Experiment No. 19

Object : *To determine the absolute values of magnetic moment of a bar magnet and the horizontal component of earth's magnetic field with the help of deflection and vibration magnetometers.*

Apparatus Required : Deflection magnetometer, vibration magnetometer, bar magnet, brass rod, compass box, stop watch, spirit level, vernier callipers and physical balance.

Description of the Apparatus : (1) Deflection magnetometer : The deflection magnetometer is shown in Fig. 63. It consists of a wooden compass box D with a small magnetic needle *ns* pivoted at the centre of a graduated circular scale S_1. The circular scale is

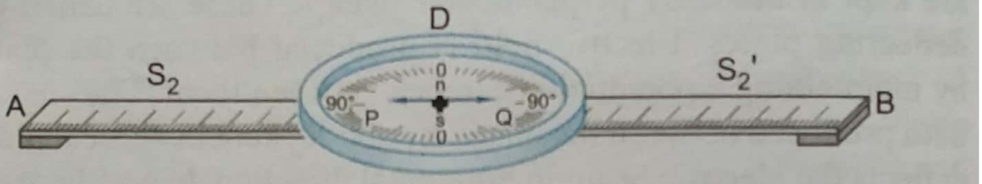

Fig. 63. Deflection magnetometer

divided in four parts, each calibrated from 0° to 90°. There is a light aluminium (non-magnetic substance) pointer PQ attached with the magnetic needle perpendicular to it. This pointer reads the deflection on the scale. The magnetic needle and the pointer both are pivoted together so both of them together can rotate freely in a horizontal plane. The pointer is flattened in the middle and raised at the ends so that it does not oscillate on either side of its equilibrium position for a long time. A plane mirror is provided below the pointer so that while reading the deflection of pointer, the parallax can be removed between the pointer and its image in the mirror. The compass box is covered with a glass lid on the top so that there may not be any effect of air etc., on the magnetic needle and pointer. The compass box is kept in the groove just in the middle of a rectangular strip. On either side of it, A and B are two arms each of 1 m length. Taking the centre of compass box as origin, the scales S_2 and S_2' on arms A and B are calibrated in cm.

(2) Vibration magnetometer : Vibration magnetometer is shown in Fig. 64. It consists of a rectangular wooden box D provided with sliding glass plates on the two opposite walls of it. On the upper face of the box there is a vertical glass tube M provided with a brass knob K at its upper end. A brass stirrup C is suspended by means of a torsionless silk thread from the knob K. The magnet is kept in the

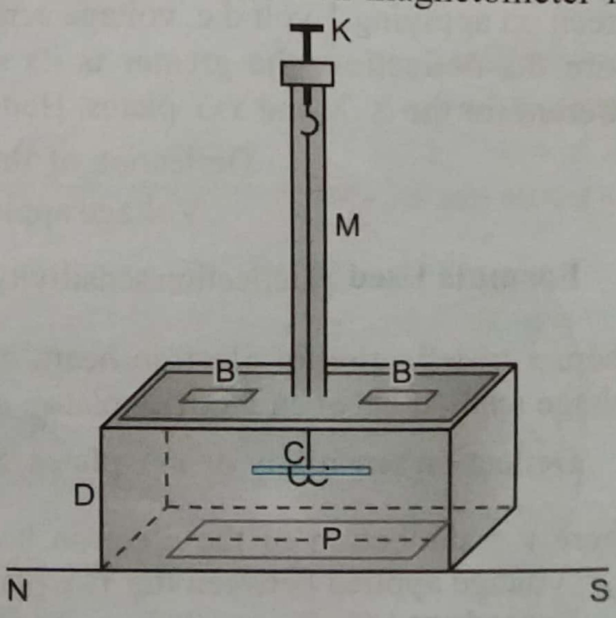

Fig. 64. Vibration magnetometer

stirrup so that it can oscillate freely in a horizontal plane. There are two slits B, B at the top and a plane mirror P at the base of the box. A reference line is etched in the middle of base, parallel to the slits B, B. This line helps in adjustment of vibration magnetometer and in counting the number of oscillations. There are levelling screws at the base of the box to adjust the apparatus horizontal.

Theory : When the arms of the deflection magnetometer are kept in east-west direction and a magnet is placed on its one arm parallel to it, it is called Tan A position of deflection magnetometer. In this position, two mutually perpendicular magnetic fields act on the magnetic needle as shown in Fig. 65. They are : (i) the magnetic field B (along east-west direction) due to the magnet along its end on position, and (ii) the horizontal component of earth's magnetic field H (along north-south direction).

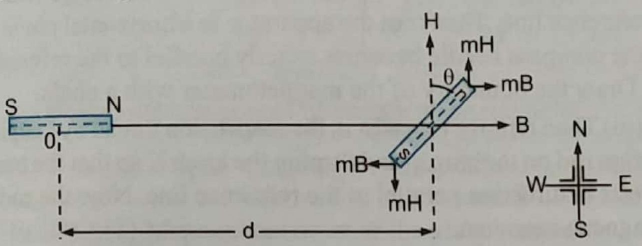

Fig. 65. Tan A position

If in equilibrium position, the magnetic needle makes an angle θ with the magnetic meridian (*i.e.*, the direction of H), then by tangent law

$$B = H \tan\theta \qquad \text{...(i)}$$

If the effective length of magnet is $2l$ metre, magnetic moment of magnet is M A m^2, the magnetic field at a distance d metre from its middle point in end on position is

$$B = \frac{2Md}{(d^2 - l^2)^2} \times 10^{-7} \text{ N/A m} \qquad \text{...(ii)}$$

From eqns. (i) and (ii),

$$\frac{2Md}{(d^2 - l^2)^2} \times 10^{-7} = H \tan\theta$$

or

$$\frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \times 10^7 \tan\theta \qquad \text{...(iii)}$$

Now if the magnet is suspended in the vibration magnetometer kept in magnetic meridian and it is displaced by a small angle φ from its equilibrium position, a restoring couple MH sin φ (or MHφ if angle φ is small) acts on the magnet which tends to bring the magnet to its initial condition. But as the magnet comes to its initial condition, its velocity increases so that it does not stop in this position, but moves ahead. Thus the magnet executes simple harmonic motion on either side of its equilibrium position. If K is the moment of inertia of the bar magnet about its axis of oscillation and α is the angular acceleration of the magnet at the instant when the angular displacement is φ, then in equilibrium

Moment of inertial couple = – Moment of restoring couple

or $$K\alpha = -MH\phi$$

(Here negative sign shows that MHφ is the restoring couple)

or $$\alpha = -\frac{MH}{K}\phi$$

i.e., $\alpha \propto \phi$ *i.e.*, the angular acceleration α is directly proportional to the angular displacement φ. Since the magnet executes angular simple harmonic oscillations whose time period is given as

$$T = 2\pi = \sqrt{\frac{\text{angular displacement}}{\text{angular acceleration}}} = 2\pi\sqrt{\frac{\phi}{\alpha}}$$

$$= 2\pi\sqrt{\frac{K}{MH}} \qquad \text{...(iv)}$$

where $K = \frac{W}{12}(a^2 + b^2)$ for a rectangular magnet of mass W, length a and breadth b.

$$\therefore \quad MH = \frac{4\pi^2 K}{T^2} \qquad \text{...(v)}$$

Multiplying eqns. (iii) and (v) and then taking the square root, we get

Magnetic moment $$M = \frac{2\pi(d^2 - l^2)}{T}\sqrt{\frac{10^7 K \tan\theta}{2d}} \qquad \text{...(vi)}$$

Dividing eqn. (v) by eqn. (iii) and then taking the square root, we get

Horizontal component of earth's magnetic field

$$H = \frac{2\pi}{T(d^2 - l^2)}\sqrt{\frac{2Kd}{10^7 \tan\theta}} \qquad \text{...(vii)}$$

Thus the absolute values of magnetic moment of the magnet M and horizontal component of earth's magnetic field H can be calculated from eqns. (vi) and (vii).

Formula Used : Magnetic moment of magnet

$$M = \frac{2\pi(d^2 - l^2)}{T}\sqrt{\frac{10^7 K \tan\theta}{2d}}$$

and horizontal component of earth's magnetic field

$$H = \frac{2\pi}{T(d^2 - l^2)}\sqrt{\frac{2Kd}{10^7 \tan\theta}}$$

where $$K = \frac{W}{12}(a^2 + b^2)$$

Here W = mass of magnet, a = length of magnet, b = breadth of magnet, l = semi-length of magnet, d = distance of middle point of magnet from the centre of compass box of deflection magnetometer, θ = deflection in the magnetic needle of deflection magnetometer by the magnet in tan A position, T = time period of the magnet when oscillated in the earth's magnetic field.

Procedure : The experiment is performed in the following two parts :

(1) To find the deflection of the magnetic needle by the magnet in Tan A position of deflection magnetometer : (i) First remove all the magnetic materials nearby the deflection magnetometer and turn the magnetometer with its compass box. Now rotate only the compass box till the pointer coincides the 0°—0° line on the circular scale. (Take care that while doing so, the arms of magnetometer do not displace).

(ii) Now place the given bar magnet on one arm (say, the east arm) of the deflection magnetometer at some distance from the compass box, with its length parallel to the arm, such that its north pole faces the compass box [Fig. 66. (a)]. Adjust the distance of magnet from the compass box such that the pointer gets deflected between 30° and 60°. Read both the ends of pointer and record the readings ϕ_1 and ϕ_2. Also read the position of middle point of the magnet on the scale and hence record the distance d of the magnet from the centre of compass box.

(iii) Now interchange the poles of the magnet, keeping it at the same position as shown in Fig. 66. (b) so that now the south pole of the magnet faces the compass box. Again record the deflections ϕ_3 and ϕ_4 from the two ends of the pointer.

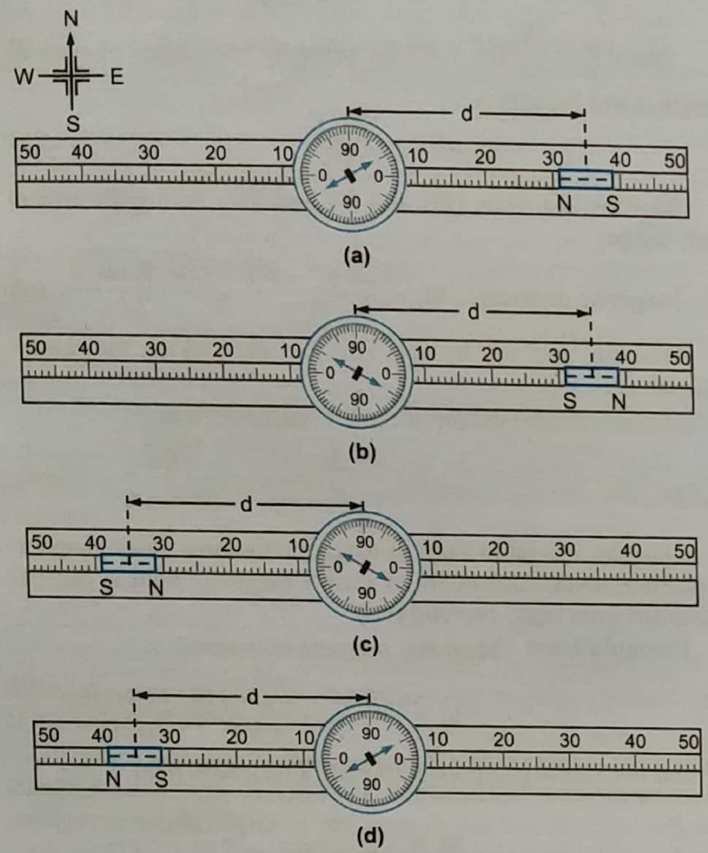

Fig. 66. For deflection in TanA position

(iv) Then place the magnet on the opposite arm at the same distance d with its north pole facing towards the compass box, as shown in Fig. 66. (c). Note the deflections of the two ends of pointer, ϕ_5 and ϕ_6.

(v) Now interchange the poles of magnet as shown in Fig 66 (d), keeping its position undisturbed (*i.e.*, the south pole of the magnet now faces the compass box) and again record the readings ϕ_7 and ϕ_8 of the two ends of the pointer.

(2) To find the time period of the magnet in the earth's magnetic field with the help of vibration magnetometer :
(i) First the vibration magnetometer is made horizontal by adjusting the levelling screws provided at its base, will the help of spirit level.

(ii) Now the magnetometer is adjusted in magnetic meridian. For this, place a compass needle on the reference line drawn on the plane mirror at its base such that the centre of needle lies on the reference line. Then turn the apparatus in a horizontal plane so that the compass needle becomes exactly parallel to the reference line. Draw the boundary of the magnetometer with a chalk.

(iii) Then remove the twist in the suspension thread by keeping the brass rod on the stirrup and turning the knob K so that the brass rod rests in direction parallel to the reference line. Now the rod is in magnetic meridian.

(iv) Now place the given magnet in the stirrup with the north pole facing towards geographic north.

(v) Now displace this magnet slightly by bringing another magnet outside it, so that the suspended magnet starts oscillating. Note the time t for 20 oscillations using a stop watch three-four times.

(vi) Measure the mass W of the given magnet with the help of physical balance.

(vii) Use vernier callipers to find the length a and breadth b of the magnet.

Observations :

(1) For the deflection produced by the magnet in the magnetic needle of the deflection magnetometer :

S. No.	Distance of mid-point of magnet d (in cm)	Magnet on east arm				Magnet on west arm				Mean deflection θ°	tan θ
		N pole of magnet facing the compass box		S pole of magnet facing the compass box		N pole of magnet facing the compass box		S pole of magnet facing the compass box			
		$\phi_1°$	$\phi_2°$	$\phi_3°$	$\phi_4°$	$\phi_5°$	$\phi_6°$	$\phi_7°$	$\phi_8°$		
1.											
2.											
3.											

Mean tan θ = ...

(2) For the time period of magnet by the vibration magnetometer :
Least count of stop watch = ... s.

S. No.	No. of oscillations n	Total time t (in s)	Time period $T = t/n$ (in s)
1.			
2.			
3.			

Mean time period T = ... s

(3) Mass of magnet W = ... g = ... kg

(4) Least count of vernier callipers = ... cm
Length of magent a = ... cm = ... m
Breadth of magnet b = ... cm = ... m

Calculations : Semi-length of magent $l = \frac{a}{2}$ = ... m

Distance of middle point of magnet in the deflection magnetometer

d = ... cm = ... m

Mean value of tan θ = ...

Mean time period of magnet by the vibration magnetometer

T = ... s

Moment of inertia of magnet $K = \frac{W}{12}(a^2 + b^2)$ = ... kg m²

(1) Magnetic moment of magnet

$$M = \frac{2\pi(d^2 - l^2)}{T}\sqrt{\frac{10^7 \times K \tan\theta}{2d}}$$

= ..... A m²

(2) Horizontal component of earth's magnetic field

$$H = \frac{2\pi}{T(d^2 - l^2)}\sqrt{\frac{2Kd}{10^7 \times \tan\theta}} = \ldots\ldots \frac{N}{Am}$$

Result : (1) Magnetic moment of the given magnet

M = ... A m²

(2) Horizontal component of earth's magnetic field at place (....)

H = ... N/A m.

Standard value of H = ... Gauss = ... $\times 10^{-4}$ N/A m

Percentage error : Percentage error in the value of H

$$= \frac{\text{Experimental value} \sim \text{Standard value}}{\text{Standard value}} \times 100\%$$

= ..... %

Precautions : (1) All the magnetic substances should be away from the magnetometer.

(2) The arms of the deflection magnetometer must be in a horizontal plane so that magnetic needle may rotate freely at the pivot.

(3) While reading deflection of pointer in the deflection magnetometer, take care that there is no parallax between the pointer and its image formed in the plane mirror.

(4) The suspension thread must be torsionless.