37. Magnetic Properties of Matter

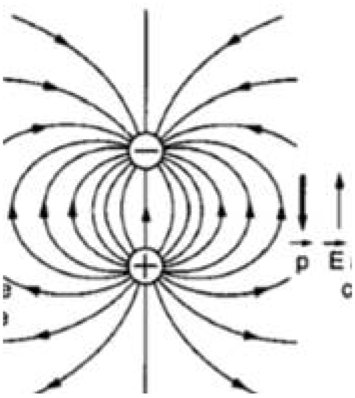
Short Answer

1. Question

When a dielectric is placed in an electric filed, it gets polarized. The electric field in a polarized material is less than the applied field. When a paramagnetic substance is kept in a magnetic field, the field in the substance is more than the applied field. Explain the reason of this opposite behavior.

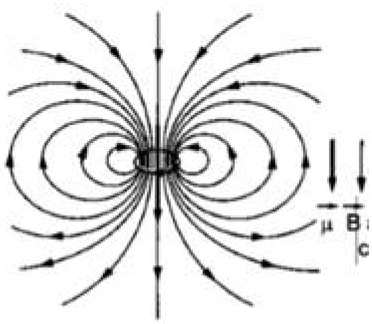
Answer

The electric field at the centre of an electric dipole is opposite to the dipole moment as shown in fig.



Therefore, the electric field in a polarized material is less than the applied field as all the electric dipoles get arranged in opposite direction of applied field.

Whereas in case of magnetic field the magnetic field at the centre of dipole is in the direction of magnetic moment as shown in fig.



Thus, when an external magnetic field is applied the dipoles in the domain grow in their direction.

This produces an extra magnetic field in the material in the direction of applied field as all the magnetic domains are arranged in one direction and the resultant intensity of magnetic field increases.

2. Question

The property of diamagnetism is said to be present in all materials. Then, why are some materials paramagnetic or ferromagnetic?

Answer

Whenever a magnetic field is applied in any material magnetic moments are induced. Diamagnetism is the property in which the resultant magnetic field is less than the applied field as the magnetic fields due to induced dipole moments opposes the original field.

Therefore, property of diamagnetism is exhibited by all materials. However in some cases the magnetic field is able to align dipoles in its direction. This results in differentiation of some materials into para and ferro-magnetic.

When the resultant magnetic field in the material is greater than the applied field then the material is paramagnetic.

Whereas some materials have a strong tendency to align themselves even without any external field such materials are ferro-magnetic.

3. Question

Do permeability and relative permeability have the same dimensions?

Answer

Magnetic permeability is given by the formula

$$\mu = \frac{B}{H}$$

Where

B=magnetic field

H=magnetization intensity

SI Unit of magnetic field B is N/Am

Its dimensional formula is $[MA^{-1}T^{-2}]$

SI unit of magnetization intensity is A/m

Its dimensional formula is $[AL^{-1}]$

Therefore, dimensional formula of permeability μ $=\frac{[MA^{-1}T^{-2}]}{[AL^{-1}]} = [MLA^{-2}T^{-2}]$

Whereas relative permeability is given as the ratio of magnetic permeabilty of any medium to the permeability of the vacuum

$$\mu_r = \frac{\mu}{\mu_0}$$

Where μ_0=absolute permeability of vacuum

So relative permeability is a dimensionless quantity

Therefore, relative permeability is dimensionless quantity a permeability have different dimensions

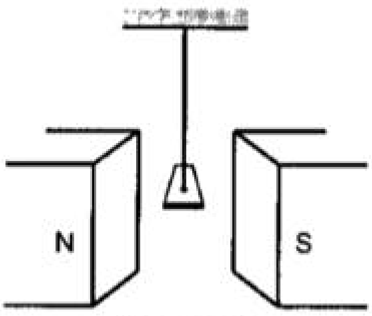
4. Question

A rod when suspended in a magnetic field stays in east-west direction. Can we be sure that the field is in the east-west direction? Can it be in the north-south direction?

Answer

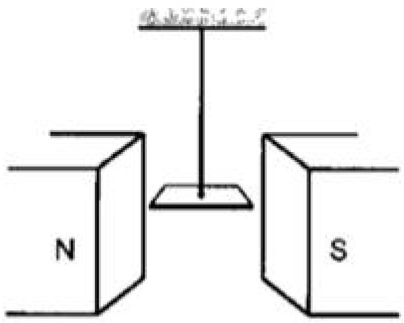
No, we can't be sure that the magnetic field is in east-west direction and it depends on the material of rod whether it is paramagnetic, ferromagnetic or diamagnetic.

Diamagnetic substances get repelled by a magnetic field therefore if the rod is diamagnetic then it becomes perpendicular to the applied field. Therefore, In this case applied field is in north-south direction



diamagnetic

Whereas if the rod is para or ferro magnetic then the rod becomes parallel to the applied field as paramagnetic and ferromagnetic substances get attracted to a magnetic field. Therefore, in this case the magnetic field is in east-west direction.



paramagnetic or ferromagnetic

Therefore, we can't be sure whether the magnetic field is in north-south or east-west direction

5. Question

Why cannot we make permanent magnets from paramagnetic materials?

Answer

for making a permanent magnet after magnetizing the material the magnetization should remain should retain to a large extent even when the magnetic field is removed(retentivity should be large)

Also the magnetization should not be easily destroyed even if the material is exposed to stray magnetic fields(coercive force should be large)

Paramagnetic materials do not retain their magnetization unlike ferromagnetic materials. When they are placed in external magnetic field after getting magnetized, they lose their magnetization easily and hence have low retentivity.

Therefore, paramagnetic materials are not used in making permanent magnets.

6. Question

Can we have magnetic hysteresis in paramagnetic or diamagnetic substances?

Answer

In ferromagnetic materials when magnetic field intensity H is increased and then decreased to its original value the magnetization I does not return to its original value. This phenomenon is known as hysteresis.

Unlike ferromagnetic materials paramagnetic and diamagnetic materials have no residual magnetization after the external magnetic field is removed. And hence they have very less retentivity.

Also, loss of dissipation of energy is more in case of para and diamagnetic materials.

Therefore, paramagnetic and diamagnetic materials do not form hysteresis loops.

7. Question

When a ferromagnetic material goes through a hysteresis loop, its thermal energy is increased. Where does this energy come from?

Answer

When a ferromagnetic material goes through a hysteresis loop, when the magnetization force is applied, the molecules of the magnetic material are aligned in one particular direction, and when this magnetic force is reversed in the opposite direction, work is done to wipe out the residual magnetism. This work done by the magnetizing force produces heat; this wastage of energy in form of heat or thermal energy is known as hysteresis loss.

8. Question

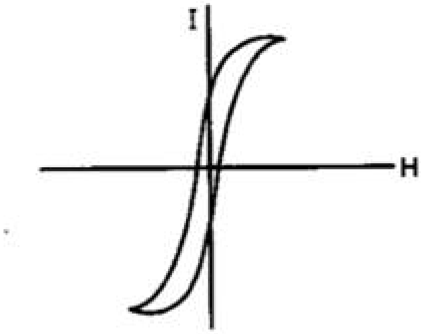
What are the advantages of using soft iron as a core, instead of steel, in the coils of galvanometers?

Answer

The retentivity and coercive force are smaller for soft iron.

Soft iron is easily magnetized by the magnetic field but only a small magnetization is retained when the field is removed.

The hysteresis loop for soft iron is as shown



Soft iron

The area of hysteresis loop is proportional to thermal energy developed per unit volume. Since soft iron has small area the thermal energy developed is low which is beneficial for using it as a core in the coils for galvanometer.

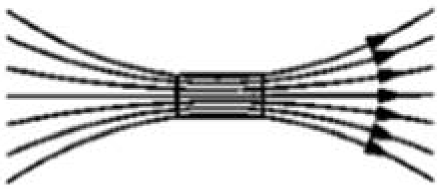
Therefore, due to low retentivity and low hysteresis loss, soft iron is used as a core in galvanometer.

9. Question

To keep valuable instruments away from the earth's magnetic field, they are enclosed in iron boxes. Explain.

Answer

Iron is a ferromagnetic material and therefore has high value of magnetic permeability (μ) A ferromagnetic substance is strongly attracted by a magnet therefore all the lines of earth magnetic field pass through the surface of iron box and no flux pass through the valuable instrument.



Ferromagnetic

Thus, the magnetic field inside the box becomes zero and there is no harm to the instrument.

Therefore, due to ferromagnetic nature of iron it is used to protect valuable instruments.

Objective I

1. Question

A paramagnetic material is placed in a magnetic field. Consider the following statements:

(A) If the magnetic field is increased, the magnetization is increased.

(B) If the temperature is increased, the magnetization is increased.

A. Both A and B are true

B. A is truer but B is false

C. B is true but A is false

D. Both A and B are false

Answer

When a paramagnetic material is placed in a magnetic field its atomic dipoles align in a direction parallel to applied magnetic field and the material produces an extra magnetic field in the direction of applied electric field

On increasing the magnetic field the magnetic moment increases in the same direction.

Magnetization or intensity of magnetization is given by formula

$$\vec{I} = \frac{\vec{M}}{V}$$

Where

M=magnetic moment

V=volume

So, on increasing the magnetic moment magnetization increases

Curies law states that susceptibility of a paramagnetic substance is inversely proportional to its absolute temperature

$$\chi = \frac{c}{T}$$

Where

C =constant called curie constant

T=temperature

Also magnetization is given by

$$\vec{I} = \chi\vec{H}$$

Where χ =susceptibility

H=magnetic intensity

Therefore, on increasing temperature, susceptibility decreases, magnetization increases

Therefore, when a paramagnetic material is placed in a magnetic field, on increasing magnetic field, magnetization increases and on increasing temperature, magnetization decreases

2. Question

A paramagnetic material is kept in a magnetic field. The field is increased till the magnetization becomes constant. If the temperature is now decreased, the magnetization.

A. will increase

B. decrease

C. remain constant

D. may increase or decrease

Answer

We know that

Curies law states that susceptibility of a paramagnetic substance is inversely proportional to its absolute temperature

$$\chi = \frac{c}{T}$$

Where

C =constant called curie constant

T=temperature

This law holds only when material is far away from saturation(i.e. magnetization has not become constant)

According to question saturation has been achieved and curie's law doesn't hold true now (i.e. χ does not changes with temperature)

Also magnetization is given by

$$\vec{I} = \chi\vec{H}$$

Where

χ =susceptibility

H=magnetic intensity

Since χ and $\vec{H}$ remains constant therefore magnetization will also remain constant

Therefore, when a paramagnetic material is placed in a magnetic field and saturation is achieved on decreasing the temperature magnetization remains constant

3. Question

A ferromagnetic material is placed in an external magnetic field. The magnetic domains

A. increase in size

B. decease is size

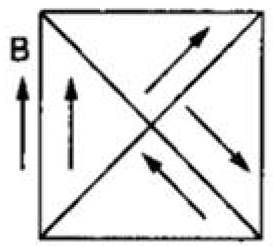
C. may increase or decrease in size

D. have no relation with the field.

Answer

When a ferromagnetic material is placed in absence of any field different domains have different directions of magnetic moment and hence the material remains unmagnetized.

When a magnetic field is applied the domains towards the direction of magnetic field increases in size whereas domains opposite to the direction of magnetic field decreases in size. This happens because walls of the domain move across the sample.



Domain-alignment

Therefore when a ferromagnetic material is placed in an external magnetic field the magnetic domains may increase or decrease in size

4. Question

A long, straight wire carries a current i. The magnetizing field intensity H is measured at a point P close to the wire. A long, cylindrical iron rod is brought close to the wire so that the point P is at the centre of the rod. The value of H and P will

A. increase many times

B. decrease many times

C. remain almost constant

D. become zero

Answer

When there is no iron rod the magnetic field at point P close to the wire is given by

$$B = \frac{\mu_0 I}{2\pi r}$$

The magnetic intensity H is then given by

$$H = \frac{B}{\mu_0} = \frac{i}{2\pi r}$$

Where

i=current through the wire

r=distance of point from the wire

Now as the wire and the iron rod are long and we are interested in magnetic intensity at the point P which is at centre of rod, the end effects of a magnetized material are neglected and the magnetic intensity due to magnetization is zero.

There is no effect of rod in magnetic intensity at the centre. The magnetic intensity in a material is then determined by external sources only. Its value in both the cases remains almost constant.

Therefore, value of magnetic intensity(H) at P remains constant.

5. Question

The magnetic susceptibility is negative for

A. paramagnetic materials only

B. diamagnetic materials only

C. ferromagnetic materials only

D. paramagnetic and ferromagnetic materials

Answer

For paramagnetic and diamagnetic materials the intensity of magnetization I of a material is directly proportional to the magnetic intensity H

$\vec{I} = \chi\vec{H}$ ..(i)

This proportionality constant χ is known as susceptibility of a material.

Now in a diamagnetic material the individual atoms of the material do not have a net magnetic dipole moment. When such a substance is placed in a magnetic field, dipole moments are induced by the applied field. From lenz's law the magnetic fields due to induced magnetic moment opposes the original field

The magnetization $(\vec{I})$ and magnetic intensity $(\vec{H})$ are therefore in opposite direction and χ of a diamagnetic material is therefore negative.

Therefore, susceptibility of a material is negative only for diamagnetic materials

6. Question

The desirable properties for making permanent magnets are

A. high retentivity and high coercive force

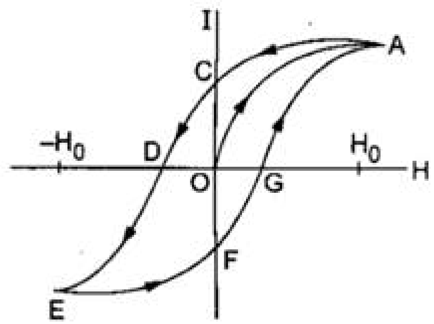
B. high retentivity and low coercive force

C. low retentivity and high coercive force

D. low retentivity and low coercive force

Answer

In a hysteresis loop the retentivity and coercive force ae defined as follows:



Retentivity: the remaining value of magnetization when magnetic intensity is made zero depicted by length OC is known as retentivity of material

Coercive force: the value of magnetic intensity (H) needed to make magnetization zero is known as zero depicted by length OD is known as coercive force .

Now, for making a permanent magnet after magnetizing the material the magnetization should remain should retain to a large extent even when the magnetic field is removed (retentivity should be large)

Also, the magnetization should not be easily destroyed even if the material is exposed to stray magnetic fields (coercive force should be large)

Therefore, desirable properties for making a permanent magnets are high retentivity and high coercive force.

7. Question

Electromagnets are made of soft iron because soft iron has

A. high retentivity and high coercive force

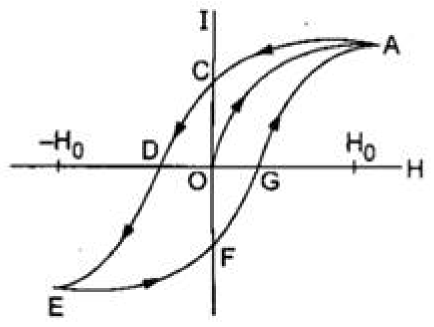
B. high retentivity and low coercive force

C. low retentivity and high coercive force

D. low retentivity and low coercive force

Answer

In a hysteresis loop the retentivity and coercive force ae defined as follows:



Retentivity : the remaining value of magnetization when magnetic intensity is made zero depicted by length OC is known as retentivity of material

Coercive force: the value of magnetic intensity (H) needed to make magnetization zero is known as zero depicted by length OD is known as coercive force .

Soft iron is easily magnetized by a magnetic field but only a small magnetization is retained when the field is removed and hence has low retentivity and low coercive force.

These properties are desired by electromagnets.

Therefore, electromagnets are made of soft iron because of low retentivity and low coercive force

Objective II

1. Question

Pick the correct options.

A. All electrons have magnetic moment

B. All protons have magnetic moment

C. All nuclei have magnetic moment

D. All atoms have magnetic moment

Answer

Any isolated charge which is in motion or in rest have a magnetic moment

Electrons and protons have magnetic moment because they are charged particles and have a magnetic moment even at rest due to their spin angular momentum.

(C) and (d) options are incorrect because atoms and nuclei have multiple number of charge particles and hence magnetic moments in different directions. The net magnetic moment of an atom or a nuclei may become equal to zero due to cancellation of magnetic moments.

Therefore, all electrons and protons have magnetic moments whereas all atoms and nuclei do not.

2. Question

The permanent magnetic moment of the atoms of a material is not zero. The material

A. must be paramagnetic

B. must be diamagnetic

C. must be ferromagnetic

D. may by paramagnetic.

Answer

The individual atoms of a material have a net magnetic dipole moment in paramagnetic and ferromagnetic materials whereas net magnetic dipole moment is zero in diamagnetic materials.

Since according to question net magnetic dipole moment is not zero.

Therefore, material is either paramagnetic or ferromagnetic.

It is not necessary that material must be ferromagnetic or paramagnetic.

Therefore, if permanent magnetic moment of the atoms of a material is not zero, Then material may be paramagnetic

3. Question

The permanent magnetic moment of the atoms of a material is zero. The material

A. must be paramagnetic

B. must be diamagnetic

C. must be ferromagnetic

D. may by paramagnetic.

Answer

The individual atoms of a material have a net magnetic dipole moment in paramagnetic and ferromagnetic materials whereas net magnetic dipole moment is zero in diamagnetic materials.

Since, according to question, permanent magnetic moment of the material is zero, it must be a diamagnetic material.

Therefore, if permanent magnetic moment of the atoms of a material is zero, then the material must be diamagnetic.

4. Question

Which of the following pairs has quantities of the same dimensions?

A. Magnetic field B and magnetizing field intensity H

B. Magnetic field B and intensity of magnetization I

C. Magnetizing field intensity H and intensity of magnetization I

D. Longitudinal strain and magnetic susceptibility.

Answer

The magnetic field B, magnetizing field intensity H and intensity of magnetization I are related by the formula

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{I}$$

Here μ_0 is the absolute permeability of vacuum having dimensional formula

$$[MLT^{-2}I^{-2}]$$

We know that,

Same dimension substance are added and subtracted to give same dimensions. So that dimensions of magnetic field intensity H and intensity of magnetization I are same. Therefore option(c) is correct.

Since H and I are of same dimensions and H and B are of different dimensions, therefore dimensions of B and I are not same. therefore option(b) is incorrect.

Magnetic susceptibility$(\chi)$is given by formula

$$\chi = \frac{\vec{I}}{\vec{H}}$$

Where,

I=magnetization

H=magnetic intensity

Since dimensions of I and H are same so, χ is a dimensionless quantity.

Similarly, longitudinal strain is given by formula

$$strain = \frac{\Delta l}{l}$$

Where,

Δl=change in length

l= length

hence, strain is also a dimensionless quantity

therefore option(d) is correct.

Therefore, H and I have same dimension and strain and susceptibility have same dimensions.

5. Question

When a ferromagnetic material goes through a hysteresis loop, the magnetic susceptibility

A. has a fixed value

B. may be zero

C. may be infinity

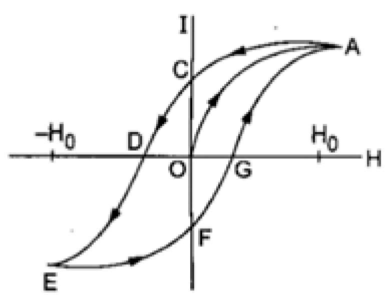
D. may be negative

Answer

Magnetic susceptibility (χ) is given by formula

$\chi = \frac{I}{H}$ ..(i)

When a ferromagnetic material goes through a hysteresis loop



At point C:

Magnetic intensity H becomes 0 whereas magnetization I is finite.

From(i) we get $\chi = \infty$

At point G:

Magnetization I, becomes 0 whereas H is finite

From(i) we get $\chi = 0$

In the second quadrant H is negative whereas I is positive therefore χ

Becomes negative here

Therefore, when a ferromagnetic material goes through hysteresis loop the magnetic susceptibility may be zero, may be negative and may be infinity.

6. Question

Mark out the correct options.

A. Diamagnetism occurs in all materials.

B. Diamagnetism results from the partial alignment of permanent magnetic moment.

C. The magnetizing field intensity H is always zero in free space.

D. The magnetic field of induced magnetic moment is opposite to the applied field.

Answer

Option(a) is correct because

Magnetic moments are induced in all materials when a magnetic field is applied. Diamagnetism is a property which states that resultant field in such materials are smaller than the applied field.

Therefore, diamagnetism is exhibited by all materials.

Option(b) is incorrect as diamagnetism results from induction of dipole moments in the atoms in presence of applied field and not due to partial alignment of permanent magnetic moment.

Option(c) is incorrect because the magnetizing field intensity is given by formula

$$\vec{H} = \frac{\vec{B}}{\mu_0} - I$$

In free space (vacuum) also magnetic field exists and μ_0 is given by

$4\pi \times 10^{-7}$henry per meter

Option(d) is correct because of lenz's law magnetic field of induced magnetic moment is always opposite to the applied field.

Lenz's Law:

Direction of current induced in a conductor by a changing magnetic field is such that the magnetic field created by the induced current opposes the initial changing magnetic field.

Therefore, the magnetic field of induced magnetic moment is opposite to the applied field.

Thus, option (a) and (d) are correct option.

Exercises

1. Question

The magnetic intensity H at the centre of a long solenoid carrying a current of 2.0 A, is found to be 1500 A m^{-1}. Find the number of turns per centimeter of the solenoid.

Answer

Given:

Current in the solenoid I=2A

Magnetic intensity H at the centre =1500Am^{-1}

We know that ,

Magnetic field produced by solenoid at the centre (B) is given by

$\vec{B} = \mu_0 nI$ (i)

Where,

n=no. of turns per unit length

I=current in the solenoid

μ_0=absolute permeability of vacuum

also magnetizing field intensity (H) in the absence of any material is given by

$$\vec{H} = \frac{\vec{B}}{\mu_0}$$

Where

B=net magnetic field

Putting the value of eqn.(i)

$$\vec{H} = \frac{\mu_0 nI}{\mu_0} = nI$$

Putting the values of H and I we get

$1500Am^{-1} = n \times 2$

$n = 750$ turns/m

$n = 7.5$ turns/cm

Therefore no. of turns per cm of the solenoid is 7.5 turn/cm

2. Question

A rod is inserted as the core in the current-carrying solenoid of the previous problem.

(a) What is the magnetic intensity H at the centre?

(b) If the magnetization I of the core is found to be 0.12 A m^{-1}, find the susceptibility of the material of the rod.

(c) Is the material paramagnetic, diamagnetic or ferromagnetic?

Answer

Given:

Magnetization field intensity $H=1500Am^{-1}$

Magnetization of the core $I=0.12Am^{-1}$

If a rod is inserted in the core of current carrying solenoid then

As the solenoid and the rod are long and we are interested in magnetic intensity at the centre, the end effects may be neglected. There is no effect of rod on magnetic intensity at the centre. Therefore, value of magnetization intensity remains same.

$$H = 1500Am^{-1}$$

Therefore, magnetic intensity H at the centre is $1500Am^{-1}$

The magnetization I is given by formula

$$\vec{I} = \chi\vec{H}$$

Where,

χ =susceptibility of the material

H=magnetization intensity

Putting the value of I and H we get

$$0.12Am^{-1} = \chi \times 1500Am^{-1}$$

$$\chi = \frac{0.12}{1500} = 8 \times 10^{-5}$$

Therefore, susceptibility of material of rod is given by 8×10^{-5}

Since $\chi = 8 \times 10^{-5} = +ve$ and less than 1 the material is paramagnetic.

Therefore, the material is paramagnetic.

3. Question

The magnetic field inside a long solenoid having 50 turns cm^{-1} is increased from 2.5×10^{-3} T to 2.5 T when an iron core of cross-sectional area 4 cm^2 is inserted into it. Find

(a) the current in the solenoid,

(b) the magnetization I of the core and

(c) the pole strength developed in the core.

Answer

Given:

No. of turns/cm=50

Magnetic field inside without iron core=2.5×10^{-3}T

Magnetic field inside solenoid with iron core=2.5T

Cross-sectional area of solenoid=$4cm^2$

We know that magnetic field(B) inside the solenoid without iron core is given by

$B = \mu_0 nI$

Where,

n=no. of turns in a given length

I=current through solenoid

Putting the values of B, I and μ_0

$$I = \frac{B}{\mu_0 n} = 2.5 \times \frac{10^{-3}}{4\pi \times 10^{-7} \times 5000}$$

$I = 0.4A$

Therefore, current through the solenoid is given by 0.4A

Magnetization I of the core is given by formula

$$I = \frac{B}{\mu_0} - H$$

Where H=magnetization intensity

$\Rightarrow B = \mu_0(H + I)$

Let the magnetic field with iron core and without iron is given by B_2 and B_1 respectively.

Then,

$$B_2 = \mu_0(H + I)$$

$$B_2 = B_1 + \mu_0 I$$

$$\Rightarrow I = \frac{B_2 - B_1}{\mu_0}$$

Putting the values of B_1,B_2 and μ

$$I = \frac{2.5 - 2.5 \times 10^{-3}}{4\pi \times 10^{-7}} \text{Am}^{-1}$$

$$I = 2 \times 10^6 Am^{-1}$$

Therefore, the magnetization in the core is 2×10^6A/m

Intensity of magnetization is given by the formula

$$I = \frac{M}{V}$$

Where,

M=magnetic moment given by the formula

$M = 2ml$ ...(i)

Where,

m=magnetic pole strength

l=length between two poles

also volume inside solenoid is given by

$V = A \times 2l$ ..(ii)

Using eqns.(i) and (ii) we get

$$I = \frac{M}{V} = \frac{2ml}{2Al} = \frac{2m}{2A} = \frac{m}{A}$$

Putting the values of I and A

$$m = IA$$

$$m = 2 \times 10^6 \times 4 \times 10^{-4} \text{A-m}$$

$$m = 800 \text{A-m}$$

Therefore, magnetic pole strength developed inside the core is given by 800A-m

4. Question

A bar magnet of length 1 cm and cross-sectional area 1.0 cm^2 produces a magnetic field of 1.5×10^{-4} T at a point in end-on position at a distance 15 cm away from the centre.

(a) Find the magnetic moment M of the magnet.

(b) Find the magnetization I of the magnet.

(c) Find the magnetic field B at the centre of the magnet.

Answer

Given:

Length of bar magnet=1cm=10^{-2}m

Cross section area of magnet=1.0cm^2 =$10^{-4}m^2$

Magnetic field at a point in end on position =1.5× 10^{-4}T

Distance of point from centre=15cm=15× 10^{-2}m

We need to find the magnetic field at a point in the axis of magnet

Which is given by

$$\vec{B} = \frac{\mu_0}{4\pi} \times \frac{2Md}{(d^2 - l^2)^2}$$

Where

M=magnetic moment of the magnet

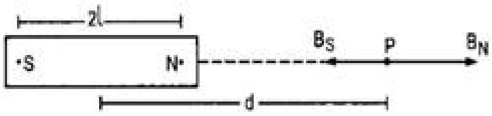
d=distance of point from centre of magnet

l=half the length of magnet

Proof:

Suppose SN is magnet of length 2l and pole strength m

We need to find the magnetic field at a point P which lies on the axis of magnet at a distance d from the centre.



The magnetic field at P due to north pole of the magnet B_N

$$B_N = \frac{\mu_0}{4\pi} \times \frac{m}{(d-l)^2}$$

And it is in rightward direction

Similarly magnetic field at P due to south pole of magnet is given by

$$B_S = \frac{\mu_0}{4\pi} \times \frac{m}{(d+l)^2}$$

Which is in leftward direction(-ve)

The net magnetic field is then given by

$$B = B_N - B_S$$

$$B = \frac{\mu_0}{4\pi} \times \left(\frac{m}{(d-l)^2} - \frac{m}{(d+l)^2}\right)$$

$$B = \frac{\mu_0 m}{4\pi} \times \left(\frac{1}{(d-l)^2} - \frac{1}{(d+l)^2}\right)$$

$$B = \frac{\mu_0 2m}{4\pi} \times \frac{2ld}{d^2 - l^2}$$

Now magnetic moment of magnet is given by

$M = 2ml$.....(i)

Where

m=pole strength

l=length of magnet

using eqn.(i) we get

$$B = \frac{\mu_0}{4\pi} \times \frac{2Md}{(d^2 - l^2)^2}$$

Putting the values of l ,d, B and μ_0 we get

$$1.5 \times 10^{-4} = (10^{-7}) \times 2 \times M \times 15 \times \frac{10^{-2}}{(0.15^2) - (0.005)^2}$$

Solving the equation we get

$M = 2.5Am^2$

Therefore magnetic moment M of the magnet is 2.5Am^2

Intensity of magnetization(I) is given by formula

$$I = \frac{M}{V}$$

Volume of bar magnet =

$V = A \times l$

Where

A=cross-section area of magnet

l=length of bar magnet

hence we get

$$I = \frac{M}{A \times l}$$

Putting the values of M, A and l

We get

$$I = \frac{2.5}{10^{-4} \times 10^{-2}}$$

$$I = 2.5 \times 10^{6}\ Am^{-1}$$

Therefore magnetization intensity is 2.5×10^{6}A/m

we know that magnetic field at a point P due to a magnetic charge m at a distance d from it is given by

$$B = \frac{\mu_0}{4\pi} \times \frac{m}{d^2}$$

Using eqn.(i) we get

$$B = \frac{\mu_0}{4\pi} \times \frac{M}{ld^2} \text{....(ii)}$$

Also magnetizing intensity H is given by formula

$$H = \frac{B}{\mu_0}$$

Using eqn.(ii) we get

$$H = \frac{M}{4\pi l d^2}$$

The total magnetic field intensity at the centre of magnet due to magnet is equal to sum of magnetic field intensities due to north pole(H_N) and south pole (H_S)

$$\therefore H = H_N + H_S$$

Magnetic field intensity due to north and south pole are equal in magnitude (by symmetry)

$\therefore$

$$H = \frac{M}{4\pi l d^2} + \frac{M}{4\pi l d^2} = \frac{M}{2\pi l d^2}$$

Putting the values of M,d and l

We get

$$H = \frac{2.5}{2 \times 3.14 \times 0.01 \times (0.15)^2}$$

$$H = 2 \times 884.6\ Am^{-1}$$

Now net magnetic at the centre B is given by

$$B = \mu_0(H + I)$$

Where

μ_0=permeability of the free space

H=magnetic field intensity

I=intensity of magnetization

Putting the value of H and I we get

$$B = 4\pi \times 10^{-7} \times (884.6 \times 2 + 2.5 \times 10^6)$$

$$B = 3.14\ T$$

Therefore, magnetic field B at the centre of the magnet is 3.14T

5. Question

The susceptibility of annealed iron at saturation is 5500. Find the permeability of annealed iron at saturation.

Answer

Given:

Susceptibility of iron at saturation=5500=χ

We know that permeability (μ) is related to susceptibility (χ)

By the given formula

$$\mu = \mu_0(1 + \chi)$$

Where,

μ_0=absolute permeability of vacuum=$4\pi \times 10^{-7}$ henry/metre

Putting the values of μ_0 and χ in the above equation

$\mu = 4\pi \times 10^{-7}(1 + 5500)$

$\mu = 4\pi \times 10^{-7} \times 5501$ henry/m

$\mu = 6.9 \times 10^{-3}\, Henry/m$

6. Question

The magnetic field B and the magnetic intensity H in a material are found to be 1.6 T and 1000 A m^{-1} respectively. Calculate the relative permeability μ_r and the susceptibility χ of the material.

Answer

Given:

Magnetic field in the material=1.6T

Magnetic intensity H=1000Am^{-1}

The relation between permeability , magnetic field B and magnetizing intensity H are given by formula

$\mu = \frac{B}{H}$ ...(i)

The relation between permeability and relative permeability is given by

$\mu_r = \frac{\mu}{\mu_0}$......(ii)

Using eqns. (i) and putting in eqn.(ii) we get

$$\mu_r = \frac{B}{H\mu_0}$$

Putting the values of B,H and μ_0 we get

$$\mu_r = \frac{1.6}{1000 \times 4\pi \times 10^{-7}}$$

$\mu_r = 1.3 \times 10^3$

Therefore, relative permeability is 1.3×10^3

the relation between susceptibility (χ) and relative permeability (μ_r) is given by

$\mu_r = 1 + \chi$

$\chi = \mu_r - 1$

Putting the value of μ_r we get

$\chi = 1.3 \times 10^3 - 1$

$\chi = 1300 - 1 = 1299$

$\chi \sim 1.3 \times 10^3$

Therefore, susceptibility of material is also approximately equal to 1.3×10^3

7. Question

The susceptibility of magnesium at 300 K is 1.2×10^{-5}. At what temperature will the susceptibility increase to 1.8×10^{-5}?

Answer

Given:

Temperature T_1=300K

Temperature T_2=?

Susceptibility at temperature $T_1 \chi_1 = 1.2 \times 10^{-5}$

Susceptibility at temperature T_2, $\chi_2 = 1.8 \times 10^{-5}$

We know that

According to Curie's law at far away from saturation susceptibility χ of paramagnetic material is inversely proportional to temperature (T)

$$\chi = \frac{C}{T}$$

Where,

C=curie's constant

T=temperature

We can say that

$$\frac{\chi_1}{\chi_2} = \frac{T_2}{T_1}$$

Putting the values of χ_1, χ_2 and T_1 we get

$$\frac{1{,}2 \times 10^{-5}}{1.8 \times 10^{-5}} = \frac{T_2}{300}$$

$$T_2 = \frac{1.2}{1.8} \times 300 = 200K$$

Therefore, susceptibility will increase to at temperature 200K

8. Question

Assume that each iron atom has a permanent magnetic moment equal to 2 Bohr magnetons (1 Bohr magneton equals 9.27×10^{-24} A m^2). The density of atoms in iron is 8.52×10^{28} atoms m^{-3}. (a) Find the maximum magnetization I in a long cylinder of iron.

(b) Find the maximum magnetic field B on the axis inside the cylinder.

Answer

Given:

Density of atoms in iron=8.52×10^{28} atoms m^{-3}

Permanent magnetic moment (M) of each atom =$2\times 9.27\times 10^{-24} Am^{-2}$

Intensity of magnetization(I) is given by the formula

$I = \frac{M}{V}$...(i)

Where

M=magnetic moment

V=volume

Considering volume to be $1m^3$

No. of atoms in this volume =8.52×10^{28}

Therefore, total magnetic moment=$8.52\times 10^{28}\times 2\times9.27\times 10^{-24} Am^{-2}$

$M = 1.58 \times 10^{6}\ Am^{2}$

Using eqn.(i) we get

$$I = \frac{M}{V} = \frac{1.58 \times 10^{6}}{1} = 1.58 \times 10^{-6} Am^{-1}$$

Therefore, maximum magnetization is $1.58\times 10^{-6} Am^{-1}$

The net magnetic field is given by formula

$B = \mu_0(I + H)$

Where

I=magnetization intensity

H=magnetic field intensity

We need to find the maximum magnetic field on the axis of cylinder.

Magnetizing field intensity (H) in this case =0

Therefore

$B = \mu_0 I$

Putting the values of I and μ we get

$B = 4\pi \times 10^{-7} \times 1.58 \times 10^{-6}$

$B = 19.8 \times 10^{-1} = 1.98 \sim 2.0T$

maximum magnetic field B on the axis inside the cylinder is 2T

9. Question

The coercive force for a certain permanent magnet is 4.0×10^4 A m^{-1}. This magnet is placed inside a long solenoid of 40 turns/cm and a current is passed in the solenoid to demagnetize it completely. Find the current.

Answer

Given:

Coercive force for magnet $=4.0\times 10^4 Am^{-1}$

No. of turns per cm inside solenoid=40

No. of turns per m inside the solenoid =4000 turns/m

We know that,

Coercive force is defined by

Coercive force: the value of magnetic intensity (H) needed to make magnetization(I) zero is known as coercive force .

Therefore, magnetic intensity $H=4.0\times 10^4 Am^{-1}$

Magnetic field produced by solenoid at the centre (B) is given by

$\vec{B} = \mu_0 n I$...(i)

Where,

n=no. of turns per unit length

I=current in the solenoid

μ_0=absolute permeability of vacuum

also magnetizing field intensity (H) in the absence of any material is given by

$$\vec{H} = \frac{\vec{B}}{\mu_0}$$

Where

B=net magnetic field

Putting the value of eqn.(i)

$$\vec{H} = \frac{\mu_0 n I}{\mu_0} = nI$$

Putting the values of n and H

$$I = \frac{\vec{H}}{n} = 4.0 \times \frac{10^4}{4000}$$

$$I = 10A$$

Therefore, current is given by 10A