



Question 5.1:

Answer the following questions regarding earth's magnetism:

- (a)** A vector needs three quantities for its specification. Name the three independent quantities conventionally used to specify the earth's magnetic field.
- (b)** The angle of dip at a location in southern India is about 18° .
Would you expect a greater or smaller dip angle in Britain?
- (c)** If you made a map of magnetic field lines at Melbourne in Australia, would the lines seem to go into the ground or come out of the ground?
- (d)** In which direction would a compass free to move in the vertical plane point to, if located right on the geomagnetic north or south pole?
- (e)** The earth's field, it is claimed, roughly approximates the field due to a dipole of magnetic moment $8 \times 10^{22} \text{ J T}^{-1}$ located at its centre. Check the order of magnitude of this number in some way.
- (f)** Geologists claim that besides the main magnetic N-S poles, there are several local poles on the earth's surface oriented in different directions. How is such a thing possible at all?

Answer

- (a)** The three independent quantities conventionally used for specifying earth's magnetic field are:
 - (i) Magnetic declination,
 - (ii) Angle of dip, and
 - (iii) Horizontal component of earth's magnetic field
- (b)** The angle of dip at a point depends on how far the point is located with respect to the North Pole or the South Pole. The angle of dip would be greater in Britain (it is about 70°) than in southern India because the location of Britain on the globe is closer to the magnetic North Pole.
- (c)** It is hypothetically considered that a huge bar magnet is dipped inside earth with its north pole near the geographic South Pole and its south pole near the geographic North Pole.
Magnetic field lines emanate from a magnetic north pole and terminate at a magnetic south pole. Hence, in a map depicting earth's magnetic field lines, the field lines at Melbourne, Australia would seem to come out of the ground.

(d) If a compass is located on the geomagnetic North Pole or South Pole, then the compass will be free to move in the horizontal plane while earth's field is exactly vertical to the magnetic poles. In such a case, the compass can point in any direction.

(e) Magnetic moment, $M = 8 \times 10^{22} \text{ J T}^{-1}$

Radius of earth, $r = 6.4 \times 10^6 \text{ m}$

Magnetic field strength, $B = \frac{\mu_0 M}{4\pi r^3}$

Where,

μ_0 = Permeability of free space = $4\pi \times 10^{-7} \text{ Tm A}^{-1}$

$$\therefore B = \frac{4\pi \times 10^{-7} \times 8 \times 10^{22}}{4\pi \times (6.4 \times 10^6)^3} = 0.3 \text{ G}$$

This quantity is of the order of magnitude of the observed field on earth.

(f) Yes, there are several local poles on earth's surface oriented in different directions. A magnetised mineral deposit is an example of a local N-S pole.

Question 5.2:

Answer the following questions:

(a) The earth's magnetic field varies from point to point in space.

Does it also change with time? If so, on what time scale does it change appreciably?

(b) The earth's core is known to contain iron. Yet geologists do not regard this as a source of the earth's magnetism. Why?

(c) The charged currents in the outer conducting regions of the earth's core are thought to be responsible for earth's magnetism. What might be the 'battery' (i.e., the source of energy) to sustain these currents?

(d) The earth may have even reversed the direction of its field several times during its history of 4 to 5 billion years. How can geologists know about the earth's field in such distant past?

(e) The earth's field departs from its dipole shape substantially at large distances (greater than about 30,000 km). What agencies may be responsible for this distortion?

(f) Interstellar space has an extremely weak magnetic field of the order of 10–12 T.

Can such a weak field be of any significant consequence? Explain.

[**Note:** Exercise 5.2 is meant mainly to arouse your curiosity. Answers to some questions above are tentative or unknown. Brief answers wherever possible are given at the end. For details, you should consult a good text on geomagnetism.]

Answer

(a) Earth's magnetic field changes with time. It takes a few hundred years to change by an appreciable amount. The variation in earth's magnetic field with the time cannot be neglected.

(b) Earth's core contains molten iron. This form of iron is not ferromagnetic. Hence, this is not considered as a source of earth's magnetism.

(c) The radioactivity in earth's interior is the source of energy that sustains the currents in the outer conducting regions of earth's core. These charged currents are considered to be responsible for earth's magnetism.

(d) Earth reversed the direction of its field several times during its history of 4 to 5 billion years. These magnetic fields got weakly recorded in rocks during their solidification. One can get clues about the geomagnetic history from the analysis of this rock magnetism.

(e) Earth's field departs from its dipole shape substantially at large distances (greater than about 30,000 km) because of the presence of the ionosphere. In this region, earth's field gets modified because of the field of single ions. While in motion, these ions produce the magnetic field associated with them.

(f) An extremely weak magnetic field can bend charged particles moving in a circle. This may not be noticeable for a large radius path. With reference to the gigantic interstellar space, the deflection can affect the passage of charged particles.

Question 5.3:

A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.25 T experiences a torque of magnitude equal to $4.5 \times 10^{-2} \text{ J}$. What is the magnitude of magnetic moment of the magnet?

Answer

Magnetic field strength, $B = 0.25 \text{ T}$

Torque on the bar magnet, $T = 4.5 \times 10^{-2} \text{ J}$

Angle between the bar magnet and the external magnetic field, $\theta = 30^\circ$

Torque is related to magnetic moment (M) as:

$$T = MB \sin \theta$$

$$\therefore M = \frac{T}{B \sin \theta}$$

$$= \frac{4.5 \times 10^{-2}}{0.25 \times \sin 30^\circ} = 0.36 \text{ J T}^{-1}$$

Hence, the magnetic moment of the magnet is 0.36 J T^{-1} .

Question 5.4:

A short bar magnet of magnetic moment $m = 0.32 \text{ J T}^{-1}$ is placed in a uniform magnetic field of 0.15 T . If the bar is free to rotate in the plane of the field, which orientation would correspond to its (a) stable, and (b) unstable equilibrium? What is the potential energy of the magnet in each case?

Answer

Moment of the bar magnet, $M = 0.32 \text{ J T}^{-1}$

External magnetic field, $B = 0.15 \text{ T}$

(a) The bar magnet is aligned along the magnetic field. This system is considered as being in stable equilibrium. Hence, the angle θ , between the bar magnet and the magnetic field is 0° .

Potential energy of the system $= -MB \cos \theta$

$$= -0.32 \times 0.15 \cos 0^\circ$$

$$= -4.8 \times 10^{-2} \text{ J}$$

(b) The bar magnet is oriented 180° to the magnetic field. Hence, it is in unstable equilibrium.

$$\theta = 180^\circ$$

Potential energy $= -MB \cos \theta$

$$= -0.32 \times 0.15 \cos 180^\circ$$

$$= 4.8 \times 10^{-2} \text{ J}$$

Question 5.5:

A closely wound solenoid of 800 turns and area of cross section $2.5 \times 10^{-4} \text{ m}^2$ carries a current of 3.0 A . Explain the sense in which the solenoid acts like a bar magnet. What is its associated magnetic moment?

Answer

Number of turns in the solenoid, $n = 800$

Area of cross-section, $A = 2.5 \times 10^{-4} \text{ m}^2$

Current in the solenoid, $I = 3.0 \text{ A}$

A current-carrying solenoid behaves as a bar magnet because a magnetic field develops along its axis, i.e., along its length.

The magnetic moment associated with the given current-carrying solenoid is calculated as:

$$M = n I A$$

$$= 800 \times 3 \times 2.5 \times 10^{-4}$$

$$= 0.6 \text{ J T}^{-1}$$

Question 5.6:

If the solenoid in Exercise 5.5 is free to turn about the vertical direction and a uniform horizontal magnetic field of 0.25 T is applied, what is the magnitude of torque on the solenoid when its axis makes an angle of 30° with the direction of applied field?

Answer

Magnetic field strength, $B = 0.25 \text{ T}$

Magnetic moment, $M = 0.6 \text{ J T}^{-1}$

The angle θ , between the axis of the solenoid and the direction of the applied field is 30° .

Therefore, the torque acting on the solenoid is given as:

$$\tau = MB \sin \theta$$

$$= 0.6 \times 0.25 \sin 30^\circ$$

$$= 7.5 \times 10^{-2} \text{ J}$$

Question 5.7:

A bar magnet of magnetic moment 1.5 J T^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T .

(a) What is the amount of work required by an external torque to turn the magnet so as to align its magnetic moment: (i) normal to the field direction, (ii) opposite to the field direction?

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