

Time : 3 Hours

Maximum Marks : 183

### READ THE INSTRUCTIONS CAREFULLY



#### GENERAL

1. This sealed booklet is your Question Paper. Do not break the seal till you are told to do so.
2. The paper CODE is printed on the right hand top corner of this sheet and the right hand top corner of the back cover of this booklet.
3. Use the Optical Response Sheet (ORS) provided separately for answering the questions.
4. The paper CODE is printed on the left part as well as the right part of the ORS. Ensure that both these codes are identical and same as that on the question paper booklet. If not, contact the invigilator for change of ORS.
5. Blank spaces are provided within this booklet for rough work.
6. Write your name, roll number and sign in the space provided on the back cover of this booklet.
7. After breaking the seal of the booklet at 2:00 pm, verify that the booklet contains 36 pages and that all the 54 questions along with the options are legible. If not, contact the invigilator for replacement of the booklet.
8. You are allowed to take away the Question Paper at the end of the examination.

#### OPTICAL RESPONSE SHEET

9. The ORS (top sheet) will be provided with an attached Candidate's Sheet (bottom sheet). The Candidate's Sheet is a carbon-less copy of the ORS.
10. Darken the appropriate bubbles on the ORS by applying sufficient pressure. This will leave an impression at the corresponding place on the Candidate's Sheet.
11. The ORS will be collected by the invigilator at the end of the examination.
12. You will be allowed to take away the Candidate's Sheet at the end of the examination.
13. Do not tamper with or mutilate the ORS. Do not use the ORS for rough work.
14. Write your name, roll number and code of the examination center, and sign with pen in the space provided for this purpose on the ORS. Do not write any of these details anywhere else on the ORS. Darken the appropriate bubble under each digit of your roll number.

#### DARKENING THE BUBBLES ON THE ORS

15. Use a **BLACK BALL POINT PEN** to darken the bubbles on the ORS.
16. Darken the bubble  **COMPLETELY**.
17. The correct way of darkening a bubble is as : 
18. The ORS is machine-gradable. Ensure that the bubbles are darkened in the correct way.
19. Darken the bubbles **ONLY IF** you are sure of the answer. There is **NO WAY** to erase or "un-darken" a darkened bubble.

Please see the last page of this booklet for rest of the instructions.

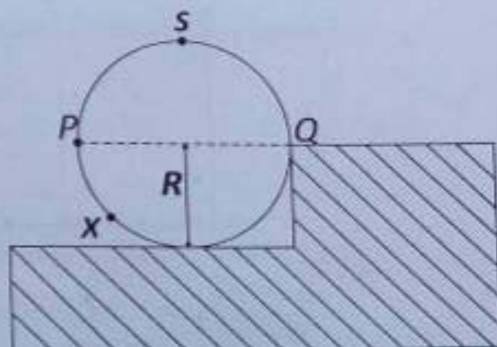
DO NOT BREAK THE SEALS WITHOUT BEING INSTRUCTED TO DO SO BY THE INVIGILATOR



*Arjun Singh*

480688

- Q.9 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 normal to the circumference at point  $P$  then  $\tau$  is zero
- [B] If the force is applied tangentially at point  $S$  then  $\tau \neq 0$  but the wheel never climbs the step
- [C] If the force is applied at point  $P$  tangentially then  $\tau$  decreases continuously as the wheel climbs
- [D] If the force is applied normal to the circumference at point  $X$  then  $\tau$  is constant

---

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

**Space for rough work**

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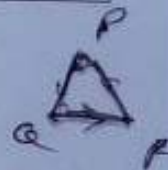
Full Marks : +3 If only the bubble corresponding to the correct option is darkened  
Zero Marks : 0 In all other cases

PARAGRAPH 1

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

Q.51 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]  $\frac{3}{2}$       [C]  $\frac{5}{3}$       [D]  $-\frac{5}{3}$



Q.52  $|\vec{OX} \times \vec{OY}| =$

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

Space for rough work

Q.49 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]  $g'(\frac{\pi}{2}) = -2\pi$

Q.50 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]  $f(x)$  attains its minimum at  $x = 0$

[B]  $f(x)$  attains its maximum at  $x = 0$

[C]  $f'(x) = 0$  at more than three points in  $(-\pi, \pi)$

[D]  $f'(x) = 0$  at exactly three points in  $(-\pi, \pi)$

Space for rough work

~~2 sin^-1 t + cos 2x~~  $\frac{d}{dx} \int_{\sin x}^{\sin 2x} \sin^{-1}(t) dt = \sin^{-1}(\sin 2x) \cdot 2 \cos 2x - \sin^{-1}(\sin x) \cdot \cos x$   
 $2 \sin 2x \cdot 2 \cos 2x - 1 \cdot \cos x = 4 \sin 2x \cos 2x - \cos x = 2 \sin 4x - \cos x$

$\begin{vmatrix} \cos 2x & 2 \cos 2x & \sin 2x \\ -\cos x & 0 & \sin x \\ \sin x & 2 \sin x & \cos x \end{vmatrix}$



20-4

2R

$0 + \frac{2}{2} \pi - 1 - 0$   
 $(2\pi)$

$\begin{vmatrix} 0 & 2 \cos x & \sin x \\ 2 \cos x & 0 & \sin x \\ 0 & \sin x & \cos x \end{vmatrix}$

$2 \cos x \sin x \cos x - 4 \sin x \cos x$   
~~2 cos x~~  
 $-2 \cos x$





Q.46 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]  $\frac{1}{2} < \alpha < 1$

[D]  $0 < \alpha \leq \frac{1}{2}$

Q.47 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]  $\tan\left(\frac{\alpha}{2}\right) - \sqrt{3} \tan\left(\frac{\beta}{2}\right) = 0$

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

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

Q.48 Let  $f(x) = \frac{1-x(1+[1-x])}{1-x} \cos\left(\frac{1}{1-x}\right)$  for  $x \neq 1$ . Then

[A]  $\lim_{x \rightarrow 1^+} f(x) = 0$

[B]  $\lim_{x \rightarrow 1^-} f(x)$  does not exist

[C]  $\lim_{x \rightarrow 1^-} f(x) = 0$

[D]  $\lim_{x \rightarrow 1^+} f(x)$  does not exist

Space for rough work

8-4x2

$x = \sqrt[3]{2}$

$\frac{2x^4}{4} + C$

$\left(\frac{y^4}{4} + C\right) = 2x^3 - 4x^{\frac{3}{2}+1}$

$16 - 8\sqrt{2} + 1$

$16$

$\frac{y^4}{4} + C = -\frac{1}{\sqrt{3}} + \sqrt{3}$

$2 \times 8 - 4 \times 8^{\frac{1}{2}} - 1 + 1$

$16 + C$

$\frac{2x^4}{4} + C = 2$

$16 = 2x^4$

$8 = x^4$

$x = \sqrt[4]{8} = \sqrt[2]{2}$

$16 + C$

$16 = 2x^4$

$8 = x^4$

$x = \sqrt[4]{8} = \sqrt[2]{2}$

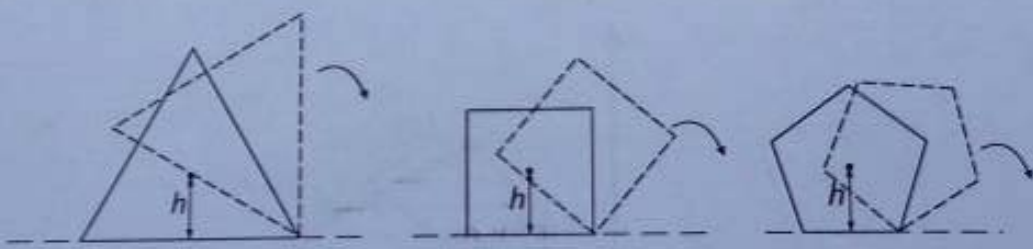
$2$

$h\nu = \phi_0 + \frac{1}{2}mv^2$   
 $\frac{hc}{\lambda} = \phi_0 + \frac{1}{2}mv^2$   
 $\frac{d}{d\lambda} \left( \frac{hc}{\lambda} \right) = \frac{d}{d\lambda} \left( \phi_0 + \frac{1}{2}mv^2 \right)$   
 $-\frac{hc}{\lambda^2} = \frac{d}{d\lambda} \left( \frac{1}{2}mv^2 \right)$   
 $-\frac{hc}{\lambda^2} = \frac{1}{2}m \cdot 2v \frac{dv}{d\lambda}$   
 $-\frac{hc}{\lambda^2} = mv \frac{dv}{d\lambda}$   
 $\frac{d\lambda}{\lambda^2} = \frac{m}{h} v dv$   
 $\frac{d\lambda}{\lambda^2} = \frac{m}{h} \frac{h}{m\lambda} d\lambda$   
 $\frac{d\lambda}{\lambda^2} = \frac{d\lambda}{\lambda}$

Q.6 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]  $\lambda_d^3/\lambda$       [C]  $\lambda_d^2/\lambda^2$       [D]  $\lambda_d/\lambda$

Q.7 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]  $\Delta = h \tan^2\left(\frac{\pi}{2n}\right)$   
 [C]  $\Delta = h \sin^2\left(\frac{\pi}{n}\right)$       [D]  $\Delta = h \left( \frac{1}{\cos\left(\frac{\pi}{n}\right)} - 1 \right)$

Space for rough work









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  $g$ .

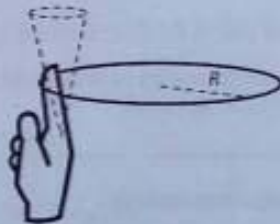


Figure 1

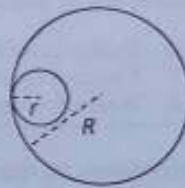


Figure 2

Q.17 The total kinetic energy of the ring is

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

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

$M \omega_0^2 R^2$

~~[C]  $M \omega_0^2 R^2$~~

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

Q.18 The minimum value of  $\omega_0$  below which the ring will drop down is

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

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

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

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

END OF PART I : PHYSICS

Space for rough work

$$mg \omega_0^2 (R-r) = mgh$$

$$= gx$$

Q.39 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] 198                      [B] 162                      [C] 126                      [D] 135

Q.40 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]  $\frac{1}{2}$                       [B]  $\frac{26}{55}$                       [C]  $\frac{6}{11}$                       ~~[D]  $\frac{5}{11}$~~

Q.41 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] 126~~                      [D] 125

Space for rough work

odd are

$$1, 3, 5, 7, 9 \quad \begin{bmatrix} 0 \\ 2 \\ 2 \end{bmatrix} \begin{bmatrix} 2 \\ 1 \\ 0 \end{bmatrix} \quad \text{S1}$$

$${}^5C_1 + {}^5C_2 + {}^5C_3 + {}^5C_4 + {}^5C_5 \quad 2 > 0 \quad 2 > 0$$

$$\frac{5 \times 4!}{3!} + \frac{5 \times 4 \times 3!}{2! \times 2!} + \frac{5 \times 4 \times 3!}{3! \times 2!} + 5$$

0, 1, 2, 3, 4, 5

$$20 + 4 + 5 + 1$$

$$= 30$$

26

$$10 + 10 +$$

$$0 \times 5 + 2 \times 10 \times 2 + 10 \times 5 + 1 \times 5$$

30

30

5

150

$$5 + 20 + 30 + 20 + 5$$

6x

$$30 + 40 + 5 \quad 30 + 10 = 100$$

27/36

${}^5C_1 \times A_{14}$

$$\frac{2 \times 4 \times 3 \times 2}{2! \times 2!}$$

$$3 \times 1 + 10 \times 4 + 60 + 5 \times 4 + 1$$

$$100 + 20 + 1$$





- Q.24 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] 58001 bar      [B] 1450 bar      [C] 14501 bar      [D] 29001 bar

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

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

Space for rough work

$\text{Cu}_2\text{O} + \text{HNO}_3 \rightarrow \text{H}_2$   
 $\text{Fe} + \text{HNO}_3 \rightarrow \text{H}_2$   
 $\text{Zn} + \text{NaOH} \rightarrow \text{H}_2$

$\Delta G = 238 \times 8.31 \log k_p$   
 $\frac{2300}{2476.38} = 1.2$   
 $1.2 = \frac{12}{10} \times 2 = 2.4$

$\begin{array}{r} 76 \\ 258 \\ \times 631 \\ \hline 1834 \\ 23844 \\ \hline 247638 \end{array}$

$\Delta G = 238 \times 8.31 \log k_p$   
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 $\Delta G = 238 \times 8.31 \log k_p$



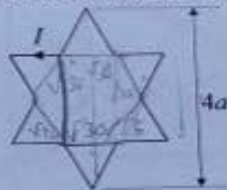
## PART I : PHYSICS

### 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 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



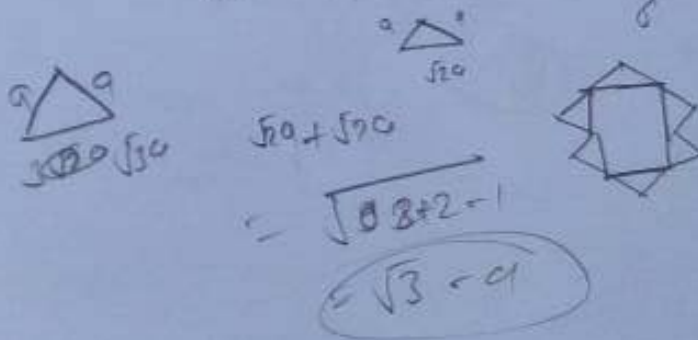
[A]  $\frac{\mu_0 I}{4\pi a} 6[\sqrt{3} - 1]$

[B]  $\frac{\mu_0 I}{4\pi a} 6[\sqrt{3} + 1]$

[C]  $\frac{\mu_0 I}{4\pi a} 3[2 - \sqrt{3}]$

~~[D]  $\frac{\mu_0 I}{4\pi a} 3[\sqrt{3} - 1]$~~

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
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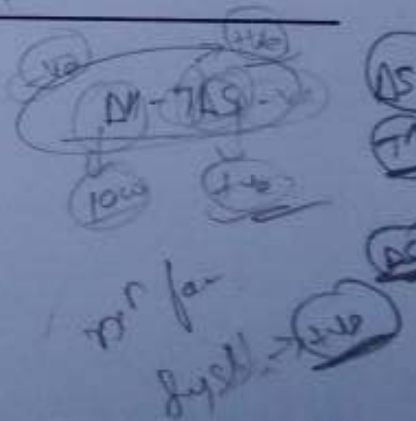
<i>Full Marks</i>	: +4	If only the bubble(s) corresponding to all the correct option(s) is(are) darkened
<i>Partial Marks</i>	: +1	For darkening a bubble corresponding to <b>each correct option</b> , provided <b>NO</b> incorrect option is darkened
<i>Zero Marks</i>	: 0	If none of the bubbles is darkened
<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.26 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 endothermic reaction increases because unfavourable change in entropy of the surroundings decreases
- [B] With increase in temperature, the value of  $K$  for exothermic reaction decreases because favourable 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 the entropy change of the system is positive

Space for rough work

endo  
exo  
K ↑  
K ↓  
K ↑  
K ↓  
T ↓ K ↓





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

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

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

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

Q.45 If  $I = \sum_{k=1}^{99} \int_k^{k+1} \frac{k+1}{x(x+1)} dx$ , then

[A]  $I > \log_e 99$

[B]  $I < \log_e 99$

[C]  $I < \frac{49}{50}$

[D]  $I > \frac{49}{50}$

Space for rough work



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

- [A]  $\text{Al}(\text{CH}_3)_3$  has the three-centre two-electron bonds in its dimeric structure  
 [B] The Lewis acidity of  $\text{BCl}_3$  is greater than that of  $\text{AlCl}_3$   
 [C]  $\text{AlCl}_3$  has the three-centre two-electron bonds in its dimeric structure  
 [D]  $\text{BH}_3$  has the three-centre two-electron bonds in its dimeric structure

Q.30 The option(s) with only amphoteric oxides is(are)

- [A]  $\text{NO}$ ,  $\text{B}_2\text{O}_3$ ,  $\text{PbO}$ ,  $\text{SnO}_2$                       [B]  $\text{Cr}_2\text{O}_3$ ,  $\text{CrO}$ ,  $\text{SnO}$ ,  $\text{PbO}$   
 [C]  $\text{Cr}_2\text{O}_3$ ,  $\text{BeO}$ ,  $\text{SnO}$ ,  $\text{SnO}_2$                       [D]  $\text{ZnO}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{PbO}$ ,  $\text{PbO}_2$

Space for rough work

Handwritten notes in the rough work space:

Left side (written vertically):  
Sn  
Pb  
Al  
Cr  
Sn  
B  
Pb  
Sn

Right side (written diagonally):  
Al  
Al  
L.P. (circled)  
Zn, Al, Pb, Sn

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

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<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

**Space for rough work**

Q.31 The correct statement(s) about surface properties is(are)

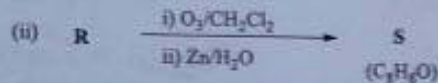
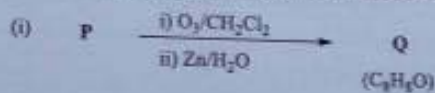
[A] The critical temperatures of ethane and nitrogen are 563 K and 126 K, respectively. The adsorption of ethane will be more than that of nitrogen on same amount of activated charcoal at a given temperature

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

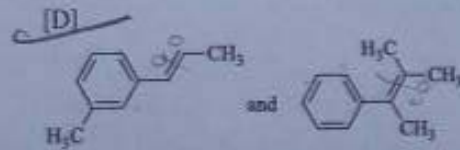
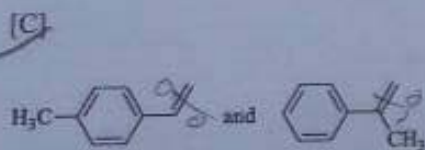
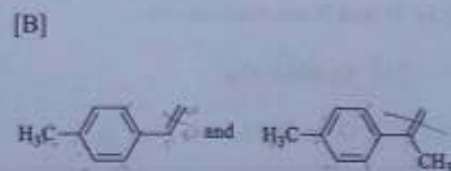
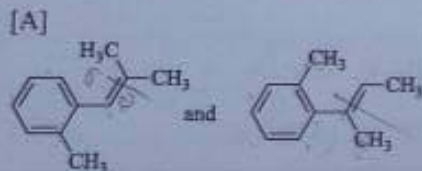
[C] Adsorption is accompanied by decrease in enthalpy and decrease in entropy of the system

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

Q.32 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)



Space for rough work



Q.42 Let  $O$  be the origin and let  $PQR$  be an arbitrary triangle. The point  $S$  is such that

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

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

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

Q.43 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]  $14x + 2y - 15z = 1$  [B]  ~~$-14x + 2y + 15z = 3$~~   
 [C]  $14x - 2y + 15z = 27$  [D]  $14x + 2y + 15z = 31$

Space for rough work



$$\begin{vmatrix} 2 & 1 & -2 \\ 3 & -6 & -2 \end{vmatrix}$$

$$1(-2-12) - 1(-4+6) + 1(-12+3)$$

$$-14 + 2 + 15$$

$$17 - 14 = 3$$

## 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 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]  $f'(1) \leq 0$

[B]  ~~$f'(1) > 1$~~

[C]  $0 < f'(1) \leq \frac{1}{2}$

[D]  $\frac{1}{2} < f'(1) \leq 1$

Q.38 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] 3

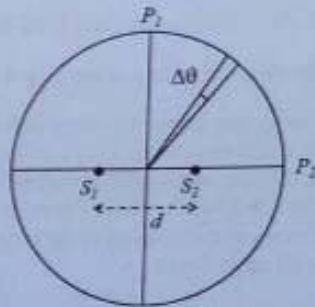
[C] 9

[D] 80

Space for rough work

$dy = \frac{dx}{(8\sqrt{x}) \left( \sqrt{4 + \sqrt{9 + \sqrt{x}}} \right)^{-1}}$   
 $\frac{dy}{dx} = \frac{1}{32x \sqrt{4 + \sqrt{9 + \sqrt{x}}}}$   
 $x^2 - \frac{2x}{2} + c$   
 $\frac{1}{4} - \frac{2}{2} + c = \frac{1-2}{4}$   
 $\frac{1}{4} - \frac{1}{4} + c$   
 $2x - \frac{1}{2}$   
 $2 \frac{1}{4} = \left( \frac{3}{2} \right)$   
 $\frac{1}{4} - \frac{1}{4}$

- Q.8 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

$$D \Delta \theta = d \sin \theta$$

$$\Delta \theta = \frac{d \sin \theta}{D} = \frac{1.8 \times 10^{-3}}{3} \frac{10^{-5}}{3}$$



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**.

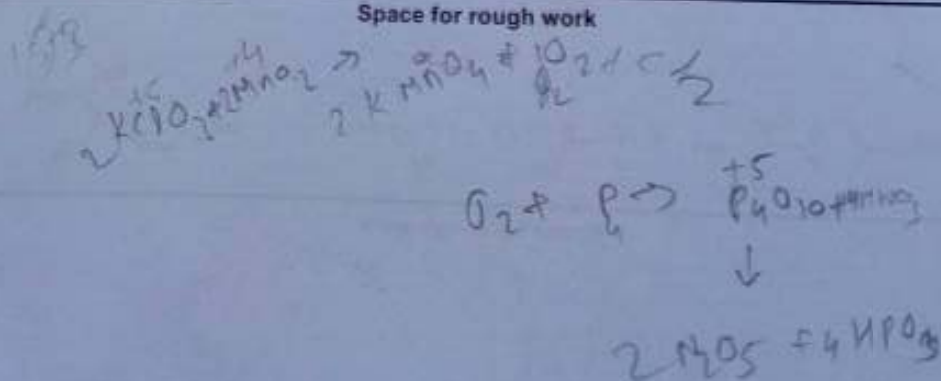
Q.33 **Y** and **Z** are, respectively

- [A]  $\text{N}_2\text{O}_4$  and  $\text{HPO}_3$  [B]  $\text{N}_2\text{O}_4$  and  $\text{H}_3\text{PO}_3$   
 [C]  $\text{N}_2\text{O}_3$  and  $\text{H}_3\text{PO}_4$  [D]  $\text{N}_2\text{O}_5$  and  $\text{HPO}_3$

Q.34 **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  $\text{P}_4\text{O}_{10}$

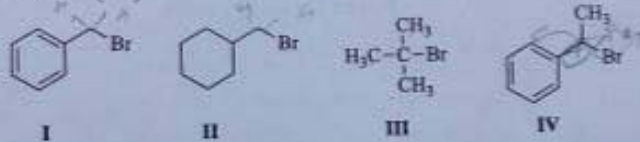
Space for rough work



Q.27 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] The activation energy of the reaction is unaffected by the value of the steric factor
- [B] Experimentally determined value of frequency factor is higher than that predicted by Arrhenius equation
- [C] The value of frequency factor predicted by Arrhenius equation is higher than that determined experimentally
- ~~[D] Since  $P = 4.5$ , the reaction will not proceed unless an effective catalyst is used~~

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



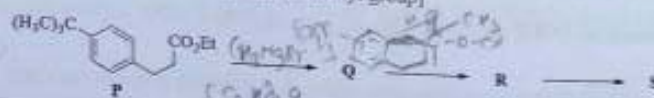
- [A] Compound **IV** undergoes inversion of configuration
- ~~[B] The order of reactivity for **I**, **III** and **IV** is:  $IV > I > III$~~
- ~~[C] **I** and **III** follow  $S_N1$  mechanism~~
- ~~[D] **I** and **II** follow  $S_N2$  mechanism~~

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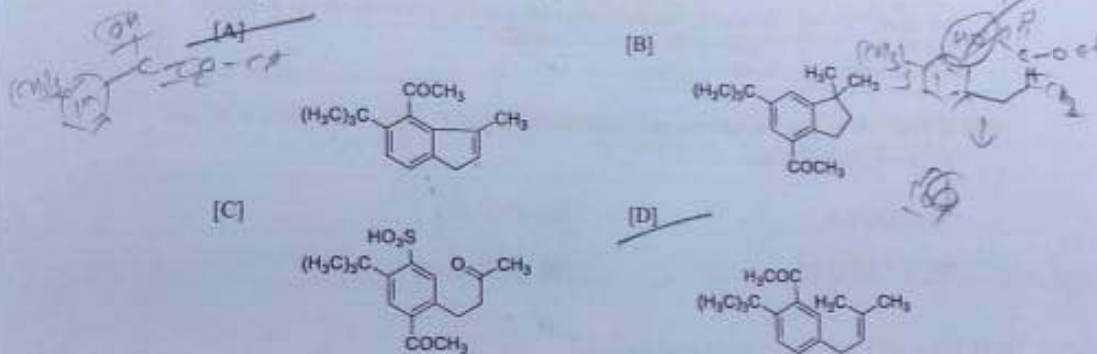
Space for rough work

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 product **S** is

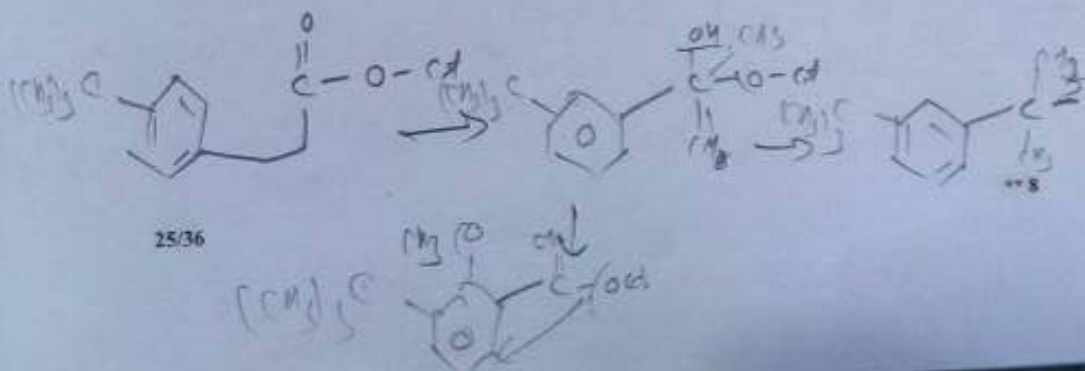


Q.36 The reactions, **Q** to **R** and **R** to **S**, are

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

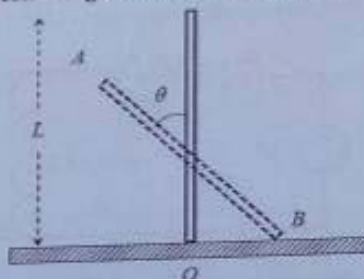
END OF PART II : CHEMISTRY

Space for rough work



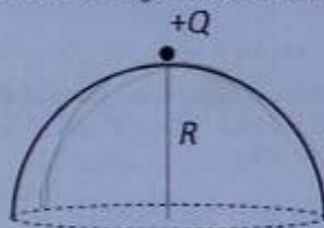


Q.13 A rigid uniform bar AB of length  $L$  is slipping from its vertical position on a frictionless floor (as shown in the figure). At some instant of time, the angle made by the bar with the vertical is  $\theta$ . Which of the following statements about its motion is/are correct?



- [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] When the bar makes an angle  $\theta$  with the vertical, the displacement of its midpoint from the initial position is proportional to  $(1 - \cos \theta)$
- [D] The midpoint of the bar will fall vertically downward

Q.14 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?



$\epsilon \cdot dA$

$\int \cdot dA$

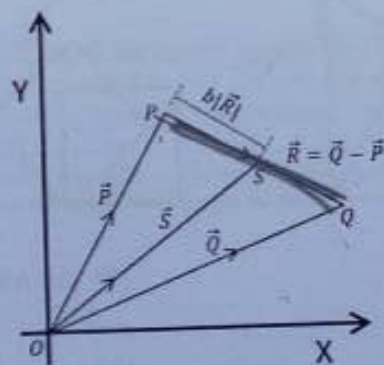
- ~~[A]~~ Total flux through the curved and the flat surfaces is  $\frac{Q}{\epsilon_0}$
- [B] The component of the electric field normal to the flat surface is constant over the surface
- ~~[C]~~ The circumference of the flat surface is an equipotential
- [D] The electric flux passing through the curved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

Space for rough work

Q.4 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]  $v_s = 72 \text{ km s}^{-1}$  [B]  $v_s = 22 \text{ km s}^{-1}$   
 [C]  $v_s = 42 \text{ km s}^{-1}$  [D]  $v_s = 62 \text{ km s}^{-1}$

Q.5 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

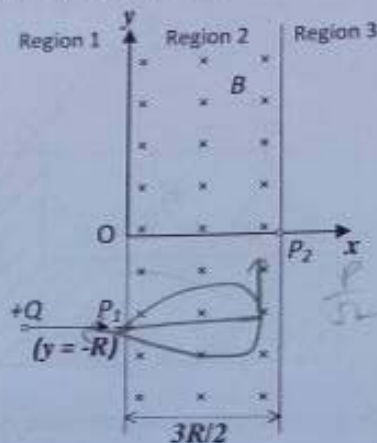


$\vec{P} - \vec{S} = b|\vec{R}|$   
 $\vec{S} = \vec{P} - b|\vec{R}|$   
 $= \vec{P} - b(\vec{Q} - \vec{P})$   
 $= (1+b)\vec{P} - b\vec{Q}$   
 $\vec{S} = (1+b)\vec{P} - b\vec{Q}$

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

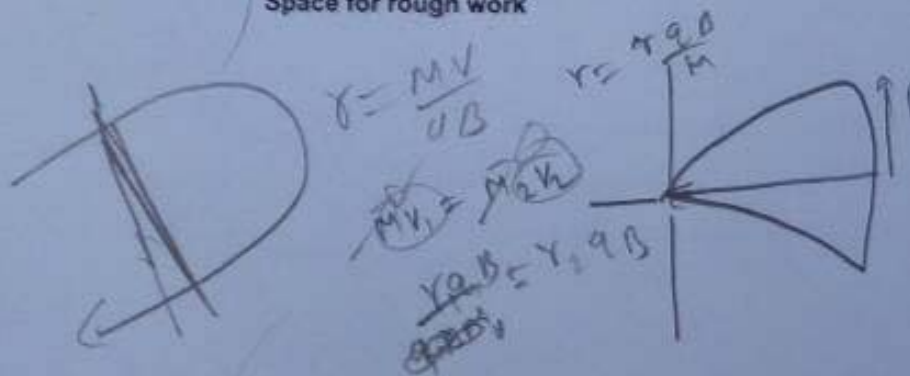
Space for rough work

- 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?



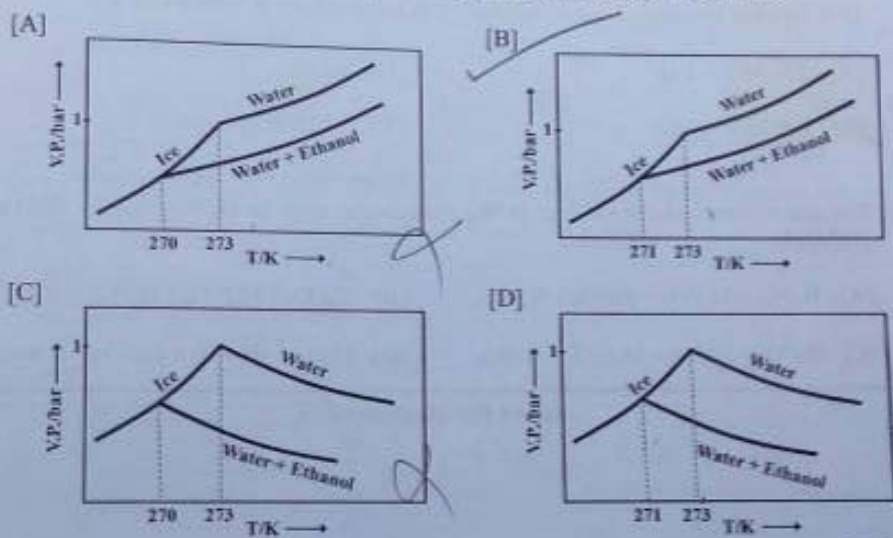
- [A] When the particle re-enters region 1 through the longest possible path in region 2, the magnitude of the change in its linear momentum between point  $P_1$  and the farthest point from  $y$ -axis is  $p/\sqrt{2}$
- [B] For a fixed  $B$ , particles of same charge  $Q$  and same velocity  $v$ , the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

Space for rough work



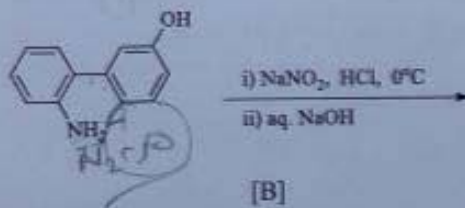


Q.20 Pure water freezes at 273 K and 1 bar. The addition of 34.5 g of ethanol to 500 g of water changes the freezing point of the solution. Use the freezing point depression constant of water as  $2 \text{ K kg mol}^{-1}$ . The figures shown below represent plots of vapour pressure (V.P.) versus temperature (T). [molecular weight of ethanol is  $46 \text{ g mol}^{-1}$ ]  
Among the following, the option representing change in the freezing point is



Handwritten calculations:  
 $\frac{34.5}{46} \times 1000$   
 $750$   
 $750 \times 2$   
 $1500$   
 $273 - 1500$   
 $273 - 1500$

Q.21 The major product of the following reaction is

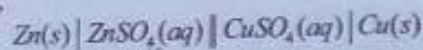


- [A]
- [B]
- [C]
- [D]

(771)

Space for rough work

Q.22 For the following cell,



when the concentration of  $\text{Zn}^{2+}$  is  $10^{10}$  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;  $E^\circ(\text{cell}) = 1.1 \text{ V}$ ]

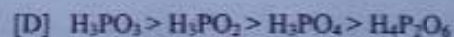
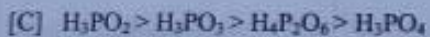
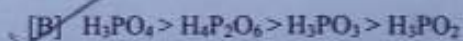
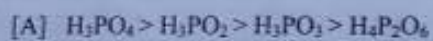
[A]  $2.303RT + 1.1F$

[B]  $1.1F$

[C]  $2.303RT - 2.2F$

[D]  $-2.2F$

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



Space for rough work

$nF\epsilon^\circ_{cell}$   
 $\Delta G = -2.303RT \log K$

$\frac{1}{10^{10}}$   
 $\frac{10^{-10}}{10^{-2}} = 10^{-8}$

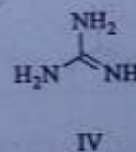
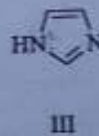
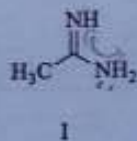
## PART II : CHEMISTRY

### 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 The order of basicity among the following compounds is



~~[A] II > I > IV > III~~

[B] I > IV > III > II

[C] IV > II > III > I

[D] IV > I > II > III

Space for rough work