THE EFFECT OF TRANSVERSE MAGNETIC FIELD ON THE LONGITUDINAL JOULE MAGNETOSTRICTION EFFECT IN NICKEL

By OM PARKASH SHARMA

ABSTRACT. The effect of a transverse magnetic field on the longitudinal Joule magnetostriction effect in nickel, predicted by Williams (1912), has been observed for low values of longitudinal magnetic fields. Williams' (1927) method of combining mechanical and optical magnifications has been used. Since the magnification of the present apparatus ($\sim 10^6$) is insufficient, no quantitative conclusions have been drawn. According to a view of Williams, the effect is possibly caused by the imposition of the transverse field on the specimen, longitudinally magnetised. However, it has been explained on Becker's ideas, assuming that the effect of a transverse field is equivalent to that of tension.

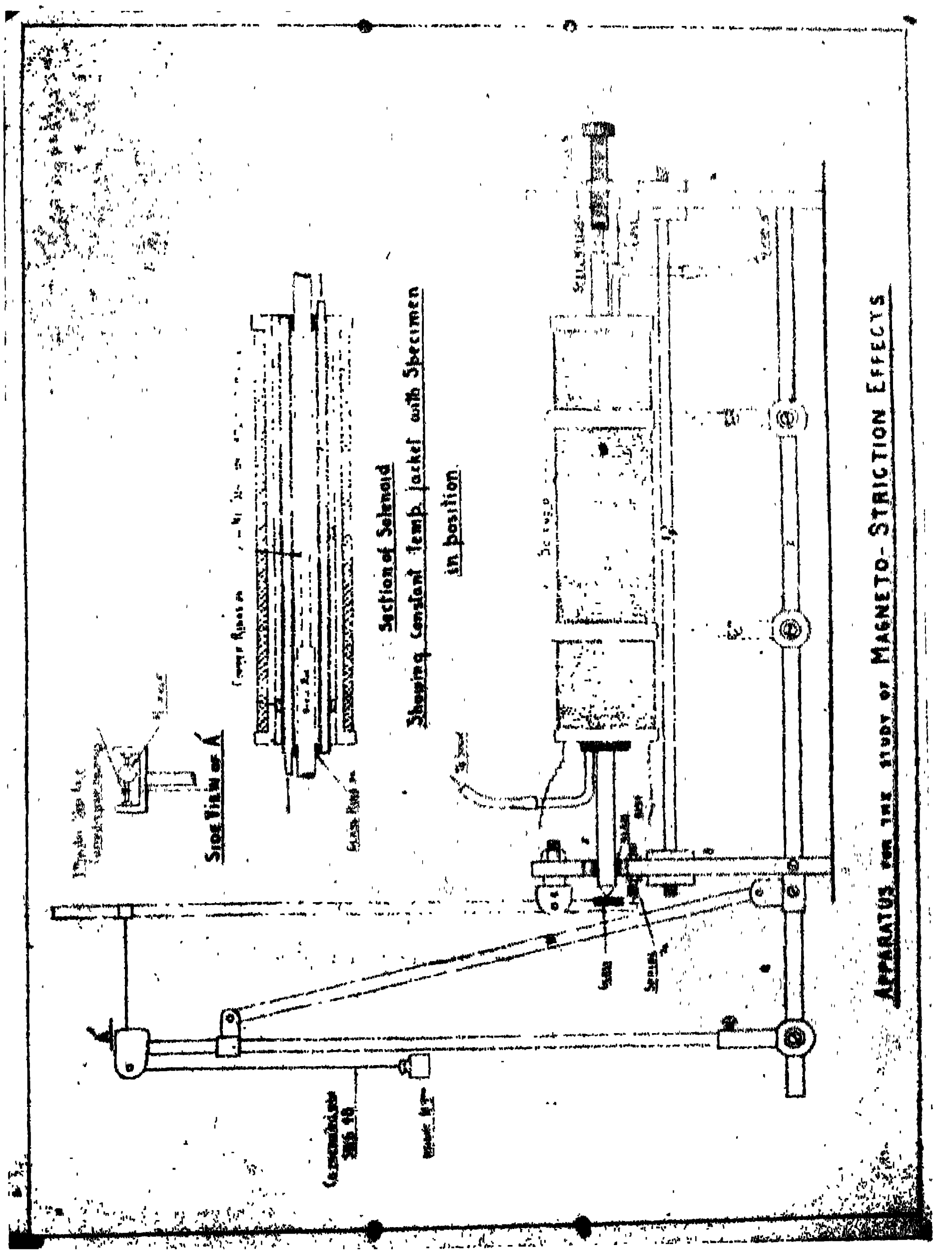
INTRODUCTION

The phenomena of magnetostriction *i.e.* changes in dimensions especially of ferromagnetic substances, when subjected to the action of magnetic fields, have been known since long. In 1912 S. R. Williams (*loc. cit.*), on the basis of his so called Planetesimal theory of magnetism, mentioned the possible occurrence of an additional change in length due to imposing a transverse magnetic field on a longitudinally magnetised rod of a ferromagnetic material. The author has not come across, in the existing literature, any attempt that may have been made to detect this effect. Recently I have observed such an effect of a transverse field on a longitudinally magnetised rod of nickel. The effect of the transverse field comes out to be an increase in the ordinary magnetostrictive contraction.

As the largest magnetostrictive changes are of the order of 10^{-5} cm per unit length of the material, it is necessary to sufficiently magnify them before they can be visually observed or suitably recorded. Out of the various methods employed, the combination of a mechanical and an optical lever has been the most frequently used. In this work also such a combination with a magnification of 4.67×10^5 was used, but since the phenomenon observed under the present conditions involves exceedingly minute changes, the present study can only be said to be of a qualitative nature.

APPARATUS

The apparatus used is shown in diagram. A solenoid (4) wound with enamelled copper wire (S. W. G. 22) on a wooden bobbin, 17 cms long, with an internal diameter of 1 inch and having 2400 turnes in all, rests on a suitable, very rigid brass frame work. This consists of two brass plates, A and B, of which A is permanently fixed at one end of the rod (2), whereas B is capable of sliding along the length of the rod and may be fixed at a desired position.



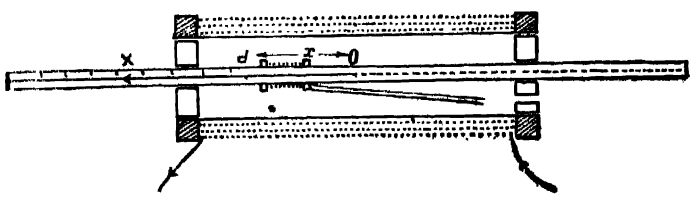
Diagram

There are two strong and stout supports (3, 3) similarly held on the rod (2). A double walled copper cylinder (9), through which water can be circulated fits symmetrically well inside the solenoid by three copper rings (9*b*). The nickel rod, (above 99% pure but the purity has not been tested) 9 cms long and .40 cm diameter, has its two ends soldered exactly straight to two extension brass rods each ¼″ in diameter (shown in section diagram), and is axially and centrally placed inside the solenoid, (or the water jacket) care being taken to allow it complete longitudinal freedom of movement. The symmetry of the rod inside the solenoid is achieved by the fact that not only the double walled copper vessel is symmetrically and tightly held inside the solenoid but also that two glass sleeves are fixed as shown (9*a*) of just the internal diameter as to allow the free sliding of the extension brass rods without any sideways movement. The free end of one brass rod has a sharp steel needle soldered to it, the tip of the needle resting in a jewelled screw, whilst the free end of the other brass rod, which is tappered to a point presses against a glass plate fixed on the shorter arm of the mechanical lever (7) with an adjustable lever ratio. On the longer arm of the mechanical lever, and at about a distance of 20 cms from the axis of rotation (6), is slid a small brass sleeve. The axle of the optical lever, having a diameter of 1.00 mm, is prepared from a thin steel needle. A small portion of the axle is filed flat and a small mirror attached to it. The optical lever is then supported in jewelled bearings mounted in a brass yoke (A′).

One end of thin copper wire (S. W. G. 48) is soldered to the brass sleeve (6). The wire is given one turn round the axle of the optical lever (kept at the same level as the brass sleeve) and is kept taut by a 10 gms weight soldered to its other end. Two terminals (not shown in the diagram) are fixed on the brass rods (which form the continuation of the nickel rod) for passing the current through the specimen. The rod is electrically insulated from the other parts of the apparatus by annular glass sleeves. Two other brass rods (1, 1) are used to ensure rigidity of the apparatus and a rod (8) to avoid any yielding of the support of the optical lever. Any changes occuring in the length of the specimen on magnetisation, are observed through the telescope on a scale placed at a distance of one metre from the optical lever.

EXPERIMENTAL PROCEDURE AND RESULTS

Calibration of the solenoid: Let $2b$ be the length of the solenoid (Fig. 1), a its mean radius and O its centre. Taking the axis of the solenoid as axis of X,



Calibration of the solenoid

FIG. 1

the magnetic field at any point P, where OP $= x$, is given by the expression (Pidduck)

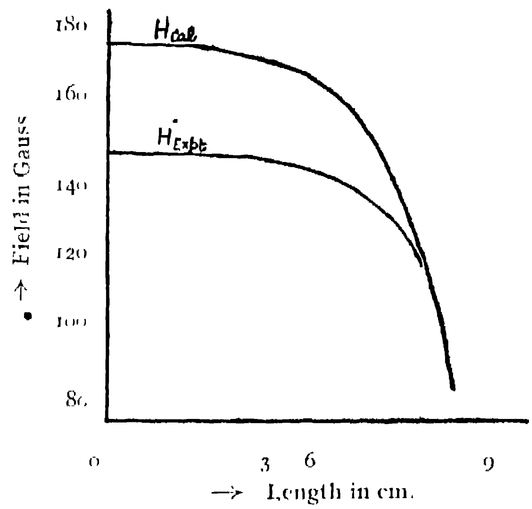
$$H = \frac{2\pi ni}{10}\left[\frac{l+x}{\{a^2+(l+x)^2\}^{\frac{1}{2}}} + \frac{l-x}{\{a^2+(l-x)^2\}^{\frac{1}{2}}}\right]$$

where n = number of turns per cm.

i = current in amps.

H = field in gauss.

The values of the field (H_{cal}) at different points along the axis of the solenoid for $i = 1$ amp., as calculated from the above expression are given in Table 1 and



Variation of H with distance from the centre of the solenoid.

FIG. 2

graphically shown in Fig. 2. However, to determine the actual values of the field, a small search coil, 2 cms long. wound on a glass rod, with enamelled copper wire (S. W. G. 38) with 263 turns, was placed along the axis of the solenoid, the search coil being at a particular position. A current of 1 amp* was passed through the solenoidal winding and the field obtained from the inductive throws of the moving coil ballistic galvanometer. The search coil was then shifted in steps of one cm and the field (H_{expt}) obtained at different places along the axis of the solenoid (Tab. 1) and graphically shown in Fig. 2. It is seen from Fig. 2, that the field is sufficiently uniform (within 2%) in the central region occupied by the rod. The experimental value (144 gauss per amp) is, however, lower than the theoretical value (169.6 gauss per amp.).

* Actually observations were taken with three values of the current, namely, .7, 1.0, and 1.4 amps.

TABLE I

Length in cms. measured from the centre of the solenoid.	0	1	2	3	4	5	6	7	7.7	8.5
H_{cal}	172.1	172.0	171.4	170.1	167.9	163.9	156.0	139.7	119.7	87.9
H_{expt}	145.5	145.5	145.5	142.9	142.9	141.6	137.7	129.7	118.0	...

EXPERIMENTAL PROCEDURE

The specimen rod was demagnetised in a separate solenoid by passing a suitable value of A.C. 50 c.p.s, reducing it slowly to zero and then carefully mounted in the solenoid. Known currents were passed through the solenoid and the corresponding scale deflections were recorded. The changes in the length of the specimen due to temperature variations being quite slow could be very well differentiated from those due to the magnetic field, which are instantaneous. Still, to minimise any temperature effects due to the heating of the solenoid, the current through the solenoidal winding was passed for short intervals. As a further precautionary measure, water was kept circulating through the double walled copper cylinder surrounding the specimen.

A set of readings for the Joule magnetostrictive changes was recorded for low values of the longitudinal magnetising fields and, immediately after each observation, a transverse magnetic field was established by passing an electric current (5 amps) through the specimen itself for a short interval, of the order of a second or so, the resulting scale deflection being recorded (Table II).

TABLE II

Showing the effect of a transverse magnetic field on the longitudinal Joule magnetostriction effect in nickel.

Serial No.	Longitudinal magnetising field†		Readings of the scale					
			No current through the Specimen			5 amps. through the specimen deflection,	Current and field both off (zero reading)	Change in deflection due to current through the specimen
	current (amps)	Field (Gauss)	Zero reading (no field)	Final reading (field on)	Deflection			
1	.20	28.8	214.5	214.6	.1 mm.	.2 mm.	214.5	.1 mm.
2	.295	42.5	221.5	221.7	2 ,,	.4 ,,	22.5	.2 ,,
3	.40	57.6	196.0	196.3	.3 ,,	.6 ,,	196.0	.3 ,,

The demagnetisation factor has not been taken into account.

REMARKS

With higher longitudinal fields, the transverse field being kept constant, the effect vanishes. Higher transverse fields were tried by increasing the value of the current through the specimen, but it was found that even during the fraction of a second, for which the current was passed, the heating of the specimen was sufficient to shift the zero reading appreciably, and give very discordant observations. However, the effect observed (*i.e.*, a greater contraction when an electric current is passed through the specimen) cannot be attributed to a temperature increase, because an increase in temperature should produce an elongation and not a contraction, which is actually observed.

It may be remarked that the effect, whether longitudinal or transverse will depend upon the specimen. Thus if we have two specimens both of the same size and cut from the same rod, the longitudinal and transverse effects will be different. This is due to the different magnetic history and heat treatments of the specimen. That is why, as Heaps has shown, the observations of two independent observers, using different samples, cannot be compared with each other with any degree of exactness.

DISCUSSION

From the above observations it is evident that qualitatively speaking, the effect of a transverse magnetic field is to double the Joule magnetostrictive contraction for low values of the longitudinal magnetising field but for higher longitudinal fields, there is practically no change observed in the ordinary contraction. Such an effect may be explained on Becker's theory of magnetostriction. Becker has shown that within the region of technical saturation, a nickel wire under the simultaneous action of a sufficiently great longitudinal tension F and a longitudinal field H, would be magnetised with the magnetic vectors making an angle of the average value θ with the axis of the wire, given by,

$$\cos\theta = \frac{I_s}{3\lambda_{0,s}\cdot F}\cdot H \qquad (i)$$

where I_s is the technical saturation intensity of magnetisation and $\lambda_{0,s}$ is the experimental value of the contraction per unit length when saturated. I_s and $\lambda_{0,s}$ being constants for a particular specimen, equation (*i*) can be written as,

$$\cos\theta = \frac{k}{F}\cdot H \qquad \text{where } k = \frac{I_s}{3\lambda_{0,s}}.$$

and under such circumstances, the magnetostriction constants $\lambda_{0,s}$ for an unstretched wire and $\lambda_{F,s}$ for a wire under tension are related as

$$\lambda_{F,s} = 3/2\ \lambda_{0,s} \qquad \ldots (ii)$$

i.e. to say the magnetostriction contraction in a stretched wire is 1.5 times that in an unstretched wire.

The effect observed is in close conformity with the above ideas of Becker. When transverse field is applied, radial contraction of the specimen results, with a necessary result of longitudinal extension (Heaps 1915). This longitudinal extension due to the transverse field being sufficiently small, does not affect the original reading appreciably. However, to check this point, the mentioned value of the current was passed through the specimen (longitudinal magnetic field being absent) and it was found that there was no change in the reading, which probably means that the longitudinal extension due to the passage of the current through the specimen (or the accompanying field) is not sufficient (Heaps) as to be detected by the present apparatus. It was found that the change in length due to temperature rise, being slow, appeared nearly after 30 seconds. However the present effect cannot be confused with the temperature effect, as the first one being instantaneous and the other being much slower the two can be very well differentiated. Thus we suppose that the imposition of transverse field is equivalent to applying tension to the specimen. The reverse of this, *i.e.* that when tension is applied to a nickel rod, a transverse magnetism is developed, is clearly evident from equation (*i*), thus showing a reciprocity of magnetic and mechanical effects (Williams), (Mckeehan, 1926).

Considering the rod to be initially magnetised by a magnetic field along OX (Fig. 3), the magnetic vectors point along OX. If such a rod is stretched

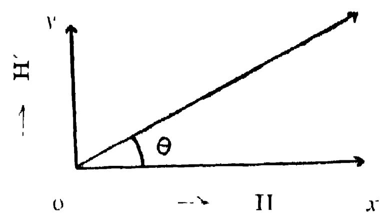


FIG. 3

the magnetic vectors make an angle θ with OX given by eq. (*i*). Instead of stretching, if we apply a transverse field (H′) along OY again the magnetic vectors will make an angle $\theta = \tan^{-1}$ OY/OX and therefore a tension should result. Under such conditions equation (*ii*) will be applicable. The results obtained are nearly 33% higher than the theoretical ones, however, the present accuracy does not allow any exact comparison.

The above also explains the null effect in higher longitudinal fields, because as H is increased H′ remaining constant, the resulting tension is insufficient and hence there is no effect. However, with higher transverse fields, greater magnification and elimination of heat effects the exact quantitative nature of the phenomenon may be studied.

ACKNOWLEDGMENTS

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PHYSICS LABORATORY,
GOVERNMENT COLLEGE,
LAHORE,

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