Experimental research in strong magnetic fields*

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INTRODUCTION

It is well known that magnetic field strengths attainable with electromagnets are limited by saturation of their cores. The highest saturation magnetization available at present is for the alloy "ferrocobalt" discovered by Prof. Weiss, but even with this alloy the maximum field that can be produced in a volume sufficient for experimental research does not even reach 100 G. Until alloys with higher saturation magnetizations are discovered, one can increase *the magnetic field only by increasing the size of the electromagnet*. However, the magnetic field increases only logarithmically with increasing size (volume) of the magnet.

Undoubtedly one could go far with this approach, following in the footsteps of Prof. Cotton, who constructed a giant electromagnet in France. It is also well known that high magnetic fields can be achieved in a coil if it is sufficiently well cooled, e.g., by a strong water jet. By this method one can achieve fields of around 60–70 kG. This is probably the practical limit, since there is obviously a limit on the amount of coolant that can be brought into contact with a unit surface area of the coil. This method, which is more complicated than the electromagnet approach, has not found practical application and does not look very promising. One can achieve a significant increase in the magnetic field by reducing the time of its existence to a small fraction of a second. Although this sacrifice of time does complicate doing research on magnetism, it seems to be the only hope for obtaining high magnetic fields at the present time, and we have therefore taken this approach.

To be sure, some phenomena that require a certain amount of time to become established, e.g., crystal growth, cannot be studied by this approach. However, there remain a great many phenomena, probably the most interesting, that are amenable to it. We are mainly interested in atomic phenomena, and since a strong magnetic field is the single most fruitful means of producing distortions in the motion of electrons in atoms, molecules, and crystals, experiments in this arena are of great interest for modern physics. The main difficulties encountered in implementing this method are, first, producing a field in a short time interval, and, second, measuring the effect. In this article we will discuss the second topic in detail, as the first question has been addressed previously.[1]

DESCRIPTION OF THE METHOD OF PRODUCING MAGNETIC FIELDS IN SHORT TIME INTERVALS

Clearly the most important thing in producing high magnetic fields in short time intervals is to prevent the coil from overheating and to design the experiment in such a way that all the heated released is absorbed by the coil itself on account of its heat capacity. If the magnetic field is produced in a coil of radius a wound with a material of resistivity ρ (the volume occupied by the insulation on the winding is also taken into account) and the applied power is w (in kW), the magnetic field strength will have the value

$$H=k\sqrt{\frac{w}{a\rho}}.$$

In this formula, which was given in this very convenient form by Fabri,[2] k is a coefficient that depends on the *shape of the coil and cannot* exceed 0.179 for *ordinary* coils. It is seen from this formula that to obtain a field of 1 million gauss in a coil with a cross-sectional diameter of 1 cm, for example, a power of 40 thousand kilowatts would have to be supplied (and in practice considerably more). At such a power level a coil of ordinary dimensions would be heated by more than 10,000 deg/s. But by decreasing the time to 0.01 s, one would have a temperature increase of only 100°, and that is admissible. From this standpoint the advantage of producing the field in short time intervals is obvious. Significant difficulties are encountered in implementing this approach. The first difficulty is to obtain the necessary high powers. Obviously the use of a several-megawatt power plant for 0.01 s is not only extremely uneconomical, it is also practically impossible for a physics laboratory, and it will obviously be necessary to develop a special energy source. The solution to this problem is self-evident: one can use any electrical device that can store energy and then release the stored energy over times of a fraction of a second. We can classify such devices into 4 main types, depending on the means of energy storage: 1) electrical, 2) magnetic, 3) chemical, and 4) mechanical.

The first type of device is represented by a large capacitor bank which is slowly discharged through the coil. This solution is entirely possible, but has many practical shortcomings. It must be remembered that one requires not only a high power but also an amount of stored energy sufficient to produce the field and maintain it for a time long enough to do the experiment. In practice the most convenient time intervals lie between 0.02 and 0.01 s. It can be shown that a capacitor bank capable of giving the necessary energy would need to be inconveniently large and charged to very high potentials, which would complicate the problem of insulating the coil. Tests along this line have been made by Dr. Wall,[3] and the results confirm our general arguments.

In the second way of storing energy, magnetic energy is usually stored in the iron core of an induction coil. Actually, we first made tests with a specially constructed induction coil with a secondary winding that consisted of very few turns and was connected to the coil. In theory this method should be workable and more practical than a capacitor bank, but we encountered great difficulties in its practical implementation. The main difficulty was that when the circuit carrying the primary current was opened,

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colossal overvoltages were formed in the secondary winding, which had almost no capacitance and was connected to a circuit with a large self-inductance (the solenoid), and, roughly speaking, it could happen that the energy was dissipated in the opening switch instead of entering the coil. Calculations showed that interrupting the primary current is an extremely difficult and practically unsolvable problem, and we therefore abandoned this approach.

The first method that permitted satisfactory energy storage was the chemical method (a detailed description of this method can be found in Ref. 1). For this purpose we constructed a special storage battery having a very small capacitance owing to the small thickness of the active layer. The cells were very ruggedly constructed and were placed close together, as in a Voltaic pile. These cells could be charged in a few seconds and ordinarily discharged completely in a fraction of a second. This storage battery could deliver a power of around 1 or 2 thousand kilowatts, and the first experiments in briefly acting magnetic fields were carried out. For example, experiments on the Zeeman effect were done in fields of up to about 125 thousand gauss,[4] and fields of this same size were used to deflect the trajectories of α rays in a Wilson chamber.[5] These experiments made it possible to determine the change in velocity of the helium particles as they passed through gases such as air or hydrogen.

The magnetic field could have been increased somewhat by increasing the size of the storage battery, but this proved quite difficult to do. After a year or two the elements suffered a gradual increase in capacitance and thus a decrease in the amount of power they could deliver, and they were destroyed.

The main difficulty, however, lies in the interruption of a direct current of several thousand amperes in a time short compared to 0.01 s. This leads us finally to the last of the energy storage possibilities, viz., the mechanical approach, based on the flywheel principle.[6] This method can be implemented with an ac generator of the turbine type, with a rapidly spinning massive rotor which hence has a high kinetic energy. In engineering practice it is well known that when such a generator is short-circuited, one can obtain high powers at the time of actuation.

For reasons of safety, ac generators intended for continuous operation are designed in such a way that a short circuit cannot result in the delivery of high powers. In designing our generator, we proceeded from the opposite principle, and our machine could deliver on short circuit about 200,000 kW (70 thousand amperes and 3 thousand volts), while its dimensions corresponded to those of a 1500 kW continuous generator. These design modifications made for an extremely interesting study of the mechanical stresses in an electrical generator. In ordinary generators this is not very important, but in our case the mechanical stresses were the most important aspect of the design, and we had to introduce many nonstandard features in order to achieve durability. Another big advantage of using an ac generator is that it greatly simplifies the problem of interrupting the current. Since only a half wave is used, our task

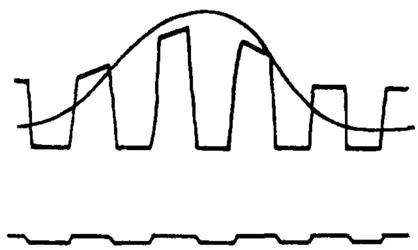

FIG. 1.

was to construct a synchronous adapter that can interrupt the current at the instant it becomes zero.

In this case the problem of interrupting the current reduces to that of constructing a fast-acting synchronous opening switch. Readers are referred to a more detailed description of the switching device, which presented an interesting mechanical problem and works on the camshaft principle.

At first glance it seems that the use of an ac generator would complicate the problem of producing a constant magnetic field for even 0.01 s, but one can suitably alter the excitation of the field to create a wave with a flat top. Figure 1 shows an oscilloscope trace of an ordinary wave, and Fig. 2 shows one of a wave with a flat top. A photograph of the generator is shown in Fig. 3. The main difficulty in this method of producing the magnetic field is the limitation imposed on the field strength by the coil itself. The high current density, reaching 100 thousand amperes per square centimeter in a strong magnetic field, unavoidably gives rise to high stresses in the body of the coil. These stresses flatten the coil along its axis and decrease the diameter. An ordinary copper coil was destroyed in a great explosion when a field of 200,000 G was created in it. This problem required a careful study of the forces arising in the coil, and after Dr. Cockroft[7] developed methods of calculating these stresses it was found that the electromechanical forces tending to spread the coil and the reaction forces exerted by the massive steel retaining band create conditions analogous to hydrostatic pressure. A coil was made from a special cadmium–copper alloy that is stronger than copper and has a higher conductivity. The coil, with an inner diameter of 1 cm, produced in its cavity a field of 320 kG, and one can hope that with the ultimate refinement of the composition of the coil a field of about half a million

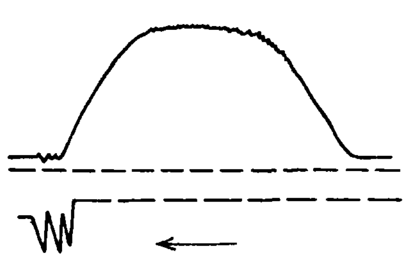

FIG. 2.

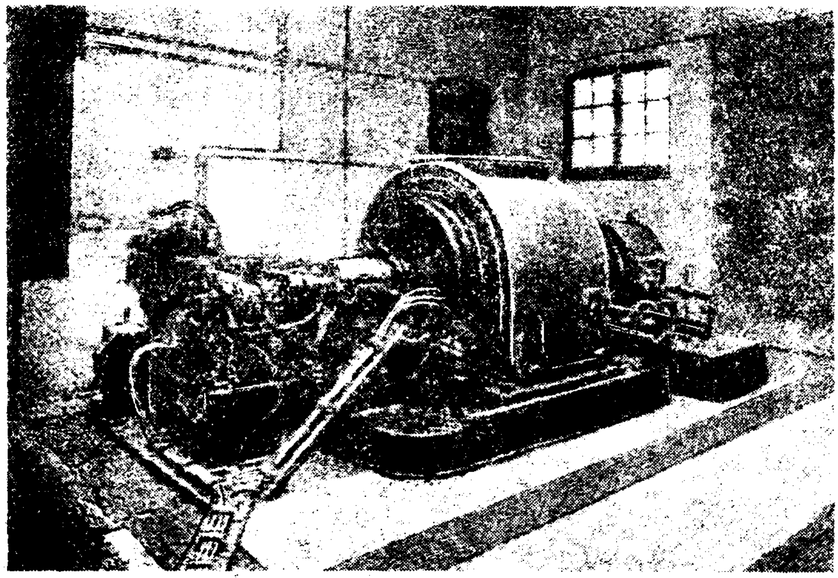

FIG. 3.

gauss can be obtained in a volume of 1–2 cm^3; unless a special alloy is found having good electrical conductivity and a strength approaching that of steel, it is extremely doubtful that fields above 1 million gauss can be attained. The hydrostatic pressure in the coil in our case reaches several thousand kilograms per square centimeter, and it is very surprising that we have never had a case in which the insulation was destroyed, although in our case we are helped out by nature, since the arc that is formed after breakdown of even thin insulation is quenched by the magnetic field, and the current continues to circulate in the usual manner. In several cases the insulation was clearly inadequate, but still no arc was formed. When a coil fails because of stress, a very large explosion occurs, and fragments of the coil fly out. We had 4 or 5 coils explode before we learned how to build coils capable of withstanding the forces involved.

Further progress in increasing the field strength must be made very gradually and cautiously.

EXPERIMENTAL METHODS

Methods of making measurements in high magnetic fields are guided by the following basic idea. Experiments must be carried out in the course of 0.01 s, which is an extremely short interval for experimental technique but long enough that the phenomena under investigation have time to become established. Actually, because the magnetic field is much stronger than usual, the phenomena occurring in it are enhanced so much that they can be investigated even in such a short time.

What is lost in terms of time is gained in size. In most cases the method of briefly acting fields cannot be extended to the region below 30 kG, and one must make additional studies with ordinary electromagnets if one is so interested.

The first problem which we will discuss is the measurement of the field itself. This problem reduces simply to measuring the current in the coil with the aid of an oscilloscope. The oscilloscope that we use has a very short characteristic period and a low sensitivity, but since the current in the coil can reach 20 thousand amperes, we can always spare 1–2 amperes to pass through the oscilloscope, and during the short time of the experiment the oscilloscope does not heat up. To determine the value of the magnetic field produced by the current, one needs to know the coil constant. This is done by a somewhat modified ballistic method.

A small coil is placed at the center of another, large coil. The small coil is short-circuited until the current in the main coil (the solenoid) reaches its maximum value; then the coil is automatically disconnected and connected to a ballistic galvanometer, from the deflection of which one can determine and the field strength in the usual way. We have found that the field in the main coil (the solenoid) is proportional to the current and that the field, of the order of 4 thousand gauss, created by the steel band of the coil does not cause a noticeable deviation from this proportionality. The various manipulations that are necessary in doing an experiment in 0.01 second make it necessary to perform a number of switchings absolutely synchronously. The whole experiment is now done at the push of a button, and everything is done automatically during the 0.01 s duration of the experiment.

MEASUREMENT OF THE RESISTANCE OF METALS IN STRONG MAGNETIC FIELDS

It is clear that for each effect that must be studied in these high fields over these short times, one must develop a special experimental method. There are no fundamental difficulties in inventing such methods for all the kinds of studies that are done in ordinary fields. The first question which we examined was, how does the magnetic field produced by a dynamo affect the resistance of metals?[8]

The basic idea of the experimental apparatus is as follows. A sample of the metal to be investigated, usually in the form of a wire, was bifilarly wound on a small coil and had 2 potential and 2 current leads, which were located on the ends in the usual way. The leads were connected, also bifilarly, to the instrumentation. The potential ends were

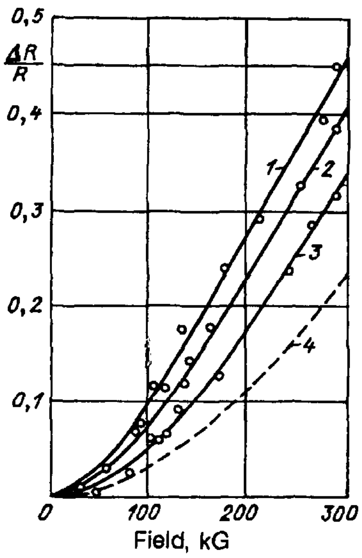

FIG. 4.

connected to a sensitive oscilloscope, and if the current passing through the leads is constant, then the deflections of the oscilloscope should be proportional to the resistance of the wire sample.

A big advantage in our case was that we could pass much larger currents along the wire than would ordinarily be allowed, since there is no danger of heating in 0.01 s. There is also a difficulty, viz., to determine the induced emf due to the change in the field in the solenoid. But this can be avoided by passing the current along the wire in individual pulses, as is shown by curve *1* in Fig. 1. The duration of a pulse was shorter by a factor of 3 or 4 than the duration of the current in the solenoid (curve H), and the current in the oscilloscope measuring the potential difference (curve P), i.e., the current due to the change in the magnetic field, will clearly be the same as before, while the current due to the potential difference, which depends on the resistance of the wire, will be superimposed on the maximum of the former current, and the amplitude arising each time the current in the wire is switched off or reversed will be proportional to the resistance of the wire. By this method we studied 35 different metals, some of them at low temperatures, since in that case the change in the resistance is more significant than at room temperature. It was found that except for ferromagnetic metals the change in the resistance in most metals obeys a quadratic law in weak fields, as was established long ago by Patterson[9] and others, but in strong fields there is a transition to a linear law. As an example, Fig. 4 shows curves for three copper wires. The second interesting effect that we found is that the physical properties of the wire have a substantial influence on the shape of the curve. For example, the purest and best-annealed wires had the shortest quadratic part and the earliest transition to linear behavior (Fig. 4). This was found in all the samples without exception. This led me to hypothesize that the increase in the resistance under the influence of chemical and physical impurities in the material are analogous to the increase in the resistance under the influence of a perturbing magnetic field. Assuming that the internal perturbation produces the same effect as some hypothetical field H_k oriented arbitrarily in all directions, and that the true change in resistance is proportional to the resultant internal magnetic field vector, one can easily obtain a formula for the change in resistance; specifically, the relative increase in the resistance is given by

$$\frac{\Delta R}{R}=\beta\frac{H^2}{H_k},\quad H\leqslant H_k,$$

$$\frac{\Delta R}{R}=\beta\left(H-H_k+\frac{H_k^2}{34}\right),\quad H\geqslant H_k,$$

where β is a constant for a given material.

This hypothesis implies that in an ideal, perfect crystal the scattering factor can be very small, and the linear law should hold almost from the very beginning and can be observed in ordinary magnetic fields. K. D. Sinel'nikov and I individually studied crystals of cadmium, zinc, and tin, and we indeed found that in the case of a rather perfect crystal the linear law began in fields below 2 thousand gauss, instead of 30–60 thousand gauss in the case of the wire. The fact is, it is not all that simple to obtain a good crystal. Indeed, it turned out that one must not pick up the crystals by hand, since the slight pressure exerted in such an act would completely spoil the crystal. We managed to obtain a perfect crystal, which gave a linear law at the very lowest fields; for this the crystalline rod to be investigated was grown together with appendages of the same metal and was introduced into the magnetic field without the slightest deformation. The technique of growing the crystals was analogous to that described previously for bismuth:[10] the metal was simply grown freely on a quartz slab, so that it would not be necessary to break apart a glass tube in removing the crystal. After being cooled in liquid air for several hours, each such crystal had a higher resistance, and the linear law began at higher fields than before cooling.

These crystals also had a lower resistance in liquid air than did crystals of the same metals investigated previously (imperfect crystals). For example, for the best Cd crystal the resistance at the temperature of liquid air relative to that at room temperature was 0.175[1)] instead of the 0.25 obtained by Meissner[11] for a crystal of the same metal. But after repeated cooling the crystal gradually acquired a higher resistance, 0.21. An x-ray diffraction analysis did not reveal any differences between the spoiled and perfect crystals; this shows that the distortions produced by heating and cooling of the crystal are extremely small, but they are nevertheless sufficient to cause a noticeable change in the conducting properties. These studies gave many interesting results which support our hypothesis and which are now being readied for publication.

The second consequence of our hypothesis is that the resistance caused by a perturbing factor can be obtained easily from the curve of the change in resistance in high magnetic fields, by constructing the tangent to the curve. It can be proven that the line segment from the origin of coordinates to where this tangent crosses the abscissa is

TABLE I.

Metal	Residual resistance at 14 K relative to resistance at room temperature	Additional resistance due to the use of magnetic measurements
Copper,	0.047	0.031 Cubic metals
hard rolled	0.036	0.027
Copper, the same	0.023	0.017
Copper, annealed	0.017	0.015
Gold	0.035	0.024
	0.048	0.05
	0.082	0.062
	0.007	0.011
	<0.0075	0.0615 Noncubic metals
	<0.0034	0.031
	0.056	0.003

equal to the additional resistance caused by the perturbations. It is natural to assume that this additional resistance should be independent of temperature and equal to the residual resistance at absolute zero.

This makes it possible to verify our hypothesis. We therefore measured the residual resistance of the samples studied in the experiments. This cannot give a conclusive answer, for which one would need a temperature below that of liquid hydrogen, and such temperatures are not yet available in our laboratory. The results of these studies showed that the residual resistance measured at liquid hydrogen temperatures and the additional resistance measured in a magnetic field agree to an accuracy of 30–40%. In Table I we give some numerical results of our studies.

One can see that in all the metals with a cubic lattice the numbers agree to an accuracy that is within the limits of experimental error and theoretical approximation; in my opinion this agreement is no accident. For metals with noncubic lattices, e.g., cadmium, zinc, and gallium, it is hopeless to look for any sort of agreement. This can easily be explained as being due to the inadequacy of the basic assumption that the additional resistance is independent of temperature. In cubic crystals this is hardly the case, as one can easily see by examining the data for the best cadmium crystal grown by Sinel'nikov and me.

At the temperature of liquid air the resistance of this crystal was 0.175 times that at room temperature, whereas for the Meissner crystal this ratio was 0.254. One can therefore expect that the residual resistance of the Meissner crystal will not exceed 0.254–0.175 = 0.079. Measurements at liquid helium temperature showed that the residual resistance of the Meissner crystal is 0.00047, or more than 100 times lower.

This means that the additional resistance must depend on temperature. It is possible that in the case when we were dealing with a set of small crystals of a noncubic system, the thermal expansion was different along different axes of the crystal, so that stresses arose when the rod was cooled or heated. These stresses are also the cause of the change in the additional resistance. Because of the ease with which a pure crystal can be deformed, one cannot expect very good agreement between the residual resistances even in the case of a pure material unless special precautions are taken in the experiment; this is probably the reason for the incomplete agreement between the residual and additional resistances of gold crystals, as observed by Meissner and Schäffers.[12] Research on the change in resistance of metals in high magnetic fields now opens up new possibilities for finding the ideal resistance of metals and will probably show that the resistance changes somewhat more rapidly with temperature than previously thought, especially at low temperatures. A conclusive answer to this question will require further experimental studies with careful precautions in respect to the perfection and purity of the samples.

MAGNETIC SUSCEPTIBILITY

The most direct topics of research in strong magnetic fields are the magnetic susceptibility and magnetostriction. As in the previous case, the strength of the magnetic field permits doing these studies only in a small fraction of a second, but the scale of the effects is greatly magnified. For example, if we take a gram of some weakly magnetic material, with a magnetic susceptibility χ of the order of 10^{-6}, and place it in a field of 300 thousand gauss with a nonuniformity of 10% per centimeter, we will have $dH/d\chi = 30 \cdot 10^3$. The force exerted on the material,

$$F = \chi H \frac{dH}{d\chi} \text{ per gram}$$

will therefore be of the order of 10 per gram.

One must therefore construct a balance with aperiodic damping, a natural frequency of around 100 oscillations per second, and a sensitivity sufficient to detect a force of 10 gf. One can easily show that a suitable balance with a natural frequency of around 1000 oscillations per second and with a mass of 1–2 g will be displaced only about 10^{-5}–10^{-4} cm by a force of 10 gf. This means that the displacement must be magnified by a factor of about 10^5. After a number of attempts we developed a hydraulic method of magnification that proved quite successful. The device, shown schematically in Fig. 5, consists of a flexible diaphragm *1* from which the sample *2* is suspended. The diaphragm is enclosed in a small chamber *3* having a small opening *4*. The space above the chamber and diaphragm is filled with oil, taking care that no air gets in. When the diaphragm is displaced under the influence of the force acting on the sample, oil passes through opening *4* with a velocity greater than the velocity of displacement of the diaphragm. In this way a magnification of 50× is achieved. To detect the motion of the oil through the opening, a small mirror *5* with a cross-sectional area of 0.5 cm^2 is freely suspended in front of the opening; the moving oil deflects the mirror, causing deflection of a light spot on a moving photographic plate. This optical lever arm gives another 2000× magnification, pushing the total magnification to 100,000×. By suitably choosing the diaphragm thickness and oil viscosity one can achieve the required sensitivity while at the same time ensuring that the balance

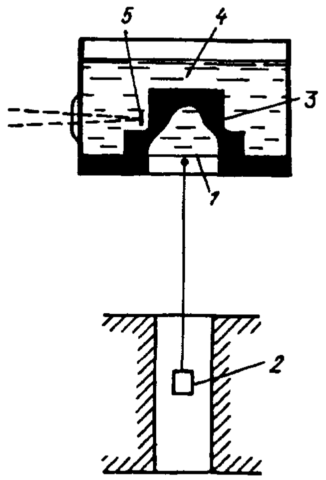

FIG. 5.

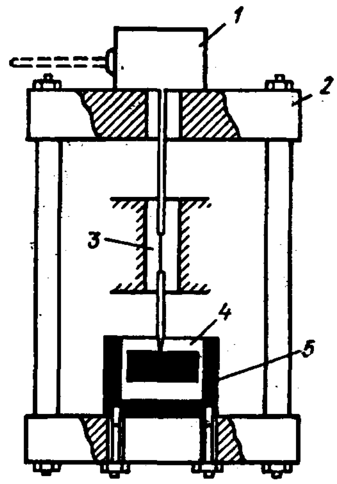

FIG. 6.

is aperiodically damped. We have found that during the short time of the experiment the small mirror exactly follows the motion of the oil without any delay, but slow motions of the oil due to thermal expansion of the device, etc., do not cause any displacement of the mirror, which is held at rest by gravity. Using this balance, which was only recently installed, we have investigated the magnetic susceptibility of amorphous bismuth at ordinary temperatures, but we have observed no deviation from the linear magnetization law in fields up to 300 thousand gauss. It is hoped that this balance will enable us to study the saturation of paramagnetic objects at low temperatures and thus to determine the value of the elementary magnetic moment. It should be noted that our method of measuring the magnetic susceptibility is different from the ordinary constant-field method. In our case it is not the isothermal but the adiabatic magnetization that we are dealing with, since the sample does not have time to come to thermal equilibrium with the surrounding medium during the brief experimental interval. The change of the sample temperature on magnetization, which was first calculated by Langevin,[13] can be appreciable down to the very lowest temperatures. In substances such as bismuth, whose diamagnetism increases with decreasing temperature, one can achieve lower temperatures through magnetization.

MAGNETOSTRICTION

When an object is placed in a magnetic field, its shape can change for many reasons. One of the first effects, which we might call classical magnetostriction, is due to the stresses caused by the magnetic forces with which the two poles of a magnetized body act on each other. In diamagnetic substances such as bismuth in fields of around 300 kG this effect is extremely small, of the order of 10^{-6}, and is not of any particular interest in the study of the magnetic properties of an object, since it can be calculated from the elastic and magnetic constants of the material. On the other hand, one expects that there should be other effects, due to the distortion of the electromagnetic structure of the atoms of a metal, that can affect the change in shape of an object. Since the size of such an effect has not yet been calculated theoretically, we could only devise a method for measuring the magnetostriction and see whether it happens to be larger than the classical magnetostriction.

The magnetostriction apparatus is very similar to that which we used to study the magnetic susceptibility and which is described above. The apparatus is shown schematically in Fig. 6. A balance *1* is mounted on a very massive framework *2*, and a rod *3* of the material to be studied is fastened to a massive plunger *4* which is free to move in a small gap in a cylinder *5*, which is firmly mounted on framework *2*. The space below and above plunger *4* is filled with oil. The rod is surrounded by a solenoid. Clearly, if the rod changes in length during 0.01 s, the plunger will be unable to move during this time because of its large inertia and the viscosity of the oil, and all the motion will be imparted to the plate, and the balance will magnify the change in length by 100,000×. On the other hand, any slow changes in the length of the rod or of the parts connected to it as a result of changes in temperature will be imparted to the plunger; thus one can eliminate all the temperature-induced distortions which cause numerous difficulties in ordinary methods of measurement. If the magnification given by the balance is 10^{-5} and the length of the sample is several centimeters, then this apparatus can measure a change in length Δl of the order of 10^{-7}. The first object that we investigated was an extended bismuth rod, which exhibited a small contraction, which was somewhat larger than expected on the basis of the classical magnetostriction. When the bismuth rod was grown in the form of a crystal we observed a more significant effect, which could be explained only on the basis of a magnetostriction due to the effect of the magnetic field on the bonds in the lattice.

A more detailed investigation revealed that if the trigonal axis is parallel to the field the rod lengthens, while if this axis perpendicular to the field the rod contracts. The contraction and extension in a given field are practically equal, so that in a rod made up of small crystals they would compensate each other; this accounts for the absence of the effect in the rod. Tests showed that the change in length in the bismuth crystal is proportional to the square of the magnetic field and increases significantly with decreasing temperature. At liquid nitrogen temperature the magnetostriction is many times larger than at room temperature, and the relative change in length $\Delta l/l$ in a field of 300 thousand gauss reaches $5 \cdot 10^{-5}$, which is larger than the values found previously for some ferromagnetic materials. These results also explain why previous attempts to detect magnetostriction in bismuth were unsuccessful.[14] In those experiments the maximum field reached only 3 thousand gauss, so that even in a bismuth single crystal the magnetostriction could amount to only $5 \cdot 10^{-8}$, while the experiment was actually done with a polycrystalline rod, so to the effect could have been of the order of 10^{-10}, too small to be measured.

We also have the capability of detecting magnetostriction in other noncubic crystals such as tin, cadmium, and graphite, but here the effect is much smaller and is still under study.

The general picture of the magnetostriction effect is roughly this: The unit cell of the bismuth crystal is very nearly a cube, slightly elongated along one of its diagonals, which coincides with the direction of the trigonal axis. Evidently, the "cube" becomes more elongated in this direction in a magnetic field.

From the general theory of magnetostriction one expects that such a deformation of the lattice, if it can be caused by external stresses, should lead to an increase in the diamagnetic susceptibility in the direction perpendicular to the axis of the crystal and to a decrease in the direction along this axis. We also made several studies of the magnetostriction of Ni and found that after the *a* several thousand gauss no further change in the length was observed as the field was increased all the way to 100 thousand gauss. It is clear from the study of all these effects that the greatest interest in the study of the magnetic properties of solids will be for crystals, and it is extremely important to have as perfect a crystal as possible. Three main factors distort the crystal lattice: first, contamination; second, stresses, and third, temperature. The future of magnetic research probably lies mainly in the study of very pure and well-grown crystals at very low temperatures. High magnetic fields eliminate the effects of distortion in the crystal in the most productive and correct way and will allow one to find the magnetic properties under these simple conditions.

There are still other topics for research, including the effect of magnetic field on the absorption, emission, and scattering of light (the Zeeman effect, Faraday effect, etc.). Our work has already shown that such studies can be done in briefly acting fields, since, e.g., the Zeeman splitting is so large that one can use a high-transmission device, and through the use of a strong light source the exposure time can be reduced to 0.01 s. Another topic of significant interest for magnetic research is the deflection of α and β rays; remarkably, the method discussed here can be applied in a number of areas of physical research more easily than it would appear at first glance.

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[1)]Translator's note: The Russian text has "...the ratio of its resistance at room temperature to the resistance at the temperature of liquid air was 0.75...," but that is inconsistent with other statements in this paper and is assumed to be a typographical error.

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