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XXXIX. On the determination of "H"

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5. "Reduced" forms of the vapour-pressure equation are obtained and an equation for the calculation of the critical density of a substance. This gives consistent values, even in cases such as that of water when the Mathias rule does not hold.

I wish to thank Professor Porter for his kindly criticism and for the interest he has taken in this paper.

XXXIX. *On the Determination of "H."* By WALTER A. JENKINS, *M.Sc., Professor of Physics, Dacca College**.

IN the Philosophical Magazine of October 1913, a new method of determining the Horizontal Component of the Earth's Magnetic Field was described by the writer. The method, suggested by Dr. Hicks, was the creation of an artificial magnetic field exactly equal in intensity to twice the Earth's field. Equality of the two fields was determined by the equality of the times of swing of a suspended magnet placed in both fields. It was there shown that the method was capable of giving an accuracy of one part in 10,000 and was as efficient a method as the Kew Magnetometer one. But in both the Kew Magnetometer method and the Solenoid method previously described, the chief part of the experiment is the determination of a time of swing, and the limit of accuracy of the methods is the accuracy with which the time of swing can be determined. In the previous method difficulty was experienced in obtaining a suspension fibre sufficiently fine, strong, and short enough to allow the magnet to oscillate for the period required for making accurate observations and at the same time to conform to the rest of the apparatus. Two methods will be described in the present paper, both of which obviate this difficulty and make the determination of "H" a short and reliable experiment.

FIRST METHOD.—The apparatus used is essentially the same as that designed for the former experiment and the principle of the method much the same. In this method, however, the equality of the fields is determined by measuring the angle of deflexion of the suspended magnet when under the influence of both the Earth's field and the Solenoid field. The Solenoid field is placed exactly at right angles to the

* Communicated by the Author.

Earth's field, so that if θ is the angle of deflexion,

$$2Hl \sin \theta = 2Fl \cos \theta,$$

$$H = F \cot \theta.$$

A determination of F and θ therefore gives the value of "H." As before F is equal to $4\pi nC \cos \alpha$, where n and α are constants of the Solenoid and the measurement of F reduces itself to the measurement of the current C .

Diagram 1.

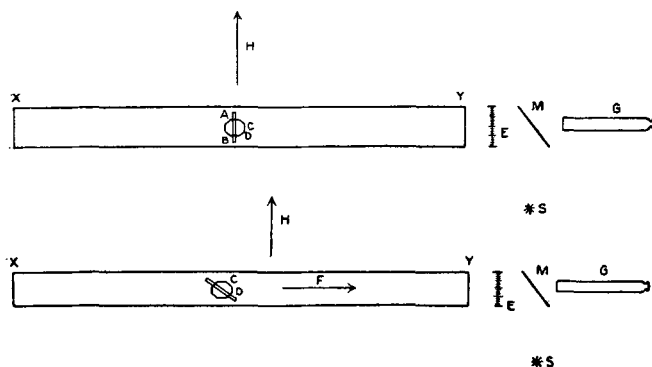


Diagram 1 illustrates the method adopted for measuring the angle of deflexion.

XY is the coil accurately placed at right angles to the Earth's field.

AB is the undeflected magnet.

An image of the scale E is reflected from the mirror surface C into the telescope G. Suppose the zero of the scale to be at the intersection of the telescope cross-wires. The current is now switched on and the magnet deflected as shown in the lower part of the diagram. The strength of the current is then adjusted until the zero of the scale is reflected from surface D to the intersection of the cross-wires of the telescope. The angle of deflexion is then the angle between the mirrors C and D. This is a constant quantity and can be accurately determined. C and D are silvered microscopic cover-glass mirrors attached to the sides of an octagonal aluminium framework which is hollowed out for the sake of lightness. Similar mirrors are attached to all sides of the octagon in order to preserve a symmetrical distribution of the weight. The framework is attached to the underside of the magnet-holder.

Details of the Experiment.—The tube, mounted as before on a board capable of rotation, was adjusted until it was exactly parallel to the Earth's field. The method used for this—that of adjusting the position of the tube until, when a large current is sent round the solenoid, no deflexion of the magnet occurs—was described in the previous paper.

The solenoid tube was then rotated through an angle of 90° . This was done by means of a telescope and scale and two mirrors at right angles to each other, mounted in a suitable position on the board carrying the solenoid. The actual angle between the mirrors was $89^\circ 25' 30''$, but so long as the angle is definitely known the fact that it is not 90° makes no difference to the experiment.

The distance of the telescope and scale from the mirrors was 210 cm., and as a rotation of 1° gave a motion of 75 divisions of the scale, an accuracy in the determination of the angle of rotation of $12''$ was obtainable, for a motion of $\frac{1}{4}$ of a division could easily be followed.

The source of light, plane reflecting glass, scale and telescope were then arranged as shown in diagram 1 and an image of the scale reflected from face C obtained. A current was now sent through the tube and adjusted until the deflexion of the magnet was such that the mirror-face D reflected the same mark of the scale on to the cross-wires of the telescope as did the mirror C. The current strength was then measured by means of a Kelvin Balance which was in the circuit, and the current was found to be 0.01945 ampere.

The balance will measure the current to 0.00001 ampere, and is a very convenient instrument for carrying out the experiment to a fair degree of accuracy. When high accuracy is desired, an electrical method similar to the one described in the previous paper can be used.

The angle between the mirrors D and C had previously been found by mounting the system on the table of an accurately calibrated spectroscope. It was found to be $44^\circ 29' 15''$. Thus we get $H = F \cot \theta$, or allowing for the fact that the angle of rotation was not 90° ,

$$\begin{aligned} H &= F \frac{\cos 44^\circ 29' 15''}{\sin 44^\circ 56' 15''} \\ &= F \cdot 99209. \end{aligned}$$

where $F = 4\pi n C \cos \alpha$, α being half the angle subtended at

the centre of the solenoid by the diameter of the end of the helix. Substituting the values $n = 13.362$, $\cos \alpha = .99986$, we get $H = \underline{.3236}$.

Accuracy obtainable.—The following sources of error were discussed in the previous paper :—

1. The magnetic axis of the solenoid not being horizontal.
2. The magnetic axis of the solenoid not being parallel to the direction of "H."
3. Irregularity in the winding.
4. The longitudinal displacement of the magnet from the centre of the tube.
5. Residual torsion of the fibre.
6. Inaccurate determination of the period of oscillation.
7. Inaccurate determination of the current.
8. An error in the determination of n .
9. Heating of the coil by passage of the current.

It was there shown that with the exception of 6, 7 and 9, the sources of error were negligible.

In the present experiment 6 is not present at all, while as the current passing is only one half of what it was in the previous method, the heating effect is diminished to $\frac{1}{4}$ of its previous value. As by taking proper precautions it was previously negligible, it is more so now. The determination of the magnitude of the current still remains one of the chief factors limiting the accuracy obtainable, but with standard resistances and a good galvanometer an accuracy of 1 part in 10,000 is not difficult to obtain. Error 5, due to the torsion of the fibre, is negligible when an extremely fine fibre is used. In the present experiment, however, when prolonged oscillation of the magnet is not only not required, but is undesirable, a thicker suspension fibre possesses considerable advantages. Consequently a moderately thick suspension fibre was used. A stronger, heavier magnet system was also inserted in the holder, and on putting into the fibre 1440° of torsion a deflexion of $\sin^{-1} .012$ was observed. The following equations give the maximum allowable value of the angle of deflexion due to the residual torsion for an accuracy of 1 in 10,000.

Suppose θ of torsion remain in the fibre and n be the coefficient of the torsion.

$2Hl \sin \alpha = n(\theta - \alpha)$, where α is the deflexion due to torsion. When the tube is rotated through 90° and the

magnet system deflected 45° ,

$$2 Hl \sin (45 + \alpha) = n (\theta - \alpha) + 2 Fl \sin 45,$$

$$H \sin (45 + \alpha) - H \sin \alpha = F \sin 45$$

$$\begin{aligned} H &= F \frac{\sin 45}{\sin (45 + \alpha) - \sin \alpha} \\ &= \frac{F}{\cos \alpha + \sin \alpha - \sqrt{2} \sin \alpha} \\ &= \frac{F}{\cos \alpha - (\sqrt{2} - 1) \sin \alpha}. \end{aligned}$$

If $\sin \alpha$ is of the order $\frac{1}{10,000}$ then $\cos \alpha$ is $1 - \frac{1}{2} 10^{-4}$, so that $\cos \alpha$ can be called 1.

Therefore $H = F (1 - .41 \sin \alpha)$, and in order that the torsion can be neglected $\sin \alpha$ must be less than $\frac{1}{4000}$.

The torsion which will give a deflexion of this order is 36° .

The torsion was eliminated, as in the previous experiment, by substituting a brass bar equal in weight to the magnet and allowing the system to come to rest. It is not probable that in such a case 36° of the torsion would remain in the fibre.

The following additional errors are possible :—

- (a) Error in the determination of the angle between the mirrors attached to the magnet.
- (b) Error in the determination of the angle through which the solenoid is rotated.
- (c) Error in the determination of the coincidence of the zero of the scale with the cross-wires of the telescope.
- (a) The angle is an invariable quantity and can easily be measured to 10 seconds. Approximately $H = F \cot 45$. An error of 10 seconds in 45 degrees gives an error of 1 in 10,000 in the calculated value of H . If desired the angle could be measured with greater accuracy than that indicated.

(b) Is similar to (2).

(c) The distance of the scale from the mirror was 75 cm. ; with care the coincidence could be determined to .1 of a division, *i. e.* .01 cm. This corresponds to an angle of rotation of the mirror of approximately 15 seconds.

The actual angle through which the mirror is rotated is about 45° . Therefore we get

$$H = F \cot (45^\circ \pm 15'').$$

This gives an accuracy of 1 in 6666, or say 1 in 7000.

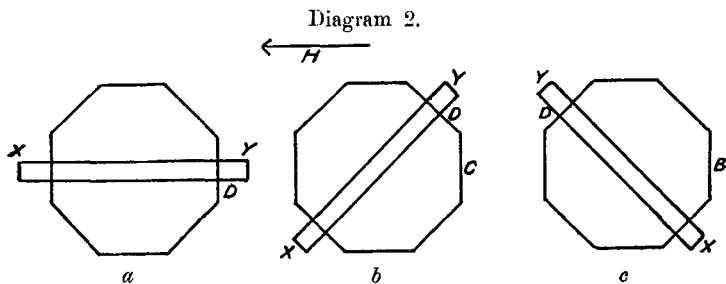
The accuracy of the experiment therefore reduces itself to

the accuracy with which the angle of deflexion can be measured. A similar measurement is involved in the Kew Magnetometer method, and the accuracy of the two methods may therefore be said to be the same.

SECOND METHOD.—The principle of this method is very similar to that described in the previous paper. An artificial field is produced in the solenoid opposite in direction to, and in intensity twice that of the Earth's field. The equality of the two fields is tested by means of the deflexions caused by a subsidiary magnet placed in the Tangent B position of Gauss.

Details of the Experiment.—The tube was first set accurately parallel to the Earth's field. The octagonal shaped framework suspended underneath the magnet had mirrors attached to all its faces and the adjustments were made so that the scale was reflected from face D (diagram 2 *a*).

The external magnet sliding in a groove at right angles to



- a.* Position under influence of Earth's field alone.
- b.* Position under influence of Earth's field + that of external magnet.
- c.* Position under influence of Earth's field + external magnet + solenoid field.

the solenoid was then adjusted until the scale was reflected from face C, diagram 2 *b*, into the telescope. Without moving the external magnet the solenoid field was switched on and adjusted in strength until the position of the suspended magnet was as in diagram 2 *c*. Then the image of the scale was reflected from face B into the telescope.

If the octagonal framework is accurately made and the angles between the adjacent faces are 135° exactly, then obviously the solenoid field is exactly twice the Earth's field, and we get

$$2H = 4\pi nC \cos \alpha.$$

The measurement of H is now simply a measurement of C . In practice, however, the angles are not exactly 135° , and

it is necessary to make an allowance for this in the calculations. The angles between the mirror faces can be accurately measured and, from the values found, the angles of deflexion θ_1 and θ_2 in the two parts of the experiment calculated. Then the following equations will give the value of H :—

$$\begin{aligned} F \cos \theta_1 &= H \sin \theta_1, \\ F \cos \theta_2 &= (X - H) \sin \theta_2, \end{aligned}$$

where X is the field of the solenoid.

$$H = \frac{X}{\tan \theta_1 \cot \theta_2 + 1}.$$

In the experiment actually carried out,

$$\theta_1 = 44^\circ 26' 30''$$

$$\theta_2 = 46^\circ 12' 15''$$

$$n = 13.362$$

$$\cos \alpha = .99986$$

$$C = .037547 \text{ ampere}$$

$$X = .62955$$

$$H = \underline{\underline{.3245}}$$

The experiment was carried out ten days after the former one, and hence coincidence of results could not be expected.

Errors.—Possibilities of errors not previously described arise in this experiment owing to the following causes :—

- (1) A lateral displacement of the subsidiary magnet from its true position opposite the centre of the suspended one.
- (2) An angular displacement of the subsidiary magnet from its true position perpendicular to the solenoid.
- (3) Alteration of magnetic moment of the subsidiary magnet.

(1) The following calculation shows the error likely to arise from a lateral displacement of the subsidiary magnet.

Suppose the magnet is displaced 1 cm. from its correct position.

Then a simple calculation shows that an error of 1 part in 3000 is introduced if, as was the case in the actual experiment, d is about 50 cm. and l about 18 cm. If the displacement is not more than 3 mm. the error is not more than 1 part in 10,000. The subsidiary magnet can easily be placed to within 3 mm. of its correct position.

(2) An angular displacement of $1\frac{1}{2}^\circ$ would introduce an error of 1 in 10,000. The magnet can be placed in its correct position to a greater degree of accuracy than this.

(3) The only factor likely to cause a sudden change of

magnetic moment of the subsidiary magnet in the interval elapsing between the two parts of the experiment is a temperature change. The temperature coefficient of magnetic moment is $\cdot 001$. Thus in order to obtain the required accuracy the temperature must be kept constant to within $\frac{1}{10}^{\circ}$ C. Suitable precautions can easily be devised to ensure this.

In both methods described in the present paper the magnet when in a deflected position lies in a field of strength $H \sqrt{2}$ approximately, and hence owing to induced magnetism its magnetic moment will be slightly greater than when in a field H . This, however, introduces no error, for the magnetic moment of the suspended magnet is a factor which does not enter into the problem except in so far as it alters the angle of deflexion due to residual torsion. At the most the change introduced into α is a small fraction, and hence α is negligible the change owing to altered magnetic moment is also negligible.

Comparison of the two methods.—Both methods give an accurate result, and both are easier to carry out than the Kew Magnetometer method. Once the constants n , $\cos \alpha$, the angles between the mirrors, and the direction of H are determined the only determination in the first method is that of the current required to give the necessary deflexion. When the solenoid is rotated through 90° the optical apparatus must also be rotated through the same angle, but in the apparatus which is being designed for permanent installation the optical system, consisting of eyepiece-scale and reflecting glass, is to be fitted into the end of the tube and will therefore rotate with it.

In the second method no rotation of the tube is necessary, but it involves the use of a subsidiary magnet. Moreover, two adjustments are necessary.

- (1) The adjustment of the position of the magnet to give the requisite deflexion under the influence of the Earth's field.
- (2) The adjustment of the current to create an oppositely directed field which gives the same deflexion.

Provided that the solenoid is mounted upon a large circular table whose rotation can be measured, as that of a spectro-scope table is, the first method is extremely simple and accurate, and in the author's opinion provides the best method of determining H with accuracy. The fact that the determination of H by both methods gives substantially the same

result when allowance is made for the variation of H from day to day, is an indication of the reliability of the method. Check experiments with a not very reliable Kew Magnetometer instrument gave the same value of H .

In conclusion I again wish to express my thanks to Dr. Hicks, who first of all suggested the use of the principle involved in the Solenoid method.

Dacca College.
7th August, 1920.

XL. *Impulsive Sparking Voltages in small gaps.*

By J. D. MORGAN, *B.Sc.* *

IN a paper entitled "Time Lag in the Spark Discharge" (Phil. Mag. vol. xxxvii., August 1919) Dr. Norman Campbell discusses the fact that the impulsive sparking voltage is in certain gaps greater than the static sparking voltage. As explained in that paper, when the voltage applied to a gap is caused to rise rapidly from zero, the value it will attain before sparking occurs is greater than that reached by a voltage which is applied gradually. The ratio of these two values has been termed by Peek the "impulse ratio," and this expression is now generally adopted. It is commonly believed that two conditions other than voltage are involved in the process of spark production, namely, time and initial ionization. Campbell recognizes these two conditions, and shows how they can be used to explain why the impulsive sparking voltage of a gap is greater than the static voltage, or in other words, why the gap has an impulse ratio greater than unity. Arguing from his own and Peek's investigations, the conclusion reached by Campbell is that there are two kinds of lag, a regular and an irregular one, in the process of spark production, though it is apparent that he sees a probable connexion between them.

Taking Campbell's mode of presenting the facts, there would appear to be justification for distinguishing between regular and irregular lags, but it is questionable whether this manner of regarding the subject is likely to lead to the most useful practical results. In the writer's opinion it is more convenient to assume only one lag, and to regard the sparking voltage of a given gap as dependent jointly on the three variable conditions which have hitherto been recognized. These conditions are (1) rate of rise of voltage,

* Communicated by the Author.