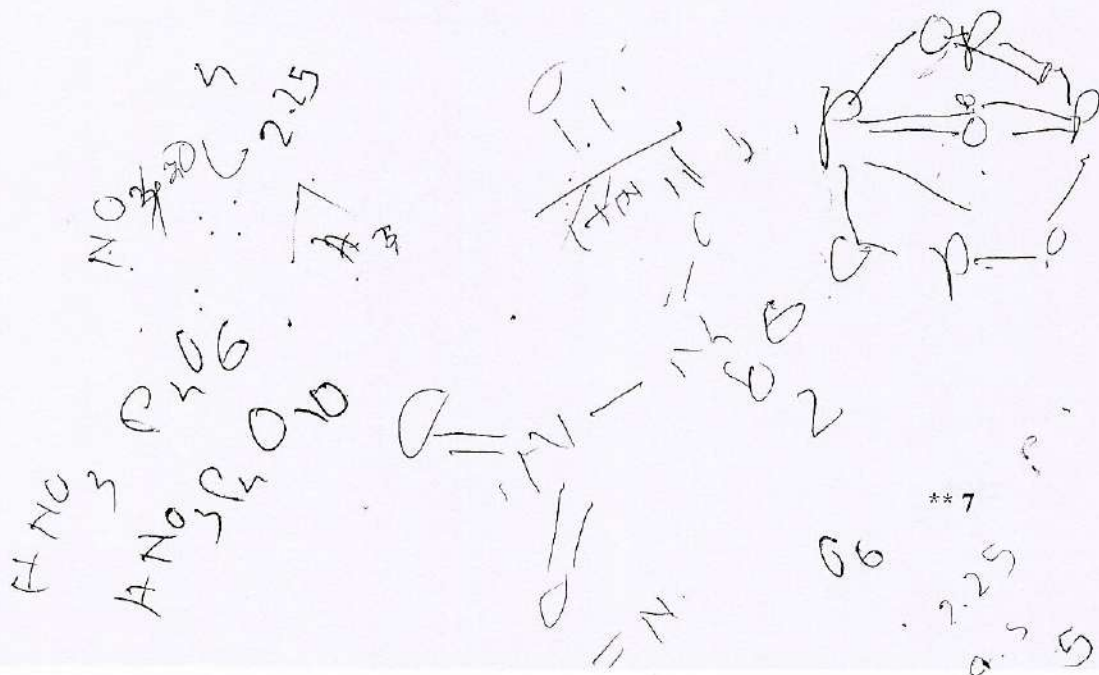
[A]  $\text{N}_2\text{O}_5$  and  $\text{HPO}_3$

[B]  $\text{N}_2\text{O}_4$  and  $\text{HPO}_3$

[C]  $\text{N}_2\text{O}_4$  and  $\text{H}_3\text{PO}_3$

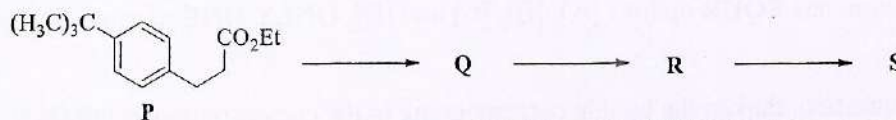
[D]  $\text{N}_2\text{O}_3$  and  $\text{H}_3\text{PO}_4$

Space for rough work



PARAGRAPH 2

The reaction of compound **P** with  $\text{CH}_3\text{MgBr}$  (excess) in  $(\text{C}_2\text{H}_5)_2\text{O}$  followed by addition of  $\text{H}_2\text{O}$  gives **Q**. The compound **Q** on treatment with  $\text{H}_2\text{SO}_4$  at  $0^\circ\text{C}$  gives **R**. The reaction of **R** with  $\text{CH}_3\text{COCl}$  in the presence of anhydrous  $\text{AlCl}_3$  in  $\text{CH}_2\text{Cl}_2$  followed by treatment with  $\text{H}_2\text{O}$  produces compound **S**. [Et in compound **P** is ethyl group]

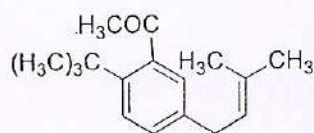


Q.35 The reactions, **Q** to **R** and **R** to **S**, are

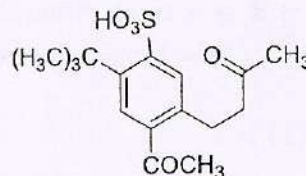
- [A] Dehydration and Friedel-Crafts acylation
- [B] Friedel-Crafts alkylation and Friedel-Crafts acylation
- [C] Friedel-Crafts alkylation, dehydration and Friedel-Crafts acylation
- [D] Aromatic sulfonation and Friedel-Crafts acylation

Q.36 The product **S** is

[A]



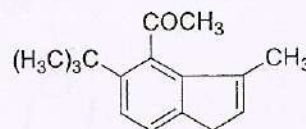
[B]



[C]



[D]



END OF PART II : CHEMISTRY

Space for rough work

## PART III : MATHEMATICS

### SECTION 1 (Maximum Marks: 21)

- This section contains **SEVEN** questions
- Each question has **FOUR** options [A], [B], [C] and [D]. **ONLY ONE** of these four options is correct
- For each question, darken the bubble corresponding to the correct option in the ORS
- For each question, marks will be awarded in one of the following categories:

*Full Marks* : +3 If only the bubble corresponding to the correct option is darkened  
*Zero Marks* : 0 If none of the bubbles is darkened  
*Negative Marks*: -1 In all other cases

Q.37 Three randomly chosen nonnegative integers  $x, y$  and  $z$  are found to satisfy the equation  $x + y + z = 10$ . Then the probability that  $z$  is even, is

- [A]  $\frac{5}{11}$                       [B]  $\frac{1}{2}$                        [C]  $\frac{6}{11}$                       [D]  $\frac{36}{55}$

Q.38 If  $f: \mathbb{R} \rightarrow \mathbb{R}$  is a twice differentiable function such that  $f''(x) > 0$  for all  $x \in \mathbb{R}$ , and  $f\left(\frac{1}{2}\right) = \frac{1}{2}, f(1) = 1$ , then

- [A]  $f'(1) > 1$                       [B]  $f'(1) \leq 0$   
 [C]  $\frac{1}{2} < f'(1) \leq 1$                       [D]  $0 < f'(1) \leq \frac{1}{2}$

Space for rough work

**Q.37 Rough Work:**  
 Tree diagram for  $x, y, z \in \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}$  such that  $x+y+z=10$ .  
 Level 1 (x): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10  
 Level 2 (y): For each x, y ranges from 0 to 10-x.  
 Level 3 (z): For each (x,y), z = 10 - x - y.  
 Total number of outcomes =  $\sum_{x=0}^{10} (10-x+1) = \sum_{k=1}^{11} k = 66$ .  
 Number of outcomes where z is even: 36.  
 Probability =  $\frac{36}{66} = \frac{6}{11}$ .

**Q.38 Rough Work:**  
 Graph of a convex function  $f(x)$  passing through  $(\frac{1}{2}, \frac{1}{2})$  and  $(1, 1)$ .  
 Tangent line at  $x=1$  is drawn. The slope of the tangent is  $f'(1)$ .  
 Since  $f''(x) > 0$ , the function is strictly convex. The slope of the secant line from  $(\frac{1}{2}, \frac{1}{2})$  to  $(1, 1)$  is  $\frac{1 - \frac{1}{2}}{1 - \frac{1}{2}} = 1$ .  
 By the property of convex functions, the slope of the tangent at  $x=1$  is greater than the slope of the secant line from  $(\frac{1}{2}, \frac{1}{2})$  to  $(1, 1)$ .  
 Therefore,  $f'(1) > 1$ .



Q.39 The equation of the plane passing through the point (1, 1, 1) and perpendicular to the planes  $2x + y - 2z = 5$  and  $3x - 6y - 2z = 7$ , is

- [A]  $-14x + 2y + 15z = 3$                        [B]  $14x + 2y - 15z = 1$   
 [C]  $14x + 2y + 15z = 31$                        [D]  $14x - 2y + 15z = 27$

Q.40 Let  $O$  be the origin and let  $PQR$  be an arbitrary triangle. The point  $S$  is such that

$$\vec{OP} \cdot \vec{OQ} + \vec{OR} \cdot \vec{OS} = \vec{OR} \cdot \vec{OP} + \vec{OQ} \cdot \vec{OS} = \vec{OQ} \cdot \vec{OR} + \vec{OP} \cdot \vec{OS}$$

Then the triangle  $PQR$  has  $S$  as its

- [A] circumcentre     [B] orthocenter  
 [C] incentre     [D] centroid

Space for rough work

Q.41 How many  $3 \times 3$  matrices  $M$  with entries from  $\{0, 1, 2\}$  are there, for which the sum of the diagonal entries of  $M^T M$  is 5?

- [A] 126                      [B] 198                      [C] 162                      [D] 135

Q.42 Let  $S = \{1, 2, 3, \dots, 9\}$ . For  $k = 1, 2, \dots, 5$ , let  $N_k$  be the number of subsets of  $S$ , each containing five elements out of which exactly  $k$  are odd. Then  $N_1 + N_2 + N_3 + N_4 + N_5 =$

- [A] 210                      [B] 252                      [C] 125                      [D] 126

Q.43 If  $y = y(x)$  satisfies the differential equation

$$8\sqrt{x} \left( \sqrt{9 + \sqrt{x}} \right) dy = \left( \sqrt{4 + \sqrt{9 + \sqrt{x}}} \right)^{-1} dx, \quad x > 0$$

and  $y(0) = \sqrt{7}$ , then  $y(256) =$

- [A] 16                      [B] 80                      [C] 3                      [D] 9

Space for rough work

Handwritten rough work for Q.42:

$$5 + 5 \times 4 \times 4$$

$$] + 5 \times 4 \times 4 + \frac{5 \times 4 \times 4 \times 2}{2!}$$

$$1 \times 20 + 10 + 1$$

$$20 + 40 + 10 \times 5$$

$$5 \times 2 \times 5 \times \frac{5!}{3!2!}$$

$$2 \times 3!$$

$$12$$

$$9 \times 2 \times \frac{9!}{4!}$$

Handwritten rough work for Q.43:

$$12$$

$$3 \times 4$$

$$\frac{12!}{5!}$$

$$\frac{12!}{3!2!}$$

$$\frac{12!}{3!2!}$$

$$\frac{12!}{3!2!}$$

$$\frac{12!}{3!2!}$$

$$\frac{12!}{3!2!}$$

**SECTION 2 (Maximum Marks: 28)**

- This section contains **SEVEN** questions
- Each question has **FOUR** options [A], [B], [C] and [D]. **ONE OR MORE THAN ONE** of these four options is(are) correct
- For each question, darken the bubble(s) corresponding to all the correct option(s) in the ORS
- For each question, marks will be awarded in one of the following categories:

<i>Full Marks</i>	: +4	If only the bubble(s) corresponding to all the correct option(s) is(are) darkened
<i>Partial Marks</i>	: +1	For darkening a bubble corresponding to <b>each correct option</b> , provided <b>NO</b> incorrect option is darkened
<i>Zero Marks</i>	: 0	If none of the bubbles is darkened
<i>Negative Marks</i>	: -2	In all other cases

- For example, if [A], [C] and [D] are all the correct options for a question, darkening all these three will get +4 marks; darkening only [A] and [D] will get +2 marks; and darkening [A] and [B] will get -2 marks, as a wrong option is also darkened

Q.44 Let  $f(x) = \frac{1-x(1+|1-x|)}{|1-x|} \cos\left(\frac{1}{1-x}\right)$  for  $x \neq 1$ . Then

- [A]  $\lim_{x \rightarrow 1^-} f(x)$  does not exist                      [B]  $\lim_{x \rightarrow 1^+} f(x)$  does not exist  
 [C]  $\lim_{x \rightarrow 1^-} f(x) = 0$                                        [D]  $\lim_{x \rightarrow 1^+} f(x) = 0$

Q.45 Let  $\alpha$  and  $\beta$  be nonzero real numbers such that  $2(\cos \beta - \cos \alpha) + \cos \alpha \cos \beta = 1$ . Then which of the following is/are true?

- [A]  $\sqrt{3} \tan\left(\frac{\alpha}{2}\right) + \tan\left(\frac{\beta}{2}\right) = 0$                       [B]  $\sqrt{3} \tan\left(\frac{\alpha}{2}\right) - \tan\left(\frac{\beta}{2}\right) = 0$   
 [C]  $\tan\left(\frac{\alpha}{2}\right) + \sqrt{3} \tan\left(\frac{\beta}{2}\right) = 0$                       [D]  $\tan\left(\frac{\alpha}{2}\right) - \sqrt{3} \tan\left(\frac{\beta}{2}\right) = 0$

Space for rough work

Handwritten work for Q.44:

$$\frac{1-x}{1-x} \frac{-2+x^2}{-2+2x} = \frac{-2+x^2}{-2}$$

$$\frac{1-x}{1-x} \frac{-2+x^2}{-2} = \frac{-2+x^2}{-2}$$

Handwritten work for Q.45:

$$\frac{1-x}{1-x} \frac{-2+x^2}{-2} = \frac{-2+x^2}{-2}$$

Q.46 If  $f(x) = \begin{vmatrix} \cos(2x) & \cos(2x) & \sin(2x) \\ -\cos x & \cos x & -\sin x \\ \sin x & \sin x & \cos x \end{vmatrix}$ , then

- [A]  $f'(x) = 0$  at exactly three points in  $(-\pi, \pi)$
- [B]  $f'(x) = 0$  at more than three points in  $(-\pi, \pi)$
- ✓ [C]  $f(x)$  attains its maximum at  $x = 0$
- [D]  $f(x)$  attains its minimum at  $x = 0$

Handwritten notes for Q.46:  
 $2 \sin 2x \sin x \cos x$   
 $+ 2 \cos 2x \cos^2 x$   
 $- 2 \sin^2 x$   
 $2 \cos 2x \cos^2 x$   
 $2 \cos 2x \cos^2 x + \cos 2x \sin^2 x$

Q.47 If the line  $x = \alpha$  divides the area of region  $R = \{(x, y) \in \mathbb{R}^2 : x^3 \leq y \leq x, 0 \leq x \leq 1\}$  into two equal parts, then

- [A]  $2\alpha^4 - 4\alpha^2 + 1 = 0$
- [B]  $\alpha^4 + 4\alpha^2 - 1 = 0$
- [C]  $0 < \alpha \leq \frac{1}{2}$
- [D]  $\frac{1}{2} < \alpha < 1$

Q.48 If  $I = \sum_{k=1}^{98} \int_k^{k+1} \frac{k+1}{x(x+1)} dx$ , then

- [A]  $I < \frac{49}{50}$
- [B]  $I > \log_e 99$
- [C]  $I > \frac{49}{50}$
- [D]  $I < \log_e 99$

Space for rough work

Handwritten work for Q.46:  
 $\cos 2x \cos^2 x - \cos^2 x \sin^2 x + \sin 2x \cos x \sin x$   
 $+ \cos 2x \cos^2 x - \sin^2 x \cos x \sin x$   
 $2 \sin 2x \sin x \cos x$   
 $\sin^2 x \cos^2 x \sin x \cos x$   
 $2k^2$   
 $1 \frac{2k^2}{x^2 + x^2}$

Q.49 If  $f: \mathbb{R} \rightarrow \mathbb{R}$  is a differentiable function such that  $f'(x) > 2f(x)$  for all  $x \in \mathbb{R}$ , and  $f(0) = 1$ , then

[A]  $f(x)$  is decreasing in  $(0, \infty)$

[B]  $f'(x) < e^{2x}$  in  $(0, \infty)$

[C]  $f(x)$  is increasing in  $(0, \infty)$

[D]  $f(x) > e^{2x}$  in  $(0, \infty)$

Q.50 If  $g(x) = \int_{\sin x}^{\sin(2x)} \sin^{-1}(t) dt$ , then

[A]  $g'(\frac{\pi}{2}) = -2\pi$

[B]  $g'(-\frac{\pi}{2}) = -2\pi$

[C]  $g'(-\frac{\pi}{2}) = 2\pi$

[D]  $g'(\frac{\pi}{2}) = 2\pi$

Space for rough work

Handwritten notes and calculations:

$2x$

$\frac{1}{\sqrt{1-\sin^2 2x}}$

$\frac{1}{\sqrt{1-\sin^2 x}}$

$e^{2x}$

$\frac{1}{\sqrt{1+x^2}}$

**SECTION 3 (Maximum Marks: 12)**

- This section contains **TWO** paragraphs
- Based on each paragraph, there are **TWO** questions
- Each question has **FOUR** options [A], [B], [C], and [D]. **ONLY ONE** of these four options is correct
- For each question, darken the bubble corresponding to the correct option in the ORS
- For each question, marks will be awarded in one of the following categories:

Full Marks : +3 If only the bubble corresponding to the correct option is darkened  
 Zero Marks : 0 In all other cases

**PARAGRAPH 1**

Let  $O$  be the origin, and  $\vec{OX}, \vec{OY}, \vec{OZ}$  be three unit vectors in the directions of the sides  $\overline{QR}, \overline{RP}, \overline{PQ}$ , respectively, of a triangle  $PQR$ .

Q.51  $|\vec{OX} \times \vec{OY}| =$

- [A]  $\sin(P + R)$      [B]  $\sin 2R$     [C]  $\sin(Q + R)$      [D]  $\sin(P + Q)$

Q.52 If the triangle  $PQR$  varies, then the minimum value of  $\cos(P + Q) + \cos(Q + R) + \cos(R + P)$  is

- [A]  $-\frac{3}{2}$     [B]  $\frac{5}{3}$     [C]  $\frac{3}{2}$      [D]  $-\frac{5}{3}$

Space for rough work

Handwritten rough work for Q.51 and Q.52. The work includes several diagrams of triangles with vectors and angles. For Q.51, it shows a triangle with vectors  $\vec{OX}, \vec{OY}, \vec{OZ}$  and calculations involving angles  $P, Q, R$ . For Q.52, it shows a calculation for the minimum value of the cosine sum, resulting in  $-\frac{3}{2}$ .

Q.51 rough work:  $\frac{1}{2} + \frac{1}{2} = \frac{-3}{2}$  1.5 1.66

Q.52 rough work:  $\cos 180^\circ = -1$ ,  $\cos 180^\circ = -1$ ,  $\cos 180^\circ = -1$ ,  $6 \ 59 + 60 + 61$ ,  $6 + 50 + 60 +$ ,  $90 \ 90$ ,  $90 \ 90$ ,  $90 \ \frac{1}{\sqrt{2}} \frac{1}{\sqrt{2}}$ ,  $3.45 \ 45 \ \sqrt{2}$ ,  $2.12$

PARAGRAPH 2

Let  $p, q$  be integers and let  $\alpha, \beta$  be the roots of the equation,  $x^2 - x - 1 = 0$ , where  $\alpha \neq \beta$ . For  $n = 0, 1, 2, \dots$ , let  $a_n = p\alpha^n + q\beta^n$ .

FACT: If  $a$  and  $b$  are rational numbers and  $a + b\sqrt{5} = 0$ , then  $a = 0 = b$ .

Q.53 If  $a_4 = 28$ , then  $p + 2q =$

[A] 7

[B] 21

[C] 14

[D] 12

Q.54  $a_{12} =$

[A]  $a_{11} + a_{10}$

[B]  $a_{11} - a_{10}$

~~[C]  $a_{11} + 2a_{10}$~~

[D]  $2a_{11} + a_{10}$

END OF THE QUESTION PAPER

Space for rough work

$$p\alpha^4 + q\beta^4$$

$$\frac{1 \pm \sqrt{1+4}}{2}$$

$$\alpha^2 \quad \alpha^3$$

$$\frac{1 \pm \sqrt{5}}{2}$$

$$p\alpha^n \quad p\alpha^{n+1} + q\beta^{n+1}$$

$$2\alpha^{10} + 2\beta^{10}$$

$$a_n \quad 2q =$$

$$p$$

$$5 \quad \sin 2x$$