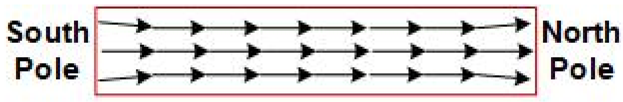
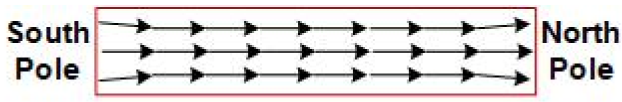
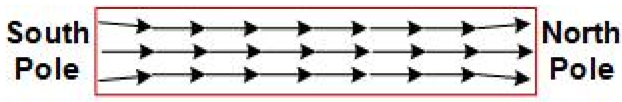
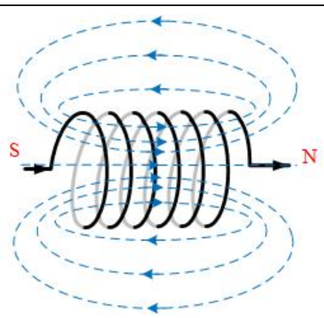
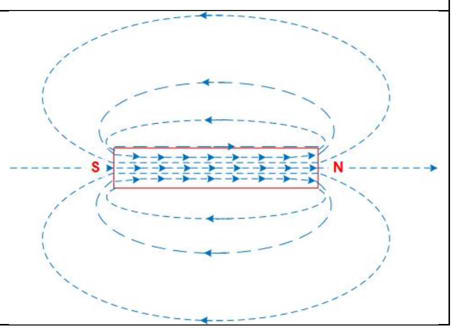
Electromagnetism: Current Electricity – Typical Questions (Part-3)

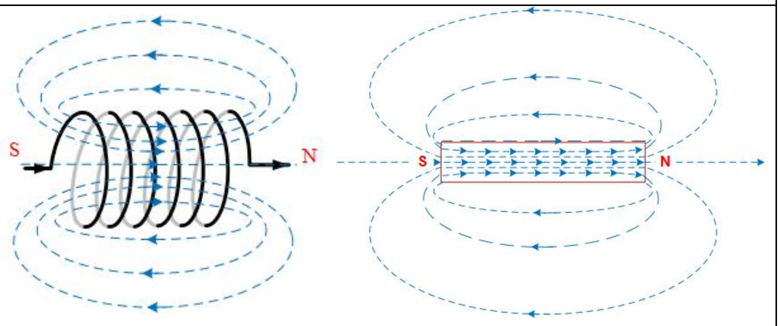
Magnetism and Magnetic Properties

(Illustrations Only)

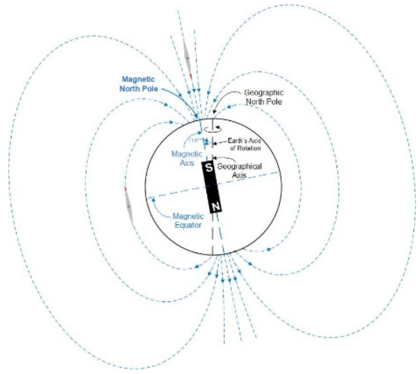
Important Note:

1. Magnetism is an important and inseparable part of study current electricity and its applications.
2. A student at a stage to refer to these questions and illustrations is expected to have attained a reasonable understanding of concepts and visualization. Moreover, forward journey involves integration of concepts on a wider canvas. Therefore, illustrations have been made a bit crisp. This would help students to harness their understanding at a faster rate.
3. Avoid fatigue due to long and continuous sitting in solving such problems. Take a reasonable break to refresh before taking next part. Gradually, capability to withstand fatigue will grow to enable you to take up bigger challenges.
4. Electromagnetism is a subject so closely intertwined that discretization of problems on Magnetism and Magnetic Effect of Electric Current fails as one goes ahead. This is brought out in footnote of illustration of such problems.

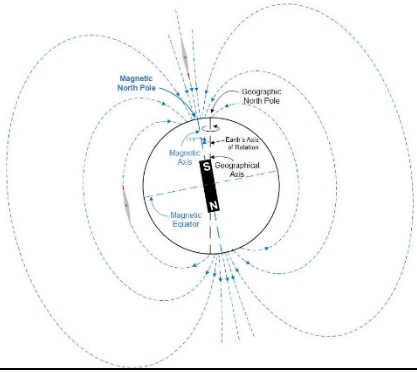
I-1	A magnet is constituted by dipoles with north pole and south pole (opposite polarities) of equal strength. Therefore, at any point strength one of the pole of a magnet is arithmetic sum of the of  the open chain dipoles at that end and thus eventually the other end is of equal and opposite pole strength. Hence answer is NO.
I-2	A magnet is constituted by dipoles with north pole and south pole (opposite polarities) of equal strength. Therefore, at any point strength one of the pole of a magnet is arithmetic sum of the of  the open chain dipoles at that end and thus eventually the other end is of equal and opposite pole strength. Therefore, at two distinct points distinct poles howsoever near or farther they are. Hence answer is Yes,
I-3	A bar magnet is like a cluster of open chains of dipoles placed back-to-back. Thus in the middle region of the magnet north and south poles, while they exist they cancel magnetic effect of  each other. Therefore, magnetic needle is not attracted. Therefore, it is incorrect to infer that magnetic material at the ends is different from that of the middle region.
I-4	In solenoid polarity depends upon direction of current while in magnetic dipole it is decided by its magnetization. On reversal of direction of current polarity of solenoid also reverses and so also direction of magnetic field.   Whereas in magnetic do[ole s identical. Direction magnetic field inside it is

	decided by magnetization process and remain fixed until it is demagnetized and re-magnetized in reverse direction. Otherwise, direction of magnetic field inside solenoid and dipole remains same.
I-5	In solenoid polarity depends upon direction of current while in magnetic dipole it is decided by its magnetization. On reversal of direction of current polarity of solenoid also reverses and so also direction of magnetic field.  Whereas in magnetic do[ole s identical. Direction magnetic field inside it is decided by magnetization process and remain fixed until it is demagnetized and re-magnetized in reverse direction. Otherwise, direction of magnetic field inside solenoid and dipole remains same.
I-6	Magnetic field exerts force on a magnetic pole in isolation and a current carrying conductor. In the instant case force due a magnetic field on a isolated magnetic pole is $\vec{F} = m\vec{B}$ …(1), where force $\vec{F}$ and magnetic field $\vec{B}$ are vectors while strength of magnetic pole is m, a scalar quantity. Though, a magnetic pole does not exist in an isolation, force on a magnetic dipole is analyzed taking force on each pole of the magnet using (1) which is experimentally verifiable. Thus, magnetic force $\vec{F}$ from (1) will be scaled in magnitude by m, but it will remain along vector $\vec{F}$, Thus it contradicts the given notion. Therefore, **the answer is Yes**.
I-7	Magnets are made of material and therefore they have a mass. When opposite magnetic poles are placed close to each other, they will experience force of attraction expressed by $\vec{F} = \frac{\mu_0}{4\pi} \times \frac{m_1 m_2}{r^2} \vec{r}$. Here, m_1 and m_2 are strengths of the magnetic poles. The force vector $\vec{F}$ is along the separation vector $\vec{r}$. When, magnetic in vicinity are of opposite signs, the force vector will be $(-)\vec{r}$ i.e. in direction opposite to separation or force of attraction. Further, as magnets come closer the force of attraction would become larger since $F \propto \frac{1}{r^2}$. The magnet with a mass under the force of attraction, as discussed, will first experience an acceleration causing increase in velocity and secondly increasing acceleration due to force will further increase the acceleration. Thus, the kinetic energy of the magnets will increase. Hence, **answer is yes**.
I-8	As per definition magnetic scalar potential combined is $U(\vec{r}_2) - U(\vec{r}_1) = \int_{\vec{r}_1}^{\vec{r}_2} \vec{B}.d\vec{l}$. Whereas, as per Ampere's law, line-integral of magnetic field around a conductor carrying current i is $\int_{\vec{r}_1}^{\vec{r}_2} \vec{B}.d\vec{l} = (-)\mu_0 i$. Here, $\vec{B}$ is the magnetic field intensity. Whereas, $\vec{B}$ due to a magnetic pole of pole strength m is $\vec{B} = \frac{\mu_0}{4\pi} \times \frac{m}{r^2} \hat{r}$. Accordingly, scalar magnetic potential $U(r) = -\int_{\infty}^{r} \vec{B}\,.d\vec{r} = -\int_{\infty}^{r} \left(\frac{\mu_0}{4\pi} \times \frac{m}{r^2} \hat{r}\right).d\vec{r} \Rightarrow U(r) = -\frac{\mu_0 m}{4\pi} \int_{\infty}^{r} \frac{1}{r^2}.dr = -\frac{\mu_0 m}{4\pi} \left[-\frac{1}{r}\right]_{\infty}^{r} \Rightarrow U(r) = \frac{\mu_0 m}{4\pi r}$. It is seen that both the definitions the definitions are conceptually different, in earlier the cause is electric current while in the latter the cause is a static magnetic pole. Thus both the equations cannot be correlated at this stage, hence, **answer is No.**

<table>
<tr><td>I-9</td><td>Distribution of earth's magnetic field is shown in the figure. It is perpendicular to the surface of the eart at is poles. Therefore, answer to the first part is Yes. As regards the second part, angle of dip is the angle of inclination of magnetic needle w.r.t. surface of the earth, and not the surface vector. Thus magnetic needle will be perpendicular to the earth's surface at its poles. Hence, angle of dip would be 90^{0}.



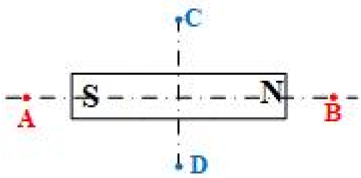
</td></tr>
<tr><td>I-10</td><td>Distribution of earth's magnetic field is shown in the figure. It is parallel to the earth's surface near the equator and perpendicular to the surface of the eart at is poles. As regards the angle of dip, it is the angle of inclination of magnetic needle w.r.t. surface of the earth, and not the surface vector. Thus magnetic needle will be parallel to the earth;s surface leading Zero angle of dip, answer to the part (a) is Yes. And it is perpendicular to the earth's surface at its poles leading to angle of dip to be 90^{0}. Thus, answer to the part (b) is Yes.



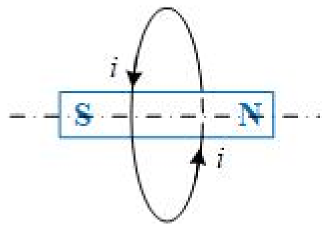
</td></tr>
<tr><td>I-11</td><td>In tangent galvanometer, at a place $\tan\theta = \frac{B}{B_H}$, here B_H is the horizontal component of the earth's magnetic field B_E, and $B = \frac{\mu_0 n i}{2r}$ is the magnetic field producied by current i in the circular coil of radius r and number of turns n. The $B_H = B_E \cos\delta$, here δ is the angle of dip and both B_E and δ varies along the meridian as one mover from equator to magnetic poles of the earth and so also B_H is place specific.

At equilibrium position at deflection θ of the needle of galvanometer $B\sin\theta = B_H\cos\theta \Rightarrow \tan\theta = \frac{B}{B_H}$. It leads to $\tan\theta = \frac{\frac{\mu_0 n i}{2r}}{B_H} \Rightarrow \tan\theta = \frac{\mu_0 n}{2rB_H} i \Rightarrow i = \frac{2rB_H}{\mu_0 n}\tan\theta \Rightarrow i = K\tan\theta$. Since, numerically $K < 1$ and hence it is called reduction factor.

Here, $K \propto B_H$, and hence the procedure will work at Nepal and error can be corrected by correlating $K' = K\frac{B_H'}{B_H}$, where B_H' corresponds to Nepal while B_H corresponds to Bhubaneshwar.

Thus, answer to first part is Yes, while answer to second part on need of taking instrument to factory is No.</td></tr>
<tr><td>I-12</td><td>

Magnet equivalent of a current carrying coil is shown in the figure. And for a magnet points A and B on the axis of the magnet are called End-On positions as the name suggests. Likewise, points C and D are called Broadside-on positions. Therefore, points on the axis of the loop shall be End-on Positions. Thus, answer is option (a).



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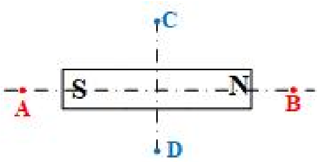
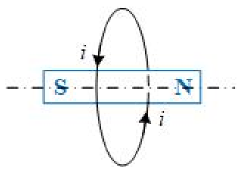
<tr><td>I-13</td><td>

Magnet equivalent of a current carrying coil is shown in the figure. And for a magnet points A and B on the axis of the magnet are called End-On positions as the name suggests. Likewise, points C and D are called Broadside-on positions. Therefore, points on the coil loop corresponds to Broadside-On position. Thus, answer is option (b).



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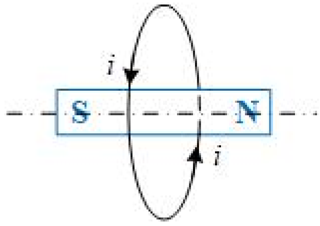
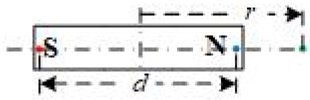
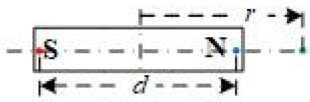
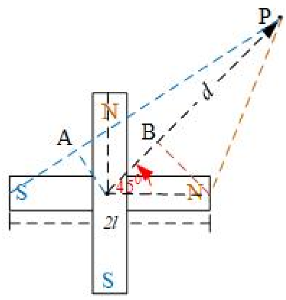
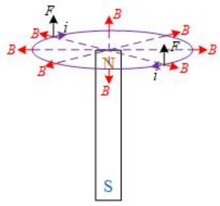
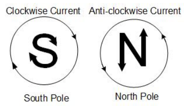
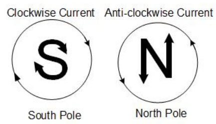
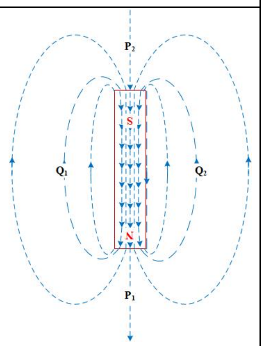
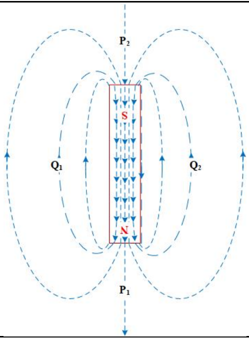
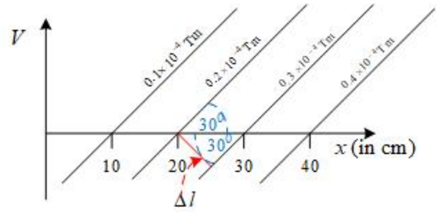
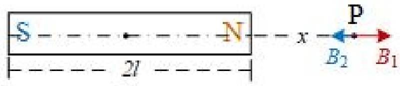
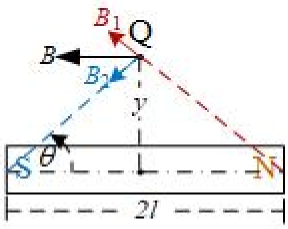
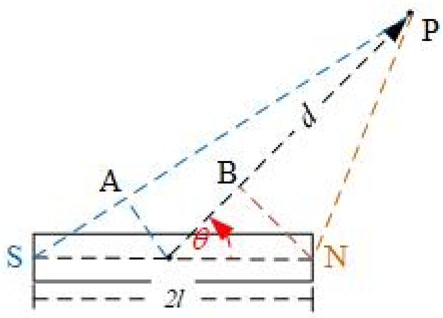
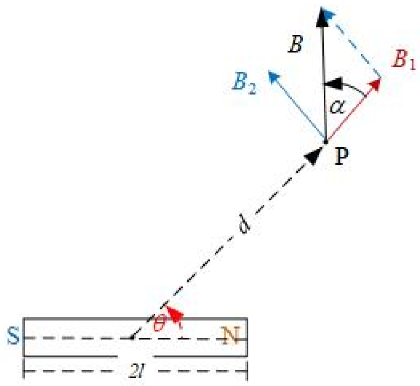
I-14	Magnet equivalent of a current carrying loop is shown in the figure. Dipole moment of a circular loop is $M = md = IA$, here m is strength of magnetic pole, d is distance between the two poles of the magnet, I is the current through the loop and A is the area of the current carrying loop. Thus, while magnetic moment of the loop is determined by its geometry and current, its equivalent magnet has two parameters m and d, such that $m \propto \frac{1}{d}$. Thus, md is constant as per **option (c) is the answer.** 
I-15	Magnetic field at a point P, at a distance r from the center of a magnet of pole stength m and length d is $B = \frac{\mu_0}{4\pi}\left[\frac{m}{\left(r-\frac{d}{2}\right)^2} - \frac{m}{\left(r+\frac{d}{2}\right)^2}\right] = \frac{\mu_0 m}{4\pi}\left[\frac{2rd}{\left(r^2-\left(\frac{d}{2}\right)^2\right)^2}\right]$. It solves into $B = \frac{\mu_0 M}{4\pi}\left(\frac{r}{\left(r^2-\left(\frac{d}{2}\right)^2\right)^2}\right)$, here $M = md$ magnetic mopment of the magnet and is its constant. None of the options provided at (a), (b) and (c) conform with the derived results. Hence, **answer is option (d).** 
I-16	Magnetic field at a far point P, at a distance r from the center of a magnet of pole stength m and length d is $B = \frac{\mu_0}{4\pi}\left[\frac{m}{\left(r-\frac{d}{2}\right)^2} - \frac{m}{\left(r+\frac{d}{2}\right)^2}\right] = \frac{\mu_0 m}{4\pi}\left[\frac{2rd}{\left(r^2-\left(\frac{d}{2}\right)^2\right)^2}\right]$. It solves into $B = \frac{\mu_0 M}{4\pi}\left(\frac{r}{\left(r^2-\left(\frac{d}{2}\right)^2\right)^2}\right)$..(1), here $M = md$ magnetic mopment of the magnet and is its constant.  Since point P is stated to be a far point it implies that $r \gg d$ and hence $r^2 \gg \left(\frac{d}{2}\right)^2$. Accordingly, the formulation at (1) reduces to $B = \frac{\mu_0 M}{4\pi}\left(\frac{r}{r^4}\right) \Rightarrow B = \frac{\mu_0 M}{4\pi} \times \frac{1}{r^3} \Rightarrow B \propto \frac{1}{r^3}$, as provide in **option (c) is the answer**.
I-17	Given that Two dipoles of pole strength m and magnetic moment $M = 2ml$ are short in length of magnets $2l \ll d$. The magnets are fastened at their centers as shown in the figure (not to the scale). Therefore, magnetic field at the point P due to North poles of one of the two magnets, at a distance $r_N \approx BP = d - l\cos 45^0 \Rightarrow r_n = d - \frac{l}{\sqrt{2}}$ would be $B_N = \frac{\mu_0}{4\pi}\frac{m}{\left(d-\frac{l}{\sqrt{2}}\right)^2}$. Likewise, due to south pole at a distance $r_S = d + \frac{l}{\sqrt{2}}$ it would be $B_S = \frac{\mu_0}{4\pi}\frac{(-)m}{\left(d+\frac{l}{\sqrt{2}}\right)^2}$. Thus, net magnetic field due to dipole is  $B_1 = B_N + B_S$. It leads to $B_1 = \frac{\mu_0}{4\pi}\frac{m}{\left(d-\frac{l}{\sqrt{2}}\right)^2} - \frac{\mu_0}{4\pi}\frac{m}{\left(d+\frac{l}{\sqrt{2}}\right)^2} = \frac{\mu_0 m}{4\pi}\left(\frac{1}{\left(d-\frac{l}{\sqrt{2}}\right)^2} - \frac{1}{\left(d+\frac{l}{\sqrt{2}}\right)^2}\right)$. It further, solves into $B_1 = \frac{\mu_0 m}{4\pi}\left(\frac{\left(d+\frac{l}{\sqrt{2}}\right)^2-\left(d-\frac{l}{\sqrt{2}}\right)^2}{\left(d^2-\frac{l^2}{2}\right)^2}\right) \approx \frac{\mu_0 m}{4\pi}\left(\frac{\left(2\times\frac{l}{\sqrt{2}}\right)\times 2d}{d^4}\right) \Rightarrow B_1 = \frac{\mu_0(m\times 2l)}{4\pi}\left(\frac{\sqrt{2}}{d^3}\right) \Rightarrow B_1 = \frac{\mu_0 M}{4\pi}\left(\frac{\sqrt{2}}{d^3}\right)$. Likewise, magnetic field due to another magnet is $B_2 = \frac{\mu_0 M}{4\pi}\left(\frac{\sqrt{2}}{d^3}\right)$, both are of same magnitude and identical signs and hence, net magnetic field at point P is $B = B_1 + B_2 = 2B_1 = 2 \times \frac{\mu_0 M}{4\pi}\left(\frac{\sqrt{2}}{d^3}\right) \Rightarrow B = \frac{\mu_0 M}{4\pi}\left(\frac{2\sqrt{2}}{d^3}\right)$. This expression matches with that in the **option (c), is the answer.**
I-18	A hypthetical plane, passing through poles, and intersecting with the surface of the earth is called meridian. Thus, it is a vertical plane, as provided in the **option (d), is the answer.**
I-19	Magnetic needle at geomagnetic poles aligns perpendicular to the earth's surface i.e. angle of dip is $\delta = 90^0$. Therefore, moving compass along horizontal plane will not affect the position of the needle, as provided in **option (d), is the answer.**

I-20	Dip circle has a magnetic needle which at equator is parallel to surface of the earth i.e. angle of dip is $\delta = 0^0$ and hence $B_H = B_E \cos\delta \Rightarrow B_H = B_E \cos 0^0 \Rightarrow B_H = B_E$ It is given that the needle is allowed to move in a vertical plane the magnetic meridian i.e. $\theta = 90^0$. In such a situation horizontal component of the earth's magnetic field is $B'_H = B_H \cos\theta \Rightarrow B'_H = B_E \cos 90^0 = 0$. Therefore, magnetic needle would stay in any angular position it is released. Thus, **answer is option (d).**
I-21	In tangent galvanometer $i \propto \tan\theta$ and as $\theta \to \frac{\pi}{2}$, $\tan\frac{\pi}{2} \to \infty$. Accordingly, the only graph that matches to this interpretation graph (c) best represents $i - \theta$ characterstic. Hence, **answer is option (c).**
I-22	In tangent galvanometer, at a place $\tan\theta = \frac{B}{B_H}$, here B_H is the horizontal component of the earth's magnetic field B_E, and $B = \frac{\mu_0 ni}{2r}$ is the magnetic field producied by current i in the circular coil of radius r and number of turns n. The $B_H = B_E \cos\delta$, here δ is the angle of dip and both B_E and δ varies along the meridian as one mover from equator to magnetic poles of the earth and so also B_H is place specific. At equilibrium position at deflection θ of the needle of galvanometer $B\sin\theta = B_H \cos\theta \Rightarrow \tan\theta = \frac{B}{B_H}$. It leads to $\tan\theta = \frac{\frac{\mu_0 ni}{2r}}{B_H} \Rightarrow \tan\theta = \frac{\mu_0 n}{2rB_H} i \Rightarrow i = \frac{2rB_H}{\mu_0 n}\tan\theta \Rightarrow i = K\tan\theta$....(1). Here, reduction factor $K = \frac{2rB_H}{\mu_0 n}$ ...(2) The question states that tangent galvanometer is directly connected to an ideal battery of emf E. It implies that the only resistance in the circuit is the resistance of the turns which is $R = \rho\frac{L}{A}$, here restivity of material of turns ρ and area of cross-section A of the wire forming turns remain same and length of wire is $L = 2\pi rn$ where r is the radius of the turns and n is the number of turns. Therefore, when number of turns are doubled i.e. $n' = 2n$, length of turns would be $L' = 2\pi rn' \Rightarrow L' = 4\pi rn$. Current through the toil of the galvanometer in this case as per Ohm's Law is initially $i = \frac{E}{R} = \frac{E}{\rho\frac{2\pi rn}{A}} \Rightarrow i = \frac{EA}{\rho\times 2\pi rn} \Rightarrow i = \frac{EA}{2\rho\pi rn}$. Accordingly, deflection as per (1) would be $\frac{EA}{2\rho\pi rn} = \frac{2rB_H}{\mu_0 n}\tan\theta$. Thus def;ection would be $\tan\theta = \frac{EA}{2\rho\pi rn} \times \frac{\mu_0 n}{2rB_H} \Rightarrow \theta = \tan^{-1}\left(\frac{\mu_0 EA}{4\pi\rho r^2 B_H}\right)$...(2). It is seen that deflection θ is not a function of number of turns n. Hence, in the given case deflection will not change with increase in number of turns. This conclusion is in accordance with **option (c), is the answer.**
I-23	Moving coil galvanometer works on the interaction of permanent magnetic field and current in the moving coil and the restraining force caused by spring. Accordingly, $niAB = k\theta \Rightarrow i = \frac{k}{nAB}\theta \Rightarrow i \propto \theta$ ...(1). While, tangent galvanometer works on the interaction of the magnetic field produced by the current carrying coil (application of Biot-Savart's Law) and terrestrial magnetic field on the needle placed at the center of the coil. Accordingly, $\tan\theta = \frac{\mu_0 n}{2rB_H} i \Rightarrow i = \frac{2rB_H}{\mu_0 n}\tan\theta \Rightarrow i = K\tan\theta$...(2). Thus, from (1) and (2) relations of current with the deflection in two galvanometers are characteristically different. But, in moving coil galvanometer from (1) when current is doubled, the deflection is also doubled as provided in **option (b), is the answer**.

I-24	Direction of magnetic field B produced by a very long bar magnet and a circular loop carrying current i as stated in the problem is shown in the figure. Force on a current carrying conductor is $\vec{F} = q\vec{v} \times \vec{B}$ …(1). In this cross product direction of force is perpendicular to the plane of circular loop carrying current as shown in the figure. Let charge on the circular loop of radius r at any instant of time is σ per unit length. Therefore, charge on the loop at any instant is $q = (2\pi\alpha)\sigma$…(2). The charge is circulating in the loop with a velocity v. Therefore, magnitude of $F = \left((2\pi\alpha)\sigma\right)vB \Rightarrow F = 2\pi\alpha(\sigma v)B \Rightarrow F = 2\pi\alpha iB$. Here, current in the loop is $i = \sigma v$. And the force on the circular wire loop is perpendicular to the plane of the loop. Hence, **answer is option (a).** 
I-25	This question requires to analyze proposition in each option, and is done as under – **Option (a):** An electric charge in a state of rest produces electric field. But when charge is set in a directed motion, not Brownian motion, it produces magnetic field as experimentally demonstrated by Oersted, and mathematically quantified by Biot-Savart and Ampere. Therefore, **this option is correct for electric current.** **Option (b):** Magnetic poles are representation of magnetic effect of electric current as per Biot-Savart-Ampere's Law. Hence, **they are mathematical assumption, and hence this option is correct.** **Option (c):** North pole is equivalent to anticlockwise current, whereas given proposition is for clockwise current, as shown in the figure. Likewise, the given proposition is opposite to the actual. Hence, **this option is incorrect.**  **Option (d):** A long bar magnet has straight axial magnetic lines of force inside it. While, a straight current produces circular magnetic lines of force. Hence, **this option is incorrect.** Thus, **answer is options (a) and (b)**
I-26	Magnetic field produced by a horizontal circular current carrying loop is as shown in the figure. In this case direction of magnetic field is along axis of the circular current carrying loop i.e, it is perpendicular to the surface of the loop. When, the loop is replaced by an equivalent magnetic dipole, magnetic field has to be equal in magnitude, direction and polarity, to that in the circular loop.  Since direction of magnetic field in a magnetic dipole is along its axis Hence, this is possible only when magnet is perpendicular to the plane of the loop, **making option (b) correct**. As regards polarity, the direction of current in the loop viewed from above is clockwise. Therefore, as per figure it would correspond to South pole, and accordingly below the loop will be North pole as provided in **option (d), making it correct.** Thus, **answer is option (b) and (d)**
I-27	The given points P_1, P_2, Q_1, and Q_2 about a magnetic dipole placed in north-south direction are shown along with the magnetic field produced by the dipole. It is seen that same direction of magnetic field exists at P_1 and P_2, as provided in option (a). Likewise, at points Q_1, and Q_2 direction of magnetic field is same, as provided in option (b) Hence, **answer is option (a) and (b).** 

I-28	The given points P_1, P_2, Q_1, and Q_2 about a magnetic dipole placed in north-south direction are shown along with the magnetic field produced by the dipole. It is seen that opposite direction of magnetic field exists at P_1 and Q_1, as provided in option (c). Likewise, at points P_2 and Q_2 direction of magnetic field is opposite, as provided in option (d). Hence, **answer is option (c) and (d).** 
I-29	Each of the option requires to correlate principle of operation of instruments given in each option. Accordingly- **Option (a):** Tangent galvanometer is used to measure electric current in presence of terrestrial magnetism which determines reduction factor K. Hence this cannot be used to measure magnetic moment of a bar magnet. Thus, **this option is incorrect.** **Option (b):** Deflection galvanometer measures $\frac{M}{B_H}$. With the known earth's horizontal magnetic field B_H, it is possible to determine magnetic moment M of a bar magnet. Hence, **this option is correct.** **Option (c):** Oscillation galvanometer measures $\frac{M}{B_H}$. With the known earth's horizontal magnetic field B_H, it is possible to determine magnetic moment M of a bar magnet. Hence, **this option is correct.** **Option (d):** Since both deflection galvanometer and Oscillation galvanometer can individually measures $\frac{M}{B_H}$. With the known earth's horizontal magnetic field B_H, it is possible to determine magnetic moment M of a bar magnet. Hence, **this option is correct.** Thus, **answer is options (b), (c) and (d).**
I-30	Magnetic field at a point due to a magnetic pole is $B = \frac{\mu_0}{4\pi} \times \frac{m}{r^2}$...(1) Here, permeability of space $\frac{\mu_0}{4\pi} = 10^{-7}$, pole strength of the magnet is given to be $m = 10$ Am, and distance of the point from the long bar magnet is $r = 5 \times 10^{-2}$. Given that the magnet is a long bar, and magnetic field at the given point is significant to magnetic pole near it while the other end of the magnet will have $r \gg$ and thus from (1) it will have insignificant magnetic field. Accordingly, $B = 10^{-7} \times \frac{10}{(5\times10^{-2})^2} = \frac{1}{25} \times 10^{-2} = \mathbf{4 \times 10^{-4}}$**T is the answer.**
I-31	Given that two long bar magnets are placed coaxially, such that north pole of first magnet is at a distance $r = 2 \times 10^{-2}$m from south pole of the second magnet. Magnitude of the pole strengths are $m = 10$ AT. Since, opposite poles are facing each other and hence if $m_1 = 10$ AT then $m_2 = -10$ AT. Force exerted by the two magnets, on each other would be $F = \frac{\mu_0}{4\pi} \times \frac{m_1 m_2}{r^2}$...(1). Using the available data $F = 10^{-7} \times \frac{10\times(-10)}{(2\times10^{-2})^2}$. It leads to $F = \frac{10^{-1}}{4} = \mathbf{2.5 \times 10^{-2}}$**N is the answer**
I-32	Change in scalar magnetic potential V is between any two points say P and Q is $\Delta V = \int_P^Q \vec{B}.d\vec{l}$ where $\vec{B}$ is the magnetic field vector and $\vec{l}$ is the displacement vector. It is given that displacement $\Delta l = 0.50$m along the uniform magnetic field $B = 2.0 \times 10^{-3}$T. Accordingly, $\Delta V = B\Delta l \Rightarrow \Delta V = B\Delta l = (2.0 \times 10^{-3})(0.50)$. It leads to $\Delta V = \mathbf{0.10 \times 10^{-3}}$**Tm is the answer.**

I-33	We know that scalar magnetic potential difference $\Delta V = \vec{B}.\Delta\vec{l} \Rightarrow \Delta V = B\Delta l\cos\alpha \Rightarrow B = \frac{\Delta V}{\Delta l\cos\alpha}$…(1). Here, $\Delta l = \Delta x\cos\alpha$ is separation between the equipotential lines. It is seen that potential difference between the equipotential lines is $\Delta V = 0.1\times10^{-4}$Tm, intercepts of the equipotential lines on X-axis are at $\Delta V = 0.10$ m, and angle $\alpha = 90^0 - \theta = 90^0 - 30^0 \Rightarrow \alpha = 60^0$. Using the given data in (1) $B = \frac{0.1\times10^{-4}}{0.10\times\cos 60^0} = \frac{0.1\times10^{-4}}{0.05} \Rightarrow B = \mathbf{2.0\times10^{-4}}$ **is the answer.** 
I-34	The problem has two parts and each is solved separately with figure (not to proportion). **Part (a):** It is given that in End-on position magnetic field at a point P at a distance $x = 0.10$m is $B = 2.0\times10^{-4}$ T and it required to find magnetic moment of the dipole $M = m\times 2l = 2ml$.  Magnetic field at P due to north pole of polarity m is $\vec{B}_1 = \frac{\mu_0}{4\pi}\times\frac{m}{x^2}\hat{x}$ and due to south pole of polarity $(-m)$ is $\vec{B}_2 = \frac{\mu_0}{4\pi}\times\frac{(-m)}{(x+2l)^2}\hat{x} \Rightarrow \vec{B}_2 = -\frac{\mu_0}{4\pi}\times\frac{m}{(x+2l)^2}\hat{x}$. Therefore, net-magnetic field at the point is $\vec{B} = \frac{\mu_0 m}{4\pi}\left(\frac{1}{x^2} - \frac{1}{(x+2l)^2}\right)\hat{x} = \frac{\mu_0 m}{4\pi}\left(\frac{(x+2l)^2 - x^2}{x^2(x+2l)^2}\right)\hat{x}$. In case of dipole $x \gg 2l$ and hence $(2l)^2 \to 0$ and $x + 2l \to x$ Therefore, magnitude of magnetic field it approximates to $B = \frac{\mu_0}{4\pi}\times m\left(\frac{4lx}{x^2x^2}\right) \Rightarrow B = \frac{\mu_0}{4\pi}\times\frac{2(2ml)}{x^3} \Rightarrow B = \frac{\mu_0}{4\pi}\times\frac{2M}{x^3} \Rightarrow M = \frac{4\pi}{\mu_0}\times\frac{Bx^3}{2x^3}$. Using the available data, $M = \frac{1}{10^{-7}}\times\frac{2.0\times10^{-4}\times(0.1)^3}{2} =$ **1 A-m², is the answer.** **Part (b):** Except the geometry, as shown in the figure, logic is same as in part (s), In this case $\vec{B}_1$ and $\vec{B}_2$ are of equal magnitudes but in directions as shown in the figure. And resultant magnetic field would be $B = 2B_1\cos\theta$.  In the figure $\cos\theta = \frac{l}{\sqrt{y^2+l^2}}$ and $B_1 = \frac{\mu_0}{4\pi}\times\frac{m}{y^2+l^2} \Rightarrow B = \frac{\mu_0}{4\pi}\times\frac{2ml}{(y^2+l^2)^{\frac{3}{2}}}$. This is approximated to $B = \frac{\mu_0}{4\pi}\times\frac{M}{y^3} \Rightarrow M = By^3\times\frac{4\pi}{\mu_0}$. Using the given data $M = 2.0\times10^{-4}\times(0.1)^3\times\frac{1}{10^{-7}} =$ **2.0 A-m², is the answer.**
I-35	Given that a dipole of pole strength m and magnetic moment $M = 2ml$ are short in length of magnets $2l \ll d$. The magnets are fastened at their centers as shown in the figure (not to the scale). Therefore, magnetic field at the point P due to North poles of one of the two magnets, at a distance $r_N \approx BP = d - l\cos\theta$ would be $V_N = \frac{\mu_0}{4\pi}\frac{m}{(d-l\cos\theta)}$. Likewise, due to south pole at a distance $r_S = d + l\cos\theta$ it would be $V_S = \frac{\mu_0}{4\pi}\frac{m}{(d-l\cos\theta)}$. Thus, net magnetic field due to dipole is $V = V_N + V_N$. It leads to $V = \frac{\mu_0}{4\pi}\frac{m}{(d-l\cos\theta)} - \frac{\mu_0}{4\pi}\frac{m}{(d-l\cos\theta)} = \frac{\mu_0 m}{4\pi}\left(\frac{(d+l\cos\theta)-(d-l\cos\theta)}{(d^2-l^2\cos^2\theta)}\right)$. It solves into $V = \frac{\mu_0 m}{4\pi}\left(\frac{2l\cos\theta}{(d^2-l^2\cos^2\theta)}\right) = \frac{\mu_0}{4\pi}\left(\frac{M\cos\theta}{d^2}\right)$, since $d^2 \gg (l\cos\theta)^2$. Therefore, $V = \frac{\mu_0}{4\pi}\left(\frac{M\cos\theta}{d^2}\right)$. 

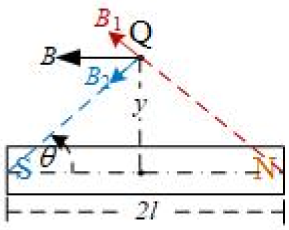


Magnetic potential $[V = f(\theta, d)]$is a scalar quantity whereas magnetic field intensity is a vector quantity $B = -\frac{\partial V}{\partial x}$, such that its radial component is $B_1 = \frac{\partial V}{\partial d} = -\frac{\partial}{\partial d}\left(\frac{\mu_0}{4\pi}\left(\frac{M\cos\theta}{d^2}\right)\right) = -\frac{\mu_0}{4\pi}\frac{M\cos\theta}{} \times \frac{\partial}{\partial d}\left(\frac{1}{d^2}\right) \Rightarrow$ $B_1 = -\frac{\mu_0}{4\pi}\frac{M\cos\theta}{} \times \left(-\frac{2}{d^3}\right)$. It leads to $B_1 = \frac{2\mu_0 M\cos\theta}{4\pi d^3}$.

Likewise Tangential component of magnetic field is $B_2 = -\frac{\partial V}{\partial(d\theta)}$, here $\partial(d\theta) = d\,(\partial\theta)$ is the tangential displacement. Accordingly, $B_2 = -\frac{1}{d} \times \frac{\partial}{\partial\theta}\left(\frac{\mu_0 M}{4\pi d^2} \times \cos\theta\right) = -\frac{\mu_0 M}{4\pi d^3} \times \frac{\partial}{\partial\theta}\cos\theta$. It solves into, $B_2 = -\frac{\mu_0 M}{4\pi d^3} \times \sin\theta$.Geometrically, as shown in the figure $\tan\alpha = \frac{B_2}{B_1} = \frac{\frac{\mu_0 M}{4\pi d^3}\times\sin\theta}{\frac{2\mu_0 M}{4\pi d^3}\times\cos\theta}$. It leads to $\tan\alpha = \frac{\tan\theta}{2}$.

Thus, net magnetic field B makes an angle $\beta = \theta + \alpha$ with the magnetic axis. Given that $\tan\theta = \sqrt{2}$. And trigonometrically $\tan\beta = \tan(\theta + \alpha) = \frac{\tan\theta + \tan\alpha}{1 - \tan\theta \times \tan\alpha} \Rightarrow \tan\beta = \frac{\tan\theta + \frac{\tan\theta}{2}}{1 - \tan\theta \times \frac{\tan\theta}{2}} \Rightarrow \tan\beta = \frac{3}{2}\left(\frac{\tan\theta}{1 - \frac{\tan^2\theta}{2}}\right)$. Using the given data $\tan\beta = \frac{3}{2}\left(\frac{\tan\theta}{1 - \frac{2}{2}}\right) = \infty \Rightarrow \beta = 90^0$. Thus, **it is proved that in the given problem net magnetic field at a point due to a dipole is perpendicular to the magnetic axis.**

I-36



Except the geometry, as shown in the figure, logic is same as in part (s), In this case $\vec{B}_1$ and $\vec{B}_2$ are of equal magnitudes but in directions as shown in the figure. And resultant magnetic field would be $B = 2B_1\cos\theta$. The length of the bar magnet $2l = 0.08 \Rightarrow l = 0.04$ m and point on broadside-on position is at $y = 0.03$ m.

As shown in the figure $\cos\theta = \frac{l}{\sqrt{y^2+l^2}}$ and $B_1 = \frac{\mu_0}{4\pi} \times \frac{m}{y^2+l^2} \Rightarrow B = \frac{2\mu_0 m\cos\theta}{4\pi} \Rightarrow$ $B = \frac{2\mu_0 m}{4\pi(y^2+l^2)} \times \frac{l}{\sqrt{y^2+l^2}} = \frac{\mu_0}{4\pi} \times \frac{2ml}{4\pi(y^2+l^2)^{\frac{3}{2}}}$.

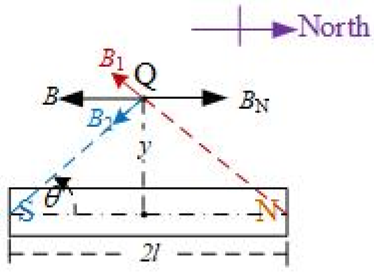
Using the available data $4 \times 10^{-6} = 10^{-7} \times \frac{m \times 0.08}{(0.03^2+0.04^2)^{\frac{3}{2}}} \Rightarrow 4 = \frac{0.08\times10^{-1}m}{(0.05)^3} \Rightarrow m = \frac{125\times10^{-6}}{2\times10^{-3}} = 62.5 \times 10^{-3}$ Am. Using principle of SDs $m =$ **6×10^{-2}Am is the answer.**

N.B.: This is a good case of application of principle of SDs.

I-37

Magnetic dipole having magnetic moment $M = 2ml = 1.44$ A.m^2 is placed horizontally. It is given that horizontal component of earth's magnetic field is $B_H = 18 \times 10^{-6}$ T.

Since, in north direction is earth's south pole and hence neutral point would occur on broadside-on position as shown in the figure.



Magnetic field due to the dipole in broadside-on position is $B = \frac{\mu_0}{4\pi} \times \frac{M}{(y^2+l^2)^{\frac{3}{2}}} \Rightarrow B = \frac{\mu_0}{4\pi} \times \frac{M}{y^3}$. Therefore, for neutral point $B = B_H$.

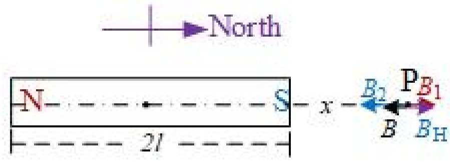
Using the available data $10^{-7} \times \frac{1.44}{y^3} = 18 \times 10^{-6} \Rightarrow y = \left(\frac{1.44}{180}\right)^{\frac{1}{3}} =$ 0.2 m. Thus, **point can be anywhere on the plane bisecting the dipole at a distance 20 cm from the center of the dipole is the answer.**

I-38

Magnetic dipole having magnetic moment $M = 2ml = 0.72$ A.m^2 is placed horizontally. It is given that horizontal component of earth's magnetic field is $B_H = 18 \times 10^{-6}$ T.

Since, in north direction is earth's south pole and hence dipole placed with its north pole pointing towards south, the neutral point would occur on end-on position as shown in the figure.

It is given that in End-on position magnetic field at a point P at a distance $x = 0.10$m is $B = 2.0 \times 10^{-4}$ T and it required to find magnetic moment of the dipole $M = m \times 2l = 2ml$.



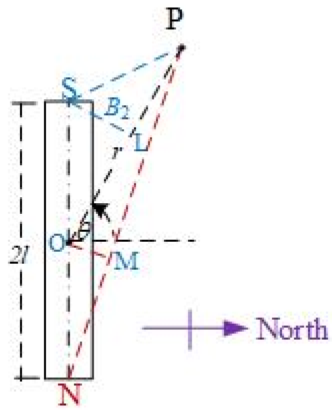
Magnetic field at P due to north pole of polarity m is $\vec{B}_1 = \frac{\mu_0}{4\pi} \times \frac{m}{(2l+x)^2}\hat{x}$ and due to south pole of polarity $(-m)$ is $\vec{B}_2 = -\frac{\mu_0}{4\pi} \times \frac{(m)}{x^2}\hat{x} \Rightarrow \vec{B}_2 = -\frac{\mu_0}{4\pi} \times \frac{m}{(x+2l)^2}\hat{x}$. Therefore, net-magnetic field at the point is $\vec{B} = \frac{\mu_0 m}{4\pi}\left(\frac{1}{(x+2l)^2} - \frac{1}{x^2}\right)\hat{x} \Rightarrow \vec{B} = -\frac{\mu_0 m}{4\pi}\left(\frac{(x+2l)^2 - x^2}{x^2(x+2l)^2}\right)\hat{x}$. In case of dipole $x \gg 2l$ and hence $(2l)^2 \to 0$ and $x + 2l \to x$ Therefore, magnitude of magnetic field it approximates to $\vec{B} = -\frac{\mu_0}{4\pi} \times m\left(\frac{4lx}{x^2x^2}\right)\hat{x} \Rightarrow \vec{B} = -\frac{\mu_0}{4\pi} \times \frac{2(2ml)}{x^3}\hat{x} \Rightarrow \vec{B} = -\frac{\mu_0}{4\pi} \times \frac{2M}{x^3}\hat{x}$.

At neutral $\vec{B} + \vec{B}_H = 0 \Rightarrow -\frac{\mu_0}{4\pi} \times \frac{2M}{x^3}\hat{x} + \vec{B}_H = 0 \Rightarrow \frac{\mu_0}{4\pi} \times \frac{2M}{x^3}\hat{x} = \vec{B}_H$. Using the available data it leads to $10^{-7} \times \frac{2\times 0.72}{x^3} = 18 \times 10^{-6} \Rightarrow x = \sqrt[3]{\frac{1.44\times 10^{-1}}{18}} \Rightarrow x = 0.2$m.

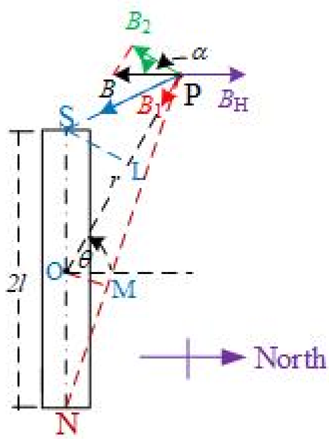
Thus, **neutral point would be at 20 cm from pole of the dipole along its axis, is the answer.**

I-39

Magnetic dipole having magnetic moment $M = 2ml = 0.72\sqrt{2}$ A.m^2 is placed horizontally. It is given that horizontal component of earth's magnetic field is $B_H = 18 \times 10^{-6}$ T.



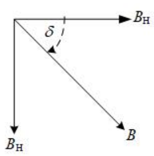
In the problem statement north pole of magnet is oriented towards East as shown in the figure. This case needs to be handled differently from Broadside-On and End-on positions, and for this magnetic potential at a point defined with radial coordinates (r, θ) have been chosen, as shown in the figure, instead of Cartesian coordinates.



Given that a dipole of pole strength m and magnetic moment $M = 2ml$ are short in length of magnets $2l \ll r$. The magnets are fastened at their centers as shown in the figure (not to the scale). Therefore, magnetic field at the point P due to North poles of one of the two magnets, at a distance $r_N \approx BP = r + l\sin\theta$ would be $V_N = \frac{\mu_0}{4\pi}\frac{m}{(r+l\sin\theta)}$. Likewise, due to south pole at a distance $r_S = r - l\sin\theta$ it would be $V_S = \frac{\mu_0}{4\pi}\frac{(-m)}{(r-l\sin\theta)}$. Thus, net magnetic field due to dipole is $V = V_N + V_N$. It leads to $V = \frac{\mu_0}{4\pi}\frac{m}{(r+l\sin\theta)} - \frac{\mu_0}{4\pi}\frac{m}{(r-l\sin\theta)} = \frac{\mu_0 m}{4\pi}\left(\frac{(r-l\sin\theta)-(r-l\sin\theta)}{(r^2-l^2\sin^2\theta)}\right) \Rightarrow V = -\frac{\mu_0 m}{4\pi}\left(\frac{2l\sin\theta}{(r^2-l^2\sin^2\theta)}\right)$. Since, $r^2 \gg (l\sin\theta)^2$. Therefore, $V = -\frac{\mu_0}{4\pi}\left(\frac{M\sin\theta}{r}\right)$.

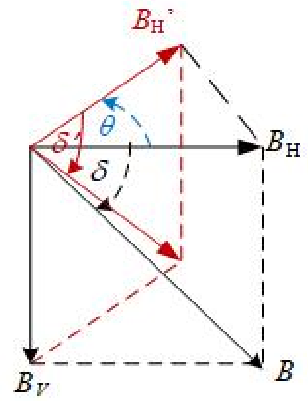
Magnetic potential $[V = f(\theta, r)]$is a scalar quantity whereas magnetic field intensity is a vector quantity $B = -\frac{\partial V}{\partial r}$, such that its radial component is $B_1 = \frac{\partial V}{\partial r} = -\frac{\partial}{\partial r}\left(-\frac{\mu_0}{4\pi}\left(\frac{M\sin\theta}{d^2}\right)\right) = \frac{\mu_0 M\sin\theta}{4\pi} \times \frac{\partial}{\partial r}\left(\frac{1}{r^2}\right) \Rightarrow B_1 = \frac{\mu_0 M\sin\theta}{4\pi} \times \left(-\frac{2}{r^3}\right)$. It leads to $B_1 = -\frac{2\mu_0 M\sin\theta}{4\pi r^3}$.

Likewise, tangential component of magnetic field is $B_2 = -\frac{\partial V}{\partial(r\theta)}$, here infinitesimal tangential displacement is $\partial(r\theta) = r\,(\partial\theta)$ is the tangential displacement. Accordingly, $B_2 = -\frac{1}{r} \times \frac{\partial}{\partial\theta}\left(\frac{\mu_0 M}{4\pi r^2} \times \sin\theta\right) = -\frac{\mu_0 M}{4\pi r^3} \times \frac{\partial}{\partial\theta}\sin\theta$. It solves into, $B_2 = -\frac{\mu_0 M}{4\pi r^3} \times \cos\theta$. Geometrically, as shown in the figure $\tan\alpha = \frac{B_1}{B_2} = \frac{-\frac{2\mu_0 M\sin\theta}{4\pi r^3}}{\frac{\mu_0 M}{4\pi r^3}\times\cos\theta}$. It leads to $\tan\alpha = 2\tan\theta$.

	As seen from the diagram, net magnetic field B due to dipole be equal and opposite to B_H makes an angle $\alpha = 90^0 - \theta$ with the magnetic axis. Therefore, $\tan\alpha = \tan(90^0 - \theta) = \cot\theta = 2\tan\theta \Rightarrow \tan^2\theta = \frac{1}{2}$. It leads to that $\tan\theta = \frac{1}{\sqrt{2}} \Rightarrow \theta = \tan^{-1}\left(\frac{1}{\sqrt{2}}\right)$. Further, magnitude of magnetic field due to dipole is $B = \sqrt{\left(\frac{2\mu_0 \mathrm{M}\sin\theta}{4\pi r^3}\right)^2 + \left(\frac{\mu_0 M}{4\pi r^3} \times \cos\theta\right)^2}$. It, further solves into $B = \frac{\mu_0}{4\pi} \times \frac{\mathrm{M}\cos\theta}{r^3}\sqrt{\left(2 \times \frac{\sin\theta}{\cos\theta}\right)^2 + 1} \Rightarrow B = \frac{\mu_0}{4\pi} \times \frac{\mathrm{M}\cos\theta}{r^3}\sqrt{(2 \times \tan\theta)^2 + 1} \Rightarrow B = \frac{\mu_0}{4\pi} \times \frac{\mathrm{M}\cos\theta}{r^3}\sqrt{\left(\sqrt{2}\right)^2 + 1}$. Further, $\cos\theta = \frac{1}{\sqrt{1+\tan^2\theta}} = \frac{1}{\sqrt{1+\frac{1}{2}}} \Rightarrow \cos\theta = \sqrt{\frac{2}{3}}$. Accordingly, $B = \frac{\mu_0}{4\pi} \times \frac{M}{r^3} \times \sqrt{\frac{2}{3}} \times \sqrt{3} \Rightarrow B = \frac{\mu_0}{4\pi} \times \frac{M}{r^3} \times \sqrt{2}$. Requirement of Null point is $B = B_H$. Therefore, using the available data $10^{-7} \times \frac{0.72\sqrt{2}}{r^3} \times \sqrt{2} = 18 \times 10^{-6} \Rightarrow r = \sqrt[3]{\frac{1.44 \times 10^{-1}}{18}} = 0.2$m or 20 cm from the center of the dipole. Thus, the null point is at 20 cm from the center of the pole with South pole at an angle $\theta = \tan^{-1}\left(\frac{1}{\sqrt{2}}\right)$ West of North is the answer.. **N.B.: 1.** The question could be solved by determining combined magnetic field at a point due to North and south Pole and then position of its equilibrium with B_H to ascertain the null point. Instead, scalar magnetic potential at a point has been determined and its radial and tangential components have been determined to arrive at the position of null point. This makes analysis and solution simple. **2.** Use of standard formulae apparently makes solution simple and fast. But, in typical problems like this ability to evolve solution from first principle builds confidence to handle any unknown problem, generally encountered in real life. This is the basic purpose of education.
I-40	Magnetic moment of a dipole of magnetism equivalent to earths magnetism is $M = 8.0 \times 10^{22}$ A.m^2. Magnetic field B at the geomagnetic-poles of the earth is that of an end on position at a distance $x = 6.4 \times 10^6$m. The value of $B = \frac{\mu_0}{4\pi} \times \frac{2M}{x^3}$. Using the available data$B = -10^{-7} \times \frac{2\times(8.0\times10^{22})}{(6.4\times10^6)^3} = 6.1 \times 10^{-5} \approx$ **60 μT is the ++++answer.**
I-41	Given is earth's magnetic at the magnetic equator B_E is similar to the broadside-on position and accordingly, $B_E = \frac{\mu_0}{4\pi} \times \frac{M}{R^3}$. Here, M is magnetic moment of an equivalent dipole and $R = 6.4 \times 10^6$ is radius of the earth. While it is required to determine magnetic field at the poles $B_P = \frac{\mu_0}{4\pi} \times \frac{2M}{R^3}$. Taking ratio $\frac{B_P}{B_E} = \frac{\frac{\mu_0}{4\pi}\times\frac{2M}{R^3}}{\frac{\mu_0}{4\pi}\times\frac{M}{R^3}} = 2$. Hence, $B_P = 2 \times B_E$. Using the given data $B_P = 2 \times (3.4 \times 10^{-5}) =$ $\mathbf{6.8 \times 10^{-5}}$ **T is the answer.**
I-42	Earth's magnetic field B at a point has two components viz. horizontal component $B_H = B\cos\delta$ and vertical component $B_V = B\sin\delta$. Here, δ is the angle of dip. Given that $B_H = 26 \times 10^{-6}$ T and $\delta = 60^0$.  With the given data $\frac{B_V}{B_H} = \frac{B\sin\delta}{B\cos\delta} \Rightarrow B_V = B_H\tan\delta \Rightarrow B_V = (26 \times 10^{-6}) \times \sqrt{3} =$ **45 μT is part One of the answer.** As regards earth's magnetic field $B_H = B = \frac{B_H}{\cos\delta} \Rightarrow B = \frac{26\times10^{-6}}{0.5} =$ **52 μT, is part Two of the answer.** **Thus answers are 45 μT and 52 μT**

<table>
<tr><td>I-43</td><td>

Geo-magnetic field in magnetic meridian has been conceptualized with Dip Circle as show in the figure. Here, $B_H = B\cos\delta$ is horizontal component and $B_V = B\sin\delta$ is vertical component of earth's magnetic field B. Accordingly, $\tan\delta = \frac{B_V}{B_H} \Rightarrow B_V = B_H\tan\delta \ldots(1)$.



In a vertical plane at an angle $\theta = 60^0$ magnetic needle stay at a new dip angle $\delta' = \tan^{-1}\left(\frac{2}{\sqrt{3}}\right)$. Thus, horizontal component of magnetic field in the vertical plane $B'_H = B_H\cos\theta$ ...(2). Accordingly, it gives new dip angle δ' such that $\tan\delta' = \frac{B_V}{B_H'} \Rightarrow B_V = B_H'\tan\delta'\ldots(3)$.

Combining (1), (2) and (3) we get $B_H\tan\delta = (B_H\cos\theta)\times\tan\delta'$. It leads to $\tan\delta = \cos\theta\times\tan\delta'$. Using the given data $\tan\delta = \cos 60^0\times\tan\left(\tan^{-1}\left(\frac{2}{\sqrt{3}}\right)\right) \Rightarrow \tan\delta = \frac{1}{2}\times\frac{2}{\sqrt{3}} \Rightarrow \tan\delta = \frac{1}{\sqrt{3}} = \tan 30^0$. It implies $\delta = \mathbf{30^0}$**, is the answer.**

N.B.: A 3-D figure helps to visualize and analyze problems and has been used in illustration to make it self-explanatory.

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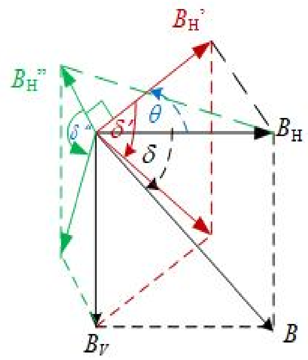
<tr><td>I-44</td><td>

Angle of dip in magnetic meridian is called here as true angle of dip δ, and it is to be determined. The problem is being analyzed in context of Dip-Circle.

In magnetic meridian Here, $B_H = B\cos\delta$ ...(1) is horizontal component and $B_V = B\sin\delta\ldots(2)$ is vertical component of earth's magnetic field B. Accordingly, $\tan\delta = \frac{B_V}{B_H} \Rightarrow B_V = B_H\tan\delta\ldots(3)$. Here, δ is true dip angle.

In a particular position on a plane at an angle θ the dip angle is measured $\delta' = 45^0$. Thus, horizontal component of magnetic field in the vertical plane $B'_H = B_H\cos\theta$ ...(4). Accordingly, it gives new dip angle δ' such that $\tan\delta' = \frac{B_V}{B_H'} \Rightarrow B_V = B_H'\tan\delta'\ldots(5)$. Combining (4) and (5) $B_V = (B_H\cos\theta)\tan\delta'\ldots(6)$.



In another plane when dip circle is rotated through 90^0 the horizontal component of geo-magnetic field is $B''_H = B_H\cos(90^0+\theta) \Rightarrow B''_H = B_H\sin\theta\ldots(7)$. Therefore, $\tan\delta'' = \frac{B_V}{B''_H} \Rightarrow \tan\delta'' = \frac{B_V}{B_H\sin\theta} \Rightarrow B_V = (B_H\sin\theta)\times\tan\delta''\ldots(8)$.

Combining (6) and (7), we have $(B_H\cos\theta)\tan\delta' = (B_H\sin\theta)\times\tan\delta''$. It leads to $\sin\theta\tan\delta'' = \cos\theta\tan\delta' \Rightarrow \tan\theta = \frac{\tan\delta'}{\tan\delta''}$. Using the given data where $\delta' = 45^0$ and $\delta'' = 53^0$ we have $\tan\theta = \frac{\tan 45^0}{\tan 53^0} \Rightarrow \tan\theta = \cot 53^0 = 0.7536\ldots(9)$.

Combining (3) and (6), $B_H\tan\delta = (B_H\cos\theta)\tan\delta' \Rightarrow \tan\delta = \cos\theta\tan\delta'\ldots(10)$.

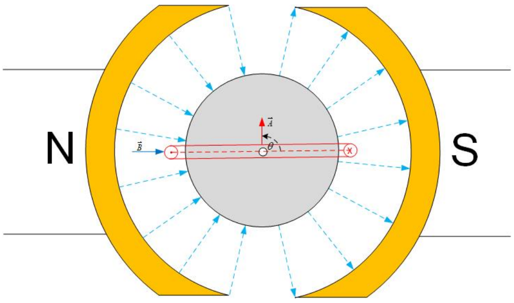
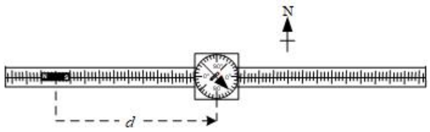
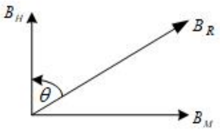
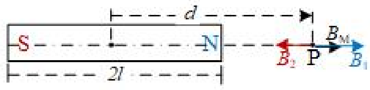
Trigonometrically $\cos\theta = \frac{1}{\sqrt{1+\tan^2\theta}} = \frac{1}{\sqrt{1+(0.7536)^2}} \Rightarrow \cos\theta = 0.7986$, using it in (10) $\tan\delta = 0.7986\times 1$ we have $\tan\delta = 0.7986 \Rightarrow \delta = 38^0 37'$ say $\mathbf{39^0}$ **is the answer.**

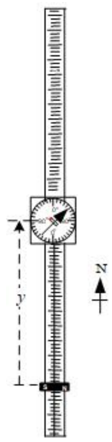
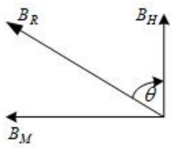
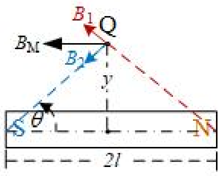
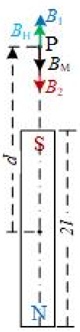
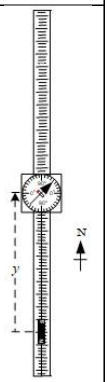
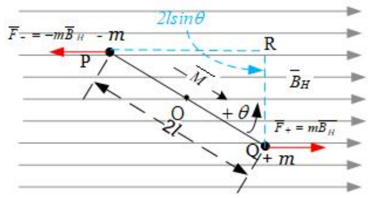
N.B.: A 3-D figure helps to visualize and analyze problems and has been used in illustration to make it self-explanatory.

</td></tr>
<tr><td>I-45</td><td>

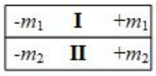
Magnetic needle in tangent galvanometer is placed horizontally while the coil is placed vertically in geo-magnetic meridian. Thus, the magnetic field produced by the coil $B = \frac{\mu_0 in}{2r}$ is perpendicular to the geo-magnetic field. Here, i is current through the coil, n is number of turns in the coil and r is radius of the coil. Thus, the needle settles at a deflection θ such that $\tan\theta = \frac{B}{B_H}$.

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

	Accordingly, using the available data $\tan 45^0 = \frac{B}{B_H} \Rightarrow \frac{(4\pi\times10^{-7})(10\times10^{-3})\times n}{2\times0.1} = 3.6\times10^{-5} \Rightarrow n = \frac{3.6}{2\pi}\times 10^3 = 57.3$, say **57 turns, is the answer.**
I-46	This problem involves electromagnetism according to which torque produced on a coil of a moving-coil galvanometer is $\vec{\tau} = nI(\vec{A}\times\vec{B})$ here $B = 0.5$ T is magnetic field of the magnetic poles, area of the coil is $A = (2\times10^{-2})\times(2\times10^{-2}) = 4\times10^{-4}\mathrm{m}^2$, number turns in the coil is $n = 50$ and current through the coil is $I = 20\times10^{-3}$A. In moving coil galvanometer magnetic field vector $\vec{B}$ is always radial and area vector $\vec{A}$ are perpendicular to each other. Accordingly, $\theta = 90^0$, as shown in the figure.  Thus using the available data, magnitude of the torque is $\tau = 50\times(20\times10^{-3})\times0.5\times(4\times10^{-4})\times\sin 90^0 \Rightarrow \tau = \mathbf{2}\times$ $\mathbf{10^{-4}}$**Nm, is the answer.**
I-47	Given is short magnet having magnetic moment $M = 2ml$ placed in Tan-A position of the deflection magnetometer as shown in the figure. It is equivalent to end-on position. The needle is deflected by an angle $\theta = 37^0$.  Magnetic needle is subjected to two magnetic fields B_M produced by the short magnet and B_H the horizontal component of geo-magnetic field. Accordingly, $\tan\theta = \frac{B_M}{B_H}$ ...(1), as shown in the figure.  Since, deflection magnetometer is placed horizontally and hence in analysis of the problem only B_H is relevant. Magnetic field at P due to north pole of polarity m is $\vec{B}_1 = \frac{\mu_0}{4\pi}\times\frac{m}{(d-l)^2}\hat{x}$ and due to south pole of polarity $(-m)$ is $\vec{B}_2 = -\frac{\mu_0}{4\pi}\times\frac{(m)}{x^2}\hat{x} \Rightarrow \vec{B}_2 = -\frac{\mu_0}{4\pi}\times\frac{m}{(d+l)^2}\hat{x}$.  Therefore, net-magnetic field at the point is $\vec{B}_M = \frac{\mu_0 m}{4\pi}\left(\frac{1}{(d-l)^2} - \frac{1}{(d+l)^2}\right)\hat{x} \Rightarrow \vec{B}_M = \frac{\mu_0 m}{4\pi}\left(\frac{(d+l)^2-(d-l)^2}{(d^2-l^2)^2}\right)\hat{x} \Rightarrow B_M = \frac{\mu_0 m}{4\pi}\times\frac{4dl}{(d^2-l^2)^2}$. In case of dipole $d \gg 2l$ and hence $(d^2-l^2)^2 \to d^4$, therefore, $B_M = \frac{\mu_0}{4\pi}\times\frac{4mld}{d^4} \Rightarrow B_M = \frac{\mu_0}{4\pi}\times\frac{2M}{d^3}$...(2). Combining (1) and (2), $\tan\theta = \frac{\frac{\mu_0}{4\pi}\times\frac{2M}{d^3}}{B_H} \Rightarrow \frac{M}{B_H} = \frac{4\pi}{\mu_0}\times\frac{(0.1)^3}{2}\times\tan\theta = \frac{(0.1)^3}{2\times10^{-7}}\times\tan 37^0 = (0.5\times10^4)\times 0.75 \Rightarrow \frac{M}{B_H} = \mathbf{3.75\times10^3}$**Am²/T is the answer.** **N.B.:** Decomposing the problem in stages with necessary diagrams adds clarity, ability to solve unknown problems and burden of remembering formulae.

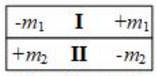
I-48	Given is short magnet having magnetic moment $M = 2ml$ placed in Tan-B position of the deflection magnetometer as shown in the figure. It is equivalent to broadside-on position. The needle is deflected by an angle $\theta = 37^0$.  Magnetic needle is subjected to two magnetic fields B_M produced by the short magnet and B_H the  horizontal component of geo-magnetic field. Accordingly, $\tan\theta = \frac{B_M}{B_H}$ ...(1), as shown in the figure. Since, deflection magnetometer is placed horizontally and hence in analysis of the problem only B_H is relevant.  Magnetic field at the needle of the deflection magnetometer is $B_M = \frac{\mu_0}{4\pi} \times \frac{M}{(y^2+l^2)^{\frac{3}{2}}}$. Since, $y \gg 2l$, therefore, $B_M = \frac{\mu_0}{4\pi} \times \frac{M}{y^3}$ ...(2). Combining (1) and (2), $\tan\theta = \frac{\frac{\mu_0}{4\pi}\times\frac{M}{y^3}}{B_H} \Rightarrow y = \sqrt[3]{\frac{\mu_0}{4\pi} \times \frac{M}{B_H} \times \frac{1}{\tan\theta}}$. Using the available data $y = \sqrt[3]{10^{-7} \times (\mathbf{3.75 \times 10^3}) \times \frac{1}{\tan 37^0}} \Rightarrow y = \sqrt[3]{\frac{3.75}{0.75} \times 10^{-4}} = \sqrt[3]{0.5 \times 10^{-3}} = 0.79 \times 10^{-1}$m or **7.9 cm is the answer.**
I-49	For the needle to stay in any position is possible when it is positioned at null point. In geo-magnetic field placing deflection magnetometer in north-south direction. Thus, for magnetic needle to be on  null point magnet should be so placed that – **(a)** magnetic needle is on end-on position, and **(b)** north pole of the magnet is oriented towards geographical south so that geo-magnetic field and magnetic field of the magnet are in opposite directions. It is shown in the figure.  Magnetic field at a point in end-on position is $B_M = \frac{\mu_0}{4\pi} \times \frac{4mdl}{(d^2-l^2)^2}$. For a short magnet $d \gg 2l$ and there the expression is modified as $B_M = \frac{\mu_0}{4\pi} \times \frac{2M}{d^3}$...(1), here magnetic moment of the magnet is $M = 2ml$. At null point $B_H = B_M \Rightarrow B_H = \frac{\mu_0}{4\pi} \times \frac{2M}{d^3} \Rightarrow d = \sqrt[3]{\frac{\mu_0}{4\pi} \times 2 \times \frac{M}{B_H}}$. Using the available data $d = \sqrt[3]{10^{-7} \times 2 \times 40} = 10^{-2} \times \sqrt[3]{8} \Rightarrow d = 2 \times 10^{-2}$m or say **2 cm is the answer.**
I-50	 In oscillating magnetometer freely suspended bar-magnet interacts with horizontal component of earth's magnetic field $B_H = 30 \times 10^{-6}$T and produces a torque $\Gamma = 2mlB_H \sin\theta$...(1), as shown in the figure For a small displaced $\theta \ll$ it approximates to $\sin\theta \to \theta$...(2). This establishes conditions of angular-SHM where $\Gamma = I\alpha$...(3). Here, moment of inertia of bar-magnet $I = 1.2 \times 10^{-4}$ kg.m^2 and α is angular acceleration of the bar magnet at a displacement θ. Thus, combining (1), (2) and (3), $I\alpha = 2mlB_H\theta \Rightarrow \alpha = \frac{MB_H}{I}\theta$...(4). Here, magnetic moment of the bar magnet $M = 2ml$. Characteristically, for a SHM magnitude of acceleration is proportional to the displacement. Accordingly for angular SHM, $\alpha = \omega^2\theta \Rightarrow \alpha = \left(\frac{2\pi}{T}\right)^2 \theta$ ...(5), here $\omega = \frac{2\pi}{T}$ is maximum angular velocity and time period of the SHM is $T = \frac{\pi}{10}$ Thus equating (4) and (5), $\frac{MB_H}{I}\theta = \left(\frac{2\pi}{T}\right)^2 \theta \Rightarrow M = \left(\frac{2\pi}{T}\right)^2 \times \frac{I}{B_H}$...(7) Using available data in (7), $M = \left(\frac{2\pi}{\frac{\pi}{10}}\right)^2 \times \frac{1.2\times10^{-4}}{30\times10^{-6}} \Rightarrow M = \frac{4.8}{30} \times 10^4 =$ **1600 A-m^2 is the answer.**
I-51	Given is two bar magnets I and II having magnetic pole strengths m_1 and m_2 and magnetic moments M_1 and M_2 These magnets, together have moment of inertia I, this being a physical property it will remain unaltered whether the two magnets are tied with like or unlike poles together.

Magnetic pole strengths of the combination-A when like poles are tied together is $M_A = M_1 + M_2$. While in combination-B when unlike poles are tied together is $M_B = M_1 - M_2$. Accordingly, ratio of magnetic moments of the combinations would be $\frac{M_A}{M_B} = \frac{M_1+M_2}{M_1-M_2}$…(1)



(Combination-A)

In oscillating magnetometer $M = \left(\frac{2\pi}{T}\right)^2 \times \frac{I}{B_H}$ and therefore $\frac{M_A}{M_B} = \frac{\left(\frac{2\pi}{T_A}\right)^2 \times \frac{I}{B_H}}{\left(\frac{2\pi}{T_B}\right)^2 \times \frac{I}{B_H}} \Rightarrow \frac{M_A}{M_B} = \left(\frac{T_B}{T_A}\right)^2$…(2)



(Combination-B)

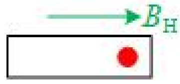
It is given that frequency of oscillation in combination-A is $f_A = 10$ c/s and in combination-B it is $f_A = 2$ c/s. Moreover, $T = \frac{1}{f}$ hence $\frac{T_B}{T_A} = \frac{\frac{1}{f_B}}{\frac{1}{f_A}} \Rightarrow \frac{T_B}{T_A} = \frac{f_A}{f_B}$…(3).

Combining (1), (2) and (3), $\frac{M_1+M_2}{M_1-M_2} = \left(\frac{f_A}{f_B}\right)^2$. Using the available data $\frac{M_1+M_2}{M_1-M_2} = \left(\frac{10}{2}\right)^2 \Rightarrow \frac{M_1+M_2}{M_1-M_2} = 25$…(4). Applying componendo-dividendo to (4), $\frac{M_1}{M_2} = \frac{25+1}{25-1} \Rightarrow \frac{M_1}{M_2} = \frac{13}{12}$. Hence, **answer is 13:12.**

I-52

This question magnetic effect of current as per Biot-Sevart's Law to determine magnetic field due to current carrying conductor, in addition to the concepts of magnetism.

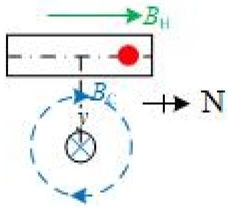
In an oscillation magnetometer $M = \left(\frac{2\pi}{T}\right)^2 \times \frac{I}{B_H}$…(1). Here, M is magnetic moment of the suspended magnet, I is the moment of inertia of the magnet, B_H is the horizontal component of the magnetic field where the instrument is placed and T is the time period of the oscillation. The (1) can be expressed as $T = 2\pi\sqrt{\frac{I}{MB_H}}$…(2). It is given that time period $T = 0.10$ s with barely the magnet is used in the instrument.



Next a vertical wire, placed $y = 0.20$ m east of the magnet, carries a downward current $I = 18$A.

Thus current modifies magnetic field affecting oscillation of the magnet in the instrument as shown in the figure. The current through conductor, as stated, in accordance with Ampere's Right-hand Thumb Rule produces magnetic field B_C in a direction adding to the B_H such that modified external magnetic field affection oscillation of the magnet is $B = B_H + B_C$….(3)

Magnetic field due to current carrying conductor $B_C = \frac{\mu_{0I}}{2\pi y}$…(4). Combining (3) and (4) with the given data $B = 24 \times 10^{-6} - \frac{4\pi\times10^{-7}}{2\pi} \times \frac{18}{0.2} \Rightarrow B = (24 + 18) \times 10^{-6} \Rightarrow B = 42 \times 10^{-6}$ T…(7)

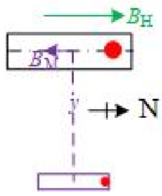
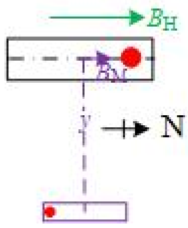


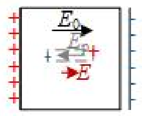
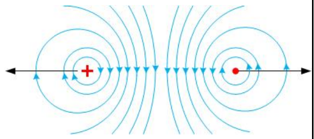
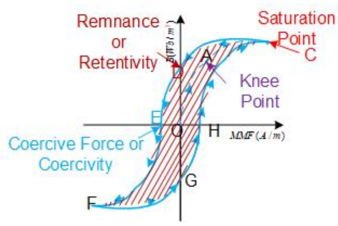
Thus, using (2) time period, when current carrying conductor is part of the system, is $T' = 2\pi\sqrt{\frac{I}{MB}}$. Accordingly, $\frac{T'}{T} = \frac{2\pi\sqrt{\frac{I}{MB}}}{2\pi\sqrt{\frac{I}{MB_H}}} \Rightarrow T' = T \times \sqrt{\frac{B_H}{B}}$. Using the available data $T' = 0.1 \times \sqrt{\frac{24}{42}} \Rightarrow T' = \mathbf{0.076}$ **s is the answer.**

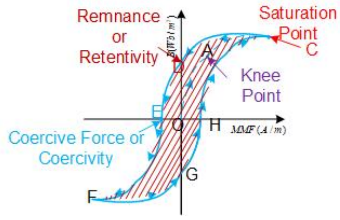
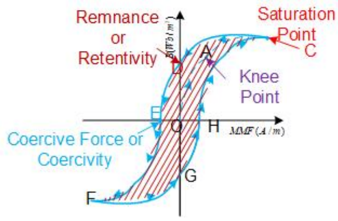
I-53

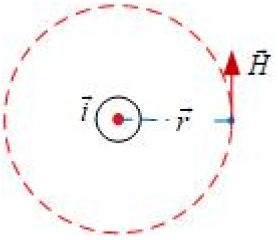
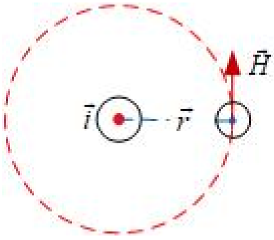
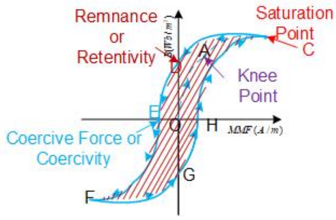
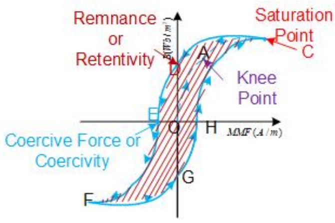
Given that 40 oscillations are made in one minute by a bar magnet an oscillation magnetometer. It implies that $T = \frac{60}{40} = \frac{3}{2}$ s. We know that $T = 2\pi\sqrt{\frac{I}{MB_H}}$…(1).

Now, system is modified by placing an identical magnet demagnetized completely, it is equivalent to another iron bar placed with the magnet such that only moment of inertia of the system changes to $I' - 2I$ while rest

	of the parameters remain unchanged. Therefore, time period of the new system is $T' = 2\pi\sqrt{\frac{I'}{MB_H}} = 2\pi\sqrt{\frac{2I}{MB_H}}$…(2). Combining (1) and (2), $\frac{T'}{T} = \frac{2\pi\sqrt{\frac{I'}{MB_H}}}{2\pi\sqrt{\frac{I}{MB_H}}} \Rightarrow \frac{T'}{T} = \sqrt{\frac{I'}{I}}$. Using the available data $T' = T\sqrt{\frac{2I}{I}} \Rightarrow \frac{2}{3}\sqrt{2}$. Therefore, time taken for 40 oscillations is $t' = 40 \times T' = 40 \times \frac{3}{2}\sqrt{2} = 60 \times \sqrt{2}$s or **$\sqrt{2}$ minutes is the answer.**
I-54	Given that a short makes 40 oscillations per minute when used in an oscillation magnetometer at a place when the earth's horizontal magnetic field is $B_H = 25 \times 10^{-6}$ T. Therefore, time period of oscillations is $T = \frac{60}{40} = \frac{3}{2}$…(1). We know that $T = 2\pi\sqrt{\frac{I}{MB_H}}$…(2). Here, N The system is modified by introducing an external-magnet having magnetic moment $M' = 1.6$ Am^2 east of the oscillation magnetometer at a distance $y = 0.20$m in two ways as Case 1 and Case 2, as under- **Case 1:** Magnet is placed with north pole towards north as shown in the figure. It is broadside-on position. Accordingly, magnetic field produced by external-magnet at the instrument is $B_M = \frac{\mu_0}{4\pi} \times \frac{M'}{y^3}$….(3). It is seen that B_M and B_H are in opposite directions and hence net magnetic field affecting oscillations is $B'_H = B_H - B_M$…(4). Therefore, time period of oscillation would be $T' = 2\pi\sqrt{\frac{I}{MB'_H}}$…(5).  Combining (2), (3), (4) and (5), $\frac{T'}{T} = \frac{2\pi\sqrt{\frac{I}{MB'_H}}}{2\pi\sqrt{\frac{I}{MB_H}}} \Rightarrow T' = T \times \sqrt{\frac{B_H}{B_H - \frac{\mu_0}{4\pi}\times\frac{M'}{y^3}}}$. Using the available data $T' = \frac{3}{2} \times \sqrt{\frac{25\times10^{-6}}{25\times10^{-6} - 10^{-7}\times\frac{1.6}{(0.2)^3}}} \Rightarrow T' = \frac{3}{2} \times \sqrt{\frac{25\times10^{-6}}{25\times10^{-6} - 20\times10^{-6}}}$. It solves into $T' = \frac{3}{2} \times \sqrt{5}$. Therefore, frequency of oscillations is $f' = \frac{60}{T'} = \frac{60\times2}{3\times\sqrt{5}} = 17.9$ oscillations per minute say **18 oscillations per minute is the answer of Case 1.** **Case 2:** In this case the magnet is placed with north pole towards south, as shown in the figure. It is broadside-on position. Accordingly, magnetic field produced by external-magnet at the instrument is same as in (3), with a difference, that both the B_M and B_H are in same direction and hence net magnetic field affecting oscillations is $B^{"}_H = B_H + B_M$…(6). Therefore, time period of oscillation would be $T" = 2\pi\sqrt{\frac{I}{MB^{"}_H}}$…(7).  Combining (2), (3), (6) and (7), $\frac{T^{"}}{T} = \frac{2\pi\sqrt{\frac{I}{MB'_H}}}{2\pi\sqrt{\frac{I}{MB_H}}} \Rightarrow T^{"\prime} = T \times \sqrt{\frac{B_H}{B_H + \frac{\mu_0}{4\pi}\times\frac{M'}{y^3}}}$. Using the available data $T' = \frac{3}{2} \times \sqrt{\frac{25\times10^{-6}}{25\times10^{-6} + 10^{-7}\times\frac{1.6}{(0.2)^3}}} \Rightarrow T^{"} = \frac{3}{2} \times \sqrt{\frac{25\times10^{-6}}{25\times10^{-6} + 20\times10^{-6}}}$. It solves into $T^{"} = \frac{3}{2} \times \sqrt{\frac{5}{9}} = \frac{\sqrt{5}}{2}$. Therefore, frequency of oscillations is $f' = \frac{60}{T^{"}} = \frac{60\times2}{\sqrt{5}} = 53.7$ oscillations per minute say 54 **oscillations per minute is the answer of Case 2.** Hence, **answer is 18 oscillations per minute and 54 oscillations per minute.**

I-55	 Electric field when a dielectric is placed in an electric field E_0 is shown in the figure. A polarized of the dipole, under influence of electric field is shown in the figure causing an electric field E_p within the dielectric. The direction of polarization is opposite to the applied electric field. Therefore, net electric field within the dielectric is $E = E_0 - E_p \Rightarrow E < E_0$. Instead, when a paramagnetic substance is placed in a magnetic field $\vec{H}$, the resultant magnetic field $\vec{B} = \mu_0 ni$ is such that $\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{I}$, where $\vec{I}$ is the intensity of magnetization, n is number of turns in the coil and i is the current in the coil. Thus, $\vec{B} = \mu_0\left(\vec{H} + \vec{I}\right)$. It is seen that behavior of magnetic and electric dipoles in magnetic field and electric field is opposite. 
I-56	Materials when placed in external magnetic field, dipole moment is induced in atoms due interaction of the magnetic field, and magnetic field produced by the electron revolving around nucleus of the atoms of the material. The direction of the magnetic field of the so induced dipole moment is opposite as per attraction of opposite poles, **similar to the electric dipoles.** Therefore, net magnetic field inside the material is small than the applied magnetic field. This property of the material is called diamagnetism. However, some material, by virtue of their electron distribution in orbits of atoms inherit some magnetic moment; it is in absence of external magnetic field. In such materials external magnetic field induces alignment of atoms in the direction of magnetic field such that $\vec{I} = \chi\vec{H}$, here $\vec{I}$ is intensity of magnetization in the material, $\vec{H}$ is intensity of magnetizing field i.e. external magnetic field and χ is susceptibility of the material (it's characteristic) to the magnetizing field. Materials having $\chi = 0$ are called diamagnetic materials, those having $1 > \chi > 0$ are called paramagnetic materials and materials having $\chi > 1$ are called ferromagnetic. Whereas, in diamagnetic materials $\chi < 0$ are called diamagnetic materials. **Thus answer is value of susceptibility; $\chi < 0$ are called diamagnetic materials, $1 > \chi > 0$ are called paramagnetic materials and $\chi > 1$ are called ferromagnetic.**
I-57	Permeability μ magnetic property of a material is $\mu = \frac{B}{H}$, here $[B] = \mathrm{MI^{-1}T^{-2}}$ is magnetic flux density having unit Tesla or Web/m^2 and $[H] = \mathrm{LI^{-1}}$ is the intensity of the magnetizing field whose unit is . Thus, dimensionally permeability is $[\mu] = \frac{[B]}{[H]} \Rightarrow [\mu] = \frac{\mathrm{MI^{-1}T^{-2}}}{\mathrm{L^{-1}I}} \Rightarrow [\mu] = \mathrm{MLI^{-2}T^{-2}}$. Since, μ is not dimension less and hence it will have a unit N/Amp^2. But, relative permeability is $\mu_r = \frac{\mu}{\mu_0}$, here μ_0 is permeability of free space and dimensionally $[\mu] = [\mu_0]$. Therefore, $\mu_r$is a dimensionless quantity and hence it has **no dimension, is the answer.**
I-58	Statement of the question is silent on magnetic property of the material i.e. diamagnetic, paramagnetic and ferromagnetic type as much as about direction of magnetic field. Diamagnetic substances are weakly repelled by magnetic field and thus they get aligned in a direction perpendicular to the magnetic field. Whereas paramagnetic and ferromagnetic are weakly and strongly respectively attracted and appropriately aligned in the4 direction of magnetic field. Thus in absence of the requisite information simply based on direction of alignment of the rod, direction of magnetic field cannot be ascertained. Hence, **answer is no.**
I-59	Basic property of material required for making a permanent magnet is high retentivity, i.e. residual magnetism when magnetizing force is reduced to zero, and high coercivity i.e. reverse magnetizing force required to reduce residual magnetism to zero. Magnetic hysteresis with crucial characteristic points is shown in the figure. Ferromagnetic substances with very large susceptivity ($\chi \gg$) exhibit this property. While, in paramagnetic materials with $\mathbf{1 > \chi > 0}$ **this property is absent, is the answer.** 

I-60	**Materials exhibiting magnetic hysteresis have some b**asic property of material required for making a permanent magnet is high retentivity, i.e. residual magnetism when magnetizing force is reduced to zero, and high coercivity i.e. reverse magnetizing force required to reduce residual magnetism to zero. It is there in ferromagnetic material having high susceptibility $\boldsymbol{\chi}$.  While paramgnetic and diamagnetic materials loose induced magnetism as soon as magnetizing field is removed, hence **they do not have magnetic hysteresis, is the answer.**
I-61	Magnetizing force is $H = ni$. Thus subjecting a magnetic material to magnetic hysteresis loop requires cyclic magnetization and demagnetization. During magnetization in hysteresis loop magnetizing force is greater than that during demagnetization. Thus energy consumed in cyclic reorientation of magnetic dipoles of the ferromagnetic material is converted into heat. Since, magnetizing force is caused by current in the magnetizing coil, hence the **energy comes from electrical energy, is the answer.** 
I-62	Soft iron being ferromagnetic material is both low retentivity and low coercivity. Thus, when coil of a galvanometer under influence of current through it rotates, it causes magnetization or demagnetization depending upon movement of the coil. The properties of soft iron enumerated above cause **low losses and high accuracy, is the answer**
I-63	Iron box as an enclosure of an instrument acts like a magnetic shield. Thus, terrestrial magnetic field does not influence magnetic field of the instrument. **It acts similar to Faraday's cage in electricity.**
I-64	In paramagnetic materials $\vec{I} = \chi\vec{H} \Rightarrow \vec{I} \propto \vec{H}$, here $\vec{I}$ is intensity of magnetization and in turn magnetic field, $\vec{H}$ is intensity of magnetizing field and χ is the susceptibility of paramagnetic material. Thus, as H increases, magnetic field B also increases. Thus, **statement A is correct**. But, with increase in temperature, thermal vibration in atoms of the material randomizes the dipoles, and magnetization decreases. Thus, **statement B is false**. These inferences are since provided in **option (b), is the correct answer**.
I-65	A paramagnetic kept in magnetizing field which is increased till magnetization becomes constant. It is the point where all dipoles are magnetized. After reaching this state when temperature is decreased, decrease in thermal energy of the system stabilizes dipole alignment unlike de-alignment of dipoles on increase of temperature. There magnetization remains constant on decrease of temperature, as provided in **option (c) is the answer.**
I-66	Given that ferromagnetic material is placed in magnetic field. But, the statement is silent on three aspects – (a) whether the material is pre-magnetized, (b) if it is magnetized then is until saturation, and (c) orientation of the material in the magnetic field. Each of the aspect is being analyzed - (a) In case material is not pre-magnetized, magnetic dipoles in the material are randomly arranged leading to zero magnetism. Therefore, when it is placed in magnetic field the dipoles would align themselves in the direction of magnetic field, leading to increase in size of magnetic domoain. (b) In case material is pre-magnetized to its saturation point, then placing the material aligned to the direction of magnetic field would not lead to increase in size of the magnetic domain. (c) In case the pre-magnetized material is against the direction of magnetic field initially the size of the magnetic material would decrease and then grow in the direction of magnetic field commensurate to magnetizing field. This illustrations matches with **option (c), is the answer.**

I-67	 This question involves understanding of electromagnetism viz-a-viz Biot-Savart's Law. Magnitude of magnetic field intensity H at a point at a distance $\vec{r}$ from a long current carrying conductor, as per Biot-Savart's Law, is $H = \frac{i}{4\pi r}$…(1), here i is the current through the wire and is the distance of the point P close to the wire, as shown in the figure.  When a long cylindrical iron rod is brought close to the wire such that point P is at the center of the rod, the magnetizing field intensity, as shown in the figure. Iron in a ferromagnetic material and its relative permeability $\mu_r = \frac{\mu}{\mu_0} \gg 1$. Yet, expression (1) is independent of μ_r hence magnetizing field intensity will remain the same, as provided in **option (c), is the answer.**
I-68	Magnetic susceptibility for paramagnetic materials is $0 < \chi < 1$, for ferromagnetic materials $\chi > 1$ but for diamagnetic material $\chi < 1$ i.e. negative. This is provided in **option (b), is the answer.**
I-69	A typical hysteresis loop is shown in the figure. Desirable property of a magnetic material to be used for permanent magnet is retention of magnetization when magnetizing force H is removed and is called retentivity. Moreover, ability of the material to retain magnetization for slight reversal of magnetizing force, for any reason, is called coercivity.  Thus, requirement of a magnetic material to be used for permanent magnets is high retentivity and coercivity as provided in **option (a), is the answer.**
I-70	Typical hysteresis loop of a magnetic material is shown in the figure . Electromagnets are used to create magnetic force as per requirement in use. Thus, it is required to be magnetized and demagnetized as per need, with minimum magnetizing force. This is achieved by placing a ferromagnetic material inside the magnetizing solenoid. Thus, required property of electromagnet can be achieved with materials having low retentivity and low coercive force as provided in **option (d), is the answer.** 
I-71	This question requires understanding of atomic and nuclear physics along with electromagnetism. It is known that electrons are revolving around the nucleus like a circular loop which exhibits magnetic moment **as provided in option (a)**. Further, nuclear forces sets protons and neutrons in a state of vibration. Neutrons being electrically neutral do not constitute electric current and hence its motion does not exhibit any magnetic behavior. But, protons being electrically positive, their vibrations cyclic in nature, exhibit magnetic moment **as provided in option (b).** **Thus answer is option (a) and (b).**
I-72	Permanent magnetic moment of atoms of a material is exhibited by its characteristic parameter susceptibility χ. The susceptibility for paramagnetic materials is $0 < \chi < 1$, for ferromagnetic materials $\chi > 1$ but for diamagnetic material $\chi < 1$ i.e. negative. Thus the materials having permanent magnetic moment zero find classification close to paramagnetic, as provided in **option (d), is the answer.**
I-73	Atoms of diamagnetic materials possess zero permanent magnetic dipole moment. Yet, they get magnetized like electric dipoles under influence of magnetizing field and thus exhibit susceptibility $\chi < 1$ i.e. negative, characteristic to diamagnetic materials, as provided in **option (b) is the answer.**

I-74

Quantities involved in the question with their units and dimensions are as under –

(i) Magnetic Field $[\mathrm{B}] = \mathrm{MI^{-1}T^{-2}}$ and unit is Tesla or Wb-m^{-2}.

(ii) Magnetizing field intensity Field $[\mathrm{H}] = \frac{[\mathrm{B}]}{[\mu_0]} = \frac{\mathrm{MI^{-1}T^{-2}}}{\mathrm{MLI^{-2}T^{-2}}} \Rightarrow [\mathrm{H}] = \mathrm{L^{-1}I}$, and unit is Amp-m^{-1}.

(iii) Intensity of magnetization $[I] = [\chi][\mathrm{H}]$ here χ is susceptibility, a proportionality constant a dimensionless quantity. Hence, $[I] = [\mathrm{H}]$ and its unit is Amp-m^{-1}.

(iv) Longitudinal strain $\left[\frac{\Delta L}{L}\right] = \mathrm{L^0}$ and is unit less.

(v) Susceptibility $[\chi]$ is a dimensionless quantity as elaborated at (iii) above.

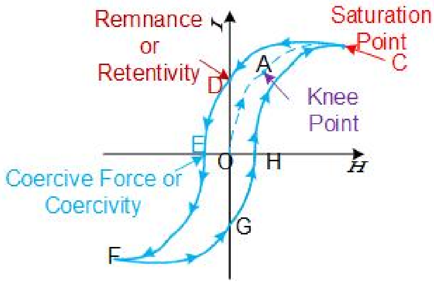
It is seen from the elaborations above that –

- Magnetizing field intensity H and intensity of magnetization I have same dimensions **as provided in option (c).**
- **Both l**ongitudinal strain and magnetic susceptibility being dimensionless quantities, have same dimension **as provided in option (d)**

Thus, **answers is option (c) and (d)**

I-75

Magnetic susceptibility $\chi = \frac{I}{H}$…(1), here I is induced magnetization and H is magnetizing force. A typical hysteresis loop is shown in the figure.



- Accordingly, as per (1) susceptibility is changing at each point of the magnetization curve thus option (a) is correct.
- At point D, since $H = 0$ hence susceptibility is infinity making option (c) correct.
- At point E, since induced magnetization is zero despite $H \neq 0$ hence option (b) is correct.
- At any point of the magnetization curve in III$^{\text{rd}}$ quadrant III magnetizing force H is negative but induced magnetization I is positive hence option (d) is correct.

Thus, **answer is option (a), (b), (c) and (d).**

I-76

It requires elaboration of each of the options and is as under –

Option (a): When a material is placed in magnetizing field either magnetic dipoles are aligned or atoms having zero magnetic dipole moment get induced dipole moment, and their alignment. Thus magnetism occurs in all materials, thus option (a) is correct.

Option (b): Atoms of diamagnetic materials do not have permanent magnetic dipole moment. Hence, **option (b) is incorrect.**

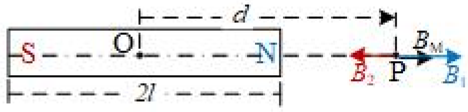
Option (c): Magnetizing field intensity$H$ produced by a long current carrying conductor at a point P is $H = \frac{i}{2\pi r} \Rightarrow H = f(i, r)$ where i is current through the conductor and r is radial distance of point P from the conductor. Thus, permeability of medium μ in which the conductor and the point are placed has no implication on value of H. Hence, **option (c) is incorrect.**

Option (d): Induced dipole moment align in a direction opposite to the magnetizing field. Hence, magnetic field of the induced magnetism is opposite to the applied magnetic field. Thus, **option (d) is correct.**

Thus, **options (a) and (d) are correct.**

I-77

Magnetizing field intensity $H = 1500$A.m^{-1}, at the center of a long solenoid is $H = ni \Rightarrow n = \frac{H}{i}$ where n is the number of turns in a solenoid per unit length and $i = 2.0$ A is the current through the solenoid. Using the given data $n = \frac{1500}{2.0} = 750$ per meter or **7.5 turns per cm is the answer**.

I-78	Magnetizing field intensity $H = 1500$A.m^{-1}, at the center of a long solenoid is $H = ni \Rightarrow n = \frac{H}{i}$ where n is the number of turns in a solenoid per unit length and $i = 2.0$ A is the current through the solenoid. A rod is inserted in the core of the current carrying solenoid. This changes magnetic field in the core to $B = \mu H$. Using the given data – **Part (a):** Magnetizing field intensity $H =$ **1500 A/m is the answer of part (a).** **Part (b):** Magnetic field intensity$I = 0.12$ A/m, such that $I = \chi H \Rightarrow \chi = \frac{I}{H}$. Therefore susceptibility of the material of the rod is $\chi = \frac{0.12}{1500} = \mathbf{8 \times 10^{-5}}$**, is the answer of part (b)**. **Part (c):** Magnetic susceptibility χ is characteristic of a material; for paramagnetic materials is $0 < \chi < 1$, for ferromagnetic materials $\chi > 1$ but for diamagnetic material $\chi < 1$ i.e. negative. Thus based on the value of $\chi = 8 \times 10^{-5}$ determined in part (b) the rod is made of **paramagnetic material, is the answer of part (c).** Thus, **answers are (a) 1500 A/m^{-1}, (b) $\mathbf{8.0 \times 10^{-5}}$ (c) Paramagnetic.**
I-79	Magnetic field strength B inside a solenoid having turns per unit length $n = 50 \times 100 = 5 \times 10^3$ turns/m is $B_1 = 2.5 \times 10^{-3}$ T . When an iron core of cross-sectional area $A = 4 \times 10^{-4}$m2, the magnetic field increases to $B_2 = 2.5$ T. This data is used find required information in each part as under – **Part (a):** Magnetizing field intensity inside a solenoid is $H = ni$…(1), here i is current through the solenoid. While magnetic field strength $B_1 = \mu_0 ni \Rightarrow i = \frac{B_1}{\mu_0 n}$…(2). Thus, with the available data $i = \frac{2.5\times10^{-3}}{(4\pi\times10^{-7})\times(5\times10^{3})} = 0.398$ A or **0.4 A is answer of part (a).** **Part (b):** Intensity of magnetization of the core $I = \frac{B_2}{\mu_0} - H \Rightarrow I = \frac{B_2}{\mu_0} - H$. Using (1) and (2), $I = \frac{B_2}{\mu_0} - \frac{B_1}{\mu_0}$. It leads to $I = \frac{1}{\mu_0}(B_2 - B_1) = \frac{1}{4\pi\times10^{-7}}(2.5 - 2.5 \times 10^{-3}) = \frac{2.5}{4\pi\times10^{-7}}\left(1 - \frac{1}{1000}\right) \Rightarrow I = \frac{2.5}{4\pi\times10^{-7}} \times \frac{999}{1000} = 1.99 \times 10^6$ or say $\mathbf{2.0 \times 10^6}$ **A/m is answer of part (b).** **Part (c):** Magnetic pole strength developed in the iron core is say m. Then for a magnetic material $I = \frac{M}{V}$ …(3), where M is magnetic moment of the iron core such that $M = m \times l$…(4), here l is the length of the iron bar, and $V = A \times l$…(5) here A is the area of cross-section of the iron bar. Combining (3), (4) and (5), $I = \frac{m\times l}{A\times l} \Rightarrow I = \frac{m}{A} \Rightarrow m = IA$. Using the available data $m = (\mathbf{2.0 \times 10^6}) \times (4 \times 10^{-4}) \Rightarrow m = 800$ Am is the answer of part (b). **Thus, answers are (a) 0.4 A (b) $\mathbf{2.0 \times 10^{-6}}$ A/m (c) 800 Am.**
I-80	System in the problem is shown in the figure where given that $2l = 10^{-2}$m and distance of point P is $d = 1.5 \times 10^{-1}$m. Magnetic field at P, end-on position, is $B_M = 1.5 \times 10^{-4}$T. Let m is the pole strength of the magnet. Therefore, $\vec{B}_1 = \frac{\mu_0}{4\pi} \times \frac{m}{(d-l)^2}\hat{x}$ and $\vec{B}_2 = \frac{\mu_0}{4\pi} \times \frac{m}{(d+l)^2}(-\hat{x})$. Therefore, net magnetic field at point P is $\vec{B}_M = \frac{\mu_0}{4\pi} \times \left(\frac{m}{(d-l)^2}\hat{x} - \frac{m}{(d+l)^2}\hat{x}\right) \Rightarrow B_M = \frac{\mu_0 m}{4\pi}\left(\frac{1}{(d-l)^2} - \frac{1}{(d+l)^2}\right) \Rightarrow B_M = \frac{\mu_0 m}{4\pi} \times \frac{4dl}{(d^2-l^2)}$. It leads to $B_M = \frac{\mu_0}{4\pi} \times \frac{2Md}{(d^2-l^2)^2}$…(1), here magnetic moment of the magnet is $M = 2ml$. Thus, $M = \frac{4\pi}{\mu_0} \times B_M \times \frac{(d^2-l^2)^2}{2d}$…(2).  Intensity of magnetization $I = \frac{M}{V}$…(3), here $V = A \times 2l$ volume of the magnet. Hence, $I = \frac{2.5}{(1\times10^{-4})\times(1\times10^{-2})} = \mathbf{2.5 \times 10^6}$**A/m is answer of part (b).** Magnetic field at O center of the magnet is result if the cause i.e. magnetizing force $\mu_0 I$ causing magnetic poles of strength m and effect of magnetic poles at the point $B = \mu_0 H$ since I and H are vectors of the magnetic poles would be $\vec{B} = \mu_0(\vec{H} + \vec{I}) = \mu_0 H + \mu_0 I \Rightarrow B = B'_M + \mu_0 I$…(4). Here, magnetic field at the center of the magnet due to its two poles is $B'_M = 2\left(\frac{\mu_0}{4\pi} \times \frac{m}{l^2}\right) = \frac{\mu_0}{4\pi} \times \frac{M}{l^3}$ …(5). The B'_M is along $(-\hat{x})$ i.e. from north pole to south pole, while the intensity of magnetization I is from south pole to north pole i.e. along $\hat{x}$.

	Further, $2l = 0.01 \Rightarrow l = \frac{0.01}{2}$ m. Using the available data in (5), $B'_M = 10^{-7} \times \frac{2.5}{\left(\frac{0.01}{2}\right)^3} = (2.5 \times 8)10^{-1} =$ 2T. Since, $\frac{\mu_0}{4\pi} = 10^{-7} \Rightarrow \mu_0 = 4\pi \times 10^{-7}$. Thus, using the available data $\vec{B} = -2\hat{x} + (4\pi \times 10^{-7}) \times (2.5 \times 10^6)\hat{x}$. It leads to $B = 3.14 - 2 = 1.14$T say **1.1T is answer of part (c)** Thus, **answers (a) 2.5 A.m^2 (b) $\mathbf{2.5 \times 10^6}$ A/m (c) 1.1 T**
I-81	Given that susceptibility of annealed iron is $\chi = 5500$. And permeability of the material has superimposed effect of the material on the vacuum, since magnetic field, like electric field can exist in vacuum i.e. free space. Therefore, permeability μ od the material is $\mu = \mu_0(1 + \chi)$. Moreover, $\frac{\mu_0}{4\pi} = 10^{-7} \Rightarrow \mu_0 = 4\pi \times 10^{-7}$. Thus using the available data $\mu = (4\pi \times 10^{-7}) \times (1 + 5500) = 5501 \times 4\pi \times 10^{-7} \Rightarrow \mu =$ $\mathbf{6.94\pi \times 10^{-3}}$ **is the answer.**
I-82	Given that magnetic field B=1.6 T and the magnetic intensity $H = 1000$ A.m^{-1}. We know that $B = \mu H \Rightarrow \mu = \frac{B}{H}$...(1). Using the available data $\mu = \frac{1.6}{1000} = 1.6 \times 10^{-3}$. Relative permeability $\mu_r = \frac{\mu}{\mu_0}$...(2). We know that $\frac{\mu_0}{4\pi} = 10^{-7} \Rightarrow \mu_0 = 4\pi \times 10^{-7}$. Thus using the available data $\mu_r = \frac{1.6\times10^{-3}}{4\pi\times10^{-7}} = \mathbf{1.2 \times 10^3}$ **is answer of one part.** Further, $\mu = \mu_0(1 + \chi)$ ...(3). Combining (2) and (3), $\mu_r = 1 + \chi \Rightarrow \chi = \mu_r - 1$. Using the available data, $\chi = 1.2 \times 10^3 - 1 \Rightarrow \chi \approx \mathbf{1.2 \times 10^3}$ **is answer of the other part.**
I-83	Given is susceptibility of magnetism of a material $\chi_1 = 1.2 \times 10^{-5}$ at temperature $T_1 = 300$ K and at some other unknown temperature T_2 the susceptibility is $\chi_2 = 1.8 \times 10^{-5}$. As per Curie's Law $\chi = \frac{C}{T}$ ...(1) , here C is Curie's constant. Using (1), it leads to $\frac{\chi_1}{\chi_2} = \frac{\frac{C}{T_1}}{\frac{C}{T_2}} \Rightarrow \frac{\chi_1}{\chi_2} = \frac{T_2}{T_1} \Rightarrow T_2 = T_1 \times \frac{\chi_1}{\chi_2}$. Using the available data $T_2 = 300 \times \frac{1.2\times10^{-5}}{1.8\times10^{-5}} =$ **200 K is the answer.**
I-84	Given that magnetic moment of each atom of iron is $M' = 2$ Bohr $=2 \times (9.27 \times 10^{-24})$ Am^2. Density of atoms in iron $n = 8.52 \times 10^{28}$ m^{-3}. Therefore, intensity of magnetization in long cylinder of iron $I = \frac{M}{V} = \frac{(nM')\times V}{V} \Rightarrow I = nM' = (8.52 \times 10^{28}) \times \left(2 \times (9.27 \times 10^{-24})\right) \Rightarrow I = \mathbf{1.58 \times 10^6}$ **A/m is the answer of part (a).** Maximum magnetic field that can be achieved when all the atoms are magnetized is $B = \mu_0 H = \mu_0 I$. Since, $\frac{\mu_0}{4\pi} = 10^{-7} \Rightarrow \mu_0 = 4\pi \times 10^{-7}$, using the available data $B = (4\pi \times 10^{-7}) \times (1.58 \times 10^6) = \mathbf{2.0}$ **T is the answer of part (a).**
I-85	Magnetic field inside a solenoid is $B = \mu_0 H$...(1), here magnetizing force $H = ni$...(2), here $n = 40 \times 100 = 4.0 \times 10^3$ turns per meter. Since, $\frac{\mu_0}{4\pi} = 10^{-7} \Rightarrow \mu_0 = 4\pi \times 10^{-7}$....(3) Coercive force H' of the magnet is 4.0×10^4A/m. Therefore, to completely demagnetize the magnet $H' = -H$...(4). Combining (1), (2), (3) and (4), magnitude of current to completely demagnetize the magnet is $ni = H' \Rightarrow i = \frac{H'}{n} = \frac{4.0\times10^4}{4.0\times10^3} =$ **10 A is the answer.**

Important Note: You may encounter need of clarification on contents and analysis or an inadvertent typographical error. We would gratefully welcome your prompt feedback on mail ID: subhashjoshi2107@gmail.com. If not inconvenient, please identify yourself to help us reciprocate you suitably.