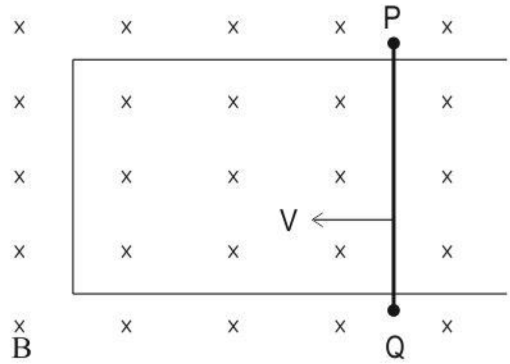
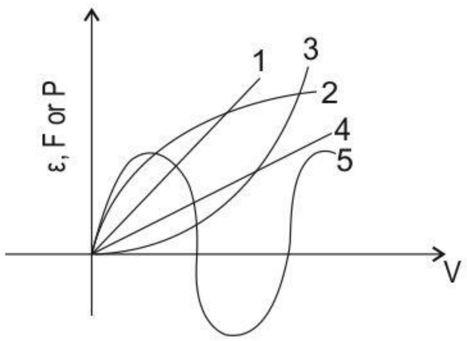
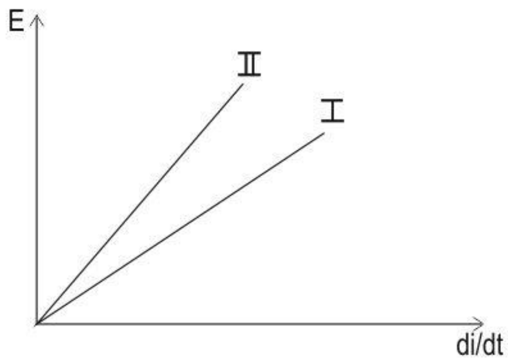
Electromagnetic Induction

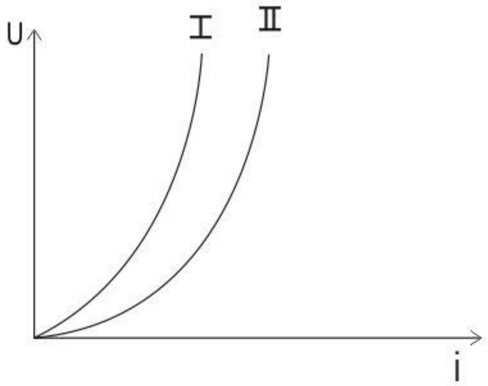
<table>
<tr><th>Q.No</th><th>Question</th><th>Marks</th></tr>
<tr><td colspan="3">Multiple Choice Question</td></tr>
<tr><td>Q.79</td><td>A conducting rod PQ of a small resistance is moved at a constant velocity v under the effect of a constant force F through a region of the constant magnetic field as shown. Assume no energy losses.


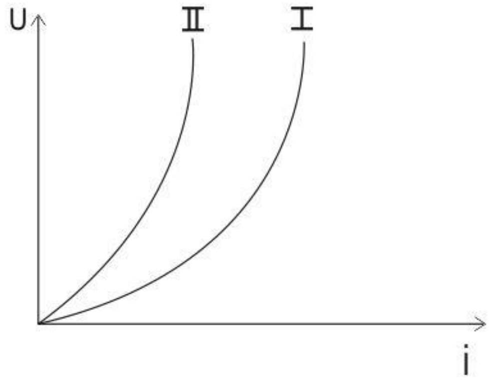
If the emf induced across PQ is ε and a force F and power P is used to move the rod, then which of the following graphs correctly represent ε, F, and P as a function of speed v respectively?


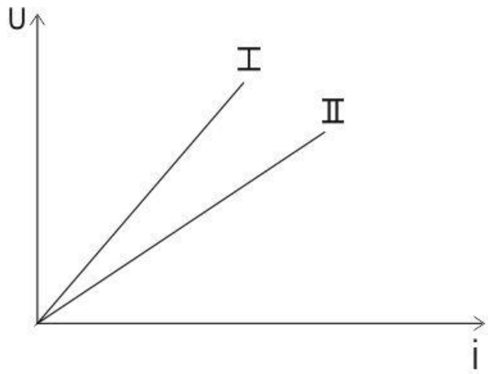
A. Graphs 5, 3 and 1
B. Graphs 2, 4 and 5
C. Graphs 4, 1 and 3
D. Graphs 3, 2 and 4</td><td>1</td></tr>
<tr><td>Q.80</td><td>Two statements are given below. One is labelled Assertion (A) and the other is labelled Reason (R). Read the statements carefully and choose the option that correctly describes statements A and R.

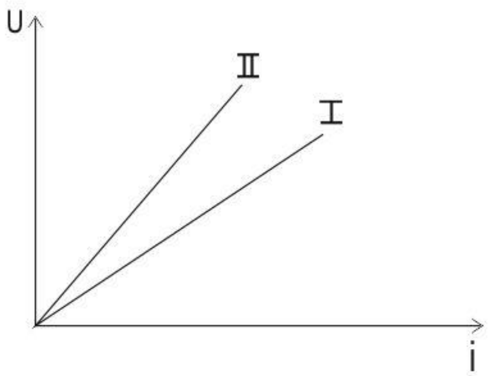
Assertion (A): The charge induced in a closed circuit increases if the rate of change of flux associated with the circuit increases rapidly.</td><td>1</td></tr>
</table>

	Reason (R): The emf induced in a closed circuit is directly proportional to the rate of change of flux associated with the coil. A. Both assertion and reason are true and reason is the correct explanation of assertion. B. Both assertion and reason are true but reason is NOT the correct explanation of assertion. C. Assertion is true but reason is false. D. Assertion is false but reason is true.	
Q.81	Two statements are given below. One is labelled Assertion (A) and the other is labelled Reason (R). Read the statements carefully and choose the option that correctly describes statements A and R. Assertion (A): The induced emf in a coil increases if the resistance of the coil is increased. Reason (R): Higher the resistance, the less the current through a coil. Select the correct option. A. Both assertion and reason are true and reason is the correct explanation for assertion. B. Both assertion and reason are true but reason is not the correct explanation for assertion. C. Assertion is true but the reason is false. D. Assertion is false but the reason is true.	1
Q.82	The following graphs represent emf induced with the rate of change of current for two different inductors.  Which of the given options correctly represents the energy stored versus current through these inductors?	1

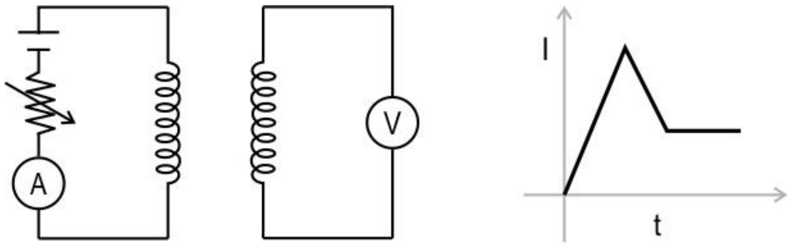
<table>
<tr><td></td><td>

A.


B.


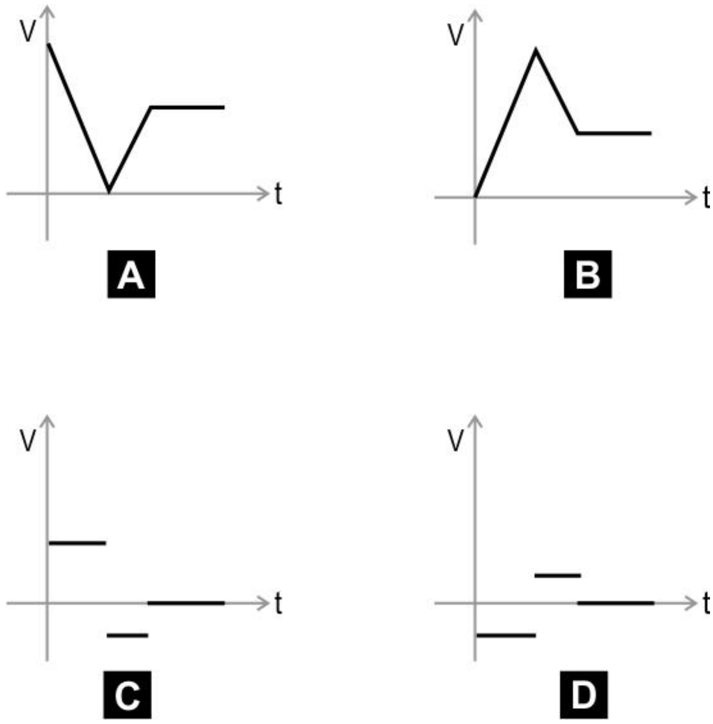
C. 4


D.</td><td></td></tr>
<tr><td>Q.83</td><td>Circuit I consists of a coil of wire, a battery, a rheostat, and an ammeter. Another coil connected to a voltmeter is placed close to the circuit I as shown below. As the resistance of the rheostat is changed, the current in the coil of the circuit I changes. The graph below shows this change in current with time.</td><td>1</td></tr>
</table>



circuit I

Which of the graphs correctly shows the voltage measured by the voltmeter with time?



A. A
B. B
C. C
D. D

Q.84 Assertion (A): For a sustained induced motional emf across a metal rod, a constant work has to be done on the rod by an external agency for moving it with constant speed through the external magnetic field. **(1)**

Reason (R): Work done by the external force keeps the charges in motion through the rod for a sustained induced current.

Select the correct option.

A. Both A and R are true and R is the correct explanation of A
B. Both A and R are true but R is NOT the correct explanation of A
C. A is true but R is false
D. A is false and R is also false

<table>
<tr><th colspan="3">Free Response Questions/Subjective Questions</th></tr>
<tr><td>Q.85</td><td>

A uniform magnetic field B exists in a direction perpendicular to the plane of motion of a conductor of length l translating at a velocity v as shown in the figures below.

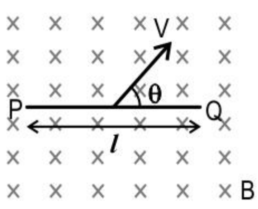


Fig a

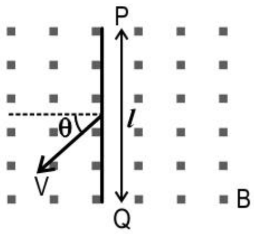


Fig b

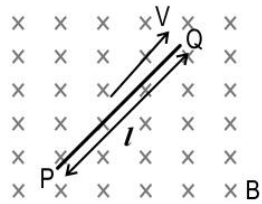
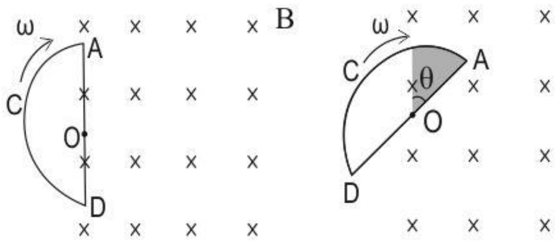


Fig c

Write an expression for induced emf in each case. Draw a figure representing the induced emf by an equivalent battery in each case.

</td><td>3</td></tr>
<tr><td>Q.86</td><td>

ADC is a semi-circular loop of conducting wire of radius r and centred at O. The initial position of the loop with respect to the magnetic field is shown in fig 1. The loop is then pulled into the magnetic field (fig 2.) and makes two complete rotations about point O.

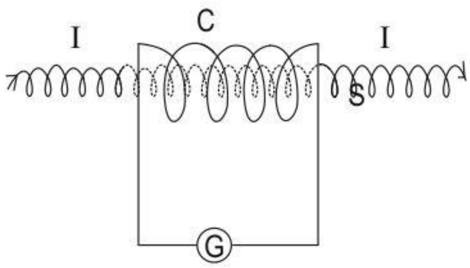


(a) Plot a graph between the induced current I and the angle of rotation θ for two complete periods of rotations.

(b) Depict the above graph in case the loop ADC revolves with angular frequency ω’ > ω. Keep all other conditions fixed as earlier. Give a reason for the change depicted in the graph.

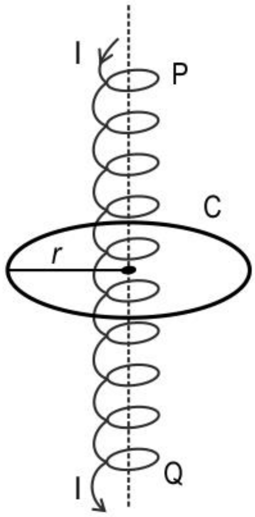
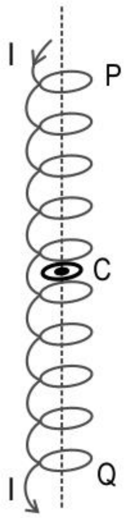
</td><td>3</td></tr>
<tr><td>Q.87</td><td>

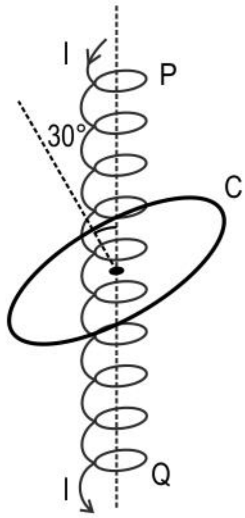
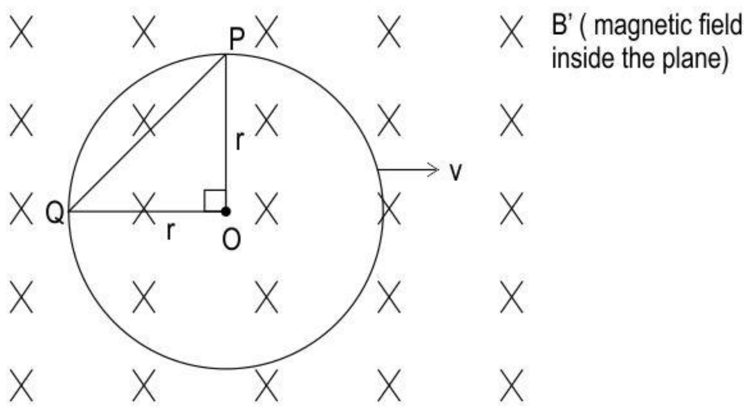
A current-carrying solenoid S of radius r with 100 turns per unit length is placed coaxially inside coil C of 100 turns and twice the radius of the solenoid as shown.

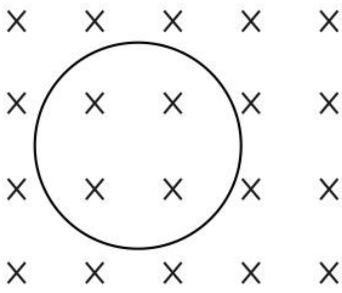
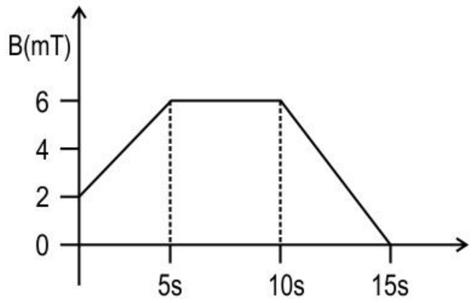
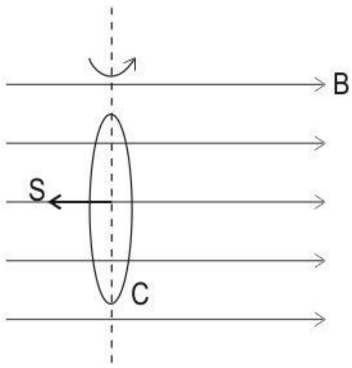
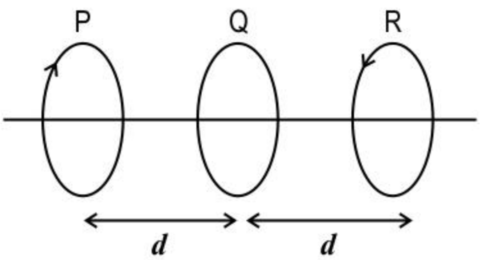


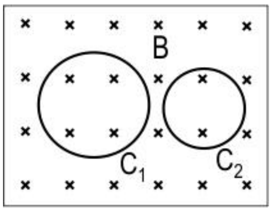
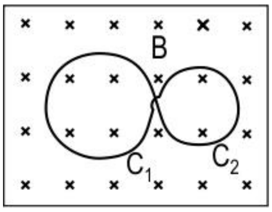
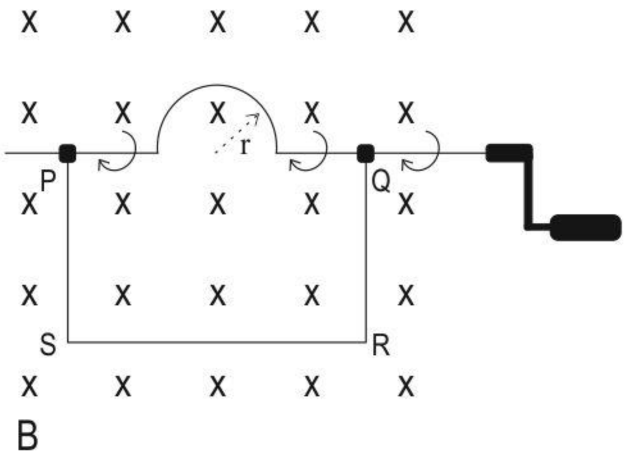
Current I through the solenoid S changes from 2 A in one direction to 2 A in the opposite direction within an interval of 2 seconds.

</td><td>3</td></tr>
</table>

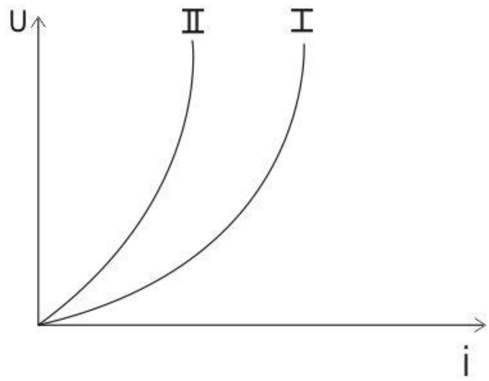
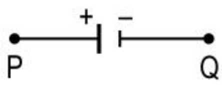
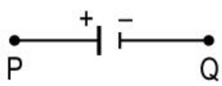
	(a) What is the rate of change in current that occurs in the solenoid? (b) Calculate the rate of change in flux experienced by coil C due to a change in current in solenoid S in terms of radius r of solenoid S. (c) If the total resistance of the coil C is 5 ohm, what is the induced current through the coil C? (d) By what factor does the induced current in coil C in part (c) change if the radius of the solenoid is changed from r to 3r/2? Keep all other conditions the same as earlier.	
Q.88	A long and an ideal solenoid of length l, radius R and number of turns N carries a steady current I. Determine the flux linked with a circular surface C of radius r in each of the following cases:  Fig i : r > R , Plane of coil ⊥ axis of the solenoid  Fig ii : r < R , Plane of coil ⊥ axis of the solenoid	3

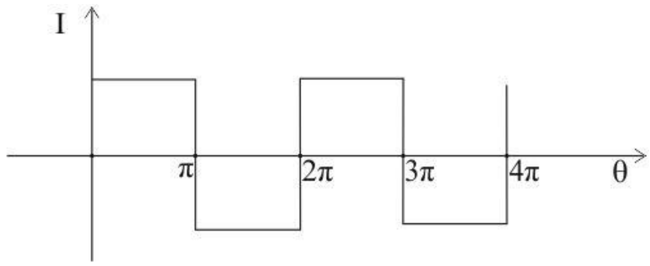
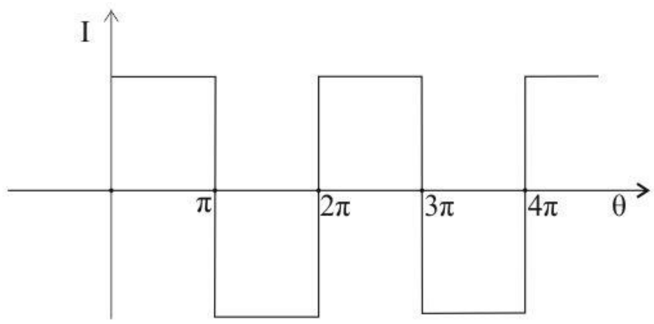
	 Fig iii : r >R , Normal to the plane of coil subtends an angle 30° with the axis of the solenoid	
Q.89	A long straight wire carrying a current of 0.1 A is placed at a distance of 10 m from a small conducting square loop in the same plane. The side of the square is 11 mm and the resistance of the square is 3 ohms. An external agent gradually changes the shape of the square loop to nearly a circle in 2 seconds. What is the average induced current in the loop?	3
Q.90	A conducting circular coil of radius 2 cm translates with a uniform velocity of 'v' in a uniform magnetic field as shown below.  (a) If ∠POQ is 90°, what is the induced potential difference between points P and Q? (b) Draw a figure representing the induced potential difference between points P and Q by an equivalent battery. (c) What is the net-induced emf in the conducting circular coil when the coil is moved within the magnetic field? Justify your answer.	4
Q.91	A circular loop of conducting wire is placed in a time-varying magnetic field such that the plane of the loop is perpendicular to the magnetic field. The graph below represents the variation of the magnetic field with time.	5

	  (a) In which time interval will the current induced in the coil be in the clockwise direction? Give reason. (b) Calculate the induced emf in the coil for the time interval t = 0s to t = 15s, if the area of the loop is 5×10^{-4} m^2. (c) Graphically represent the induced emf as a function of time.	
Q.92	A coil C of N turns and area S is placed normal to the magnetic field B as shown.  Determine the rate of change in flux linked with coil C as it turns about its diameter from the initial position as shown in the figure through an angle of 180^o with angular velocity ω.	2
Q.93	Given three identical coils P, Q and R placed coaxially as shown. Equal and opposite currents flow through the coils P and R.  a. Coil P is moved to the right keeping the coils Q and R fixed. i. Will the flux linked with coil Q increase or decrease? Give reason. ii. Using Lenz's law, identify the direction of induced current through coil Q.	2

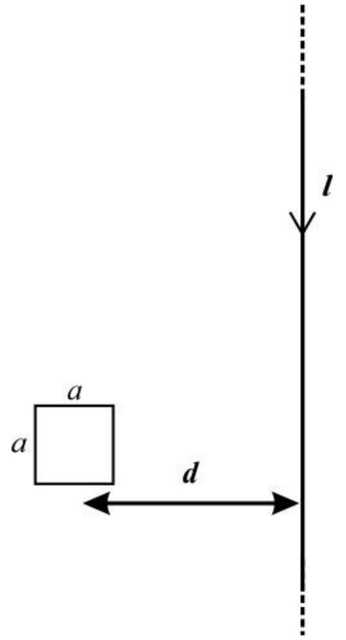
	b. Coil P is moved to the left keeping the coils Q and R fixed. i. Will the flux linked with coil Q increase or decrease? Give reason. ii. Using Lenz's law, identify the direction of induced current through coil Q.	
Q.94	(a) Two static coils C_1 and C_2 are placed in the same plane in a region of uniform magnetic field B. If the magnetic field begins to increase at a constant rate, identify the directions of the induced currents in the two coils as seen from above.  (b) The two coils C_1 and C_2 of the above arrangement are now connected as shown below keeping all other conditions the same as earlier.  Identify the directions of the induced current through the coils C_1 and C_2 as seen from above. Give an appropriate reason for the answer.	2
Q.95	Part of the wire belonging to the loop PQRS is bent into a semicircle of radius r = 0.2 m as shown in the diagram.  Initially, the plane of the loop is perpendicular to the magnetic field B = 0.5 T. Find the change in the flux linked with the loop PQRS, when the wire PQ is rotated from the starting position as shown in the figure to the final position attained after half a rotation.	2

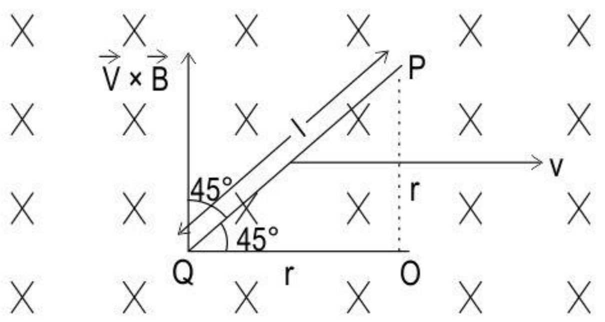
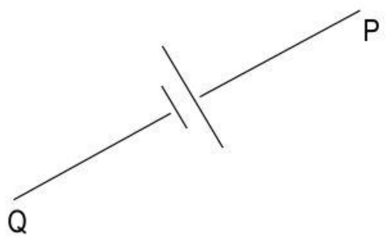
Answer key and Marking Scheme

Q.No	Answers	Marks
Q.79	C. Graphs 4, 1 and 3	1
Q.80	D. Assertion is false but reason is true.	1
Q.81	D. Assertion is false but the reason is true.	1
Q.82	 B.	1
Q.83	D. D	1
Q.84	C. A is true but R is false	1
Q.85	For Fig a : $\varepsilon = v_{\perp} l\, B = vlB \sin\theta$  [0.5 mark for correct formula and 0.5 mark for correct representation of the battery] For Fig b : $\varepsilon = v_{\perp} l\, B = vlB \cos\theta$  [0.5 mark for correct formula and 0.5 mark for correct representation of the battery] For Fig c : $\varepsilon = 0$	3

	 [0.5 mark for correct formula and 0.5 mark for correct representation of the battery]	
Q.86	(a) The graph between I and angle of rotation θ when the loop revolves with angular frequency ω :  (1 mark for the correct graphical representation) (b) The graph between I and angle of rotation θ when the loop revolves with higher angular frequency ω' :  (1 mark for the correct graphical representation) Reason: As angular frequency increases, the rate of change in the flux linked with the loop increases. This increases the induced emf and hence the corresponding value of the induced current also increases. (1 mark for the correct statement of the reason)	3
Q.87	a. Rate of change in current, $\Delta I/\Delta t = 4/2 = 2$ A/s [0.5 mark for correct value] b. Let n be the number of turns per unit length of coil S and N be the number of turns for coil C. Flux through S $\Phi_s = BA = (\mu_o nI)(\pi r^2)$ Rate of change in flux linked to coil C, $\Delta\Phi_C/\Delta t$ $= N \,.\, \Delta\Phi_s/\Delta t$ $= N\, \mu_o\, n\pi r^2 \,.\, \Delta I/\Delta t$	3

	$= 100 \times 4\pi \times 10^{-7} \times 100 \times \pi \times r^2 \times 2$ $= 8\pi^2 r^2 \times 10^{-3}$ [1 mark for the correct result of rate of change in flux of C] c. Induced emf in coil C $\varepsilon = \Delta\Phi_C/\Delta t = 8\pi^2 r^2 \times 10^{-3}$ V Induced current I through coil C $= \varepsilon / R = (8\pi^2 r^2 \times 10^{-3})/5$ [1 mark for the correct result of induced current in C] d. Induced Current I' $= [8\pi^2(3r/2)^2 \times 10^{-3}]/5$ $I'/I = (3/2)^2 = 9/4$ $I' = 9I/4 = 2.25\ I$ The induced current increases by a factor of 2.25 [0.5 mark for correct final answer]	
Q.88	Fig i : Here $\theta = 0$, $\phi_{in} = B_{in}A\cos\theta$ $\phi_{in} = \frac{\mu_0 NI}{l}\pi R^2 \cos 0$ $\phi_{in} = \frac{\mu_0 NI}{l}\pi R^2$ $\Phi_{out} = 0$ (Magnetic field outside the solenoid is zero.) $\phi_c = \phi_{in} + \phi_{out}$ $\phi_c = \frac{\mu_0 NI}{l}\pi R^2$ [1 mark for the correct result] Fig ii : $\phi_{in} = B_{in}A\cos\theta$ $\phi_{in} = \frac{\mu_0 NI}{l}\pi r^2 \cos 0$ $\phi_{in} = \frac{\mu_0 NI}{l}\pi r^2$ [1 mark for the correct result] Fig iii : $\phi_{in} = B_{in}A\cos\theta$ $\phi_{in} = \frac{\mu_0 NI}{l}\pi R^2 \cos 30$ $\phi_{in} = \frac{\sqrt{3}\mu_0 NI}{2l}\pi R^2$ [1 mark for the correct result]	3

Q.89	 Given: Distance between wire and the centre of the loop, d = 10 m Current in the wire, I = 0.1 A Side of the square loop, a = 11 mm Resistance of the loop, R = 3 ohm Time taken for changing from square to circle, Δt = 2 s To find: Average induced current = I_{avg} = (Average induced EMF)/Resistance = $\Delta\Phi/R\Delta t$ .....(i) $\Delta\Phi = B\Delta A = (\mu_0 I/2\pi d) \times \Delta A$ (B is magnetic field due to the long straight wire) Substituting the known values we get, $\Delta\Phi = (\mu_0 \times 0.1/2\pi \times 10)\times \Delta A = 2\ 10^{-9} \times \Delta A$ .....(ii) [0.5 marks for writing correct formula of flux change and 0.5 marks for correct formula of magnetic field due to long straight wire] When the square changes to circle its perimeter will remain the same so we can say $2\pi r = 4a$ $r = 2a/\pi$ Now, $\Delta A = \pi r^2 - a^2 = \pi(2a/\pi)^2 - a^2$ $= (4a^2/\pi) - a^2$ Substituting the value of a	3

	$\Delta A = (4 \times 11 \times 11 \times 7/22)-(11 \times 11) = 33\ mm^2 = 33 \times 10^{-6}\ m^2$ Substituting value of ΔA in (ii) we have $\Delta\Phi = 2 \times 10^{-9} \times 33 \times 10^{-6} = 6.6 \times 10^{-14}\ T.m^2$ [1 mark for finding change in area] Substituting values in equation (i) $I_{avg} = 6.6 \times 10^{-14}/(3 \times 2) = 1.1 \times 10^{-14}$ A [1 mark for final answer]	
Q.90	(a) Δ POQ is right angled triangle at O. By Pythagoras theorem, the displacement vector between points A and B has a magnitude of √2r. $\left\lvert\vec{l}\right\rvert = \sqrt{2}r$ (1 mark) $e = (\vec{v} \times \vec{B}).\vec{l}$ The angle between $(\vec{v} \times \vec{B})$ and $\vec{l}$ is 45° as shown below.  e = (vBsin90°) lcos 45° e = vlB/√2 = vBr (1 mark) (b)  (c) Since neither the area of the loop nor the magnetic field linked with the field is changing, there is no change in the flux through the coil.	4
Q.91	(a) For the induced current to be clockwise, the magnetic flux associated with the circular coil should decrease. (1 mark) The flux associated with the coil decreases when the magnetic field associated with the coil decreases as ϕ =B.A	5

<table>
<tr><td></td><td>
Hence, in the time interval t=10s to t=15s, the induced current will be clockwise. (1 mark)

(b) $e = -d\phi/dt$ (0.5 marks)

For t = 0s to t = 5 s

$d\phi = dB.A = (6-2) \times 10^{-3} \times 5 \times 10^{-4}$

$d\phi = 2 \times 10^{-6}$ Wb

$e = - 2 \times 10^{-6}/5 = -0.4 \times 10^{-6}$ V (0.5 marks)

Induced emf from t= 5 s to t = 10s = 0 as there is no change in magnetic flux. (0.5 marks)

induced emf from t = 10s to t = 15 s

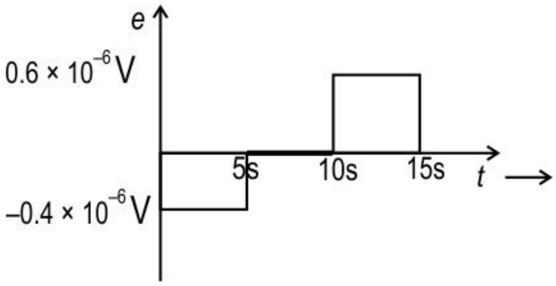
$d\phi = (0 - 6) \times 10^{-3} \times 5 \times 10^{-4}$

$d\phi = - 3 \times 10^{-6}$ Wb

$e = - d\phi/dt$

$e = 3 \times 10^{-6}/5 = 0.6 \times 10^{-6}$ V (0.5 marks)

(c)



</td><td></td></tr>
<tr><td>Q.92</td><td>
Flux linked with a coil is given by the formula,

$\phi = \vec{B}.\vec{A} = BA\cos\theta$

Here, B is the magnetic field strength and A is the area of the coil and θ is the angle between the magnetic field and the area vector.

Initial flux linked with coil,

$\Phi_1 = BNS \cos 180 = - BNS$

Final flux linked with coil,

$\Phi_2 = BNS \cos 0 = BNS$

Change in flux = $\Delta\Phi = BNS - (-BNS) = 2BNS$

[1 mark for correct result of change in flux]

Time duration, $\Delta t = \pi/\omega$

Rate of change in flux

$\Delta\Phi/\Delta t = 2BNS\omega/\pi$

[0.5 mark for time formula]

[0.5 mark for correct final result]
</td><td>2</td></tr>
</table>

Q.93	a. i. Flux linked with coil Q due to coil P increases. Flux linked with coil Q due to coil R remains the same. So the overall flux linked with the coil Q increases. [0.5 mark for correct conclusion of overall change in flux linked with Q] ii. Induced current through Q flows in the direction opposite to that in P, that is anti-clockwise direction. [0.5 mark for correct conclusion of the direction of induced current through coil Q] b. i. Flux linked with coil Q due to coil P decreases. Flux linked with coil Q due to coil R remains the same. Overall flux linked with the coil Q decreases. [0.5 mark for correct conclusion of overall change in flux linked with Q] ii. Induced current through Q flows in the direction same as that in P, that is clockwise direction. [0.5 mark for correct conclusion of the direction of induced current through coil Q]	2
Q.94	(a) The direction of the induced current through C_1 : Anticlockwise The direction of the induced current through C_2 : Anticlockwise [0.5 mark for the correct identification of directions through C_1 and C_2] (b) The direction of the induced current through C_1 : Anticlockwise The direction of the induced current through C_2 : Clockwise [0.5 mark for the correct identification of directions through C_1 and C_2] C_1 is a coil of a larger area, hence it will experience higher induced emf in comparison to the coil C_2 of a smaller area. Since coils C_1 and C_2 are connected to each other, the induced emf across coil C1 will drive the current through the closed-loop. So the direction of the current in C_1 remains as anticlockwise, whereas C_2 becomes clockwise. [1 mark for the correct statement of reason]	2
Q.95	Change in flux, $\Delta\Phi = B.\ \Delta A$ Here B = 0.5 T $\Delta A = (\text{Area})_{\text{Rectangle}} + \pi r^2/2 - [(\text{Area})_{\text{Rectangle}} - \pi r^2/2\ ] = \pi r^2$ [1 mark for correct calculation of change in the area] So change in flux, $\Delta\Phi = 0.5 \times \pi\ (0.2)^2 = 0.2\ \pi$ Wb [1 mark for correct calculation of change in flux]	2