Magnetostriction

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THE term *"Magnetostriction"* is applied to denote that class of phenomena in which changes in the state of magnetisation of a body are accompanied by changes in its physical dimensions or form and conversely, mechanical deformations of the body are accompanied by changes in its state of magnetisation. A number of such effects all closely related have been reported. Although these phenomena have been known for a very long time, they were, until recently, only of academic interest. During the last ten years, however, increasing attention has been devoted to the subject and considerable progress has been made. The subject has now acquired a theoretical importance on account of its intimate connection with the theory of magnetism and a practical significance through applications such as the magnetostriction oscillator.

Mechanical Deformations due to Changes in Magnetisation

It was first discovered by Joule in 1842 that a ferromagnetic rod, when placed in a magnetic field with its length parallel to the lines of force, alters in length when the strength of the field is changed. This phenomenon is known as *"The Joule Effect"*. The actual change is very small and its accurate measurement is possible only by means of sensitive instruments like extensometers, interferometers, or ultramicrometers.

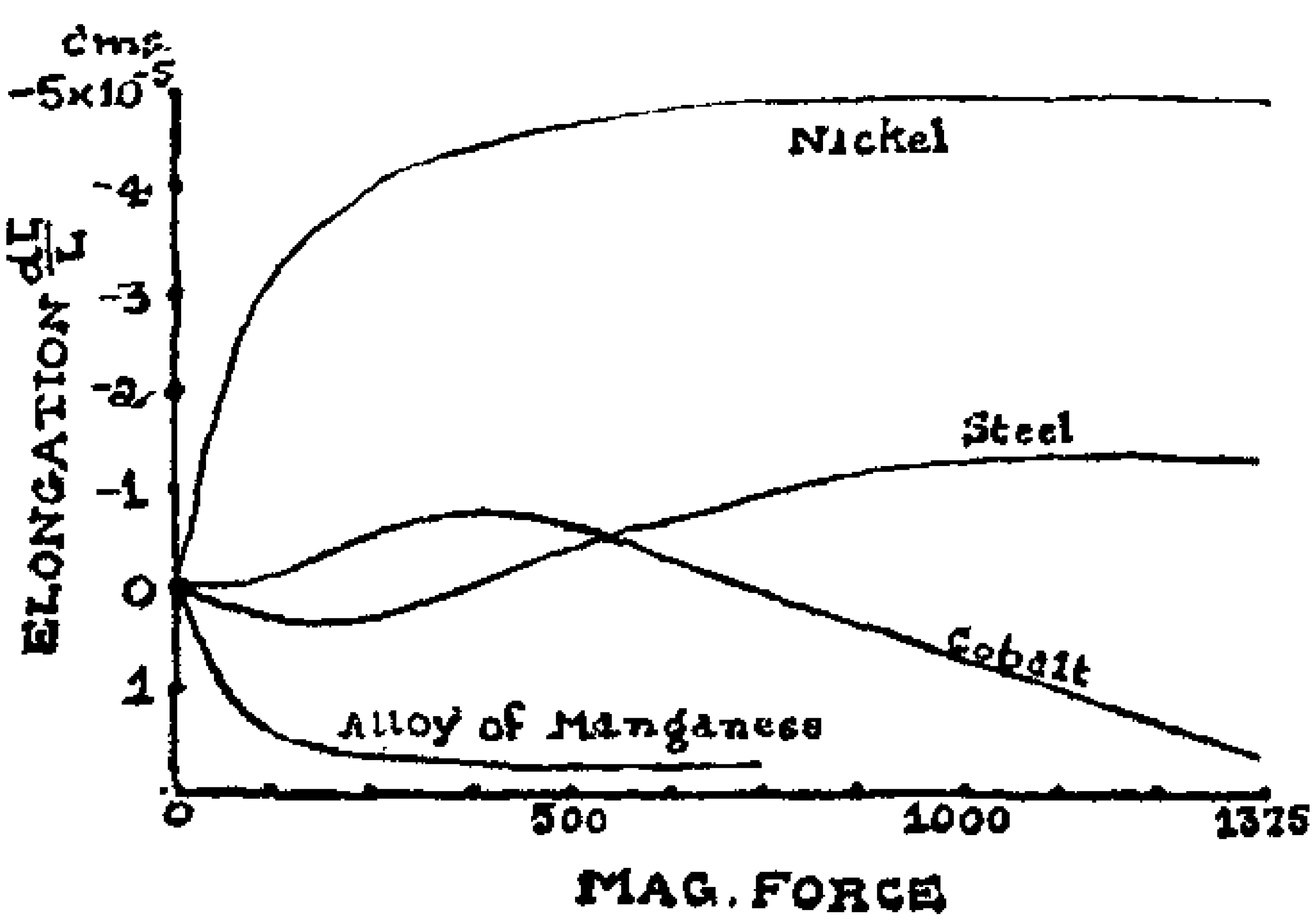

Fig. 1

The curves in Fig. 1 illustrate the influence of magnetic fields in the case of iron, cobalt, nickel and an alloy of manganese. Iron shows an increase in length for weak fields and decrease for strong fields. Nickel exhibits a shortening for all field strengths and the Heusler alloy behaves in quite the opposite way. Cobalt behaves in a manner just the opposite of iron. It has also been found that there is hysteresis attending the Joule Effect and it is closely related to the familiar magnetisation hysteresis.

In addition to the change of length, it has been found that the area of cross-section changes when the rod is magnetised longitudinally (the so-called *'transverse Joule Effect'*). There is also a change in the Young's modulus consequent on magnetisation. Wiedemann discovered that due to the interaction of longitudinal and circular magnetic fields a twisting of the specimen ensues (*'Wiedemann Effect'*). The coefficient of rigidity is affected considerably by change in magnetisation. Barett showed that the volume of a magnetic material changes if its magnetisation is altered (*Barett Effect*).

Changes in Magnetisation due to Mechanical Deformations

The effect of mechanical deformations on the magnetisation discovered by Villari is of great interest. Villari found that if an iron rod is stretched its intensity of magnetisation increases in a weak magnetic field but de-

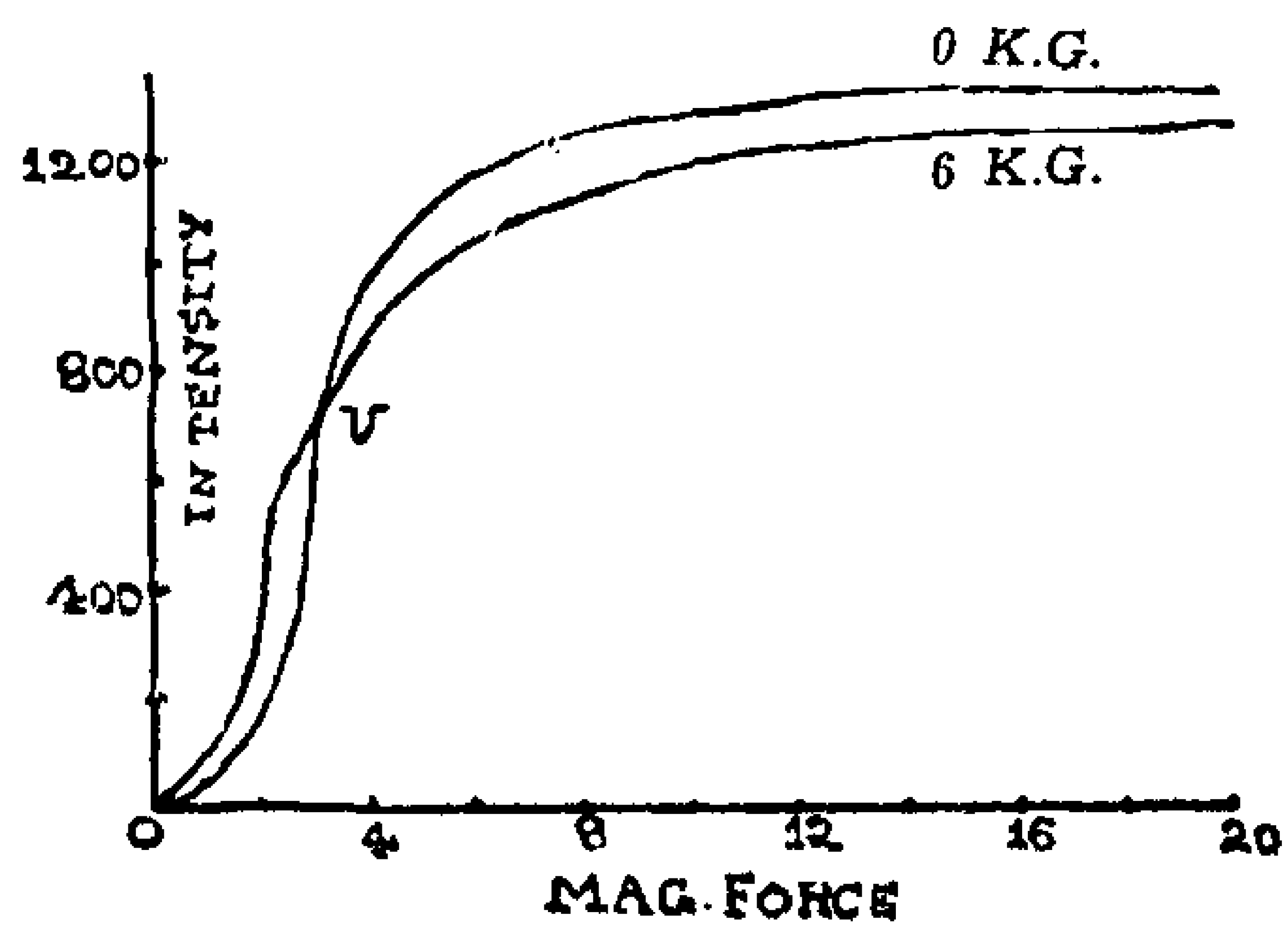

Fig. 2

creases in a strong field. This is known as the *Villari Reversal Effect* and the point V where stretching or compressing does not affect the intensity of magnetisation is known as the Villari Reversal Point. The *Villari Effect* is the reciprocal of the Joule Effect. A change in magnetic induction due to normal stress has also been shown to exist and is known as the "*transverse Villari Effect*" as against the transverse Joule effect.

Wiedemann has found that if a circularly magnetised rod is twisted it develops longitudinal magnetisation (*Second Wiedemann Effect*) and Wertheim, that a longitudinally magnetised rod when twisted develops circular magnetisation (*Wertheim Effect*). Nagaoka and Honda have shown that a change in the volume of the specimen is accompanied by a change in its state of magnetisation (*Nagaoka-Honda Effect*). This is the opposite of the *Barett Effect*.

In all these experiments great care must be taken to maintain the external conditions such as temperature and pressure constant. The exact nature of the change in any specimen depends upon its previous history (thermal treatment, magnetisation, stresses and the like) and may be considerably altered by processes such as annealing. The actual magnitudes of these changes being very small, special devices have to be employed to measure them. A detailed account of these various effects and their measurements is given by S. R. Williams.[1]

Single Crystals of Magnetic Materials

It is obvious that work with single crystals would be more useful in disclosing the nature of the magnetostriction phenomenon than with samples of polycrystalline material about the history and structure of which little is generally known. Webster,[2] Honda and Mashiyama[3] have studied the Joule effect in single crystals of iron using different orientations of the specimen. They find that the Joule effect exhibits anisotropy, its sign and magnitude depending upon the orientation. The effects are much larger in single crystals than in the polycrystalline metal. Takaki[4] has studied the variation of the magnetostriction of iron crystals with temperature. The behaviour of the crystal is markedly different along different crystallographic axes. Similar experiments have been made by Nishiyama[5] and Mashiyama[6] on crystals of cobalt and nickel.

Alloys of Magnetic Materials

Studies of magnetostriction in alloys of magnetic materials have been carried out by Schulze,[7] Mashiyama[8] and others. It is interesting to observe the gradual change exhibited by iron-nickel alloys with varying percentages of nickel. The curves in Fig. 3

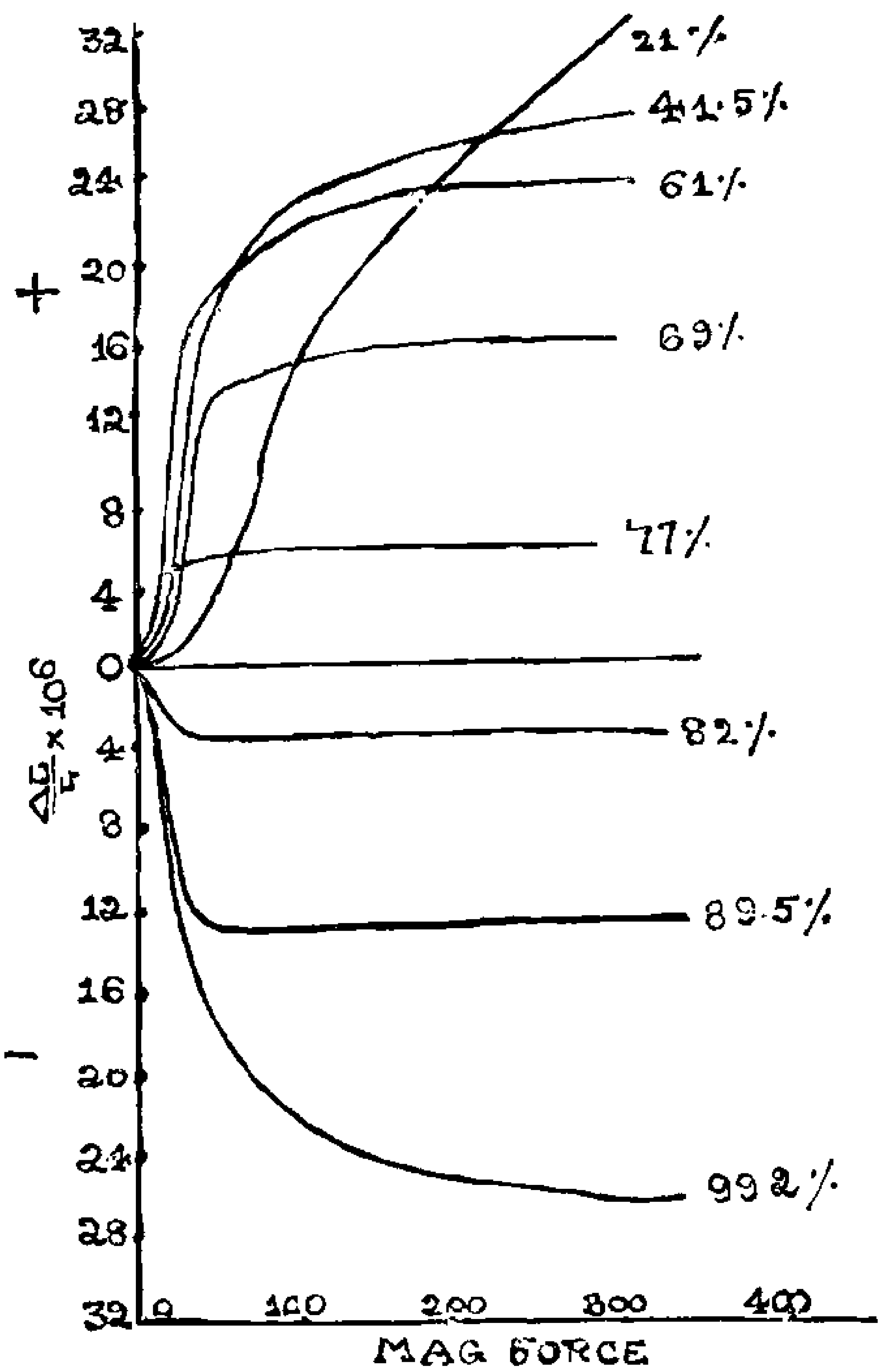

Fig. 3

illustrate this strikingly. With small percentages of nickel the curve is seen to be entirely positive, while with nearly pure nickel the curve is practically inverted. The change from positive to negative is continuous with increasing percentages of nickel, with the result that an alloy in which there is no magnetostriction whatever the magnetising force, is possible and does in fact occur at about 80% nickel. This alloy is the well-known '*permalloy*' in which the magnetic permeability is very high for small values of the magnetising force. In the case of the silicon-steel alloys there appears to be some evidence that at a percentage of silicon slightly above that used for stalloy, the curves from being similar to that in iron tend suddenly to invert as in the case of nickel-iron.

PARA- AND DIA-MAGNETIC MATERIALS

In ferromagnetic substances, magnetostriction is easily observed in ordinary magnetic fields. In para- and dia-magnetic substances however, no magnetostriction is observed at such fields. Kapitza[9] made a study of non-ferromagnetic substances using very intense fields. The measurements in strong fields lasted only for a fraction of a second and hence had the advantage that while the scale of the phenomenon was much magnified, all disturbances due to accidental variations in temperature were eliminated. He also made an extensometer, capable of measuring to 10^{-7} cm. which was as sensitive in the brief time of experiment as those used for long duration measurements. Using single crystals of bismuth, Kapitza found that magnetostriction was very closely connected with crystal orientation both as regards its sign and magnitude. Variation of the effect due to changes in field strength, changes in temperature, and addition of impurities were studied. Some effects were also observed in antimony, graphite, gallium and other substances.

The phenomenon of magnetostriction is of fundamental importance in the theory of magnetism. It has been the usual practice in building up theories of ferromagnetism to ignore effects such as these and then by rather arbitrary additions to give them place within it. Of late, however, several attempts have been made to include the magnetostrictive data in the foundations of a theory of ferromagnetism. McKeenhan,[10] Fowler and Kapitza[11] have considered the question. Kapitza has also discussed the results he has obtained with diamagnetic materials in relation to the modern theory of diamagnetism. However, it may be said that only a beginning has been made in this direction. The study of magnetostriction promises to throw light on the subject of interatomic forces in solids and the architectural design of the elementary magnet, the atom. It is of great importance therefore to obtain accurate data in ferromagnetic as well as non-ferromagnetic substances under specified conditions. Study of other phenomena which are related to magnetostriction such as the change in resistance in a magnetic field, change in thermo e.m.f. due to a magnetic field, e.m.f.'s due to magnetisation and the Barkhausen Effect on the same specimens of material may provide the theoretical investigator with useful information.

THE MAGNETOSTRICTION OSCILLATOR

The principle of magnetostriction has found several practical applications in the laboratory and elsewhere. What appears to be of rather great significance is the development of valve oscillating circuits whose frequency can be controlled by the utilisation of the magnetostriction effect, and conversely of circuits which can maintain intense vibrations based on the same principle. The first "magnetostriction oscillator" was set up by Pierce[12] ten years ago, in which the frequency was controlled magnetostrictively. The circuit used (Fig. 4) is essentially a Hartley

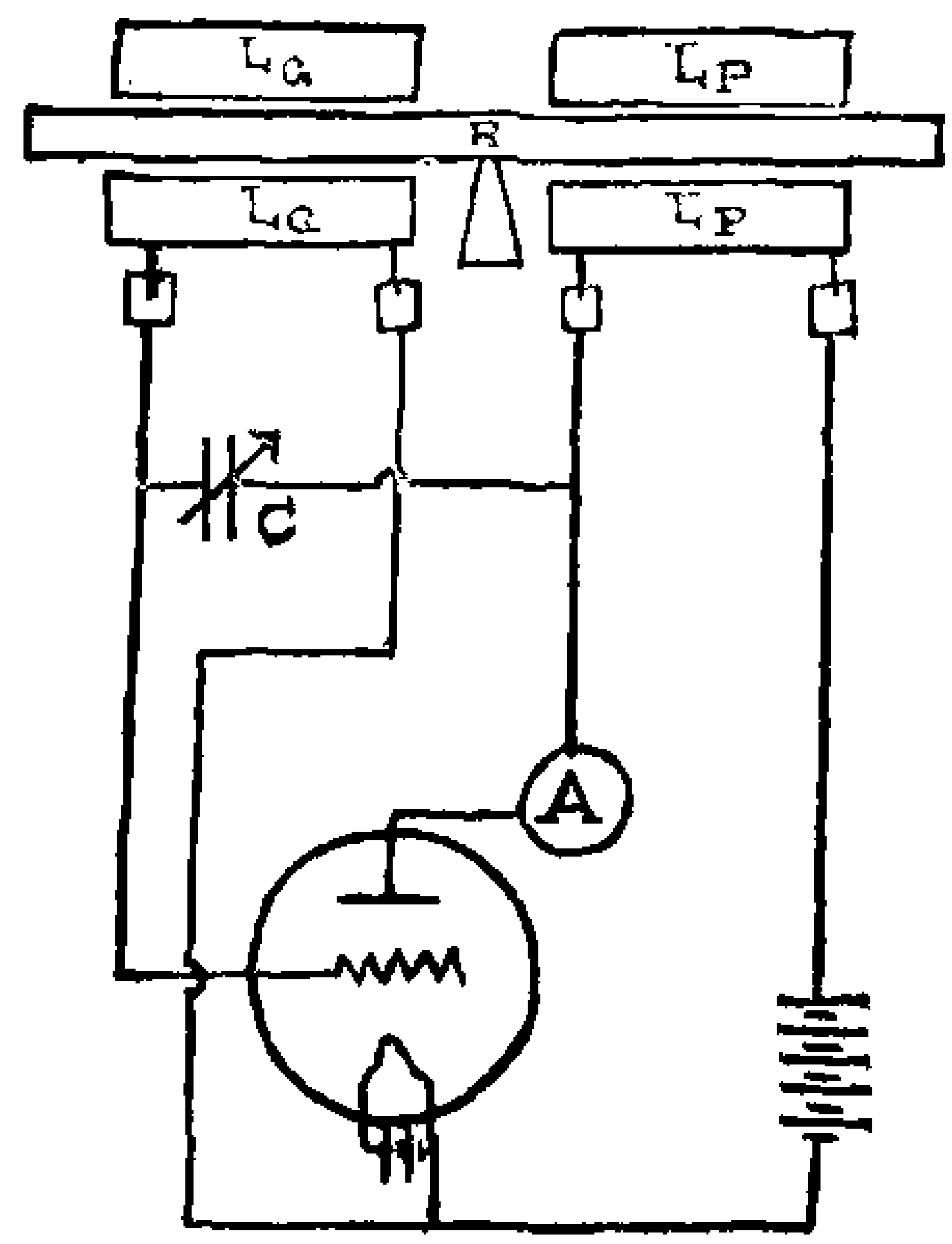

FIG. 4

arrangement with two separate grid and anode coils, which are tuned by a variable capacity C. The spatial coupling between the coils is loose, and the magnestrictive rod is placed axially in the centre of the two coils, supported at its midpoint. When the oscillating circuit is tuned to near the natural frequency of the rod, an additional coupling due to magnetostrictive action arises thus: a small change of current through L_p changes the magnetisation of the rod, which thereby suffers a change in length. This deformation of the rod transmitted to the grid coil side, causes an equivalent change in magnetisation and induces an e.m.f. in the coil L_g. This induced e.m.f. on the grid produces an amplified change in the plate circuit and thus in L_p. This coupling is maximum at the natural frequency of the rod and the oscillations are maintained at the same frequency. More recently Pierce[13] has developed an oscillator which functions only under the control of the vibrating rod, and is inactive otherwise.

Magnetostriction Oscillator used as a Frequency Standard

Extensive investigations have been made by Pierce and his collaborators on the development of magnetostriction controlled frequency standards. The material suitable for use as a vibrator must have a large magnetostrictive effect and must maintain constancy of frequency in spite of changes in temperature, magnetisation, condenser settings and vacuum tube characteristics. For these purposes iron and irons with various carbon contents are found to be relatively useless, as they have too small magnetostriction coefficients. Pure nickel, and alloys of nickel and iron, or alloys of cobalt and iron, nichrome and monel metal are found to be very powerful vibrators. The temperature effects can be overcome by using composite vibrators, consisting of a tube of one material and a core of different material, the two having opposite coefficients of expansion. In order to prevent undue lengths at low frequencies, nickel tubes filled with a material such as lead in which the velocity of sound is small are used.

The magnetostriction oscillator is found to be effective in the range between the very low audible frequencies and nearly two million cycles per second in the supersonic range. Harmonics can be developed up to frequencies of several million cycles per second. Above 300,000 cycles per second, however, the vibrations are found to be too feeble. In the range between 300,000 cycles and 25,000 cycles per second, the magnetostriction oscillators and the piezo-electric oscillators have a common range of usefulness. Below 25,000 cycles per second however, *i.e.*, in the upper audible range, on account of the difficulty of obtaining sufficiently large crystal vibrators, the magnetostriction oscillator is very useful. The constancy of frequency of the magnetostriction oscillator compares favourably with that obtained by the piezo-electric crystal oscillators.

Magnetostrictive standards of frequency have been set up by Pierce and his co-workers. They have been used to control electric circuits in the apparatus for supersonic research such as superhet sonic amplifier, standard signal generator and microvoltmeter and in the calibration of wavemeter and frequency meters. The velocity of sound in various metals and alloys have been measured and their elastic constants (with their temperature coefficients) have been obtained. By using the vibrator as a source of sound, the transmission of sound over reflecting surfaces has been investigated.

The relevant literature on these developments is largely to be found in the *Journal of the Acoustical Society of America*, 1938, Vol. 9.

Oscillators of very High Amplitude

Newton Gaines[14] was the first to study the effects at very high amplitudes of the oscillator. The object was to increase the power input of the resonant magnetostrictive nickel tubes to the limit set by the mechanical properties of nickel and then to discover and investigate properties of the intense sound produced by longitudinal vibration. The apparatus is essentially a high power oscillator with the nickel tube mounted axially in the field of the coils.[15]

With a vibrator of this type it is found that the amplitudes of vibration could be easily measured with ocular micrometers. The amplitudes are so high that nickel tubes are quickly ruptured. The sound produced is of sufficient intensity to cause pain to the unprotected ear. Metal plates, when held at one end to touch the rod are found to be eroded. When the sound beam is directed on to a beaker or a flask, the vessel is broken. A piece of cork driven into the tube is found to be burnt. The vibrations produce a considerable emulsifying effect, stable emulsions of transformer oil, benzene and mercury in water being easily obtained. Dispersions of carbon and other substances could be obtained. When introduced into a vessel of water from below, fountains as high as 9 cm. are produced. All these disruptive effects are due to cavitations produced by the intense sound waves. Chambers[16] reports that there is emission of light from the cavity in the case of some liquids (fourteen liquids, among the thirty-six examined show this effect). Using a magnetostriction oscillator, Porter and Leona Young[17] have shown that a molecular rearrangement can be brought about by powerful ultrasonic waves. Salisbury and Porter[18] have constructed a very powerful magnetostriction oscillator which operates with a power input which can be varied continuously between 0 and 2000 watts in order to use it as a source of intense ultrasonic waves in connection with their experimental work on the mechanisms of some organic reactions. The oscillator was also satisfactorily adopted by Gaines and Chambers, to form a continuous laboratory process for the sterilization of market milk. One of the most important applications of magnetostriction is found in the magnetostriction echo depth recorder[19] which is used for taking soundings at sea and has now reached the stage of being produced commercially.

Summary

The phenomena which have been grouped together under the heading "*Magnetostriction*" are briefly described. Experimental results on the magnetostriction of ferro-, para- and dia-magnetic substances, single crystals and alloys are considered and the theoretical importance of the phenomenon pointed out. The development by Pierce of the magnetostriction oscillator and its importance as a frequency standard has been indicated. Use of oscillators of very high amplitudes in the laboratory for the investigation of physico-chemical problems and their important industrial applications have been mentioned. The article is in the nature of a review of the recent progress made in the subject of magnetostriction that has become one of great importance.

The author of this article feels grateful to his Professor, Sir C. V. Raman, F.R.S., N.L., who gave him facilities to set up a magnetostriction oscillator in his laboratory at the Indian Institute of Science, Bangalore.

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