Gyromagnetic Measurements and their Significance

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THERE have recently appeared a number of articles in foreign periodicals, and of footnotes in treatises on magnetism concerning gyromagnetic measurements, which, perhaps unintentionally, show three main tendencies. First, they tend to obscure the fact that credit is certainly due to O. W. Richardson, who was the first to show that, if the electron is responsible for ferromagnetism, then it ought to be possible to make quantitative measurements in gyromagnetism. Secondly, they tend to disregard much of the earlier work on the subject, to view certain results as merely approximate and to neglect much of the latest work on the subject. Thirdly, they suggest that important sources of error were entirely overlooked by some workers. Consequently, it seems desirable to examine the present position so far as is possible in a short article.

In practice it is necessary to consider only two gyromagnetic effects. One such effect is produced when we take a cylinder of any substance and rotate it rapidly about its long axis ; on account of the Larmor precession of the electrons, the cylinder becomes magnetised parallel to the axis of rotation. Actually, such magnetisations have been measured so far only in the case of ferromagnetic substances. Many experiments on this effect have been successfully made by Barnett in the United States since 1914. It is sometimes suggested that this effect is not strictly the converse of the other effect, with which the above publications are almost exclusively concerned. It will not be considered further here, although Barnett's results agree as well as can be expected with others described below.

The other effect may be described as the production of angular momentum by change in magnetisation. Richardson showed in 1908, as mentioned above, that if the magnetic moment of a freely suspended body be changed by an amount M, then the angular momentum about the same direction should be changed by an amount U, the ratio U/M, the gyromagnetic ratio, being equal to $2m/e$, on the assumption that the electron is a point charge moving in a closed orbit.

It was not until 1915 that the effect was even experimentally detected by Einstein and de Haas, and, consequently, on the Continent the effect is known as the Einstein-de Haas effect. Incidentally, when two English workers termed it the Richardson effect in a well-meant effort to credit Richardson with its prediction, Sir Oliver Lodge, in the course of a lecture, part of which was published as a supplement to NATURE of August 4, 1923, strongly deprecated the attachment of personal names to such effects. Einstein and de Haas stated that they found exact agreement between experiment and the theory, which they had independently re-discovered. Such agreement was not confirmed by later workers, for in 1918, J. Q. Stewart found the ratio for iron to be $0{\cdot}98\, m/e \pm 15$ per cent by a direct method, and in 1919 Beck found $1{\cdot}06\, m/e \pm 5$ per cent and Arvidsson $0{\cdot}94\, m/e \pm 4$ per cent by resonance methods.

At this stage the problem was attempted by Chattock and Bates, who used the direct method of observation. They suspended a thin iron or nickel wire from a fine quartz fibre so that its axis coincided with that of a vertical solenoid, and measured the angular momentum produced on reversing the magnetisation of the wire, by the deflection of the wire against the torsion of the fibre. The ratio was thus found to be exactly equal to m/e within the limits of experimental error, which were considered to be about 1 per cent. It was not thought necessary to neutralise the vertical component of the earth's magnetic field in these experiments, and this has been a source of criticism. Such criticism, however, takes no account of the fact that Chattock and Bates proved that U is strictly proportional to M for a wide range of values, which would have been impossible if the unneutralised component had produced a serious source of error. Since magnetostriction and electron inertia effects loom large in criticisms of later work, it is as well to state here that they could not have been sources of error in these direct experiments.

This result was confirmed by Sucksmith and Bates in 1923, using a null method of measurement designed by Chattock, with an error of about 1 per cent. Now, measurements more recently made by Barnett by a very similar method, in which lower magnetising fields and lower frequencies were employed, gave the values $1{\cdot}04\, m/e$ and $1{\cdot}05\, m/e \pm 0{\cdot}5$ per cent for iron and permalloy, and $1{\cdot}06\, m/e$ and $1{\cdot}08\, m/e$ for nickel and cobalt, respectively. It has been suggested that the differences between Barnett's results and those of Sucksmith and Bates arise because the latter did not attempt to neutralise the vertical component of the earth's field, or to eliminate the effects of magnetostriction and inequalities in the half cycles of the alternating current supplied to the magnetising solenoid. Against this suggestion, however, it must be stated that if such serious errors existed in their work, it is very surprising that of the thirty-eight results recorded for iron, nickel and Heusler alloy by Sucksmith and Bates, not one exceeds the value $1{\cdot}03\, m/e$.

Other workers, presumably aware of the discrepancy, have recently provided independent support for the value m/e, but their results have not received the attention they deserve. Thus Coeterier and Scherrer[1] give a provisional value of $0{\cdot}995\, m/e$ for iron, whilst in his 1933 Amsterdam thesis, Coeterier gives the final value $1{\cdot}01\, m/e$ for iron in powder form. These values were obtained by a resonance method in which a special photoelectric relay reversed the direction of the magnetising field as the oscillating system passed through its zero position.

Again, Ray-Chaudhuri[2] has published the values 1·008, 1·016 and 1·022 m/e for Fe_3O_4, Fe_2O_3 and $NiO \cdot Fe_2O_3$, respectively, with a possible error of 2 per cent. These substances were used in powder form packed inside thin glass tubes. A resonance method with an apparatus similar to that used by Sucksmith in his measurements with paramagnetic substances was employed, the apparatus being evacuated to give large resonance oscillations.

It is, however, desirable to consider the theoretical grounds on which the ratio may conceivably be greater than m/e. For any electron system, the ratio is accurately given by the expression $\frac{1}{g} \cdot 2 \cdot \frac{m}{e}$, where g is the Lande splitting factor, which is equal to 1 for purely orbital motion and equal to 2 for spin motion alone. If ferromagnetism is due entirely to electron spin, then the ratio must be m/e, but if due to an electron system which is distorted by the fields of neighbouring atoms, it is suggested that g may lie between 1 and 2, the ratio being correspondingly increased. Again, van Vleck has suggested that two types of ion with g values of 3/2 and 2 may be simultaneously present in the iron lattice and thus give an effective value of g less than 2.

A measurement of great interest in this connexion is that of Coeterier on pyrrhotite, which shows well-known ferromagnetic peculiarities; this substance in powder form gave a value of 0·63 for g by the method outlined above. Inglis has shown, on the basis of a simple model in which the orbital momenta of the effective electrons are orientated antiparallel to their spins, that the theoretical value for g is 2/3. It is, perhaps, noteworthy that the experimental value of the ratio is thus somewhat higher than the theoretical value, so that perhaps Coeterier's value for iron is also a little too high, but incomplete orientation, as suggested by Inglis, would also account for this difference.

In the case of simple paramagnetic compounds of the rare earth and iron groups, we have fairly definite knowledge of the g values for the appropriate ions based on spectroscopic data. The direct determination of the gyromagnetic ratio for such substances is a matter of extreme difficulty, but such measurements have been successfully made by Sucksmith, who finds satisfactory agreement between the calculated and experimental values. The limits of experimental error were about 6 per cent, but, in view of the great experimental difficulties, Sucksmith was fortunate to get measurements at all. Therefore, the suggestion in a recent article by Barnett[3] that even these most skilful measurements are open to the serious errors supposed peculiar to English work on gyromagnetism is a little difficult to understand.

In conclusion, then, there appears to be no valid reason why theoretical physicists should consider the gyromagnetic ratio for simple ferromagnetic substances, and for simple paramagnetic substances, to be other than m/e and $\frac{1}{g}\, 2\, m/e$, respectively, in the present state of our knowledge.

[1] *Helvetica Physica Acta*, 1932.
[2] NATURE, **130**, 891, Dec. 10, 1932.
[3] *Phys. Z.*, March 1, 1934.

Research in Australia and New Zealand

WHEN the prices of wheat and wool fell calamitously four years ago, Australia found herself on the verge of economic collapse, and every State department was compelled to tighten its belt in order to avert a general disaster. Among them, the Commonwealth Council for Scientific and Industrial Research discovered some economic truths for which it had not been consciously seeking, and it is now both suffering from, and benefiting by, its discoveries*. It is an undoubted fact that under boom conditions, research is liable to become far more costly than it need be; a successful investigation may well yield a continuous profit of 1,000 per cent or more on the original capital outlay, and rapidly lead to the initiation of a host of superfluous and hopeless projects. These are the first to be weeded out when contributions to research are curtailed. The Australian Research Council deserves sympathy for the enforced curtailment of its activities, but congratulation for making immediate use of adversity by pressing forward existing schemes for inter-State co-ordination and imperial co-operation in agricultural research. Proposals for establishing a Commonwealth organisation in agricultural and pastoral research were put forward seven years ago, but in view of the wide divergence of interests between the different States and the great distances separating the chief research institutions, it is doubtful how far those proposals would have materialised in the absence of the pressure exerted by recent economic events. In making grateful acknowledgment of the assistance of the now defunct Empire Marketing Board, the Council emphasises the inestimable services performed by the Board in bringing research institutions in different parts of the Empire into close touch with one another.

The report of the Council for the past year, although not recording any outstanding new results of research, gives some very striking figures illustrating the cash returns that have been, and

* Seventh Annual Report of the Council for Scientific and Industrial Research for the year ended 30th June. (Canberra: Commonwealth Government Printer, 1933.) 3*s*. 8*d*.