Indian National Physics Olympiad – 2010

Roll Number: P 1 0 _ _ _

INPhO – 2010

Date: 31st January 2010

Duration: **Three Hours**

Maximum Marks: **60**

Please fill in all the data below correctly. The contact details provided here would be used for all further correspondence.

Full Name (BLOCK letters) Ms. / Mr.: ______________________________

____

Male / Female Date of Birth (dd/mm/yyyy): ______________

Name of the school / junior college: ______________________________

____

Class: XI/ XII Board: ICSE / CBSE / State Board / Other

Address for correspondence (include city and PIN code): ______________

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______________________________ PIN Code: _ _ _ _ _ _

Telephone (with area code): ______________ Mobile: ______________

Email address: ______________________________

Besides the International Physics Olympiad, do you also want to be considered for the Asian Physics Olympiad? For APhO - 2010 your presence will be required in Delhi/Taiwan from April 13 to May 02, 2010.

Yes/No.

I have read the procedural rules for INO and agree to abide by them.

Signature

==

(Do not write below this line)

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MARKS

Que.	**Part A**						**Part B**	**Total**
	1	2	3	4	5	Subtotal **A**	Subtotal **B**	
Marks								

HOMI BHABHA CENTRE FOR SCIENCE EDUCATION
Tata Institute of Fundamental Research
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Instructions:

1. Write your Roll Number on every page of this booklet.
2. Fill out the attached performance card. **Do not detach it from this booklet.**
3. This booklet has two (2) parts: Part A and Part B and consists of 22 pages.
4. Part A consists of five (5) questions. These should be answered in the space provided along with the question.
5. Part B is a set of multiple choice questions. One of the given choices is the best choice. Select this most appropriate choice and darken the bubble in the corresponding space in the answer booklet which is attached at the end of Part B (Page no. 16).
6. In Part B, there are **20** questions. Each right answer carries 0.5 marks. There is **no negative marking** for this part. You are encouraged to attempt all questions in this part.
7. Computational tools such as calculators, mobiles, pagers, smart watches, slide rules, log tables etc. are **not** allowed.
8. You may use blank pages at the end of this booklet for rough work.
9. **This entire booklet must be returned.**

Table of Information

Speed of light in vacuum	c	=	3.00×10^{8} m·s^{-1}
Planck's constant	h	=	6.63×10^{-34} J·s
Universal constant of Gravitation	G	=	6.67×10^{-11} N·m^{2}·kg^{-2}
Magnitude of the electron charge	e	=	1.60×10^{-19} C
Stefan-Boltzmann constant	σ	=	5.67×10^{-8} W·m^{-2} · K^{-4}
Permittivity constant	ϵ_0	=	8.85×10^{-12} F·m^{-1}
Permeability constant	μ_0	=	$4\pi \times 10^{-7}$ H·m^{-1}
Acceleration due to gravity	g	=	9.81 m·s^{-2}
Universal Gas Constant	R	=	8.31 J· K^{-1}·mole^{-1}

PART - A

1. Two skaters (A and B), each of mass 70 kg, are approaching each another on a frictionless surface, each with a speed of 1 m·s^{-1}. Skater A carries a ball of mass 10 kg. Both skaters can toss the ball at 5 m·s^{-1} relative to themselves such that when A tosses the ball at $t = 0$ s to B then the ball leaves at 6 m·s^{-1} with respect to the ground. Further, they start ($t = 0$ s) tossing the ball back and forth when they are 10 m apart (see Fig. (1)). Assume that the motion is one dimensional, all collisions are completely inelastic and that the time delay between receiving the ball and tossing it back is 1 s.

[1 + 2 + 2 + 1.5 + 3.5 = 10]

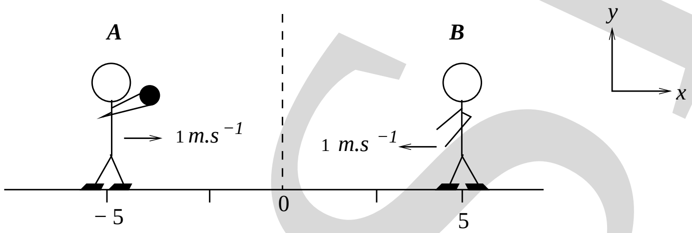


Figure 1:

(a) State initial momenta of skaters (just before t = 0 s).

$\vec{P_A} =$; $\vec{P_B} =$

(b) At $t = 0$ s skater A tosses the ball to skater B. State momenta of both the skaters immediately after B catches the ball.

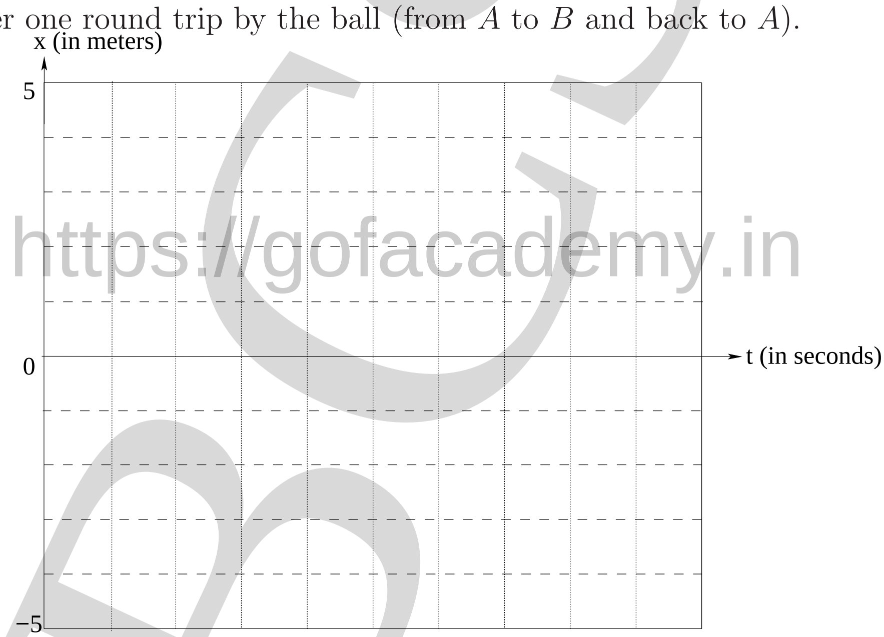
$\vec{P_A} =$; $\vec{P_B} =$

(c) Indicate the minimum number of tosses by each skater required to avoid collision.

Number of tosses by $A =$; Number of tosses by $B =$

(d) Indicate motion of each skater on the following $x - t$ plot if no tosses are made. [Note : For this and the next part you must select the scale on the time axis appropriately. You may use a pencil for sketching.]

(e) Indicate motion of each skater on the following x-t plot from $t = 0$ s till just after one round trip by the ball (from A to B and back to A).



2. Consider a closed cylinder whose walls are adiabatic. The cylinder lies in a horizontal position and is divided into three parts $A_1,\ A_2$ and A_3 by means of partitions S_1 and S_2 which can move along the length of the cylinder without friction. Piston S_1 is adiabatic while S_2 is conducting. Initially each of the parts $A_1,\ A_2$ and A_3 contains one mole of Helium gas at pressure P_0, temperature T_0, and volume V_0 (see Fig. (2)). Helium is to be regarded as an ideal monoatomic gas. Also $C_v = 3R/2,\ C_p = 5R/2$ and $\gamma = 5/3$.
Now heat is slowly supplied to the gas in part A_1 till the temperature in part A_3 becomes $T_3 = 9T_0/4$.

[3.5 + 2 + 2 + 2.5 = 10]

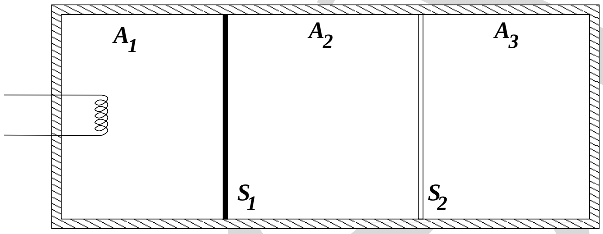


Figure 2:

(a) Let the final thermodynamic coordinates of the partitions $A_1,\ A_2$ and A_3 be $\{P_1,\ V_1,\ T_1\}$, $\{P_2,\ V_2,\ T_2\}$ and $\{P_3,\ V_3,\ T_3\}$ respectively. Fill the table below expressing the pressure in terms of P_0, volume in terms of V_0 and temperature in terms of T_0:

$P_1 =$	$P_2 =$	$P_3 =$
$V_1 =$	$V_2 =$	$V_3 =$
$T_1 =$	$T_2 =$	$T_3 =$

(b) What work is done by the gas in A_1 on the gases in A_2 and A_3 in terms of $\{P_0,\ V_0\}$ and related quantities?

Work done =

(c) What is the amount of heat supplied to the gas in part A_1 in terms of $\{P_0,\ V_0\}$ and related quantities?

Heat supplied =

(d) Obtain the entropy change in systems $A_2 + A_3$ and A_1?

Entropy Change in $A_2 + A_3$ =

Entropy change in A_1 =

3. A small angle prism of crown glass and a small angle prism of flint glass are arranged to deviate a light beam in opposite directions. A white light beam is incident on the crown glass prism of the arrangement. The refracting angle of the crown prism is 10.0^0 and that of the flint prism is such that the net deviation of the light beam from both the prisms for the C and F spectral lines are equal. Assume minimum deviation condition for both the prisms. See Table 1 below.

Table 1: Values of n (refractive indices) for three different spectral lines.

	C	D	F
Flint	1.644	1.650	1.665
Crown	1.517	1.520	1.527

[3 + 2 + 5 = 10]

(a) State the refracting angle (A_F) of the flint prism in degrees.

$A_F =$

(b) State the net deviation (Δ_D) for the D line in degrees.

$\Delta_D =$

(c) Draw a schematic ray diagram of the D line for this arrangement indicating the numerical values of the following important angles: (i) incidence on each prism; (ii) deviation from each prism and (iii) angle between the adjacent surfaces of the two prisms. You may use a pencil for this diagram.

4. Consider a long thin uniform electrically insulating and magnetically nonpermeable cylindrical shell of length l, radius R (with $l \gg R$) and moment of inertia I about the horizontal axis (see Fig. 3). A massless string is wound around the shell surface and a vertically hanging mass m is attached to its free end and released from rest at time $t = 0$.

[1 + 1 + 1 + 2 + 2 + 1 + 2 + 1.5 + 2 + 1.5 = 15]

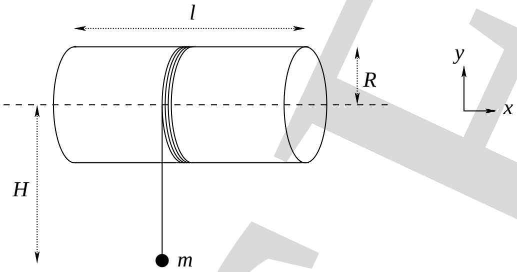


Figure 3:

(a) State the magnitude of angular acceleration α in terms of $\{m,\ g,\ R, \text{ and } I\}$.

$\alpha =$

(b) State the magnitude of angular velocity (ω) of the shell in terms of $\{\alpha,\ H$ and $R\}$. Here H is the height through which mass 'm' has fallen.

$\omega =$

(c) State the total kinetic energy (K) of the assembly in terms of m, g and H.

$K =$

Let a charge Q be uniformly distributed on the shell. As the shell rotates it will produce a magnetic field ($\vec{B}$) and an electric field of magnitude E associated with electromotive force in accordance with Faraday's law of induction. Let α' and ω' denote the magnitudes of angular acceleration and angular velocity of this rotating charged shell respectively. Ignore radiation losses due to acceleration.

(d) State magnetic field in terms of Q, ω' and relevant quantities.

$\vec{B} =$

(e) State E in terms of α' and relevant quantities.

$E =$

(f) Electric field produces a torque ($\vec{\tau}_{em}$) on this shell. State τ_{em} in terms of E and relevant quantities.

$\tau_{em} =$

(g) State α'.

$\alpha' =$

(h) State total kinetic energy (K') of the shell in terms of m, g, H and relevant quantities.

$K' =$

(i) State the difference in energies obtained in parts (4c) and (4h) in terms of B, R, l and relevant quantities.

$K' - K =$

(j) Interpret $K' - K$.

5. Tc^{99}_{43} radio-nuclide decays by γ-emission with a half-life of 6 hours and by β-emission with a half-life of 2.12 $\times 10^5$ years. A small quantity of solution containing Tc^{99}_{43} with an activity of 1.0 μCi (micro Curie) is injected into the bloodstream of an adult person. The solution mixes rapidly and uniformly in the person's blood. It is excreted from the kidneys with an effective half-life of 6 hours. A 1 ml sample of the blood taken after 3.0 hours reveals an activity of 3.70 disintegrations per second on an average. Note, 1 Ci (Curie) = 3.70 $\times 10^{10}$ disintegrations per second.

[1 + 2 + 2 = 5]

(a) State the decay constant λ_k (in hour^{-1}) for excretion from the kidney?

$\lambda_k =$

(b) State the total activity A at the end of 3 hours?

$A =$

(c) State the total volume (V) of blood in the person's body in liters?

$V =$

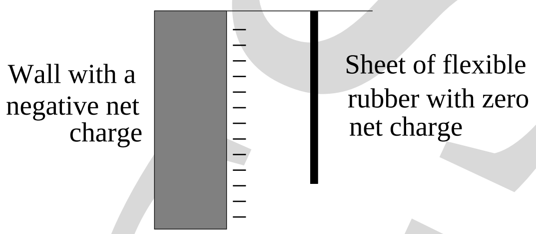
****** END OF "**PART A**" OF THE QUESTION PAPER ******

Part - B

1. An isolated hollow metal sphere is electrically neutral (no excess charge) and supported on an insulating stand. A small amount of negative charge is suddenly placed at one point P on this metal sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities:

   (a) All of the excess charge remains right around P.
   (b) The excess charge has distributed itself evenly over the outside surface of the sphere.
   (c) The excess charge is evenly distributed over the inside and outside surface.
   (d) Most of the charge is still at point P, but some will have spread over the sphere.
   (e) There will be no excess charge left on the sphere.

2. A non-conducting wall is given a negative net charge. Next, a sheet of very flexible rubber with zero net charge is suspended from the ceiling near the charged wall as shown below. The rubber sheet will:

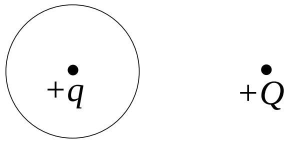


   (a) not be affected by the charges on the wall since rubber is an insulator.
   (b) not be affected by the charged wall because the rubber sheet has zero net charge.
   (c) bend away from the wall due to the electrical repulsion between the electrons in the rubber and the charges on the wall.
   (d) bend away from the wall due to the polarization of the rubber molecules by the charged wall.
   (e) bend towards the wall due to the polarization of the rubber molecules by the charged wall.

3. Two small objects each with a net charge of $+Q$ exert a force of magnitude F on each other. We replace one of the objects with another whose net charge is $+4Q$. We move the $+Q$ and $+4Q$ charges to be 3 times as far apart as they were. What is the magnitude of the force on the $+4Q$ charge?

   (a) F
   (b) $4F$
   (c) $4F/3$
   (d) $4F/9$
   (e) $F/3$

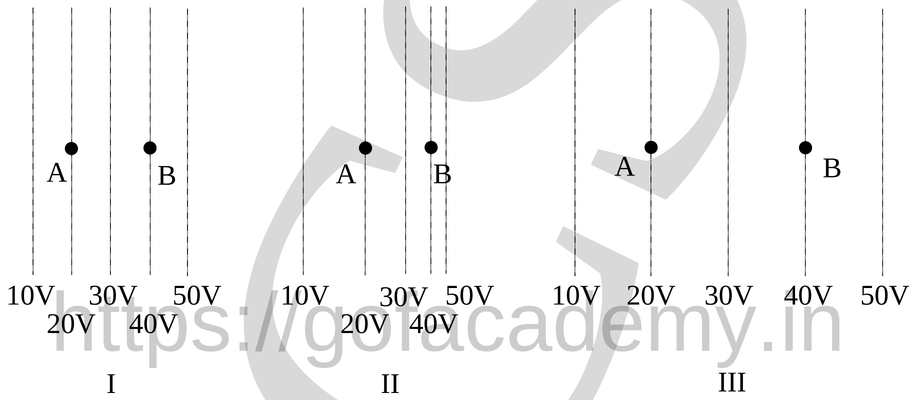
4. The associated figure shows an electric charge $+q$ located at the centre of a hollow uncharged conducting metal sphere. Outside the sphere is a second charge $+Q$. Both charges are positive. Choose the description below that describes the net electrical forces on each charge in this situation.



(a) Both charges experience the same net force directed away from each other.
(b) No net force experienced by either charge.
(c) There is no net force on Q but a net force on q.
(d) There is no net force on q but a net force on Q.
(e) Both charges experience a net force but they are different from each other.

FOR QUESTIONS 5-7:

In the following figures, the dotted lines show the equipotential lines of electric fields. (A charge moving along a line of equal potential would have a constant electric potential energy.) A charged object is moved directly from point A to point B. The charge on the object is $+1\ \mu$C.



5. How does the amount of work needed to move this charge compare for these three cases?

(a) Most work required in I.
(b) Most work required in II.
(c) Most work required in III.
(d) I and II require the same amount of work but less than III.
(e) All three would require the same amount of work.

6. How does the magnitude of the electric field at B compare for these three cases?

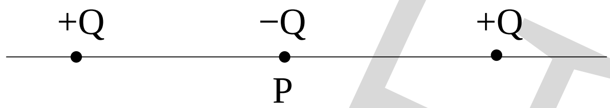
(a) I > III > II
(b) I > II > III
(c) III > I > II
(d) II > I > III
(e) I = II = III

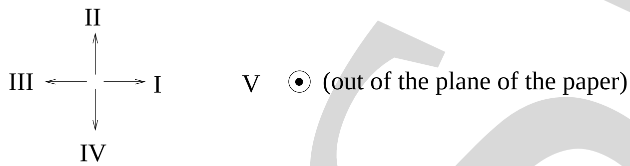
7. For case III what is the direction of the electric force exerted by the field on the +1 μC charged object when at A and when at B?

(a) left at A and left at B
(b) right at A and right at B
(c) left at A and right at B

(d) right at A and left at B
(e) no electric force at either positions.

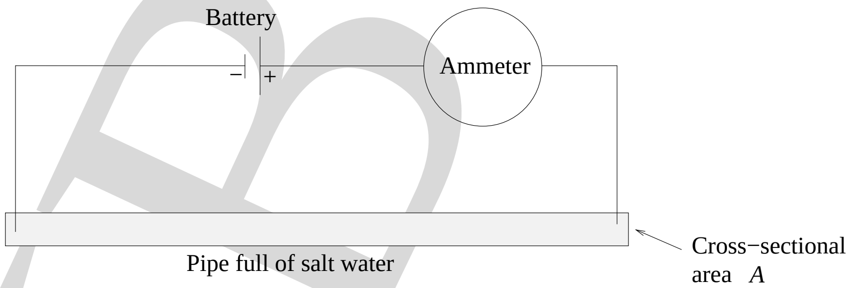
8. Two identical charges of magnitude $+Q$ are fixed as shown. A third charge $-Q$ is placed midway between them at point P. Then small displacements of $-Q$ are made in the directions indicated by arrows. The $-Q$ is stable with respect to displacement.





(a) I and III
(b) I and V
(c) II and V
(d) III and V
(e) stable for any small displacement.

9. Salt water contains n sodium ions (Na^+) per cubic meter and n chloride ions (Cl^-) per cubic meter. A battery is connected to metal rods that dip into a narrow pipe full of salt water. The cross sectional area of the pipe is A. The magnitude of the drift velocity of the sodium ions is V_{Na} and the magnitude of the drift velocity of the chloride ions is V_{Cl}. Assume that $V_{Na} > V_{Cl}$ ($+e$ is the charge of a proton).

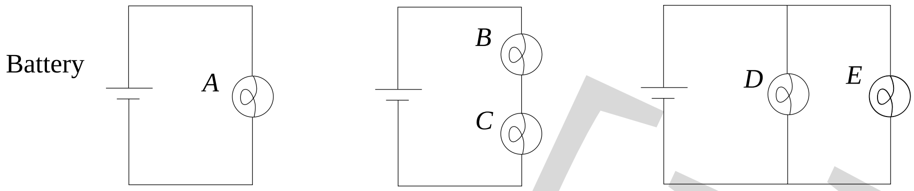


What is the magnitude of the ammeter reading?

(a) $enAV_{Na} - enAV_{Cl}$
(b) $enAV_{Na} + enAV_{Cl}$
(c) $enAV_{Na}$
(d) $enAV_{Cl}$
(e) zero

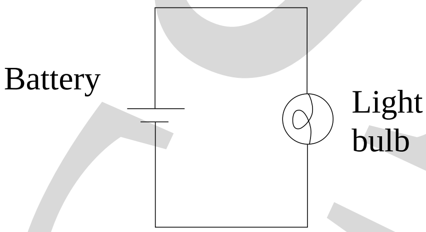
10. In these three circuits all the batteries are identical and have negligible internal resistance, and all the light bulbs are identical. Rank all 5 light bulbs (A, B, C, D, E)

in order of brightness from brightest to dimmest.



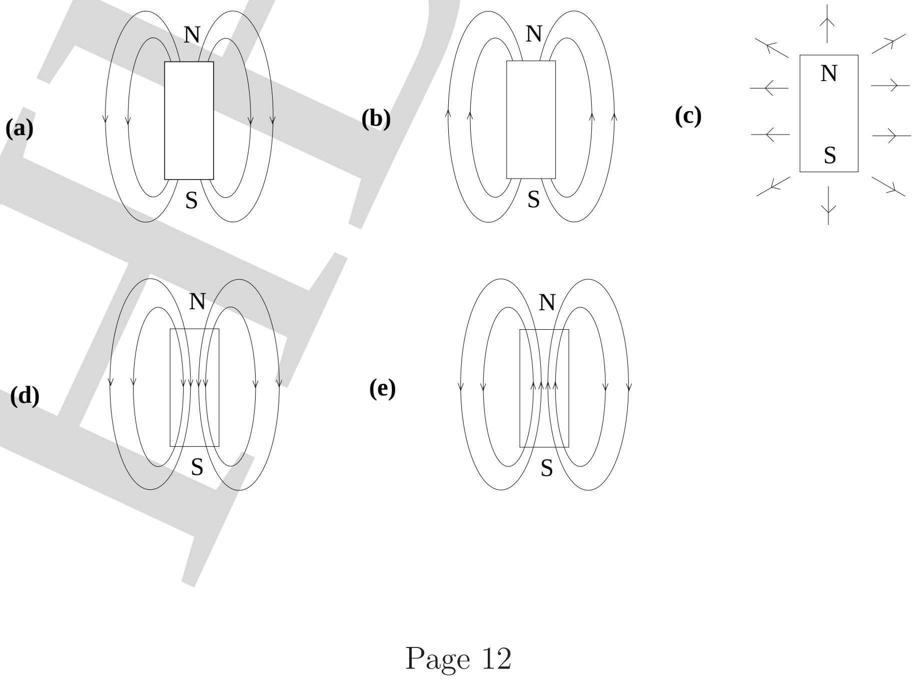
(a) $A = B = C > D = E$
(b) $A > B = C > D = E$
(c) $A = D = E > B = C$
(d) $A = D = E > B > C$
(e) $D = E > A > B = C$

11. Which of the following statements is true about the electric field inside the bulb filament?

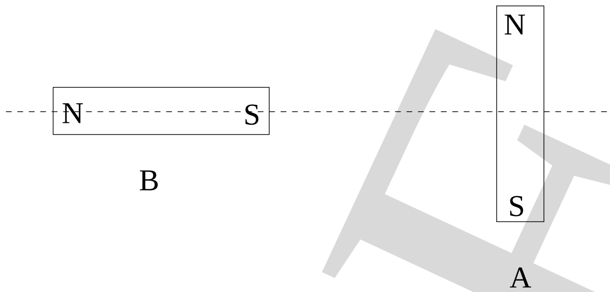


(a) The field must be zero because the filament is made of metal.
(b) The field must be zero because a current is flowing.
(c) The field must be zero because any excess charges are on the surface of the filament.
(d) The field must be non-zero because the flowing current produces an electric field.
(e) The field must be non-zero because no current will flow without an applied field.

12. The magnetic field lines due to a bar magnet are correctly shown in

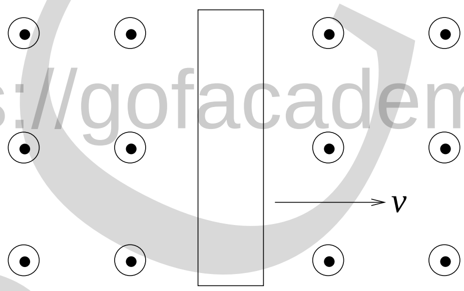


13. Two strong bar magnets A and B are placed on a horizontal table such that the axis of B intersects A at mid-point as shown in figure. B is fixed while A is free to move. There are no magnetic fields except those due to A and B. Then A will

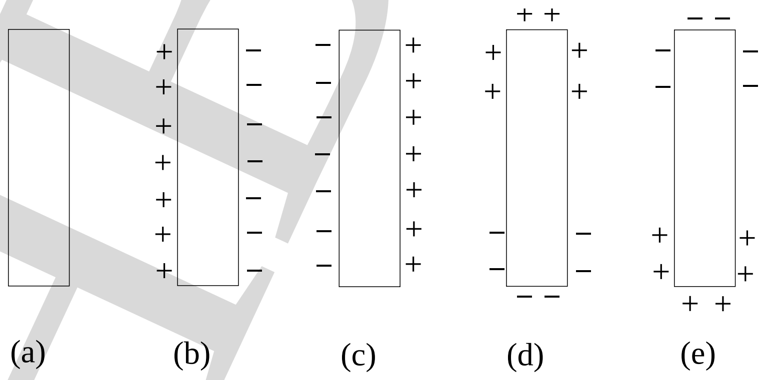


(a) rotate but not move toward or away from B.
(b) rotate and move toward B.
(c) move toward B and not rotate.
(d) rotate and move away from B.
(e) move away from B and not rotate.

14. A neutral metal bar is moving at constant velocity v to the right through a region where there is a uniform magnetic field pointing out of the page. The magnetic field is produced by some large coils which are not shown in the diagram.



Which one of the following diagrams best describes the charge distribution on the metal bar?



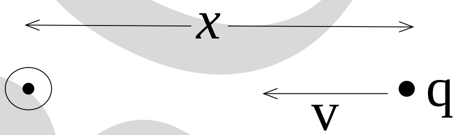
15. A wire is placed between the poles of two fixed bar magnets as shown. A small current in the wire is into the plane of the paper. The direction of the magnetic force on the wire is

(a) ↑
(b) ↓
(c) →
(d) ←
(e) ⊙ out of the plane of the paper.

16. The Earth's magnetic field at a point P near the equator has only a horizontal component. A horizontal overhead high tension wire above this point carries a current such that it completely nullifies this horizontal component at P. The direction of the current in the wire is most likely

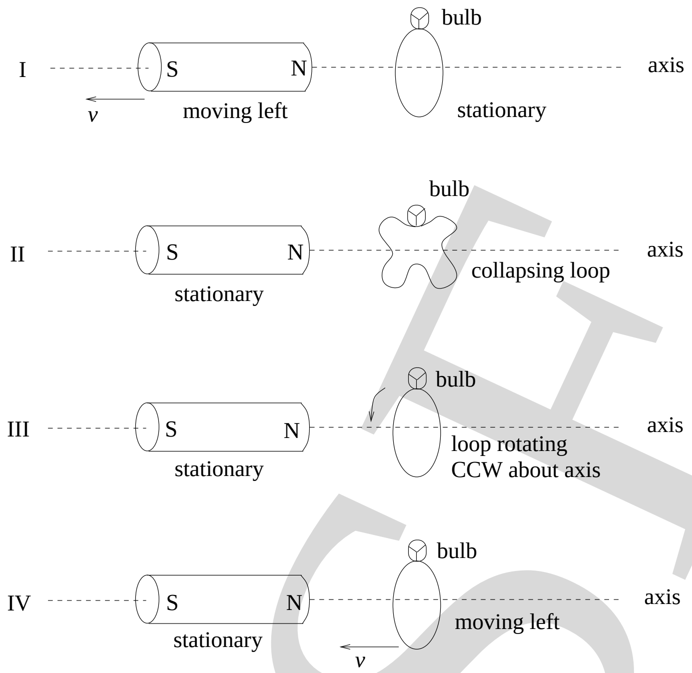
(a) north to south.
(b) south to north.
(c) east to west.
(d) west to east.
(e) such that the direction does not matter.

17. The figure below depicts a long wire carrying a current coming out of the plane of the paper. A charge q at a distance x from it is moving towards it with speed v and experiences a magnetic force of magnitude F. If the distance of the charge from the wire were $2x$ (and all other conditions remaining the same) then the force would be



(a) F
(b) $2F$
(c) $F/2$
(d) $F/4$
(e) zero.

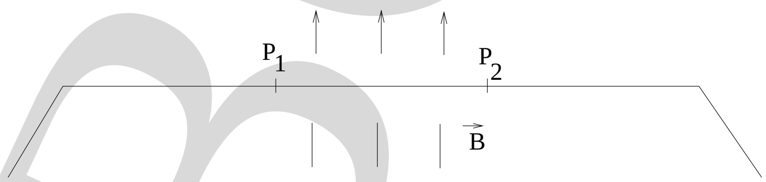
18. The four separate figures below involve a cylindrical magnet and a tiny light bulb connected to the ends of a loop of copper wire. These figures are to be used in the following question. The plane of the wire loop is perpendicular to the reference axis. The states of motion of the magnet and of the loop of wire are indicated in the diagram. Speed will be represented by v and CCW represents counter clockwise.

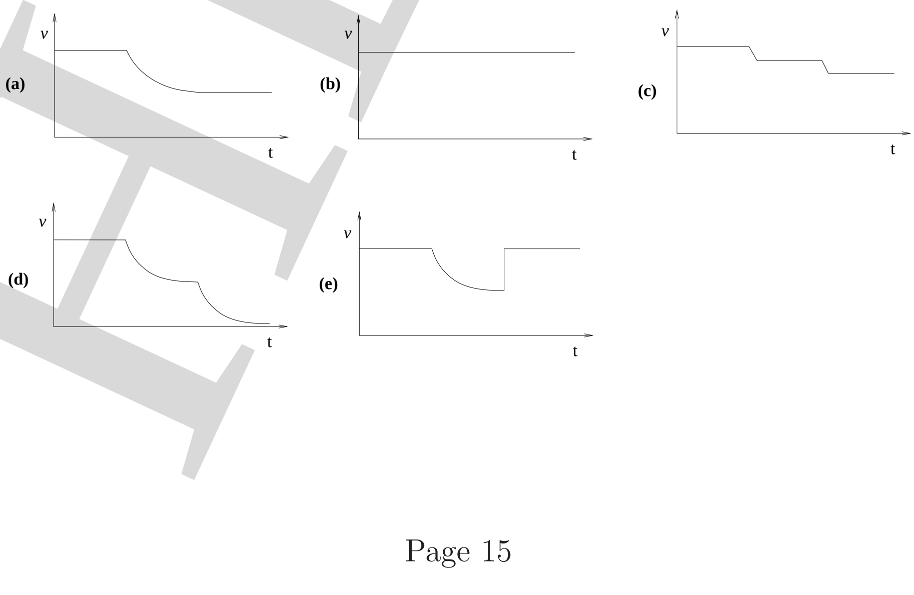


In which one of the above figures will the light bulb be glowing?

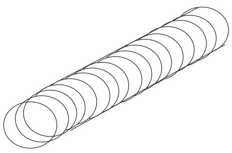
(a) I, II, III
(b) II, III, IV
(c) I, III, IV
(d) I, II, IV
(e) I, II, III, IV

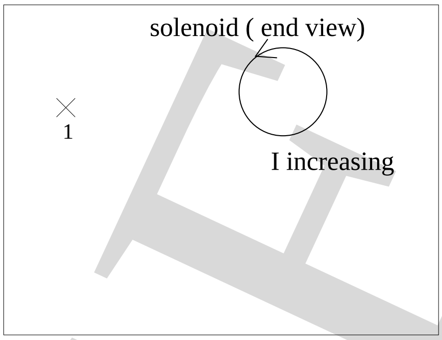
19. A metallic coin is sliding on a long frictionless horizontal table. A uniform vertical magnetic field $\vec{B}$ exists between points P_1 and P_2 of this table as shown. Which figure below accurately depicts the speed of the coin as it slides across the table?





20. Shown below is a long solenoid (coils of wire along a long cylinder), and an end view of the solenoid. Conventional current runs counter clockwise in the solenoid and is increasing with time.





What is the direction of the electric field at location 1 (marked with x)?

(a) $\uparrow$
(b) $\downarrow$
(c) $\odot$ out of page
(d) $\otimes$ into page
(e) Zero

****** END OF "**PART B**" OF THE QUESTION PAPER ******

PART - B Answers

(You may use a pencil)

No.	(a)	(b)	(c)	(d)	(e)	Mark	No.	(a)	(b)	(c)	(d)	(e)	Mark
1.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		11.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	
2.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		12.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	
3.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		13.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	
4.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		14.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	
5.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		15.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	
6.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		16.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	
7.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		17.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	
8.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		18.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	
9.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		19.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	
10.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ		20.	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	

Subtotal : **Subtotal :**

Subtotal B:

****** END OF THE QUESTION PAPER ******

Rough Work

Rough Work

Rough Work

Rough Work

Rough Work

Rough Work

Solutions
Indian National Physics Olympiad - 2010

Please note that equivalent methods/solutions may exist.

PART - A

1. (a) $\vec{P}_A = 80\,\hat{i}$ kg·m·s^{-1}, also acceptable $\vec{P}_A = 70\,\hat{i}$ kg·m·s^{-1};
   $\vec{P}_B = -70\,\hat{i}$ kg·m·s^{-1}

   (b) $\vec{P}_A = 20\,\hat{i}$ kg·m·s^{-1};
   $\vec{P}_B = -10\,\hat{i}$ kg·m·s^{-1}, also acceptable $\vec{P}_B = -70/8\,\hat{i}$ kg·m·s^{-1}

   (c) Number of tosses by A = 1 ; Number of tosses by B = 1

   (d) See Fig. (1).

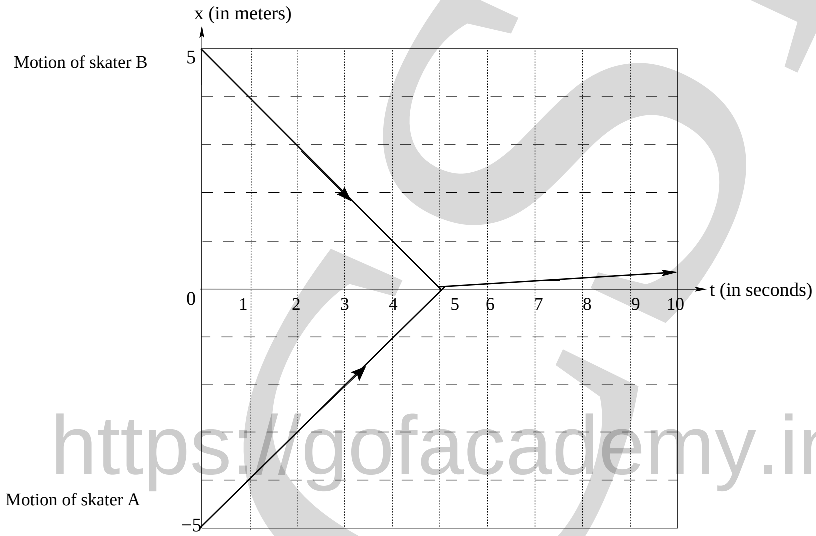


Figure 1:

   (e) See Fig. (2).

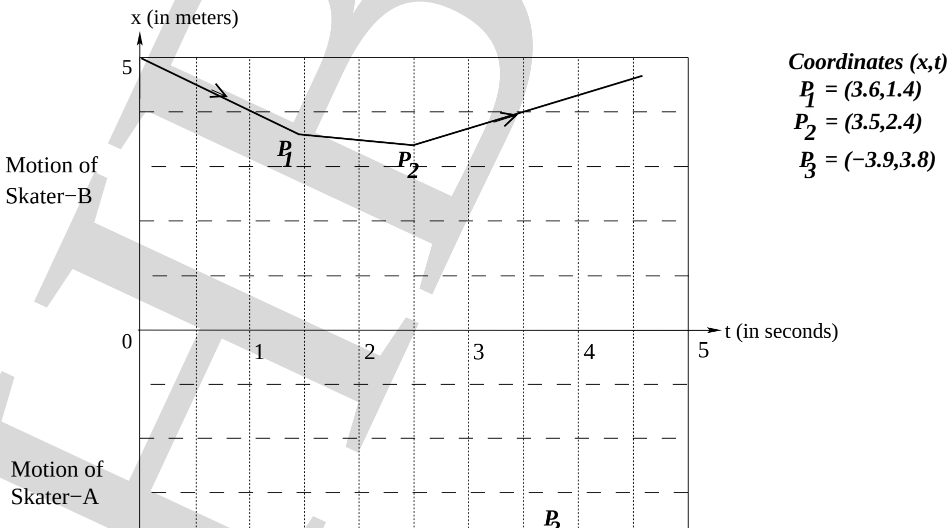


Figure 2:

2. (a) $P_1 = \frac{243}{32} P_0 \quad ; \quad P_2 = \frac{243}{32} P_0 \quad ; \quad P_3 = \frac{243}{32} P_0$

$V_1 = \frac{65}{27} V_0 \quad ; \quad V_2 = \frac{8}{27} V_0 \quad ; \quad V_3 = \frac{8}{27} V_0$

$T_1 = \frac{585}{32} T_0 \quad ; \quad T_1 = \frac{9}{4} T_0 \quad ; \quad T_1 = \frac{9}{4} T_0$

(b) Work done $= \frac{15}{4} P_0 V_0$

(c) Heat supplied $= \frac{1899}{64} P_0 V_0$

(d) Entropy change in $A_2 + A_3 = 0$

Entropy change in $A_1 = \frac{3R}{2} \ \ln \frac{585}{32} + R \ \ln \frac{65}{27}$

3. (a) $A_F = 4.76\ ^0$

(b) $\Delta_D = -2.1\ ^0$

(c) See Fig. (3). Note that all angles are expressed in degrees.

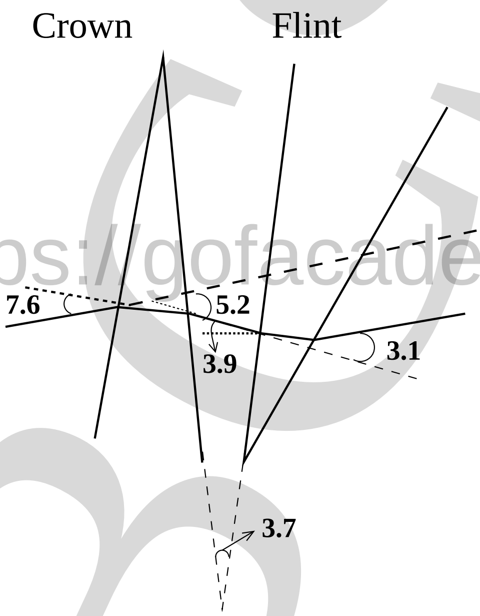


Figure 3:

4. (a) $\alpha = \frac{mgR}{I + mR^2}$

(b) $\omega = \sqrt{\frac{2\alpha H}{R}}$

(c) $K = mgH$

(d) $\vec{B} = \frac{\mu_0}{2\pi} \frac{Q\omega'}{l}\, \hat{i}$ for $r < R$

$= 0$ for $r > R$

(e) $E = \frac{\mu_0 Q R^2 \alpha\,'}{4\pi l r}$ for $r \geq R$

$= \frac{\mu_0 Q r \alpha\,'}{4\pi l}$ for $r < R$

(f) $\tau_{em} = QER$

(g) $\alpha' = \dfrac{mgR}{I + mR^2 + \dfrac{\mu_0 Q^2 R^2}{4\pi l}}$

(h) $K' = \dfrac{mgH(I + mR^2)}{I + mR^2 + \dfrac{\mu_0 Q^2 R^2}{4\pi l}}$

(i) $K' - K = -\dfrac{B^2}{2\mu_0}\pi R^2 l$

(j) Some possible interpretations are

i. It is the magnetic energy stored in shell.
magnetic energy = magnetic energy density$(B^2/2\mu_0)$ × Volume $(\pi R^2 l)$
and/or

ii. It is the self inductance energy $(1/2\ Li^2)$ of the system.
and/or

iii. Poynting vector argument can also show that it is magnetic energy.
$(2\pi Rl)\left(\dfrac{1}{\mu_0}\int \bar{E} \times \bar{B} dt\right) = K' - K = \dfrac{-B^2 \pi R^2 l}{2\mu_0}$

5. (a) $\lambda_k = 0.12\ \text{hr}^{-1}$

(b) $A = 3.70{\times}10^4\ \text{s}^{-1}$, also acceptable $A = 2.62{\times}10^4\ \text{s}^{-1}$.

(c) 5.0 liters

PART - B

1. b
2. e
3. d
4. d
5. e
6. d
7. a
8. c
9. b
10. c
11. e
12. e
13. b
14. e
15. d
16. c
17. c
18. d
19. c
20. a