

Date: 26/05/2024



# Aakash

Medical | IIT-JEE | Foundations

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Time : 3 hrs.

## Answers & Solutions

Max. Marks: 180

for

## JEE (Advanced)-2024 (Paper-1)

### PART-I : MATHEMATICS

#### SECTION 1 (Maximum Marks : 12)

- This section contains **FOUR (04)** questions.
- Each question has **FOUR** options (A), (B), (C) and (D). **ONLY ONE** of these four options is the correct answer.
- For each question, choose the option corresponding to the correct answer.
- Answer to each question will be evaluated according to the following marking scheme:

**Full Marks** : +3 If **ONLY** the correct option is chosen;

**Zero Marks** : 0 If none of the options is chosen (i.e. the question is unanswered);

**Negative Marks** : -1 In all other cases.

1. Let  $f(x)$  be a continuously differentiable function on the interval  $(0, \infty)$  such that  $f(1) = 2$  and

$$\lim_{t \rightarrow x} \frac{t^{10}f(x) - x^{10}f(t)}{t^9 - x^9} = 1$$

for each  $x > 0$ . Then, for all  $x > 0$ ,  $f(x)$  is equal to

(A)  $\frac{31}{11x} - \frac{9}{11}x^{10}$

(B)  $\frac{9}{11x} + \frac{13}{11}x^{10}$

(C)  $\frac{-9}{11x} + \frac{31}{11}x^{10}$

(D)  $\frac{13}{11x} + \frac{9}{11}x^{10}$

Answer (B)

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**100**  
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4 Year Classroom

Telangana Topper

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**100**  
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**M. Sai Divya Teja Reddy**  
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Telangana Topper

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Punjab Topper

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**100**  
PERCENTILE OVERALL  
**Rachit Aggarwal**  
4 Year Classroom



**Tanishka Kabra**  
4 Year Classroom  
**ALL INDIA RANK 1**  
AIR-16 CRL  
JEE (Adv.)  
2022  
(Female)



**Chirag Falor**  
4 Year Classroom  
**ALL INDIA RANK 1**  
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JEE (Adv.)  
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Sol.  $\lim_{t \rightarrow x} \frac{t^{10}f(x) - x^{10}f(t)}{t^9 - x^9} = 1$

$$\lim_{t \rightarrow x} \frac{10t^9f(x) - f'(t)x^{10}}{9t^8} = 1$$

$$\Rightarrow 10x^9f(x) - f'(x)x^{10} = 9x^8$$

$$\Rightarrow f'(x) - \frac{10}{x}f(x) = -\frac{9}{x^2}$$

$$IF = e^{-\int \frac{10}{x} dx} = \frac{1}{x^{10}}$$

∴ Sol<sup>n</sup>

$$\frac{y}{x^{10}} = \int -\frac{9}{x^{10}} \times \frac{1}{x^2} dx$$

$$= -9 \int x^{-12} dx$$

$$\frac{y}{x^{10}} = \frac{9}{11} x^{-11} + C$$

$$\because y(1) = 2 \Rightarrow C = \frac{13}{11}$$

$$\Rightarrow y = \frac{9}{11x} + \frac{13}{11} x^{10}$$

2. A student appears for a quiz consisting of only true-false type questions and answers all the questions. The student knows the answers of some questions and guesses the answers for the remaining questions. Whenever the student knows the answer of a question, he gives the correct answer. Assume that the probability of the student giving the correct answer for a question, given that he has guessed it, is  $\frac{1}{2}$ . Also assume that the probability of the answer for a question being guessed, given that the student's answer is correct, is  $\frac{1}{6}$ . Then the probability that the student knows the answer of a randomly chosen question is

(A)  $\frac{1}{12}$

(B)  $\frac{1}{7}$

(C)  $\frac{5}{7}$

(D)  $\frac{5}{12}$

Answer (C)

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Sol. Let  $P(\text{knows answer}) = k$

$$P(\text{guesses}) = 1 - k$$

$$P\left(\frac{\text{correct ans}}{\text{guessed}}\right) = \frac{1}{2}$$

$$P\left(\frac{\text{guessed}}{\text{correct answer}}\right) = \frac{P(\text{guessed}) P\left(\frac{\text{correct ans}}{\text{guessed}}\right)}{P(\text{guessed}) P\left(\frac{\text{correct ans}}{\text{guessed}}\right) + P(\text{knows}) P\left(\frac{\text{correct ans}}{\text{knows}}\right)}$$

$$= \frac{(1-k)\left(\frac{1}{2}\right)}{(1-k)\left(\frac{1}{2}\right) + k(1)} = \frac{1}{6}$$

$$\Rightarrow (3 - 3k) = \frac{1}{2} + \frac{k}{2}$$

$$\Rightarrow \frac{5}{2} = \frac{7k}{2} \Rightarrow k = \frac{5}{7}$$

3. Let  $\frac{\pi}{2} < x < \pi$  be such that  $\cot x = \frac{-5}{\sqrt{11}}$ . Then  $\left(\sin \frac{11x}{2}\right)(\sin 6x - \cos 6x) + \left(\cos \frac{11x}{2}\right)(\sin 6x + \cos 6x)$  is equal to

(A)  $\frac{\sqrt{11}-1}{2\sqrt{3}}$

(B)  $\frac{\sqrt{11}+1}{2\sqrt{3}}$

(C)  $\frac{\sqrt{11}+1}{3\sqrt{2}}$

(D)  $\frac{\sqrt{11}-1}{3\sqrt{2}}$

Answer (B)

Sol. Let  $E = \sin 6x \cos \frac{11x}{2} - \cos 6x \sin \frac{11x}{2} + \cos 6x \cos \frac{11x}{2} + \sin 6x \sin \frac{11x}{2}$

$$E = \sin \frac{x}{2} + \cos \frac{x}{2}$$

Now,  $E^2 = 1 + \sin x$

$$\therefore \cot x = \frac{-5}{\sqrt{11}}$$

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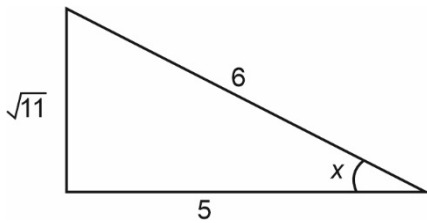
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$$= 1 + \frac{\sqrt{11}}{6}$$



$$\begin{aligned} \therefore E &= \sqrt{\frac{6 + \sqrt{11}}{6}} \\ &= \sqrt{\frac{12 + 2\sqrt{11}}{12}} \\ &= \frac{\sqrt{11} + 1}{2\sqrt{3}} \end{aligned}$$

4. Consider the ellipse  $\frac{x^2}{9} + \frac{y^2}{4} = 1$ . Let  $S(p, q)$  be a point in the first quadrant such that  $\frac{p^2}{9} + \frac{q^2}{4} > 1$ . Two tangents are drawn from  $S$  to the ellipse, of which one meets the ellipse at one end point of the minor axis and the other meets the ellipse at a point  $T$  in the fourth quadrant. Let  $R$  be the vertex of the ellipse with positive  $x$ -coordinate and  $O$  be the center of the ellipse. If the area of the triangle  $\triangle ORT$  is  $\frac{3}{2}$ , then which of the following options is correct?

- (A)  $q = 2, p = 3\sqrt{3}$   
 (B)  $q = 2, p = 4\sqrt{3}$   
 (C)  $q = 1, p = 5\sqrt{3}$   
 (D)  $q = 1, p = 6\sqrt{3}$

Answer (A)

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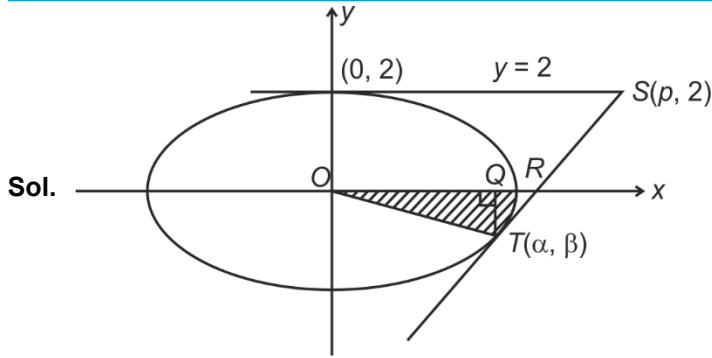
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$$q = 2$$

$$\text{Area (ORT)} = \frac{3}{2}$$

$$\Rightarrow \left| \frac{1}{2} \times OR \times QT \right| = \frac{3}{2}$$

$$\Rightarrow \left| \frac{1}{2} \times 3 \times \beta \right| = \frac{3}{2}$$

$$\Rightarrow \beta = -1$$

$$\therefore \frac{\alpha^2}{9} + \frac{\beta^2}{4} = 1$$

$$\Rightarrow \frac{\alpha^2}{9} = 1 - \frac{1}{4} = \frac{3}{4}$$

$$\Rightarrow \alpha^2 = \frac{27}{4} \Rightarrow \alpha = \frac{3\sqrt{3}}{2}$$

Tangent at T

$$T = 0$$

$$x \cdot \frac{3\sqrt{3}}{2} + \frac{y(-1)}{4} = 1 \Big|_{(p, 2)}$$

$$\Rightarrow \frac{p\sqrt{3}}{6} - \frac{1}{2} = 1 \Rightarrow \frac{p\sqrt{3}}{6} = \frac{3}{2} \Rightarrow p = 3\sqrt{3}$$

$$\therefore p = 3\sqrt{3}, q = 2$$

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**SECTION 2 (Maximum Marks : 12)**

- This section contains **THREE (03)** questions.
- Each question has **FOUR** options (A), (B), (C) and (D). **ONE OR MORE THAN ONE** of these four option(s) is(are) correct answer(s).
- For each question, choose the option(s) corresponding to (all) the correct answer(s).
- Answer to each question will be evaluated according to the following marking scheme:

**FULL MARKS** : +4 **ONLY** if (all) the correct option(s) is(are) chosen;

**Partial Marks** : +3 If all the four options are correct but **ONLY** three options are chosen;

**Partial Marks** : +2 If three or more options are correct but **ONLY** two options are chosen, both of which are correct;

**Partial Marks** : +1 If two or more options are correct but **ONLY** one option is chosen and it is a correct option;

**Zero Marks** : 0 If none of the options is chosen (i.e. the question is unanswered);

**Negative Marks** : -2 In all other cases.

5. Let  $S = \{a + b\sqrt{2} : a, b \in \mathbb{Z}\}$ ,  $T_1 = \{(-1 + \sqrt{2})^n : n \in \mathbb{N}\}$  and  $T_2 = \{(1 + \sqrt{2})^n : n \in \mathbb{N}\}$ . Then which of the following statements is (are) TRUE?
- (A)  $\mathbb{Z} \cup T_1 \cup T_2 \subset S$
- (B)  $T_1 \cap \left(0, \frac{1}{2024}\right) = \phi$ , where  $\phi$  denotes the empty set
- (C)  $T_2 \cap (2024, \infty) \neq \phi$
- (D) For any given  $a, b \in \mathbb{Z}$ ,  $\cos(\pi(a + b\sqrt{2})) + i \sin(\pi(a + b\sqrt{2})) \in \mathbb{Z}$  if and only if  $b = 0$ , where  $i = \sqrt{-1}$

**Answer (A, C, D)**

**Sol.**  $S = \{a + b\sqrt{2} : a, b \in \mathbb{Z}\}$

For  $b = 0$ ;  $\mathbb{Z} \subset S$

$T_1 = \{(-1 + \sqrt{2})^n : n \in \mathbb{N}\}$  and  $T_2 = \{(1 + \sqrt{2})^n : n \in \mathbb{N}\}$

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For  $n \in \mathbb{N}$  elements of  $T_1$  and  $T_2$  are of the form  $a + b\sqrt{2}$

Hence  $Z \cup T_1 \cup T_2 \subset S$

- Now,  $-1 + \sqrt{2} < 1$  and its higher powers decreases

$\Rightarrow (-1 + \sqrt{2})^n < 1$  and can be made in  $(0, \frac{1}{2024})$  for some higher  $n$ .

- $1 + \sqrt{2} > 1$  and its higher power increases

$\Rightarrow (1 + \sqrt{2})^n$  can be made in  $(2024, \infty)$  for some higher  $n$ .

- $\cos \pi(a + b\sqrt{2}) + i \sin \pi(a + b\sqrt{2}) \in Z$  if

$a + b\sqrt{2}$  is an integer  $\Rightarrow b = 0$

6. Let  $\mathbb{R}^2$  denote  $\mathbb{R} \times \mathbb{R}$ . Let

$S = \{(a, b, c) : a, b, c \in \mathbb{R} \text{ and } ax^2 + 2bxy + cy^2 > 0 \text{ for all } (x, y) \in \mathbb{R}^2 - \{(0, 0)\}\}$ .

Then which of the following statements is (are) TRUE?

(A)  $(2, \frac{7}{2}, 6) \in S$

(B) If  $(3, b, \frac{1}{12}) \in S$ , then  $|2b| < 1$

(C) For any given  $(a, b, c) \in S$ , the system of linear equations  $\begin{cases} ax + by = 1 \\ bx + cy = -1 \end{cases}$  has a unique solution.

(D) For any given  $(a, b, c) \in S$ , the system of linear equations  $\begin{cases} (a+1)x + by = 0 \\ bx + (c+1)y = 0 \end{cases}$  has a unique solution.

**Answer (B, C, D)**

**Sol.**  $ax^2 + 2bxy + cy^2 > 0$

$y, x \in \mathbb{R} - \{(0, 0)\}$

$$\Rightarrow c\left(\frac{y}{x}\right)^2 + 2b\left(\frac{y}{x}\right) + a > 0$$

$$\Rightarrow c > 0, D < 0$$

$$4b^2 - 4ac < 0$$

$$\Rightarrow b^2 < ac$$

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(A)  $\left(2, \frac{7}{2}, 6\right)$

$$\left(\frac{7}{2}\right)^2 > 2 \times 6$$

∴ option A is incorrect

(B) If  $\left(3, b, \frac{1}{12}\right) \in S$

$$\Rightarrow b^2 < 3 \cdot \frac{1}{12}$$

$$\Rightarrow b^2 < \frac{1}{4}$$

$$\Rightarrow 4b^2 < 1$$

$$\Rightarrow |2b| < 1 \text{ option B is correct}$$

(C)  $ax + by = 1$

$$bx + cy = -1$$

$$D = \begin{vmatrix} a & b \\ b & c \end{vmatrix} = ac - b^2 \neq 0$$

∴ unique solution option C is correct.

(D)  $(a + 1)x + by = 0$

$$bx + (c + 1)y = 0$$

$$D = \begin{vmatrix} (a+1) & b \\ b & (c+1) \end{vmatrix}$$

$$= (a + 1)(c + 1) - b^2$$

$$\Rightarrow ac - b^2 + a + c + 1$$

$$b^2 < ac \Rightarrow ac \text{ is +ve}$$

$$\Rightarrow a \text{ and } c \text{ are positive then } (ac - b^2) + a + c + 1 > 0 \therefore \text{unique solution}$$

∴ option D is correct.

7. Let  $\mathbb{R}^3$  denote the three-dimensional space. Take two points  $P = (1, 2, 3)$  and  $Q = (4, 2, 7)$ . Let  $\text{dist}(X, Y)$  denote the distance between two points  $X$  and  $Y$  in  $\mathbb{R}^3$ . Let

$$S = \{X \in \mathbb{R}^3 : (\text{dist}(X, P))^2 - (\text{dist}(X, Q))^2 = 50\} \text{ and}$$

$$T = \{Y \in \mathbb{R}^3 : (\text{dist}(Y, Q))^2 - (\text{dist}(Y, P))^2 = 50\}.$$

Then which of the following statements is (are) TRUE?

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- (A) There is a triangle whose area is 1 and all of whose vertices are from  $S$ .
- (B) There are two distinct points  $L$  and  $M$  in  $T$  such that each point on the line segment  $LM$  is also in  $T$ .
- (C) There are infinitely many rectangles of perimeter 48, two of whose vertices are from  $S$  and the other two vertices are from  $T$ .
- (D) There is a square of perimeter 48, two of whose vertices are from  $S$  and the other two vertices are from  $T$ .

**Answer (A, B, C)**

**Sol.**  $S : \{(x-1)^2 + (y-2)^2 + (z-3)^2 - ((x-4)^2 + (y-2)^2 + (z-7)^2) = 50\}$

$\Rightarrow S : \{6x + 8z - 105 = 0\}$

Similarly  $T = \{6x + 8z - 5 = 0\}$

$S$  represents a plane. So it will contain a triangle of area 1. So (A) is correct.

$T$  represents a plane. So (B) is correct.

$S$  &  $T$  are two parallel planes at a distance of 10 units from each other.

$\therefore$  (C) is correct and (D) is incorrect.

**SECTION 3 (Maximum Marks : 24)**

- This section contains **SIX (06)** questions.
- The answer to each question is a **NON-NEGATIVE INTEGER**.
- For each question, enter the correct integer corresponding to the answer using the mouse and the on-screen virtual numeric keypad in the place designated to enter the answer.
- Answer to each question will be evaluated according to the following marking scheme:

**Full Marks** : +4 If **ONLY** the correct integer is entered;

**Zero Marks** : 0 In all other cases.

8. Let  $a = 3\sqrt{2}$  and  $b = \frac{1}{5^6 \sqrt{6}}$ . If  $x, y \in \mathbb{R}$  are such that

$3x + 2y = \log_a(18)^{\frac{5}{4}}$  and

$2x - y = \log_b(\sqrt{1080})$ ,

then  $4x + 5y$  is equal to \_\_\_\_\_.

**Answer (8)**

**Sol.**  $a = 3\sqrt{2} \Rightarrow a^2 = 18$

Notice that  $1080 = 5 \cdot 6^3 \Rightarrow$

$5^{\frac{1}{6}} \cdot 6^{\frac{1}{2}} = (1080)^{\frac{1}{6}} = \frac{1}{b} \Rightarrow 1080^{\frac{1}{2}} = \frac{1}{b^3}$

$\Rightarrow 3x + 2y = \log_a(a^2)^{\frac{5}{4}} = \frac{5}{2} \dots(i)$

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$$2x - y = \log_b \frac{1}{b^3} = \log_b b^{-3} = -3 \quad \dots(ii)$$

⇒ Solving (i) & (ii)

$$\Rightarrow x = \frac{-1}{2}, y = 2 \Rightarrow 4x + 5y = 8$$

9. Let  $f(x) = x^4 + ax^3 + bx^2 + c$  be a polynomial with real coefficients such that  $f(1) = -9$ . Suppose that  $i\sqrt{3}$  is a root of the equation  $4x^3 + 3ax^2 + 2bx = 0$ , where  $i = \sqrt{-1}$ . If  $\alpha_1, \alpha_2, \alpha_3$ , and  $\alpha_4$  are all the roots of the equation  $f(x) = 0$ , then  $|\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2 + |\alpha_4|^2$  is equal to \_\_\_\_\_.

**Answer (20)**

**Sol.**  $\because f(1) = -9 \Rightarrow 1 + a + b + c = -9 \quad \dots(1)$

$$4x^3 + 3ax^2 + 2bx = 0$$

$$\Rightarrow x = 0, \quad 4x^2 + 3ax + 2b = 0 \quad \dots(2)$$

⇒  $\sqrt{3}i$  and  $-\sqrt{3}i$  are roots of (2)

$$\Rightarrow \sqrt{3}i - \sqrt{3}i = \frac{-3a}{4}, \quad \sqrt{3}i(-\sqrt{3}i) = \frac{2b}{4}$$

$$\Rightarrow a = 0, b = 6, c = -16$$

$$\Rightarrow f(x) = 0 \Rightarrow x^4 + 6x^2 - 16 = 0$$

$$\Rightarrow x^2 = \frac{-6 \pm \sqrt{36 + 64}}{2} = -3 \pm 5 = 2, -8$$

$$x = -\sqrt{2}, +\sqrt{2}, -2\sqrt{2}i, 2\sqrt{2}i$$

$$\Rightarrow |\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2 + |\alpha_4|^2 = 20$$

10. Let  $S = \left\{ A = \begin{pmatrix} 0 & 1 & c \\ 1 & a & d \\ 1 & b & e \end{pmatrix} : a, b, c, d, e \in \{0, 1\} \text{ and } |A| \in \{-1, 1\} \right\}$ , where  $|A|$  denotes the determinant of  $A$ . Then the number of elements in  $S$  is \_\_\_\_\_.

**Answer (16)**

**Sol.**  $|A| = -(e - d) + c(b - a) = \pm 1$

**Case (i) :**  $c = 0 \Rightarrow (e, d) = (1, 0), (0, 1) \rightarrow 2$  ways

$b$  and  $a$  can be each 2 ways

⇒ Total = 8 ways

**Case (ii) :**  $c \neq 0 \Rightarrow c = 1$

⇒  $d - e + b - a = \pm 1$

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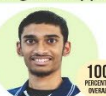
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$$\left. \begin{matrix} 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{matrix} \right\} \rightarrow 4 \times 2 = 8 \text{ ways}$$

Total = 16 ways

11. A group of 9 students,  $s_1, s_2, \dots, s_9$ , is to be divided to form three teams X, Y and, Z of sizes 2, 3, and 4, respectively. Suppose that  $s_1$  cannot be selected for the team X, and  $s_2$  cannot be selected for the team Y. Then the number of ways to form such teams, is \_\_\_\_\_.

**Answer (665)**

**Sol.** Number of required ways

$$\begin{aligned} &= \frac{9!}{2!3!4!} - (n(s_1 \in X) + n(s_2 \in Y) - n(s_1 \in X \text{ and } s_2 \in Y)) \\ &= \frac{9!}{2!3!4!} - \left( \frac{8!}{1!3!4!} + \frac{8!}{2!2!4!} - \frac{7!}{1!2!4!} \right) \\ &= 665 \end{aligned}$$

12. Let  $\overline{OP} = \frac{\alpha-1}{\alpha}\hat{i} + \hat{j} + \hat{k}$ ,  $\overline{OQ} = \hat{i} + \frac{\beta-1}{\beta}\hat{j} + \hat{k}$  and  $\overline{OR} = \hat{i} + \hat{j} + \frac{1}{2}\hat{k}$  be three vectors, where  $\alpha, \beta \in \mathbb{R} - \{0\}$  and O denotes the origin. If  $(\overline{OP} \times \overline{OQ}) \cdot \overline{OR} = 0$  and the point  $(\alpha, \beta, 2)$  lies on the plane  $3x + 3y - z + l = 0$ , then the value of  $l$  is \_\_\_\_\_.

**Answer (5)**

**Sol.**  $(\overline{OP} \times \overline{OQ}) \cdot \overline{OR} = 0$

$$\begin{vmatrix} \frac{\alpha-1}{\alpha} & 1 & 1 \\ 1 & \frac{\beta-1}{\beta} & 1 \\ 1 & 1 & \frac{1}{2} \end{vmatrix} = 0 \Rightarrow \frac{\alpha-1}{\alpha} \left( \frac{\beta-1}{2\beta} - 1 \right) - \left( \frac{1}{2} - 1 \right) + 1 \left( 1 - \frac{\beta-1}{\beta} \right) = 0$$

$$\frac{\alpha-1}{\alpha} \left( \frac{-\beta-1}{2\beta} \right) + \frac{1}{2} + \frac{1}{\beta} = 0$$

$$\Rightarrow \frac{\beta+2}{2\beta} = \frac{\alpha\beta + \alpha - \beta - 1}{2\alpha\beta}$$

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$$\Rightarrow \alpha\beta + 2\alpha = \alpha\beta + \alpha - \beta - 1 \Rightarrow \boxed{\alpha + \beta + 1 = 0} \quad \dots (1)$$

Now  $(\alpha, \beta, 2)$  lies on  $3x + 3y - z + l = 0$

$$\Rightarrow 3(\alpha + \beta) - 2 + l = 0 \quad \dots (2)$$

$$\Rightarrow -3 - 2 + l = 0 \Rightarrow l = 5$$

13. Let  $X$  be a random variable, and let  $P(X = x)$  denote the probability that  $X$  takes the value  $x$ . Suppose that the points  $(x, P(X = x))$ ,  $x = 0, 1, 2, 3, 4$ , lie on a fixed straight line in the  $xy$ -plane, and  $P(X = x) = 0$  for all  $x \in \mathbb{R} - \{0, 1, 2, 3, 4\}$ . If the mean of  $X$  is  $\frac{5}{2}$ , and the variance of  $X$  is  $\alpha$ , then the value of  $24\alpha$  is \_\_\_\_\_.

**Answer (42)**

Sol.  $\sum_{x=0}^4 xP(x) = \frac{5}{2}$

$$\sum_{x=0}^4 x^2P(x) = ?$$

$(0, P(0)), (1, P(1)), (2, P(2)), (3, P(3)), (4, P(4))$

$$K = P(1) - P(0) = P(2) - P(1) = P(3) - P(2) = P(4) - P(3)$$

$$P(1) = K + P(0)$$

$$P(2) = 2K + P(0)$$

$$P(3) = 3K + P(0)$$

$$P(4) = 4K + P(0)$$

$$P(0) + P(1) + P(2) + P(3) + P(4) = 1$$

$$\Rightarrow 5P(0) + 10K = 1$$

$$K + P(0) + 4K + 2P(0) + 9K + 3P(0) + 16K + 4P(0) = \frac{5}{2}$$

$$30K + 10P(0) = \frac{5}{2}$$

$$\therefore 10K = \frac{1}{2}$$

$$K = \frac{1}{20}, P(0) = \frac{1}{10}$$

$$P(1) = \frac{3}{20}, P(2) = \frac{4}{20}, P(3) = \frac{5}{20}, P(4) = \frac{6}{20}$$

$$\sum_{x=0}^4 x^2P(x) = 8$$

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$$\therefore \text{Variance} = 8 - \frac{25}{4} = \frac{32 - 25}{4} = \frac{7}{4}$$

$$\therefore 24\alpha = \frac{24 \times 7}{4} = 42$$

**SECTION 4 (Maximum Marks : 12)**

- This section contains **FOUR (04)** Matching List Sets.
- Each set has **ONE** Multiple Choice Question.
- Each set has **TWO** lists: **List-I** and **List-II**.
- **List-I** has **Four** entries (P), (Q), (R) and (S) and **List-II** has **Five** entries (1), (2), (3), (4) and (5).
- **FOUR** options are given in each Multiple Choice Question based on **List-I** and **List-II** and **ONLY ONE** of these four options satisfies the condition asked in the Multiple Choice Question.
- Answer to each question will be evaluated according to the following marking scheme:

**Full Marks** : +3 **ONLY** if the option corresponding to the correct combination is chosen;

**Zero Marks** : 0 If none of the options is chosen (i.e. the question is unanswered);

**Negative Marks** : -1 In all other cases.

14. Let  $\alpha$  and  $\beta$  be the distinct roots of the equation  $x^2 + x - 1 = 0$ . Consider the set  $T = \{1, \alpha, \beta\}$ . For a  $3 \times 3$  matrix  $M = (a_{ij})_{3 \times 3}$ , define  $R_i = a_{i1} + a_{i2} + a_{i3}$  and  $C_j = a_{1j} + a_{2j} + a_{3j}$  for  $i = 1, 2, 3$  and  $j = 1, 2, 3$ . Match each entry in **List-I** to the correct entry in **List-II**.

	List-I		List-II
(P)	The number of matrices $M = (a_{ij})_{3 \times 3}$ with all entries in $T$ such that $R_i = C_j = 0$ for all $i, j$ is	(1)	1
(Q)	The number of symmetric matrices $M = (a_{ij})_{3 \times 3}$ with all entries in $T$ such that $C_j = 0$ for all $j$ is	(2)	12
(R)	Let $M = (a_{ij})_{3 \times 3}$ be a skew symmetric matrix such that $a_{ij} \in T$ for $i > j$ . Then the number of elements in the set $\left\{ \begin{pmatrix} x \\ y \\ z \end{pmatrix} : x, y, z \in R, M \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} a_{12} \\ 0 \\ -a_{23} \end{pmatrix} \right\}$ is	(3)	Infinite
(S)	Let $M = (a_{ij})_{3 \times 3}$ be a matrix with all entries in $T$ such that $R_i = 0$ for all $i$ . Then the absolute value of the determinant of $M$ is	(4)	6
		(5)	0

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The correct option is

- (A)  $(P) \rightarrow (4) (Q) \rightarrow (2) (R) \rightarrow (5) (S) \rightarrow (1)$   
 (C)  $(P) \rightarrow (2) (Q) \rightarrow (4) (R) \rightarrow (3) (S) \rightarrow (5)$

- (B)  $(P) \rightarrow (2) (Q) \rightarrow (4) (R) \rightarrow (1) (S) \rightarrow (5)$   
 (D)  $(P) \rightarrow (1) (Q) \rightarrow (5) (R) \rightarrow (3) (S) \rightarrow (4)$

**Answer (C)**

**Sol.**  $x^2 + x - 1 = 0 \rightarrow$  roots are  $\alpha$  and  $\beta$

$$\alpha + \beta = -1 \quad \alpha\beta = -1$$

Set  $T = \{1, \alpha, \beta\}$   $M = (a_{ij})_{3 \times 3}$

$$R_i = a_{i1} + a_{i2} + a_{i3} \quad C_j = a_{1j} + a_{2j} + a_{3j}$$

(P)  $R_i = C_j = 0$  for all  $i, j$

$$\alpha + \beta = -1 \quad T = \{1, \alpha, \beta\}$$

$$\begin{aligned} \text{Number of matrices} \\ = \underline{3} \times 2 \times 1 = 12 \end{aligned}$$

Number of ways to arrange  $1, \alpha, \beta$  in  $R_1$       Number of ways to arrange  $1, \alpha, \beta$  in  $R_2$

$$\begin{bmatrix} 1 & \alpha & \beta \\ - & - & - \end{bmatrix}$$

(Q) Number of symmetric matrices = ?

$$C_j = 0 \quad \forall j$$

Number of symmetric matrices

$$= \underline{3} \times 1 = 6 \quad \begin{bmatrix} 1 & \alpha & \beta \\ \alpha & \beta & 1 \\ \beta & 1 & \alpha \end{bmatrix}$$

(R)  $M \rightarrow$  skew symmetric of  $3 \times 3$

$$|M| = 0 \quad a_{ij} \in T \text{ for } i > j$$

$$M \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} a_{12} \\ 0 \\ -a_{23} \end{pmatrix}$$

$$\begin{bmatrix} 0 & -a_{21} & -a_{31} \\ a_{21} & 0 & -a_{32} \\ a_{31} & a_{32} & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} a_{12} \\ 0 \\ -a_{23} \end{bmatrix}$$

As  $x, y, z \in R$  and  $a_{12}$  &  $a_{23} \in R$

$$\& |M| = 0$$

$\therefore$  System has infinite solutions

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(S)  $R_i = 0 \forall i$

$$M = \begin{bmatrix} 1 & \alpha & \beta \\ \alpha & \beta & 1 \\ \beta & 1 & \alpha \end{bmatrix}$$

$$C_1 \rightarrow C_1 + C_2 + C_3 \quad |M| = \begin{vmatrix} 1+\alpha+\beta & \alpha & \beta \\ 1+\alpha+\beta & \beta & 1 \\ 1+\alpha+\beta & 1 & \alpha \end{vmatrix} = 0$$

(P)  $\rightarrow$  (2) (Q)  $\rightarrow$  (4) (R)  $\rightarrow$  (3) (S)  $\rightarrow$  (5)

15. Let the straight line  $y = 2x$  touch a circle with center  $(0, \alpha)$ ,  $\alpha > 0$ , and radius  $r$  at a point  $A_1$ . Let  $B_1$  be the point on the circle such that the line segment  $A_1B_1$  is a diameter of the circle. Let  $\alpha + r = 5 + \sqrt{5}$ .

Match each entry in **List-I** to the correct entry in **List-II**.

	List-I		List-II
(P)	$\alpha$ equals	(1)	$(-2, 4)$
(Q)	$r$ equals	(2)	$\sqrt{5}$
(R)	$A_1$ equals	(3)	$(-2, 6)$
(S)	$B_1$ equals	(4)	5
		(5)	$(2, 4)$

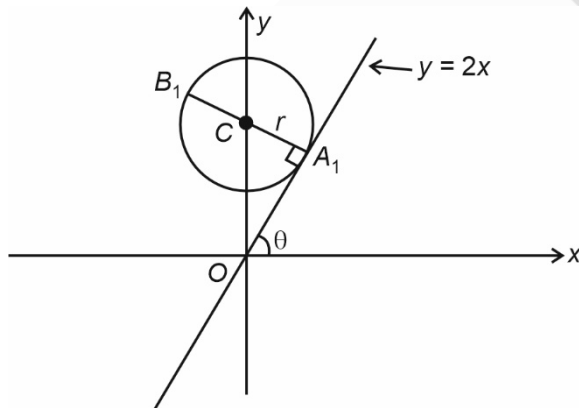
The correct option is

- (A) (P)  $\rightarrow$  (4) (Q)  $\rightarrow$  (2) (R)  $\rightarrow$  (1) (S)  $\rightarrow$  (3)  
 (C) (P)  $\rightarrow$  (4) (Q)  $\rightarrow$  (2) (R)  $\rightarrow$  (5) (S)  $\rightarrow$  (3)

- (B) (P)  $\rightarrow$  (2) (Q)  $\rightarrow$  (4) (R)  $\rightarrow$  (1) (S)  $\rightarrow$  (3)  
 (D) (P)  $\rightarrow$  (2) (Q)  $\rightarrow$  (4) (R)  $\rightarrow$  (3) (S)  $\rightarrow$  (5)

Answer (C)

Sol.



Slope of line = 2  $\Rightarrow \tan\theta = 2$

$C(0, \alpha) \quad \alpha > 0$

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$$\alpha + r = 5 + \sqrt{5} \quad \dots(1)$$

Line  $y = 2x$  is tangent to the circle

$$\therefore \left| \frac{0 - \alpha}{\sqrt{4 + 1}} \right| = r$$

$$\Rightarrow |\alpha| = r\sqrt{5}$$

$$\Rightarrow \alpha = r\sqrt{5} \quad \text{as } \alpha > 0$$

From equation (1)  $r\sqrt{5} + r = 5 + \sqrt{5}$

$$\Rightarrow r(\sqrt{5} + 1) = \sqrt{5}(\sqrt{5} + 1)$$

$$\Rightarrow r = \sqrt{5}$$

And  $\alpha = r\sqrt{5} = \sqrt{5} \times \sqrt{5} = 5$

Centre  $C(0, 5)$

$$OC = 5$$

$$A_1C = \sqrt{5}$$

$$\therefore OA_1 = \sqrt{25 - 5} = \sqrt{20} = 2\sqrt{5}$$

$$\tan \theta = 2$$

(from figure)

$$\cos \theta = \frac{1}{\sqrt{5}} \quad \sin \theta = \frac{2}{\sqrt{5}}$$

$$A_1(0 + OA_1 \cos \theta, 0 + OA_1 \sin \theta)$$

$$A_1 \left( 2\sqrt{5} \times \frac{1}{\sqrt{5}}, 2\sqrt{5} \times \frac{2}{\sqrt{5}} \right)$$

$$A_1(2, 4)$$

Let  $B_1(x_1, y_1)$

$$\therefore \frac{x_1 + 2}{2} = 0 \quad \text{and} \quad \frac{y_1 + 4}{2} = 5$$

$$x_1 = -2 \quad y_1 = 6$$

$$B_1(-2, 6)$$

$$\alpha = 5 \quad r = \sqrt{5} \quad A_1(2, 4) \quad B_1(-2, 6)$$

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16. Let  $\gamma \in \mathbb{R}$  be such that the lines  $L_1 : \frac{x+11}{1} = \frac{y+21}{2} = \frac{z+29}{3}$  and  $L_2 : \frac{x+16}{3} = \frac{y+11}{2} = \frac{z+4}{\gamma}$  intersect. Let  $R_1$  be the point of intersection of  $L_1$  and  $L_2$ . Let  $O = (0, 0, 0)$ , and  $\hat{n}$  denote a unit normal vector to the plane containing both the lines  $L_1$  and  $L_2$ .

Match each entry in **List-I** to the correct entry in **List-II**.

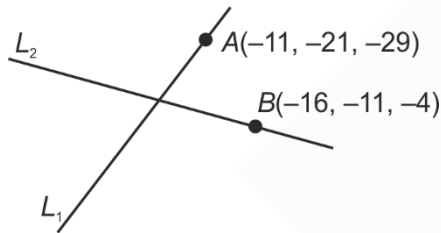
	List-I		List-II
(P)	$\gamma$ equals	(1)	$-\hat{i} - \hat{j} + \hat{k}$
(Q)	A possible choice for $\hat{n}$ is	(2)	$\sqrt{\frac{3}{2}}$
(R)	$\overline{OR_1}$ equals	(3)	1
(S)	A possible value of $\overline{OR_1} \cdot \hat{n}$ is	(4)	$\frac{1}{\sqrt{6}}\hat{i} - \frac{2}{\sqrt{6}}\hat{j} + \frac{1}{\sqrt{6}}\hat{k}$
		(5)	$\sqrt{\frac{2}{3}}$

The correct option is

- (A) (P)  $\rightarrow$  (3) (Q)  $\rightarrow$  (4) (R)  $\rightarrow$  (1) (S)  $\rightarrow$  (2)      (B) (P)  $\rightarrow$  (5) (Q)  $\rightarrow$  (4) (R)  $\rightarrow$  (1) (S)  $\rightarrow$  (2)  
 (C) (P)  $\rightarrow$  (3) (Q)  $\rightarrow$  (4) (R)  $\rightarrow$  (1) (S)  $\rightarrow$  (5)      (D) (P)  $\rightarrow$  (3) (Q)  $\rightarrow$  (1) (R)  $\rightarrow$  (4) (S)  $\rightarrow$  (5)

**Answer (C)**

**Sol.** Vector parallel to the line  $L_1$  (say  $\vec{b}_1$ ) =  $\hat{i} + 2\hat{j} + 3\hat{k}$



Normal vector of plane ( $\vec{n}$ ) containing  $L_1$  and  $L_2$  will be perpendicular to both  $\vec{b}_1$  and  $\vec{AB}$

$$\begin{aligned} \Rightarrow \vec{n} &= p(\vec{AB} \times \vec{b}_1) = p(5\hat{i} - 10\hat{j} - 25\hat{k}) \times (\hat{i} + 2\hat{j} + 3\hat{k}) \\ &= p(20\hat{i} - 40\hat{j} + 20\hat{k}) \\ \Rightarrow \hat{n} &= \frac{1}{\sqrt{6}}\hat{i} - \frac{2}{\sqrt{6}}\hat{j} + \frac{1}{\sqrt{6}}\hat{k} \end{aligned}$$

Now, vector parallel to  $L_2$  (say  $\vec{b}_2$ ) is perpendicular to  $\vec{n} \Rightarrow \vec{b}_2 \cdot \vec{n} = 0$

$$\begin{aligned} (3\hat{i} + 2\hat{j} + \gamma\hat{k}) \cdot p(20\hat{i} - 40\hat{j} + 20\hat{k}) &= 0 \\ \Rightarrow \gamma &= 1 \end{aligned}$$

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Now, for point of intersection (POI)

$$L_1: \frac{x+11}{1} = \frac{y+21}{2} = \frac{z+29}{3} = \lambda \text{ and } L_2: \frac{x+16}{3} = \frac{y+11}{2} = \frac{z+4}{\gamma} = u$$

Comparing x and y coordinates,  $-11 + \lambda = -16 + 3u$  and  $-21 + 2\lambda = -11 + 2u$

$$\Rightarrow \lambda = 10, u = 5$$

$$\Rightarrow \text{POI i.e., } \overline{OR}_1: (-\hat{i} - \hat{j} + \hat{k}) \text{ and } \overline{OR} \cdot \hat{n} = \sqrt{\frac{2}{3}}$$

17. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  and  $g: \mathbb{R} \rightarrow \mathbb{R}$  be functions defined by

$$f(x) = \begin{cases} x |x| \sin\left(\frac{1}{x}\right), & x \neq 0, \\ 0, & x = 0, \end{cases} \text{ and } g(x) = \begin{cases} 1-2x, & 0 \leq x \leq \frac{1}{2}, \\ 0, & \text{otherwise} \end{cases}$$

Let  $a, b, c, d \in \mathbb{R}$ . Define the function  $h: \mathbb{R} \rightarrow \mathbb{R}$  by

$$h(x) = af(x) + b\left(g(x) + g\left(\frac{1}{2} - x\right)\right) + c(x - g(x)) + d g(x), x \in \mathbb{R}$$

Match each entry in **List-I** to the correct entry in **List-II**.

List-I		List-II	
(P)	If $a = 0, b = 1, c = 0$ and $d = 0$ , then	(1)	$h$ is one-one
(Q)	If $a = 1, b = 0, c = 0$ and $d = 0$ , then	(2)	$h$ is onto.
(R)	If $a = 0, b = 0, c = 1$ and $d = 0$ , then	(3)	$h$ is differentiable on $\mathbb{R}$ .
(S)	If $a = 0, b = 0, c = 0$ and $d = 1$ , then	(4)	the range of $h$ is $[0, 1]$
		(5)	the range of $h$ is $\{0, 1\}$

The correct option is

(A) (P)  $\rightarrow$  (4) (Q)  $\rightarrow$  (3) (R)  $\rightarrow$  (1) (S)  $\rightarrow$  (2)

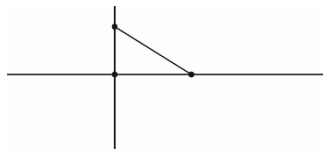
(B) (P)  $\rightarrow$  (5) (Q)  $\rightarrow$  (2) (R)  $\rightarrow$  (4) (S)  $\rightarrow$  (3)

(C) (P)  $\rightarrow$  (5) (Q)  $\rightarrow$  (3) (R)  $\rightarrow$  (2) (S)  $\rightarrow$  (4)

(D) (P)  $\rightarrow$  (4) (Q)  $\rightarrow$  (2) (R)  $\rightarrow$  (1) (S)  $\rightarrow$  (3)

**Answer (C)**

Sol.  $g(x) = \begin{cases} 1-2x, & 0 \leq x \leq \frac{1}{2} \\ 0, & \text{otherwise} \end{cases}$



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$$g\left(\frac{1}{2}-x\right) = \begin{cases} 1-2\left(\frac{1}{2}-x\right), & 0 \leq \frac{1}{2}-x \leq \frac{1}{2} \\ 0, & \text{otherwise} \end{cases}$$

$$= \begin{cases} 2x, & 0 \leq x \leq \frac{1}{2} \\ 0, & \text{otherwise} \end{cases}$$

$$g(x) + g\left(\frac{1}{2}-x\right) = \begin{cases} 1, & 0 \leq x \leq \frac{1}{2} \\ 0, & \text{otherwise} \end{cases}$$

Now, option (P), at  $b = 1$

$$h(x) = g(x) + g\left(\frac{1}{2}-x\right) \text{ has range } \{0, 1\}$$

(P)  $\rightarrow$  (5)

Option (Q) at  $a = 1$ ,  $h(x) = f(x)$

$$f'(0^+) = \lim_{h \rightarrow 0} \frac{f(0+h) - f(0)}{h} = \lim_{h \rightarrow 0} \frac{h^2 \sin \frac{1}{h}}{h}$$

$$f'(0^-) = \lim_{h \rightarrow 0} \frac{f(0-h) - f(0)}{-h} = \lim_{h \rightarrow 0} h \sin h = 0$$

$$\Rightarrow f'(0^+) = f'(0^-)$$

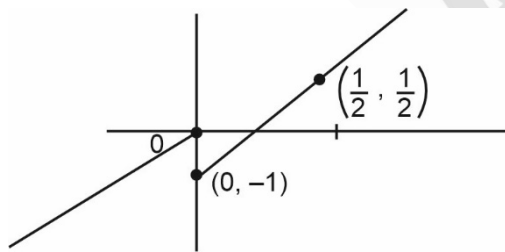
as  $f(0^+) = f(0^-)$

$\Rightarrow h(x) = f(x)$  is differentiable at  $x = 0$  and all other points  $f(x) = h(x)$  is differentiable as product of two differentiable functions

(Q)  $\rightarrow$  (3)

Option (R)

$$h(x) = x - g(x) = \begin{cases} 3x - 1, & 0 \leq x \leq \frac{1}{2} \\ x, & \text{otherwise} \end{cases}$$



by graph  $h(x)$  has range  $\mathbb{R}$  and onto  $(\mathbb{R}) \rightarrow$  (2)

(S) at  $d = 1$   $h(x) = g(x)$  has range  $[0, 1]$  (S)  $\rightarrow$  (4)

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## PART-II : PHYSICS

### SECTION 1 (Maximum Marks : 12)

- This section contains **FOUR (04)** questions.
- Each question has **FOUR** options (A), (B), (C) and (D). **ONLY ONE** of these four options is the correct answer.
- For each question, choose the option corresponding to the correct answer.
- Answer to each question will be evaluated according to the following marking scheme:

**Full Marks** : +3 If **ONLY** the correct option is chosen;

**Zero Marks** : 0 If none of the options is chosen (i.e. the question is unanswered);

**Negative Marks** : -1 In all other cases.

1. A dimensionless quantity is constructed in terms of electronic charge  $e$ , permittivity of free space  $\epsilon_0$ , Planck's constant  $h$ , and speed of light  $c$ . If the dimensionless quantity is written as  $e^\alpha \epsilon_0^\beta h^\gamma c^\delta$  and  $n$  is a non-zero integer, then  $(\alpha, \beta, \gamma, \delta)$  is given by
- (A)  $(2n, -n, -n, -n)$  (B)  $(n, -n, -2n, -n)$   
 (C)  $(n, -n, -n, -2n)$  (D)  $(2n, -n, -2n, -2n)$

**Answer (A)**

**Sol.**  $[AT]^\alpha [M^{-1}L^{-3}T^4A^2]^\beta [ML^2T^{-1}]^\gamma [LT^{-1}]^\delta = 0$

$$\Rightarrow \alpha + 2\beta = 0$$

$$-\beta + \gamma = 0 \quad \Rightarrow \alpha = -2\beta$$

$$-3\beta + 2\gamma + \delta = 0 \quad \gamma = \beta$$

$$\alpha + 4\beta - \gamma - \delta = 0 \quad \delta = \beta$$

$$(-2\beta, \beta, \beta, \beta)$$

2. An infinitely long wire, located on the z-axis, carries a current  $I$  along the +z-direction and produces the magnetic field  $\vec{B}$ . The magnitude of the line integral  $\int \vec{B} \cdot d\vec{l}$  along a straight line from the point  $(-\sqrt{3}a, a, 0)$  to  $(a, a, 0)$  is given by
- $[\mu_0$  is the magnetic permeability of free space.]

(A)  $7\mu_0 I / 24$

(B)  $7\mu_0 I / 12$

(C)  $\mu_0 I / 8$

(D)  $\mu_0 I / 6$

**Answer (A)**

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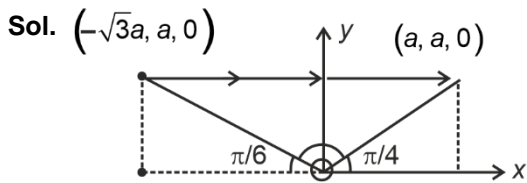
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$$\theta = \pi - \frac{\pi}{4} - \frac{\pi}{6}$$

$$\Rightarrow \theta = \frac{12\pi - 3\pi - 2\pi}{12} = \frac{7\pi}{12}$$

So,  $\int \vec{B} \cdot d\vec{l}$  along the line is

$$\int \vec{B} \cdot d\vec{l} = -\frac{\mu_0(I)}{2\pi} \cdot \theta = -\frac{\mu_0 I}{2\pi} \cdot \frac{7\pi}{12}$$

$$\Rightarrow \left| \int \vec{B} \cdot d\vec{l} \right| = \frac{7\mu_0 I}{24}$$

Option (A) is correct Answer.

3. Two beads, each with charge  $q$  and mass  $m$ , are on a horizontal, frictionless, non-conducting, circular hoop of radius  $R$ . One of the beads is glued to the hoop at some point, while the other one performs small oscillations about its equilibrium position along the hoop. The square of the angular frequency of the small oscillations is given by

[ $\epsilon_0$  is the permittivity of free space.]

(A)  $q^2 / (4\pi\epsilon_0 R^3 m)$

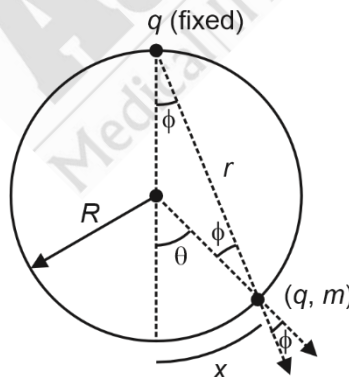
(B)  $q^2 / (32\pi\epsilon_0 R^3 m)$

(C)  $q^2 / (8\pi\epsilon_0 R^3 m)$

(D)  $q^2 / (16\pi\epsilon_0 R^3 m)$

**Answer (B)**

Sol. As the hoop mass is not given so it must not move or else its inertia must have some effect.



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Here  $r = 2R \cos \phi$

Also  $\theta = 2\phi$

$$\Rightarrow \theta = \frac{\phi}{2}$$

And  $\theta = \frac{x}{R}$

If  $\theta$  is the small angular displacement of free charge, then  $F(\phi) = \frac{Kq^2}{r^2}$

So, restoring force towards mean position is  $F_{(R)} = \frac{Kq^2}{r^2} \sin \phi$

$$a_R = \frac{F_{(R)}}{m} = \frac{-Kq^2}{mr^2} \cdot \sin \phi = \frac{-Kq^2 \cdot \sin \phi}{m 4R^2 \cos^2 \phi}$$

$$\Rightarrow a_R = -\frac{Kq^2}{4mR^2 \cos^2\left(\frac{\phi}{2}\right)} \cdot \sin\left(\frac{\theta}{2}\right) \approx \frac{-Kq^2}{4mR^2} \cdot \frac{1}{2} \cdot \frac{x}{R} = \omega^2 \cdot x$$

So,  $\omega^2 = \frac{q^2}{32\pi\epsilon_0 mR^3}$

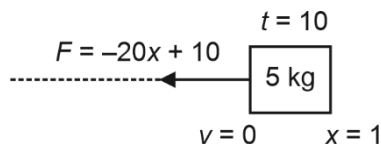
Option (B) is correct answer.

4. A block of mass 5 kg moves along the x-direction subject to the force  $F = (-20x + 10)$  N, with the value of x in metre. At time  $t = 0$  s, it is at rest at position  $x = 1$  m. The position and momentum of the block at  $t = (\pi/4)$  s are

- (A) -0.5 m, 5 kg m/s
- (B) 0.5 m, 0 kg m/s
- (C) 0.5 m, -5 kg m/s
- (D) -1 m, 5 kg m/s

**Answer (C)**

**Sol.**



Now,

$$a = -\frac{20x + 10}{5} = -4x + 2$$

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$$a = \frac{vdv}{dx} = -4x + 2$$

$$\text{Hence } \int_0^v v dv = \int_1^x (-4x + 2) dx \rightarrow \frac{v^2}{2} = [-2x^2 + 2x]_1^x$$

$$\boxed{v = -2\sqrt{x - x^2}} \text{ (as particle starts moving in } \neg\text{-ve } x\text{-direction)}$$

$$\Rightarrow \frac{dx}{dt} = -2\sqrt{x - x^2} \rightarrow \int_{x=1}^{x=x} \frac{dx}{\sqrt{x - x^2}} = -2 \int_0^{\pi/4} dt$$

$$\sin^{-1}[2x - 1]_1^x = -\frac{\pi}{2}$$

$$\boxed{x = \frac{1}{2} = 0.5 \text{ m}}$$

Also, momentum =  $mV = 5(V)_{x=\frac{1}{2}} = -5 \text{ kg-m/s}$

Hence correct option is (C)

**SECTION 2 (Maximum Marks : 12)**

- This section contains **THREE (03)** questions.
- Each question has **FOUR** options (A), (B), (C) and (D). **ONE OR MORE THAN ONE** of these four option(s) is(are) correct answer(s).
- For each question, choose the option(s) corresponding to (all) the correct answer(s).
- Answer to each question will be evaluated according to the following marking scheme:

*Full Marks* : +4 **ONLY** if (all) the correct option(s) is(are) chosen;

*Partial Marks* : +3 If all the four options are correct but **ONLY** three options are chosen;

*Partial Marks* : +2 If three or more options are correct but **ONLY** two options are chosen, both of which are correct;

*Partial Marks* : +1 If two or more options are correct but **ONLY** one option is chosen and it is a correct option;

*Zero Marks* : 0 If none of the options is chosen (i.e. the question is unanswered);

*Negative Marks* : -2 In all other cases.

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5. A particle of mass  $m$  is moving in a circular orbit under the influence of the central force  $F(r) = -kr$ , corresponding to the potential energy  $V(r) = kr^2/2$ , where  $k$  is a positive force constant and  $r$  is the radial distance from the origin. According to the Bohr's quantization rule, the angular momentum of the particle is given by  $L = nh$ , where  $h = h/(2\pi)$ ,  $h$  is the Planck's constant, and  $n$  a positive integer. If  $v$  and  $E$  are the speed and total energy of the particle, respectively, then which of the following expression(s) is(are) correct?

(A)  $r^2 = nh\sqrt{\frac{1}{mk}}$

(B)  $v^2 = nh\sqrt{\frac{k}{m^3}}$

(C)  $\frac{L}{mr^2} = \sqrt{\frac{k}{m}}$

(D)  $E = \frac{nh}{2}\sqrt{\frac{k}{m}}$

**Answer (A, B, C)**

**Sol.**  $L = mvr = nh$ , also,  $\frac{mv^2}{r} = kr$

$$mv^2 = kr^2$$

$$m^2v^2 = mkr^2$$

$$mv = \sqrt{mkr^2}$$

$$mvr = r^2\sqrt{mk}$$

$$nh = r^2\sqrt{mk}$$

$$\boxed{\frac{nh}{\sqrt{mk}} = r^2}$$

Option (A) is correct

Also,  $v^2 = \frac{kr^2}{m}$

$$= \frac{nh}{\sqrt{mk}} \cdot \frac{k}{m}$$

$$\boxed{v^2 = nh\sqrt{\frac{k}{m^3}}}$$

Option (B) is correct

Now,

$$\text{T.E} = E = \frac{1}{2}kr^2 + \frac{1}{2}kr^2$$

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$$E = kr^2$$

$$= k \frac{nh}{\sqrt{mk}}$$

$$= nh\sqrt{\frac{k}{m}}$$

Option (D) is incorrect

$$\Rightarrow \frac{L}{mr^2} = \frac{h\sqrt{mk}}{mnh}$$

$$\boxed{\frac{L}{mr^2} = \sqrt{\frac{k}{m}}}$$

Option (C) is correct

6. Two uniform strings of mass per unit length  $\mu$  and  $4\mu$ , and length  $L$  and  $2L$ , respectively, are joined at point  $O$ , and tied at two fixed ends  $P$  and  $Q$ , as shown in the figure. The strings are under a uniform tension  $T$ . If we define the frequency  $\nu_0 = \frac{1}{2L} \sqrt{\frac{T}{\mu}}$ , which of the following statement(s) is(are) correct?



- (A) With a node at  $O$ , the minimum frequency of vibration of the composite string is  $\nu_0$
- (B) With an antinode at  $O$ , the minimum frequency of vibration of the composite string is  $2\nu_0$
- (C) When the composite string vibrates at the minimum frequency with a node at  $O$ , it has 6 nodes, including the end nodes
- (D) No vibrational mode with an antinode at  $O$  is possible for the composite string

**Answer (A, C, D)**

**Sol.** With node at  $O$

$$\begin{array}{c}
 \text{Node} \\
 | \\
 m \quad | \quad n \\
 \hline
 \end{array}$$

$$v = \sqrt{\frac{T}{\mu}} \quad v' = \sqrt{\frac{T}{4\mu}} = \frac{1}{2}v$$

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$$\Rightarrow m \frac{1}{2l} \sqrt{\frac{T}{\mu}} = n \frac{1}{2(2l)} \sqrt{\frac{T}{4\mu}}$$

$$\Rightarrow m = \frac{n}{2} \times \frac{1}{2}$$

$$\Rightarrow \frac{m}{n} = \frac{1}{4}$$

$$\therefore m = 1, n = 4$$

With antinode at O

$$m \frac{1}{4l} \sqrt{\frac{T}{\mu}} = n \frac{1}{4(2l)} \sqrt{\frac{T}{4\mu}}$$

$$\Rightarrow \frac{m}{n} = \frac{1}{2} \times \frac{1}{2}$$

$$\Rightarrow \frac{m}{n} = \frac{1}{4}$$

$$\therefore m = 1 \quad f_{\min} = 1 \frac{1}{4l} \sqrt{\frac{T}{\mu}} = \frac{v_0}{2}$$

(B is wrong)

Also, when node at O.

Total nodes = 6

(C is correct)

A, C, D are correct

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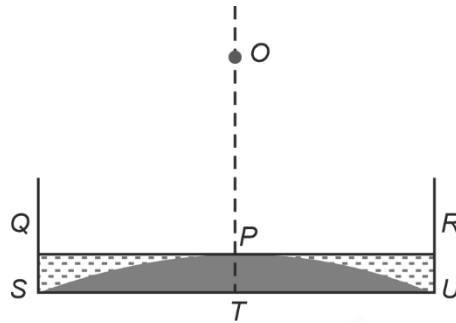


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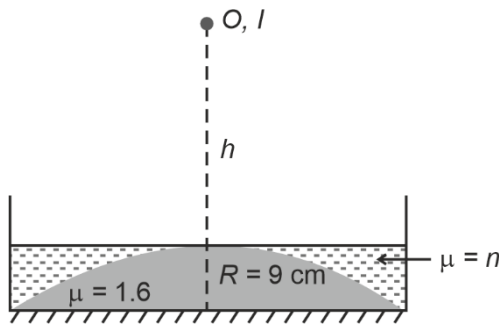
7. A glass beaker has a solid, plano-convex base of refractive index 1.60, as shown in the figure. The radius of curvature of the convex surface (SPU) is 9 cm, while the planar surface (STU) acts as a mirror. This beaker is filled with a liquid of refractive index  $n$  up to the level  $QPR$ . If the image of a point object  $O$  at a height of  $h$  ( $OT$  in the figure) is formed onto itself, then, which of the following option(s) is (are) correct?



- (A) For  $n = 1.42, h = 50$  cm  
 (B) For  $n = 1.35, h = 36$  cm  
 (C) For  $n = 1.45, h = 65$  cm  
 (D) For  $n = 1.48, h = 85$  cm

Answer (A, B)

Sol.



For image to coincide with object

$$-h = 2(f_{\text{net}})$$

$$\Rightarrow -\frac{1}{f_{\text{net}}} = 2\left(\frac{1}{f_{\text{liq}}}\right) + 2\left(\frac{1}{f_{\text{lens}}}\right) + \left(\frac{-1}{f_{\text{mirror}}}\right) \quad \dots(i)$$

$$-\frac{1}{f_{\text{net}}} = 2\left(\frac{n-1}{-9}\right) + 2\left(\frac{0.6}{9}\right) + \left(-\frac{1}{\infty}\right) \quad \dots(ii)$$

From (i) and (ii)

$$h = \frac{9}{(1.6 - n)}$$

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For  $n = 1.42$ ,  $h = 50$  cm (A is correct)

For  $n = 1.35$ ,  $h = 36$  cm (B is correct)

For  $n = 1.45$ ,  $h = 60$  cm (C is incorrect)

For  $n = 1.48$ ,  $h = 75$  cm (D is incorrect)

**SECTION 3 (Maximum Marks : 24)**

- This section contains **SIX (06)** questions.
- The answer to each question is a **NON-NEGATIVE INTEGER**.
- For each question, enter the correct integer corresponding to the answer using the mouse and the on-screen virtual numeric keypad in the place designated to enter the answer.
- Answer to each question will be evaluated according to the following marking scheme:

Full Marks : +4 If **ONLY** the correct integer is entered;

Zero Marks : 0 In all other cases.

8. The specific heat capacity of a substance is temperature dependent and is given by the formula  $C = kT$ , where  $k$  is a constant of suitable dimensions in SI units, and  $T$  is the absolute temperature. If the heat required to raise the temperature of 1 kg of the substance from  $-73^\circ\text{C}$  to  $27^\circ\text{C}$  is  $nk$ , the value of  $n$  is \_\_\_\_\_.  
[Given:  $0\text{ K} = -273^\circ\text{C}$ .]

**Answer (25000)**

Sol.  $C = \frac{dQ/m}{dT}$

$\Rightarrow dQ = m \cdot C \cdot dT$

$= 1 \cdot kTdT$

$Q = \int_{200}^{300} kTdT = \frac{k}{2} [300^2 - 200^2]$

$= \frac{10^4}{2} \cdot k \cdot 5$

$= 25000k$

$\Rightarrow n = 25000$

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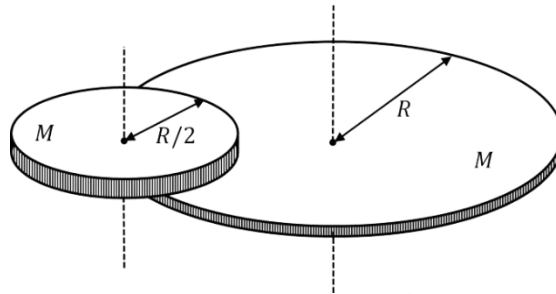


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9. A disc of mass  $M$  and radius  $R$  is free to rotate about its vertical axis as shown in the figure. A battery operated motor of negligible mass is fixed to this disc at a point on its circumference. Another disc of the same mass  $M$  and radius  $R/2$  is fixed to the motor's thin shaft. Initially, both the discs are at rest. The motor is switched on so that the smaller disc rotates at a uniform angular speed  $\omega$ . If the angular speed at which the large disc rotates is  $\omega/n$ , then the value of  $n$  is \_\_\_\_\_.



**Answer (12)**

**Sol.** Conserving angular momentum of the system (bigger disc + smaller disc) about the symmetric axis of bigger disc:

$$\frac{MR^2}{2} \omega' + M \cdot R \omega \cdot R + \frac{M(R/2)^2}{2} \omega = 0$$

Where  $\omega'$  : required angular speed.

$$\Rightarrow \frac{3}{2} MR^2 \omega' = \frac{-MR^2 \omega}{8}$$

$$\Rightarrow \omega' = -\frac{\omega}{12}$$

$$\Rightarrow n = 12$$

10. A point source  $S$  emits unpolarized light uniformly in all directions. At two points  $A$  and  $B$ , the ratio  $r = I_A/I_B$  of the intensities of light is 2. If a set of two polaroids having  $45^\circ$  angle between their pass-axes is placed just before point  $B$ , then the new value of  $r$  will be \_\_\_\_\_.

**Answer (8)**

**Sol.**  $I \propto \frac{1}{l^2}$

Where  $l$  : distance from point source.

$$\Rightarrow \frac{I_A}{I_B} = \frac{l_B^2}{l_A^2} = 2$$

$$\Rightarrow I_B = \sqrt{2} I_A \quad \dots(1)$$

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Also, due to polaroids:

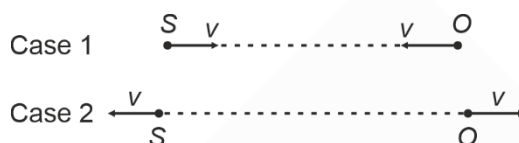
$$I_B' = \frac{I_B}{2} \cos^2 45^\circ = \frac{I_B}{4}$$

$$\Rightarrow I_B' = \frac{I_B}{4} \quad \dots(2)$$

$\Rightarrow$  Ratio becomes 4 times.

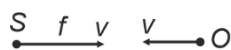
$$\Rightarrow r_{\text{new}} = 8$$

11. A source (S) of sound has frequency 240 Hz. When the observer (O) and the source move towards each other at a speed  $v$  with respect to the ground (as shown in Case 1 in the figure), the observer measures the frequency of the sound to be 288 Hz. However, when the observer and the source move away from each other at the same speed  $v$  with respect to the ground (as shown in Case 2 in the figure), the observer measures the frequency of sound to be  $n$  Hz. The value of  $n$  is \_\_\_\_\_.



**Answer (200)**

**Sol.** For Case 1 :



$$f_{\text{app}} = f \left( \frac{c+v}{c-v} \right) \Rightarrow 288 = 240 \left( \frac{c+v}{c-v} \right) \quad \dots(i)$$

For Case 2 :



$$f_{\text{app}} = f \left( \frac{c-v}{c+v} \right)$$

$$= 240 \left( \frac{c-v}{c+v} \right) \quad \dots(ii)$$

From (i) and (ii)

$$288 \times f_{\text{app}} = 240 \left( \frac{c+v}{c-v} \right) \times 240 \left( \frac{c-v}{c+v} \right)$$

$$288 f_{\text{app}} = 240 \times 240$$

$$f_{\text{app}} = 200 \text{ Hz}$$

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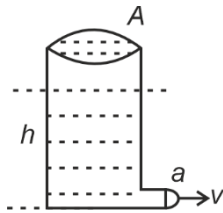


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12. Two large, identical water tanks, 1 and 2, kept on the top of a building of height  $H$ , are filled with water up to height  $h$  in each tank. Both the tanks contain an identical hole of small radius on their sides, close to their bottom. A pipe of the same internal radius as that of the hole is connected to tank 2, and the pipe ends at the ground level. When the water flows the tanks 1 and 2 through the holes, the times taken to empty the tanks are  $t_1$  and  $t_2$ , respectively. If  $H = \left(\frac{16}{9}\right)h$ , then the ratio  $t_1/t_2$  is \_\_\_\_\_.

**Answer (3)**

**Sol.** In general case



$$a\sqrt{2gh} = -A \frac{dh}{dt}$$

$$dt = -\frac{A}{a} \frac{dh}{\sqrt{2gh}}$$

$$T = \int dt = \frac{-2A}{a\sqrt{2g}} (\sqrt{h_f} - \sqrt{h_i})$$

$$T = \frac{2A}{a\sqrt{2g}} (\sqrt{h_i} - \sqrt{h_f})$$

For tank 1 :

$$h_i = h, h_f = 0$$

$$T_1 = \frac{2A}{a\sqrt{2g}} (\sqrt{h})$$

For tank 2 :

$$h_f = \frac{16h}{9}, h_i = h + H = \frac{25h}{9}$$

$$T_2 = \frac{2A\sqrt{h}}{a\sqrt{2g}} \left(\frac{5}{3} - \frac{4}{3}\right) = \frac{2A\sqrt{h}}{a\sqrt{2g}} \times \frac{1}{3}$$

$$\frac{T_1}{T_2} = 3$$

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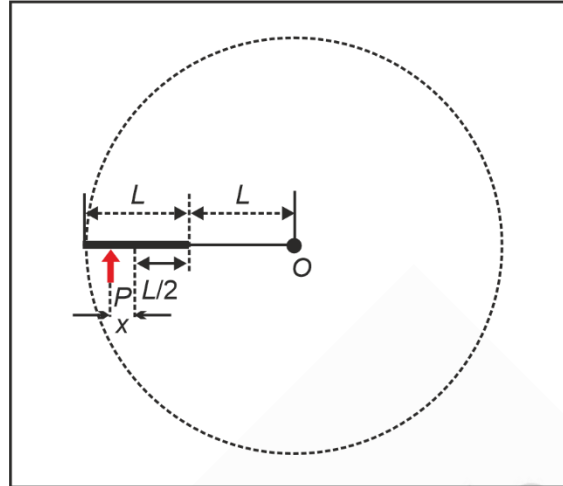


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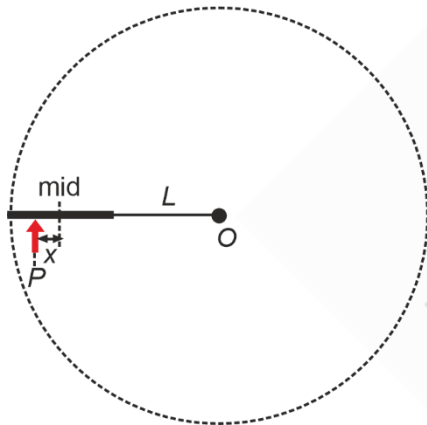
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13. A thin uniform rod of length  $L$  and certain mass is kept on a frictionless horizontal table with a massless string of length  $L$  fixed to one end (top view is shown in the figure). The other end of the string is pivoted to a point  $O$ . If a horizontal impulse  $P$  is imparted to the rod at a distance  $x = L/n$  from the mid-point of the rod (see figure), then the rod and string revolve together around the point  $O$ , with the rod remaining aligned with the string. In such a case, the value of  $n$  is \_\_\_\_\_.



**Answer (18)**

**Sol.**



$$\text{M.I. of rod about centre (O)} = \frac{mL^2}{12} + m\left(L + \frac{L}{2}\right)^2$$

$$I_0 = \frac{7mL^2}{3}$$

Since rod is in pure rotation about 'O'

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So, angular impulse =  $P\left(x + \frac{3L}{2}\right) = I_0\omega_0$  ... (i)

and linear impulse =  $mv_c$  ... (ii)

where  $V_c = \frac{3L}{2}\omega_0$  ... (iii)

(20 m (i))  $m\left(\frac{3L}{2}\omega_0\right)\left(x + \frac{3L}{2}\right) = \frac{7}{3}mL^2 \cdot \omega_0$

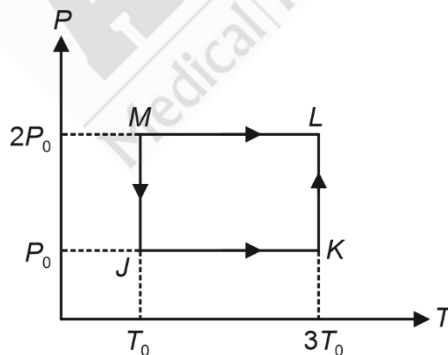
$x + \frac{3L}{2} = \frac{14}{9}L$

$x = \frac{L}{18}$

**SECTION 4 (Maximum Marks : 12)**

- This section contains **FOUR (04)** Matching List Sets.
- Each set has **ONE** Multiple Choice Question.
- Each set has **TWO** lists: **List-I** and **List-II**.
- **List-I** has **Four** entries (P), (Q), (R) and (S) and **List-II** has **Five** entries (1), (2), (3), (4) and (5).
- **FOUR** options are given in each Multiple Choice Question based on **List-I** and **List-II** and **ONLY ONE** of these four options satisfies the condition asked in the Multiple Choice Question.
- Answer to each question will be evaluated according to the following marking scheme:  
*Full Marks* : +3 **ONLY** if the option corresponding to the correct combination is chosen;  
*Zero Marks* : 0 If none of the options is chosen (i.e. the question is unanswered);  
*Negative Marks* : -1 In all other cases.

14. One mole of a monatomic ideal gas undergoes the cyclic process  $J \rightarrow K \rightarrow L \rightarrow M \rightarrow J$ , as shown in the P-T diagram.



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Match the quantities mentioned in List-I with their values in List-II and choose the correct option.

[ $R$  is the gas constant.]

	List-I		List-II
(P)	Work done in the complete cyclic process	(1)	$RT_0 - 4RT_0 \ln 2$
(Q)	Change in the internal energy of the gas in the process $JK$	(2)	0
(R)	Heat given to the gas in the process $KL$	(3)	$3RT_0$
(S)	Change in the internal energy of the gas in the process $MJ$	(4)	$-2RT_0 \ln 2$
		(5)	$-3RT_0 \ln 2$

(A)  $P \rightarrow 1; Q \rightarrow 3; R \rightarrow 5; S \rightarrow 4$

(B)  $P \rightarrow 4; Q \rightarrow 3; R \rightarrow 5; S \rightarrow 2$

(C)  $P \rightarrow 4; Q \rightarrow 1; R \rightarrow 2; S \rightarrow 2$

(D)  $P \rightarrow 2; Q \rightarrow 5; R \rightarrow 3; S \rightarrow 4$

**Answer (B)**

**Sol.** From  $M \rightarrow J$ , isothermal

$$W = nRT \ln 2$$

$$= RT_0 \ln 2$$

$$\Delta U = 0$$

From  $J \rightarrow K$ , isobaric

$$W = nR(3T_0 - T_0)$$

$$W = 2RT_0$$

$$\Delta U = nC_v \Delta T$$

$$= \frac{3R}{2} \times 2T_0 = 3RT_0$$

From  $K \rightarrow L$ , isothermal

$$W = -nR(3T_0) \ln 2$$

$$W = -3RT_0 \ln 2$$

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$$\Delta U = 0$$

$$Q = -3RT_0 \ln 2$$

From  $L \rightarrow M$ , isobaric

$$W = nR(T_0 - 3T_0)$$

$$W = -2RT_0$$

$$\Delta U = nC_V \Delta T$$

$$= n \times \frac{3R}{2} \times (-2T_0)$$

$$= -3RT_0$$

For  $P$  :-

$$W_{\text{net}} = RT_0 \ln 2 + 2RT_0 - 3RT_0 \ln 2 - 2RT_0$$

$$= -2RT_0 \ln 2$$

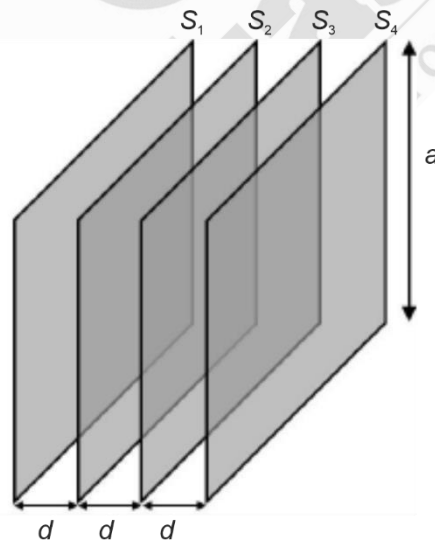
$P \rightarrow 4$

for  $Q \rightarrow 3$

for  $R \rightarrow 5$

for  $S \rightarrow 2$

15. Four identical thin, square metal sheets,  $S_1, S_2, S_3,$  and  $S_4$ , each of side  $a$  are kept parallel to each other with equal distance  $d$  ( $d \ll a$ ) between them, as shown in the figure. Let  $C_0 = \epsilon_0 a^2/d$ , where  $\epsilon_0$  is the permittivity of free space.



Match the quantities mentioned in List-I with their values in List-II and choose the correct option.

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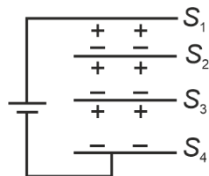
<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p><b>Tanishka Kabra</b> 4 Year Classroom</p> <p><b>AIR-16</b> CRL JEE (Adv.) 2022</p> <p><small>ALL INDIA RANK (Female)</small></p> </div> <div style="text-align: center;"> <p><b>Chirag Falor</b> 4 Year Classroom</p> <p><b>AIR</b> JEE (Adv.) 2020</p> </div> </div>
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	List-I		List-II
(P)	The capacitance between $S_1$ and $S_4$ , with $S_2$ and $S_3$ not connected, is	(1)	$3C_0$
(Q)	The capacitance between $S_1$ and $S_4$ , with $S_2$ shorted to $S_3$ , is	(2)	$C_0/2$
(R)	The capacitance between $S_1$ and $S_3$ , with $S_2$ shorted to $S_4$ , is	(3)	$C_0/3$
(S)	The capacitance between $S_1$ and $S_2$ , with $S_3$ shorted to $S_1$ , and $S_2$ shorted to $S_4$ , is	(4)	$2C_0/3$
		(5)	$2C_0$

- (A)  $P \rightarrow 3; Q \rightarrow 2; R \rightarrow 4; S \rightarrow 5$   
 (B)  $P \rightarrow 2; Q \rightarrow 3; R \rightarrow 2; S \rightarrow 1$   
 (C)  $P \rightarrow 3; Q \rightarrow 2; R \rightarrow 4; S \rightarrow 1$   
 (D)  $P \rightarrow 3; Q \rightarrow 2; R \rightarrow 2; S \rightarrow 5$

**Answer (C)**

**Sol.** For  $P$



All are in series

$$C_{eq} = \frac{C_0}{3}$$

$P \rightarrow (3)$

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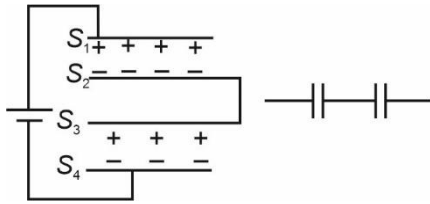


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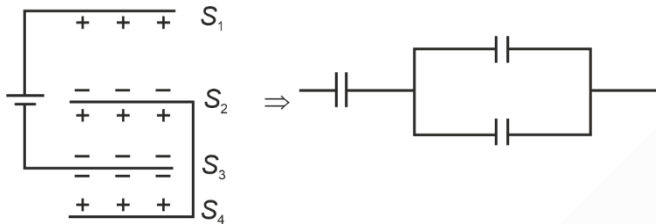
For Q



$$C_{eq} = \frac{C_0}{2}$$

Q → (2)

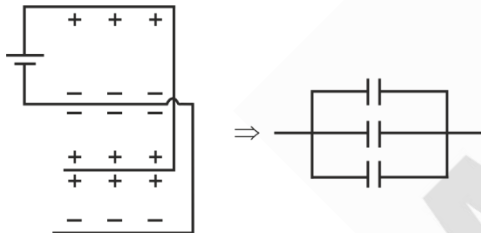
For R



$$C_{eq} = \frac{2C}{3}$$

R → (4)

For S



$$\Rightarrow C_{eq} = 3C_0$$

S → (1)

16. A light ray is incident on the surface of a sphere of refractive index  $n$  at an angle of incidence  $\theta_0$ . The ray partially refracts into the sphere with angle of refraction  $\phi_0$  and then partly reflects from the back surface. The reflected ray then emerges out of the sphere after a partial refraction. The total angle of deviation of the emergent ray with respect to the incident ray is  $\alpha$ . Match the quantities mentioned in List-I with their values in List-II and choose the correct option.

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	List-I		List-II
(P)	If $n = 2$ and $\alpha = 180^\circ$ , then all the possible values of $\theta_0$ will be	(1)	$30^\circ$ and $0^\circ$
(Q)	If $n = \sqrt{3}$ and $\alpha = 180^\circ$ , then all the possible values of $\theta_0$ will be	(2)	$60^\circ$ and $0^\circ$
(R)	If $n = \sqrt{3}$ and $\alpha = 180^\circ$ , then all the possible values of $\phi_0$ will be	(3)	$45^\circ$ and $0^\circ$
(S)	If $n = \sqrt{2}$ and $\theta_0 = 45^\circ$ , then all the possible values of $\alpha$ will be	(4)	$150^\circ$
		(5)	$0^\circ$

(A)  $P \rightarrow 5; Q \rightarrow 2; R \rightarrow 1; S \rightarrow 4$

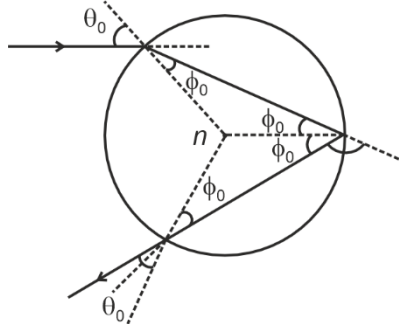
(B)  $P \rightarrow 5; Q \rightarrow 1; R \rightarrow 2; S \rightarrow 4$

(C)  $P \rightarrow 3; Q \rightarrow 2; R \rightarrow 1; S \rightarrow 4$

(D)  $P \rightarrow 3; Q \rightarrow 1; R \rightarrow 2; S \rightarrow 5$

**Answer (A)**

Sol.



$$\alpha = (\theta_0 - \phi_0) + (\pi - 2\phi_0) + (\theta_0 - \phi_0)$$

$$\alpha = \pi + 2\theta_0 - 4\phi_0 \quad \dots(i)$$

$$\sin \theta_0 = n \sin \phi_0 \quad \dots(ii)$$

For (P)

$$n = 2, \alpha = 180$$

$$\text{if } \alpha = \pi, 2\theta_0 - 4\phi_0 = 0$$

$$\theta_0 = 2\phi_0$$

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$$\sin \theta_0 = 2 \sin \left( \frac{\theta_0}{2} \right)$$

P → (5)

For Q,  $n = \sqrt{3}$ ,  $\alpha = 180$

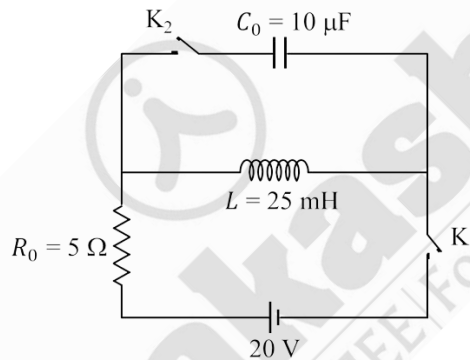
$$\theta_0 = 2\phi_0$$

Q → (2)

$$\sin \theta_0 = \sqrt{3} \sin \left( \frac{\theta_0}{2} \right)$$

$$\theta_0 = 60, 0^\circ$$

17. The circuit shown in the figure contains an inductor  $L$ , a capacitor  $C_0$ , a resistor  $R_0$  and an ideal battery. The circuit also contains two keys  $K_1$  and  $K_2$ . Initially, both the keys are open and there is no charge on the capacitor. At an instant, key  $K_1$  is closed and immediately after this the current in  $R_0$  is found to be  $I_1$ . After a long time, the current attains a steady state value  $I_2$ . Thereafter,  $K_2$  is closed and simultaneously  $K_1$  is opened and the voltage across  $C_0$  oscillates with amplitude  $V_0$  and angular frequency  $\omega_0$ .



Match the quantities mentioned in List-I with their values in List-II and choose the correct option.

	List-I		List-II
(P)	The value of $I_1$ in Ampere is	(1)	0
(Q)	The value of $I_2$ in Ampere is	(2)	2
(R)	The value of $\omega_0$ in kilo-radians/s is	(3)	4
(S)	The value of $V_0$ in Volt is	(4)	20
		(5)	200

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(A)  $P \rightarrow 1; Q \rightarrow 3; R \rightarrow 2; S \rightarrow 5$

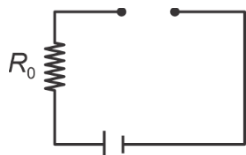
(B)  $P \rightarrow 1; Q \rightarrow 2; R \rightarrow 3; S \rightarrow 5$

(C)  $P \rightarrow 1; Q \rightarrow 3; R \rightarrow 2; S \rightarrow 4$

(D)  $P \rightarrow 2; Q \rightarrow 5; R \rightarrow 3; S \rightarrow 4$

**Answer (A)**

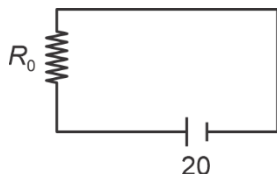
**Sol.** Just after closing  $K_1$



$$i_1 = 0,$$

$P \rightarrow (1)$

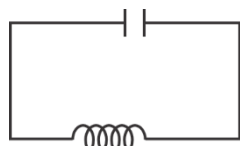
After long time



$$i_2 = \frac{20}{5} = 4A,$$

$Q \rightarrow (3)$

After opening  $K_1$  & closing  $K_2$



$$\omega = \frac{1}{\sqrt{LC}}$$

$$= \frac{1}{\sqrt{25 \times 10^{-3} \times 10 \times 10^{-6}}}$$

$$\omega = 2000 \text{ rad/s}$$

$$\omega = 2 \text{ krad/s}$$

$R \rightarrow (2)$

$$i_0 = 4$$

$$Q_0 = \frac{i_0}{\omega} = \frac{4}{2 \times 10^3} = 2 \text{ mC}$$

$$\therefore V_0 = \frac{Q_0}{C} = \frac{2 \times 10^{-3}}{10} = 200$$

$S \rightarrow (5)$

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## PART-III : CHEMISTRY

### SECTION 1 (Maximum Marks : 12)

- This section contains **FOUR (04)** questions.
- Each question has **FOUR** options (A), (B), (C) and (D). **ONLY ONE** of these four options is the correct answer.
- For each question, choose the option corresponding to the correct answer.
- Answer to each question will be evaluated according to the following marking scheme:

*Full Marks* : +3 If **ONLY** the correct option is chosen;

*Zero Marks* : 0 If none of the options is chosen (i.e. the question is unanswered);

*Negative Marks* : -1 In all other cases.

1. A closed vessel contains 10 g of an ideal gas **X** at 300 K, which exerts 2 atm pressure. At the same temperature, 80 g of another ideal gas **Y** is added to it and the pressure becomes 6 atm. The ratio of root mean square velocities of **X** and **Y** at 300 K is

(A)  $2\sqrt{2} : \sqrt{3}$

(B)  $2\sqrt{2} : 1$

(C) 1 : 2

(D) 2 : 1

**Answer (D)**

**Sol.** Given,

$$W_X = 10 \text{ g}$$

$$P_X = 2 \text{ atm}$$

$$W_Y = 80 \text{ g}$$

$$P_Y = P_{\text{total}} - P_X$$

$$\Rightarrow 6 - 2 = 4 \text{ atm}$$

$$\text{As } V_{\text{rms}} = \sqrt{\frac{3RT}{M}},$$

$$\frac{(V_{\text{rms}})_X}{(V_{\text{rms}})_Y} = \sqrt{\frac{M_Y}{M_X}}$$

As we know,

$$PV = nRT$$

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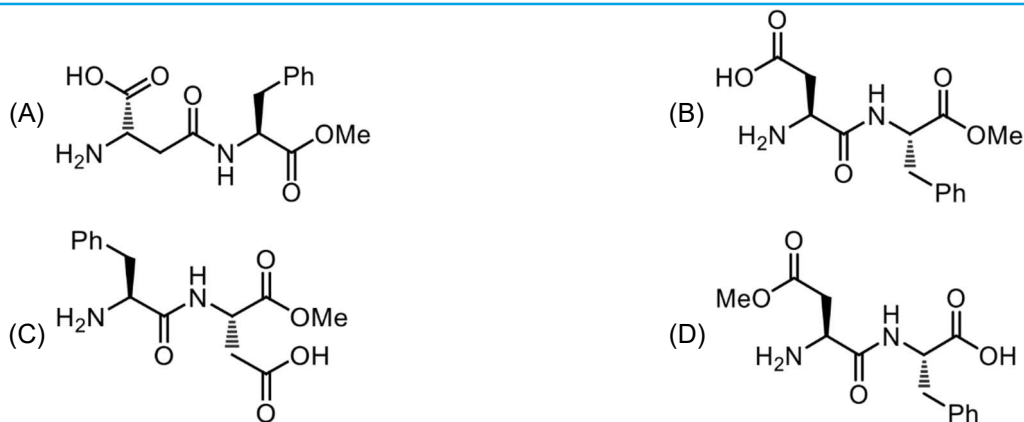
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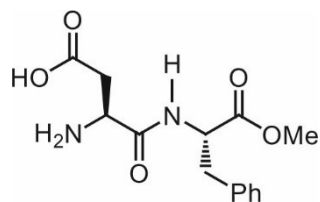
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**Answer (B)**

**Sol.** Aspartame is



4. Among the following options, select the option in which each complex in **Set-I** shows geometrical isomerism and the two complexes in **Set-II** are ionization isomers of each other.

[en = H<sub>2</sub>NCH<sub>2</sub>CH<sub>2</sub>NH<sub>2</sub>]

- (A) **Set-I:** [Ni(CO)<sub>4</sub>] and [PdCl<sub>2</sub>(PPh<sub>3</sub>)<sub>2</sub>]  
**Set-II:** [Co(NH<sub>3</sub>)<sub>5</sub>Cl]SO<sub>4</sub> and [Co(NH<sub>3</sub>)<sub>5</sub>(SO<sub>4</sub>)]Cl
- (B) **Set-I:** [Co(en)(NH<sub>3</sub>)<sub>2</sub>Cl<sub>2</sub>] and [PdCl<sub>2</sub>(PPh<sub>3</sub>)<sub>2</sub>]  
**Set-II:** [Co(NH<sub>3</sub>)<sub>6</sub>][Cr(CN)<sub>6</sub>] and [Cr(NH<sub>3</sub>)<sub>6</sub>][Co(CN)<sub>6</sub>]
- (C) **Set-I:** [Co(NH<sub>3</sub>)<sub>3</sub>(NO<sub>2</sub>)<sub>3</sub>] and [Co(en)<sub>2</sub>Cl<sub>2</sub>]  
**Set-II:** [Co(NH<sub>3</sub>)<sub>5</sub>Cl]SO<sub>4</sub> and [Co(NH<sub>3</sub>)<sub>5</sub>(SO<sub>4</sub>)]Cl
- (D) **Set-I:** [Cr(NH<sub>3</sub>)<sub>5</sub>Cl]Cl<sub>2</sub> and [Co(en)(NH<sub>3</sub>)<sub>2</sub>Cl<sub>2</sub>]  
**Set-II:** [Cr(H<sub>2</sub>O)<sub>6</sub>]Cl<sub>3</sub> and [Cr(H<sub>2</sub>O)<sub>5</sub>Cl]Cl<sub>2</sub>·H<sub>2</sub>O

**Answer (C)**

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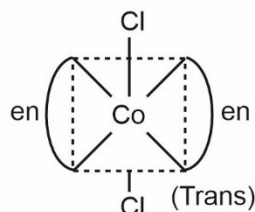
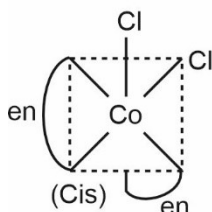
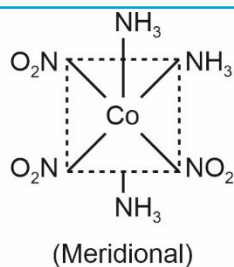
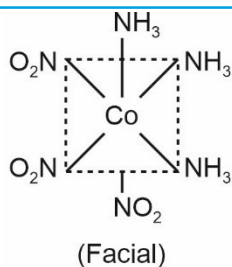


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**Sol. Set-I:**



**Set-II:**  $[\text{Co}(\text{NH}_3)_5\text{Cl}]\text{SO}_4$  and  $[\text{Co}(\text{NH}_3)_5\text{SO}_4]\text{Cl}$  are ionisation isomers.

**SECTION 2 (Maximum Marks : 12)**

- This section contains **THREE (03)** questions.
- Each question has **FOUR** options (A), (B), (C) and (D). **ONE OR MORE THAN ONE** of these four option(s) is(are) correct answer(s).
- For each question, choose the option(s) corresponding to (all) the correct answer(s).
- Answer to each question will be evaluated according to the following marking scheme:

*Full Marks* : +4 **ONLY** if (all) the correct option(s) is(are) chosen;

*Partial Marks* : +3 If all the four options are correct but **ONLY** three options are chosen;

*Partial Marks* : +2 If three or more options are correct but **ONLY** two options are chosen, both of which are correct;

*Partial Marks* : +1 If two or more options are correct but **ONLY** one option is chosen and it is a correct option;

*Zero Marks* : 0 If none of the options is chosen (i.e. the question is unanswered);

*Negative Marks* : -2 In all other cases.

5. Among the following the correct statement(s) for electrons in an atom is(are)
- (A) Uncertainty principle rules out the existence of definite paths for electrons.
- (B) The energy of an electron in 2s orbital of an atom is lower than the energy of an electron that is infinitely far away from the nucleus.
- (C) According to Bohr's model, the most negative energy value for an electron is given by  $n = 1$ , which corresponds to the most stable orbit.
- (D) According to Bohr's model, the magnitude of velocity of electrons increases with increase in values of  $n$ .

**Answer (A, B, C)**

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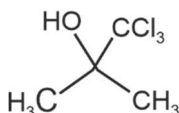
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- Sol.** (A) Uncertainty principle rules out existence of definite paths or trajectories of electron and other similar particles.  
So, option (A) is correct.
- (B) Shell or orbit more near to nucleus has less energy than faraway.  
So, option (B) is also correct.
- (C)  $E = -13.6 \frac{Z^2}{n^2} \text{ eV/atom}$   
So,  $n = 1$  has most negative energy.  
So, option (C) is also correct.
- (D)  $V = V_0 \times \frac{Z}{n}$   
when  $n$  increases velocity decreases.  
So, option (D) is incorrect.

- 6.** Reaction of *iso*-propylbenzene with  $O_2$  followed by the treatment with  $H_3O^+$  forms phenol and a by-product **P**. Reaction of **P** with 3 equivalents of  $Cl_2$  gives compound **Q**. Treatment of **Q** with  $Ca(OH)_2$  produces compound **R** and calcium salt **S**.

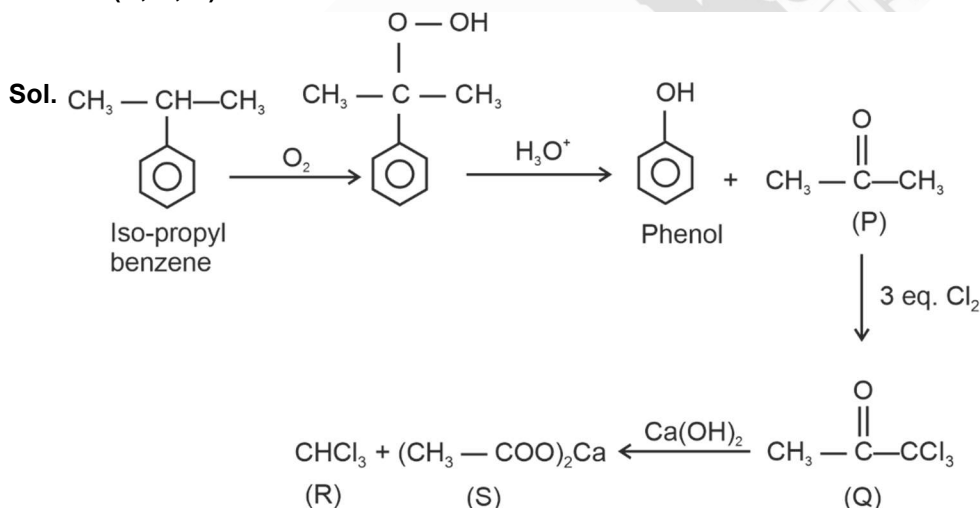
The correct statement(s) regarding **P**, **Q**, **R** and **S** is(are)

- (A) Reaction of **P** with **R** in the presence of KOH followed by acidification gives



- (B) Reaction of **R** with  $O_2$  in the presence of light gives phosgene gas  
(C) **Q** reacts with aqueous NaOH to produce  $Cl_3CCH_2OH$  and  $Cl_3CCOONa$   
(D) **S** on heating gives **P**

**Answer (A, B, D)**



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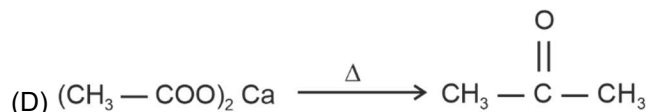
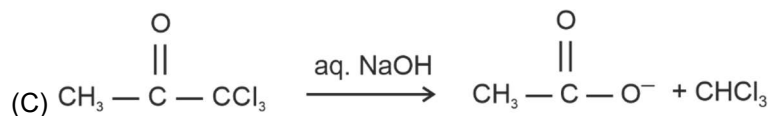
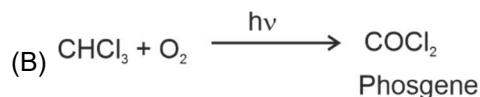
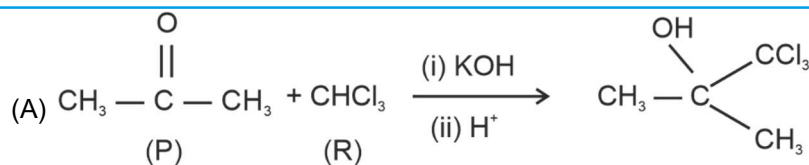
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7. The option(s) in which at least three molecules follow Octet Rule is(are)

- (A) CO<sub>2</sub>, C<sub>2</sub>H<sub>4</sub>, NO and HCl  
 (B) NO<sub>2</sub>, O<sub>3</sub>, HCl and H<sub>2</sub>SO<sub>4</sub>  
 (C) BCl<sub>3</sub>, NO, NO<sub>2</sub> and H<sub>2</sub>SO<sub>4</sub>  
 (D) CO<sub>2</sub>, BCl<sub>3</sub>, O<sub>3</sub> and C<sub>2</sub>H<sub>4</sub>

**Answer (A, D)**

**Sol.** (A) CO<sub>2</sub>, C<sub>2</sub>H<sub>4</sub> and HCl follow octet rule.

(B) O<sub>3</sub> and HCl and follow octet rule.

(C) None of them follow octet rule.

(D) CO<sub>2</sub>, O<sub>3</sub> and C<sub>2</sub>H<sub>4</sub> follow octet rule.

Correct answer is (A) and (D)

**SECTION 3 (Maximum Marks : 24)**

- This section contains **SIX (06)** questions.
- The answer to each question is a **NON-NEGATIVE INTEGER**.
- For each question, enter the correct integer corresponding to the answer using the mouse and the on-screen virtual numeric keypad in the place designated to enter the answer.
- Answer to each question will be evaluated according to the following marking scheme:

**Full Marks** : +4 If **ONLY** the correct integer is entered;

**Zero Marks** : 0 In all other cases.

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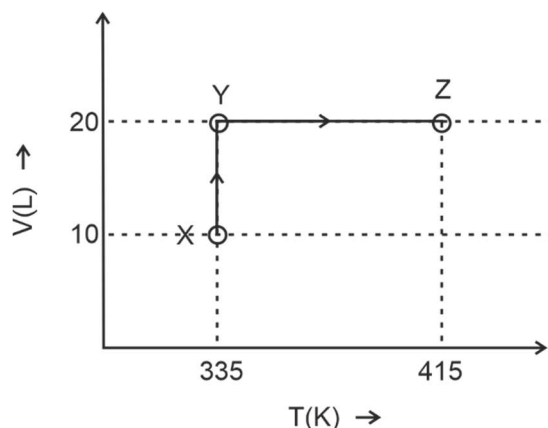


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8. Consider the following volume–temperature ( $V$ – $T$ ) diagram for the expansion of 5 moles of an ideal monoatomic gas.



Considering only P-V work is involved, the total change in enthalpy (in Joule) for the transformation of state in the sequence  $X \rightarrow Y \rightarrow Z$  is \_\_\_\_\_.

[Use the given data: Molar heat capacity of the gas for the given temperature range,  $C_{V,m} = 12 \text{ J K}^{-1} \text{ mol}^{-1}$  and gas constant,  $R = 8.3 \text{ J K}^{-1} \text{ mol}^{-1}$ ]

**Answer (8120)**

**Sol.**  $X \rightarrow Y$  is an isothermal process an ideal gas:

$$\Delta H = 0$$

$Y \rightarrow Z$  is an isochoric process

$$\therefore w = 0$$

$$\begin{aligned} \Delta U &= nC_{V,m} (T_2 - T_1) \\ &= 5 \times 12 (415 - 335) \\ &= 4800 \text{ J} \end{aligned}$$

$$\begin{aligned} \Delta H &= \Delta U + \Delta(PV) \\ &= \Delta U + nR\Delta T \\ &= 4800 + 5 \times 8.3 \times (415 - 335) \\ &= 8120 \text{ J} \end{aligned}$$

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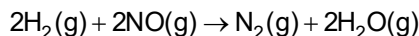


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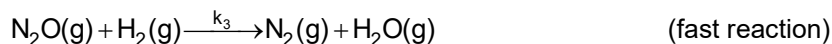
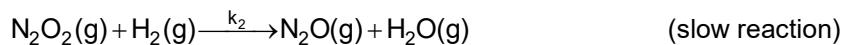


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9. Consider the following reaction,



which follows the mechanism given below:



The order of the reaction is \_\_\_\_\_?

**Answer (3)**

**Sol.** Rate of reaction (according to slowest step)

$$\Rightarrow r = k_2[\text{N}_2\text{O}_2][\text{H}_2] \quad \dots(1)$$

Now for intermediate  $[\text{N}_2\text{O}_2]$ ,

$$\frac{k_1}{k_{-1}} = \frac{[\text{N}_2\text{O}_2]}{[\text{NO}]^2}$$

$$\Rightarrow [\text{N}_2\text{O}_2] = \frac{k_1}{k_{-1}}[\text{NO}]^2 \quad \dots(2)$$

from equation (1) and (2)

$$r = \frac{k_2 k_1}{k_{-1}} [\text{NO}]^2 [\text{H}_2]$$

Overall order of reaction = 2 + 1 = 3

10. Complete reaction of acetaldehyde with excess formaldehyde, upon heating with conc. NaOH solution, gives **P** and **Q**. Compound **P** does not give Tollens' test, whereas **Q** on acidification gives positive Tollens' test. Treatment of **P** with excess cyclohexanone in the presence of catalytic amount of p-toluenesulfonic acid (PTSA) gives product **R**.

Sum of the number of methylene groups ( $-\text{CH}_2-$ ) and oxygen atoms in **R** is \_\_\_\_\_.

**Answer (18)**

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13. Among the following complexes, the total number of diamagnetic species is \_\_\_\_\_.



[Given, atomic number: Mn = 25, Fe = 26, Co = 27; en = H<sub>2</sub>NCH<sub>2</sub>CH<sub>2</sub>NH<sub>2</sub>]

**Answer (1)**

**Sol.**  $[\text{Mn}(\text{NH}_3)_6]^{3+}$  : Paramagnetic

$[\text{MnCl}_6]^{3-}$  : Paramagnetic

$[\text{FeF}_6]^{3-}$  : Paramagnetic

$[\text{CoF}_6]^{3-}$  : Paramagnetic

$[\text{Fe}(\text{NH}_3)_6]^{3+}$  : Paramagnetic

$[\text{Co}(\text{en})_3]^{3+}$  : Diamagnetic

Only 1 complex is diamagnetic.

#### SECTION 4 (Maximum Marks : 12)

- This section contains **FOUR (04)** Matching List Sets.
- Each set has **ONE** Multiple Choice Question.
- Each set has **TWO** lists: **List-I** and **List-II**.
- List-I** has **Four** entries (P), (Q), (R) and (S) and **List-II** has **Five** entries (1), (2), (3), (4) and (5).
- FOUR** options are given in each Multiple Choice Question based on **List-I** and **List-II** and **ONLY ONE** of these four options satisfies the condition asked in the Multiple Choice Question.
- Answer to each question will be evaluated according to the following marking scheme:

**Full Marks** : +3 **ONLY** if the option corresponding to the correct combination is chosen;

**Zero Marks** : 0 If none of the options is chosen (i.e. the question is unanswered);

**Negative Marks** : -1 In all other cases.

14. In a conductometric titration, small volume of titrant of higher concentration is added stepwise to a larger volume of titrate of much lower concentration, and the conductance is measured after each addition.

The limiting ionic conductivity ( $\Lambda_0$ ) values (in mS m<sup>2</sup> mol<sup>-1</sup>) for different ions in aqueous solutions are given below:

Ions	Ag <sup>+</sup>	K <sup>+</sup>	Na <sup>+</sup>	H <sup>+</sup>	NO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	OH <sup>-</sup>	CH <sub>3</sub> COO <sup>-</sup>
$\Lambda_0$	6.2	7.4	5.0	35.0	7.2	7.6	16.0	19.9	4.1

For different combinations of titrates and titrants given in **List-I**, the graphs of 'conductance' versus 'volume of titrant' are given in **List-II**.

Match each entry in **List-I** with the appropriate entry in **List-II** and choose the correct option.

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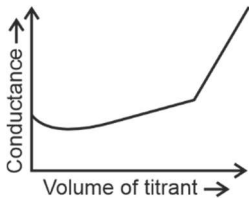
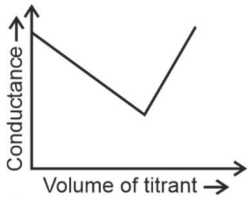
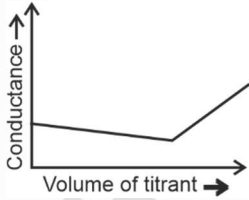
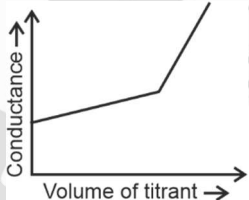
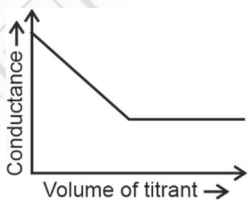
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	List-I		List-II
(P)	Titrate: KCl Titrant: AgNO <sub>3</sub>	(1)	
(Q)	Titrate: AgNO <sub>3</sub> Titrant: KCl	(2)	
(R)	Titrate: NaOH Titrant: HCl	(3)	
(S)	Titrate: NaOH Titrant: CH <sub>3</sub> COOH	(4)	
		(5)	

- (A) P-4, Q-3, R-2, S-5  
 (B) P-2, Q-4, R-3, S-1  
 (C) P-3, Q-4, R-2, S-5  
 (D) P-4, Q-3, R-2, S-1

Answer (C)

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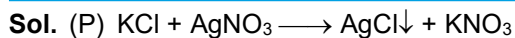
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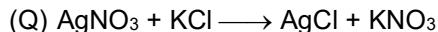
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$Cl^-$  is replaced by  $NO_3^-$

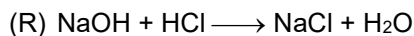
Conductance will first decrease and then after equivalence point, it will increase

$P \longrightarrow 3$

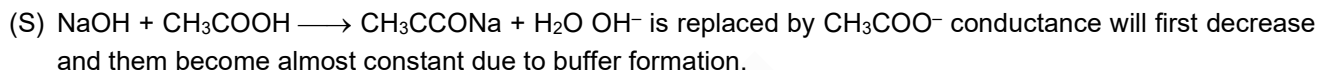


$Ag^+$  is replaced by  $K^+$

Conductance will first increase slightly and then will increase further



$OH^-$  is replaced by  $Cl^-$



15. Based on VSEPR model, match the xenon compounds given in **List-I** with the corresponding geometries and the number of lone pairs on xenon given in **List-II** and choose the correct option.

	List-I		List-II
(P)	$XeF_2$	(1)	Trigonal bipyramidal and two lone pair of electrons
(Q)	$XeF_4$	(2)	Tetrahedral and one lone pair of electrons
(R)	$XeO_3$	(3)	Octahedral and two lone pair of electrons
(S)	$XeO_3F_2$	(4)	Trigonal bipyramidal and no lone pair of electrons
		(5)	Trigonal bipyramidal and three lone pair of electrons

(A) P-5, Q-2, R-3, S-1

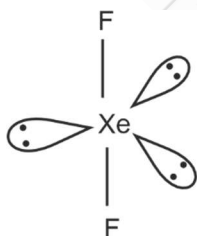
(B) P-5, Q-3, R-2, S-4

(C) P-4, Q-3, R-2, S-1

(D) P-4, Q-2, R-5, S-3

Answer (B)

Sol.  $XeF_2$  :



Hybridisation –  $sp^3d$

Geometry:-

Trigonal bipyramidal and three lone pair of electrons

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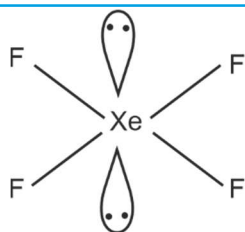
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XeF<sub>4</sub> :

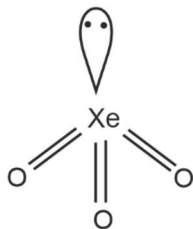


Hybridisation –  $sp^3d^2$

Geometry:-

Octahedral and two lone pair of electrons.

XeO<sub>3</sub> :

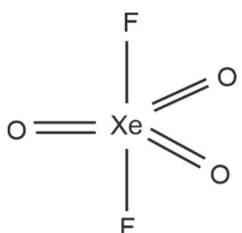


Hybridisation -  $sp^3$

Geometry :-

tetrahedral & one lone pair of electrons.

XeO<sub>3</sub>F<sub>2</sub> :




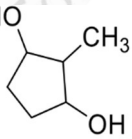
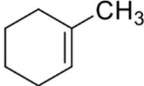
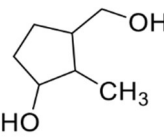
Hybridisation -  $sp^3d$

Geometry :-

Trigonal bipyramidal and no lone pair of electrons.

Correct match : P → 5; Q → 3; R → 2; S → 4

16. List-I contains various reaction sequences and List-II contains the possible products. Match each entry in List-I with the appropriate entry in List-II and choose the correct option.

	List-I		List-II
(P)	 <p>i) O<sub>3</sub>, Zn ii) aq. NaOH, Δ iii) ethylene glycol, PTSA iv) a) BH<sub>3</sub>, b) H<sub>2</sub>O<sub>2</sub>, NaOH v) H<sub>3</sub>O<sup>+</sup> vi) NaBH<sub>4</sub></p>	(1)	
(Q)	 <p>i) O<sub>3</sub>, Zn ii) aq. NaOH, Δ iii) ethylene glycol, PTSA iv) a) BH<sub>3</sub>, b) H<sub>2</sub>O<sub>2</sub>, NaOH v) H<sub>3</sub>O<sup>+</sup> vi) NaBH<sub>4</sub></p>	(2)	

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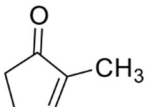
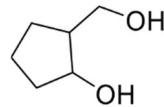
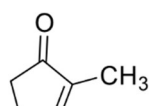
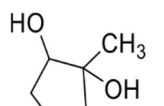
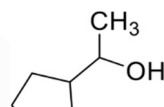
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(R)	 i) ethylene glycol, PTSA ii) a) $\text{Hg}(\text{OAc})_2$ , $\text{H}_2\text{O}$ , b) $\text{NaBH}_4$ iii) $\text{H}_3\text{O}^+$ iv) $\text{NaBH}_4$	(3)	
(S)	 i) ethylene glycol, PTSA ii) a) $\text{BH}_3$ , b) $\text{H}_2\text{O}_2$ , $\text{NaOH}$ iii) $\text{H}_3\text{O}^+$ iv) $\text{NaBH}_4$	(4)	
		(5)	

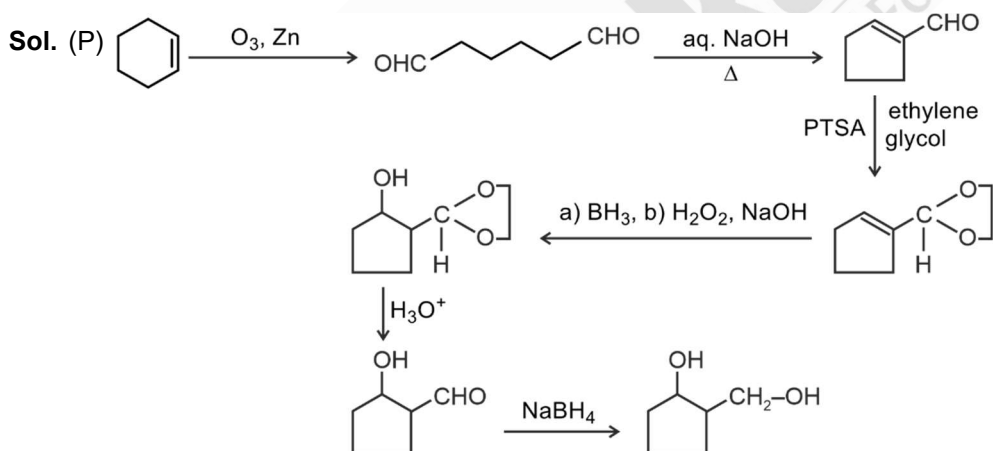
(A) P-3, Q-5, R-4, S-1

(B) P-3, Q-2, R-4, S-1

(C) P-3, Q-5, R-1, S-4

(D) P-5, Q-2, R-4, S-1

**Answer (A)**



P-3

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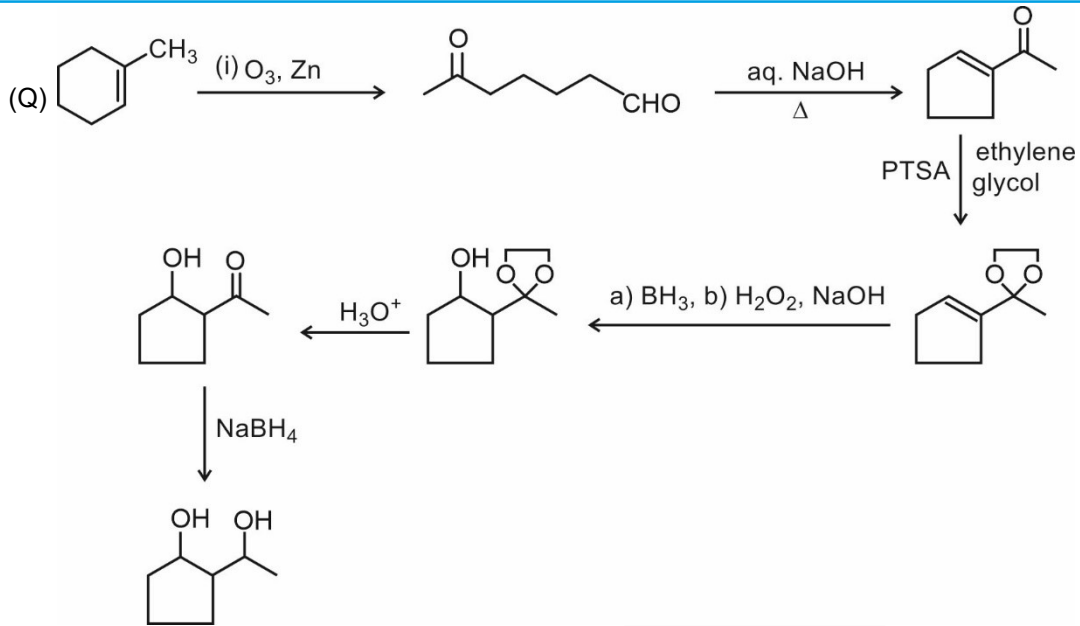
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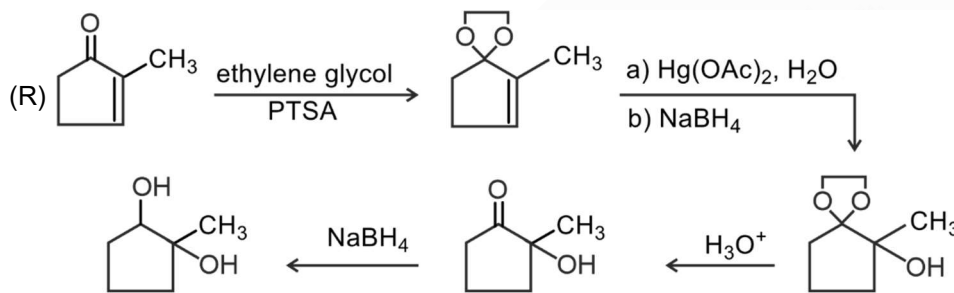
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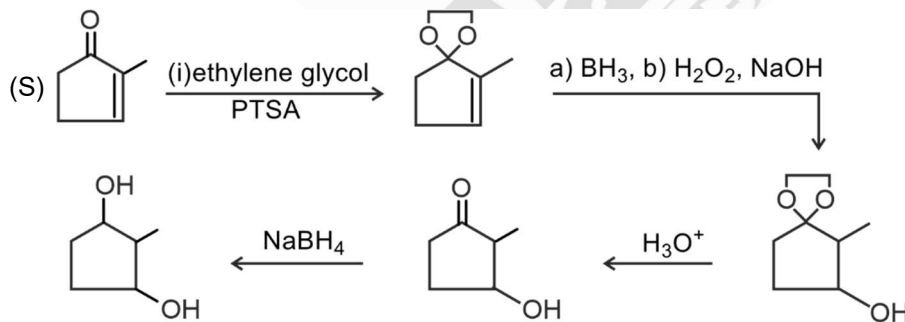
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Q-5



R-4



S-1

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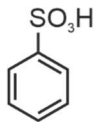
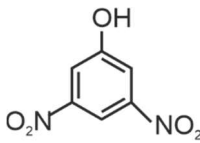
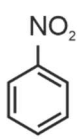
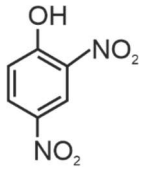
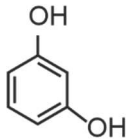
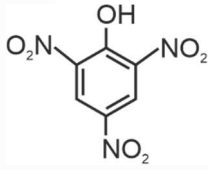
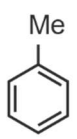
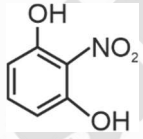
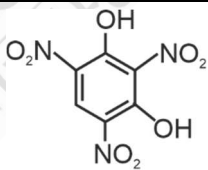
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**1**  
ALL INDIA RANK (Female)  
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4 Year Classroom  
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17. List-I contains various reaction sequences and List-II contains different phenolic compounds. Match each entry in List-I with the appropriate entry in List-II and choose the correct option.

	List-I		List-II
(P)	 $\xrightarrow{\text{(i) molten NaOH, H}_3\text{O}^+}$ $\xrightarrow{\text{(ii) Conc. HNO}_3}$	(1)	
(Q)	 $\xrightarrow{\text{(i) Conc. HNO}_3/\text{Conc. H}_2\text{SO}_4}$ $\xrightarrow{\text{(ii) Sn/HCl}}$ $\xrightarrow{\text{(iii) NaNO}_2/\text{HCl, 0-5}^\circ\text{C}}$ $\xrightarrow{\text{(iv) H}_2\text{O}}$ $\xrightarrow{\text{(v) Conc. HNO}_3/\text{Conc. H}_2\text{SO}_4}$	(2)	
(R)	 $\xrightarrow{\text{(i) Conc. H}_2\text{SO}_4}$ $\xrightarrow{\text{(ii) Conc. HNO}_3}$ $\xrightarrow{\text{(iii) H}_3\text{O}^+, \Delta}$	(3)	
(S)	 $\xrightarrow{\text{(i) (a) KMnO}_4/\text{KOH, } \Delta; \text{ (b) H}_3\text{O}^+}$ $\xrightarrow{\text{(ii) Conc. HNO}_3/\text{Conc. H}_2\text{SO}_4, \Delta}$ $\xrightarrow{\text{(iii) (a) SOCl}_2, \text{ (b) NH}_3}$ $\xrightarrow{\text{(iv) Br}_2, \text{ NaOH}}$ $\xrightarrow{\text{(v) NaNO}_2/\text{HCl, 0-5}^\circ\text{C}}$ $\xrightarrow{\text{(vi) H}_2\text{O}}$	(4)	
		(5)	

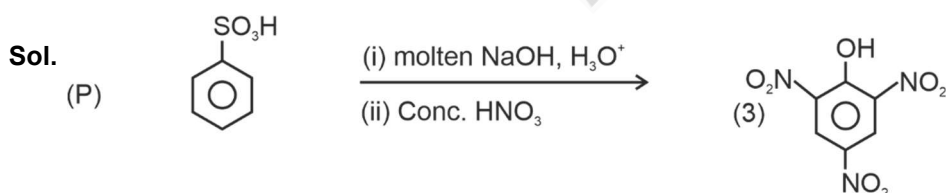
(A) P-2, Q-3, R-4, S-5

(B) P-2, Q-3, R-5, S-1

(C) P-3, Q-5, R-4, S-1

(D) P-3, Q-2, R-5, S-4

Answer (C)



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**15**  
AIR 15  
**M. Sai Divya Teja Reddy**  
2 Year Classroom  
100 PERCENTILE OVERALL

Telangana Topper



**19**  
AIR 19  
**Rishi Shekher Shukla**  
2 Year Classroom  
100 PERCENTILE OVERALL

Punjab Topper



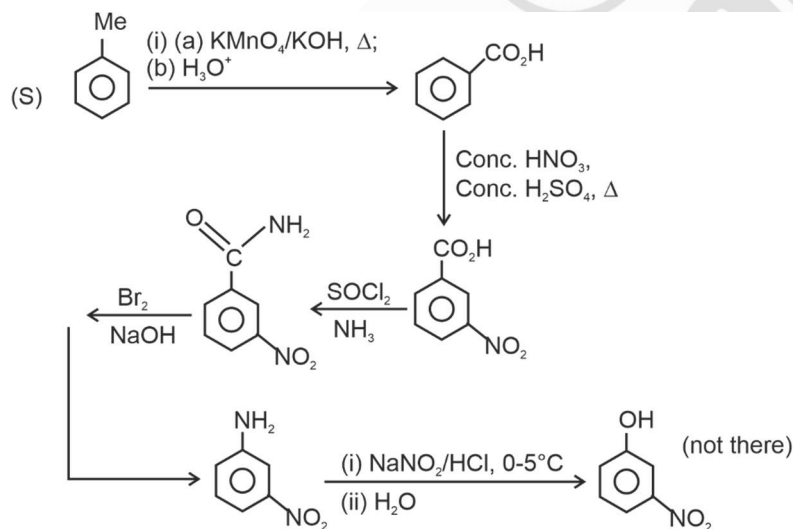
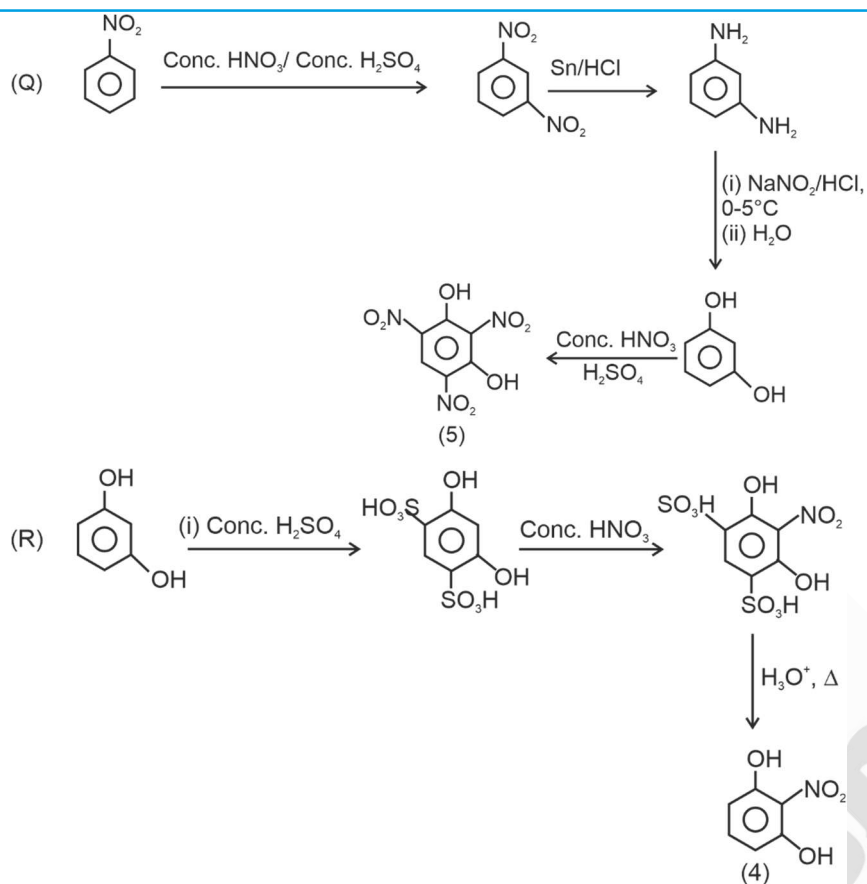
**25**  
AIR 25  
**Rachit Aggarwal**  
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AIR-16 crl JEE (Adv.) 2022



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