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THE ATOMIC THEORY FROM THE STANDPOINT OF MAGNETISM[1]

WHEN any substance is exposed to the influence of a magnetic field it behaves in various ways, depending upon the physical and chemical properties of the material examined. Oxygen is attracted to the poles of a magnet, while carbon dioxide is repelled. Bismuth shows a marked change in resistance when magnetized and copper only slightly. Varying degrees of hardness in steel are accompanied by corresponding changes in length due to a magnetic field. Each substance discloses its own peculiar temperament in a magnetic field, whether it be a gas, a liquid or a solid.

Magnetic phenomena are classified as effects according to the form of behavior which matter is observed to undergo when magnetized. If a magnetic field changes the optical properties of a substance it is called a magneto-optical effect, which is a very suggestive term. Unfortunately, corresponding terms to designate those effects which are produced when a magnetic field changes the mechanical, acoustical, electrical, magnetical and thermal properties of matter have not been adopted to any great extent, and while it may be unorthodox, nevertheless, such a division gives an excellent bird's-eye view of magnetic phenomena. Introducing these terms which would correspond to the term magneto-optical, the following outline of magnetic phenomena is herewith given.

OUTLINE OF MAGNETIC PHENOMENA

(1) Magneto-Magnetics	The magnetic field, forces in dia, para and ferromagnetism. Magnetic induction, intensity, hysteresis, permeability, susceptibility, coercive force, retentivity, reluctance and leakage.
(2) Magneto-Mechanics	Joule effect—Villari effect—Wiedemann effect—2nd. and 3d. Wiedemann effect—Barrett effect—converse effect—Wertheim effect—Piezo effect. Change in moduli. Volume change on solidification.
(3) Magneto-Acoustics	Production of sound by magnetization "magnetic tick."

[1] Read before the chemistry and physics section of the Mid-year Educational Conference held at the Michigan State Normal College, Ypsilanti, January 18 and 19, 1924.

	Barkhausen effect.
	Influence of magnetism on periodicity.
	Influence of vibrations on magnetism.
(4) Magneto-Electrics	Hall effect.
	Change in resistance.
	I and II v. Ettingshausen and Nernst effects.
	Change in Thermo-Electric properties.
	Induced currents—A. C., electrodeless discharge, etc.
	E. M. F. due to magnetization.
(5) Magneto-Thermics	Leduc effect.
	Change in heat conductivity.
	Pyromagnetism.
	Critical temperatures and effects of heat.
	Energy dissipation in hysteresis.
	Change in boiling point, in specific heats (?).
	Transverse temperature effects accompanying the Hall effect.
	Change in Thermal E. M. F.
(6) Magneto-Optics	Faraday effect.
	Kerr effects.
	Zeemann effect.
	Magnetic double refraction.
	Effect of light on magnetism.
(7) Cosmical Magnetism	

With a meaning analogous to magneto-optics, magneto-mechanics will include those magnetic phenomena in which mechanical effects occur due to a magnetic field. Changes in dimensions produced by a magnetizing force is an illustration of this type of phenomena. So are also those reciprocal effects in which mechanical stresses produce changes in the magnetic properties of the substance examined. The terms serving as captions for the other subdivisions may be defined in a similar fashion, as, for instance, magneto-acoustics include those phenomena in which sound is produced by a magnetic field as well as those changes in magnetic properties due to vibrations of noises, etc.

If all matter could be examined with reference to the effects classified in these six divisions it would not only be a complete magnetic analysis of all the physical properties, but at the same time would involve all the chemical properties as well. In magneto-optics, for example, if the Faraday effect was studied in all substances it would not be complete until the chemical relations were all known also. Even after a complete magnetic survey of matter was made, the study would not be ended, for there are all sorts of correlations to be made between the six groups of magnetic phenomena. As an illustration, in magneto-acoustics it is observed that the period of a tuning fork is varied by being magnetized. In magneto-mechanics there is the well-known effect that magnetism changes both the dimensions of steel and the modulus of elasticity. Here are several phenomena which may be correlated. To the extent that physical phenomena may be coordinated to that degree may a unified whole be obtained. As another example of correlation it seems to have been rather conclusively established in the field of magneto-mechanics[2] that there is one and only one set of mechanical characteristics corresponding to a given set of magnetic characteristics, and, *vice versa,* there is one and only one set of magnetic characteristics corresponding to a given set of mechanical characteristics. Can this principle which is so important in magnetostriction, for example, be applied to the other five fields of magnetic phenomena? If this is possible, then the generalized statement may be made as follows:

FUNDAMENTAL PRINCIPLE

There is one and only one set of physical and chemical properties corresponding to a given set of magnetic characteristics, and conversely, there is one and only one set of magnetic properties corresponding to a given set of physical and chemical characteristics.

Such a principle suggests a vital relation between magnetism and theories of atomic structure. The electron theory of matter, which has been so helpful in picturing the structure of the atom and adding knowledge concerning the physical and chemical properties of matter, will it portray the phenomena of magnetism? Shall we ultimately be able to isolate the elementary magnet as we have the elementary electrical charge? For instance, if a bar magnet is broken in two, the positive and negative poles will not be separated, but two magnets are formed each with their own positive and negative poles. It is conceivable that if the subdivision went far enough a portion would finally be reached whose division would not result in two magnets. What is that ultimate elementary magnet which shows this property? Is it an electron,[3] an atom,[4] a molecule[5] or an aggregation of one or more of these?[6] This is one of the outstanding questions in the field of magnetism with adherents for all the various points of view.

Naturally, in seeking for an answer to such a

[2] Burrows, Scientific Papers, No. 272, Bur. Stands., 1916.

[3] Compton, *Jour. Frank. Inst.*, August, 1921.

[4] Ewing, Proc. Roy. Soc., p. 97, Vol. 42, 1921–22.

[5] Knowlton, Trans. Faraday Soc., p. 204, October, 1912.

[6] Young, *Phil. Mag.*, p. 305, August, 1923.

question, one turns to the recent developments of atomic models to see what they have to offer by way of explanation of magnetic phenomena. The nucleus atom formulated largely by Rutherford[7] in 1911 has been instrumental in producing some very remarkable advances in both physics and chemistry and is now almost universally accepted as correct in its main principles. The nuclear atom is likened to a planetary system and is assumed to consist of a nucleus surrounded by a number of negatively charged particles called electrons, whose distances from one another and from the nucleus are very large compared to the dimensions of the electrons themselves. These electrons, like planets, revolve about the nucleus in circular and elliptical orbits. The central nucleus contains all the positive electricity in the atom and therefore practically all its mass. Not only its mass but also the radioactive properties of an atom are associated with the nucleus; its chemical properties and spectrum, on the other hand, are properties of its planetary electrons.[7] In the hands of Bohr[8] and Sommerfeld[9] and others who have applied the quantum and relativity theories to this type of atomic structure, this model has been particularly powerful in the analysis of spectral phenomena. Such an atomic model has electrons in it; it goes to make up molecules. Where in such a piece of machinery lies that element which is responsible for magnetic phenomena?

In a recent and very suggestive paper Young[10] has studied the crystal structure of the Heusler alloys, which are magnetic alloys formed from non-magnetic elements. He sets out to learn, if possible, the origin of magnetic phenomena. Discussing the various explanations that have been offered in explanation of the magnetic properties of the Heusler alloys, he finally arrives at the conclusion that "the evidence to date points to the probable seat of magnetic phenomena in the behavior and configuration of the outer or valence electrons," and adds, "this, of course, is in agreement with the well-known changes in magnetic properties that take place as the result of chemical action, and those due to temperature variation which might be expected to have a direct influence on the loosely-bound valence electrons."

At best the picture we draw of the elementary magnet is a hazy one. We can speak of it only in glowing generalities. While we do know a little about the magnetic moment of the elementary magnet, yet we do not seem to be able to bound it as we do the elementary electrical charge. One feels, however, that the picture of negative charges revolving swiftly in orbits about the positive nucleus must, in the end, explain magnetic phenomena, but how? It all means to say that there is a very great need for physicists to turn their attention to sustained research in magnetic phenomena. This need will produce investigators, and it is a fairly safe prediction to make that the next decisive advance in the conception of atomic structures will be in the field of magnetic behavior. There are several lines of research in magnetism that should be pushed at once. One is an investigation of the magnetic properties of *atomic* hydrogen. The magneto-optical behavior of the fine-line spectrum, together with the diamagnetic properties of *molecular* hydrogen, indicate that the molecule of hydrogen should possess no magnetic moment, and which is in accord with Bohr's model. On the other hand, since in the atom of hydrogen there is a single electron cruising around the nucleus there should be a magnetic moment and therefore paramagnetic in its behavior. Experimental confirmation of this would be an important contribution.

Thus far the Rutherford-Bohr-Sommerfeld atom has contributed largely to the theory of the origin of spectra. For that reason an extensive study of the Zeemann effect would add to our knowledge of how magnetic phenomena are related to atomic structures.

From a rather extended study of magnetostrictive phenomena one is led to the point of view that if magnetic phenomena are due to the outer or valence electrons, then the spatial distribution of these electronic orbits are exceedingly important. This is supported in particular by the effect of temperature treatment (hardness) as related to the changes in length produced by a magnetic field (Joule effect). Bohr[11] has emphasized this point of spatial distribution of the electronic orbits in the atoms in seeking for "the ultimate cause of the pronounced stability of certain arrangement of electrons." If the spatial distribution of the orbits within the atom is important, no less so is it in the internuclear space. The work of Hull[12] in showing that the property of ferromagnetism does not depend upon the arrangement of atoms so much as upon the distance between them confirms this important point of view. It is supported by the work of Perrier and Onnes[13] in a study of the paramagnetism of liquid oxygen diluted with nitrogen. As the concentration diminished, *i.e.,* as the distance between the electronic orbits of the molecules increased, the specific magnetization coefficient of oxygen became greater. Continued studies of this spatial rela-

7 Aston, "Isotopes," p. 92 and p. 93, 1922.

8 Bohr, *Zeit. Physik.*, 9, pp. 1–67, 1922.

9 Sommerfeld, "Atomic Structure and Spectral Lines," 3d. Ed., 1922.

10 Young, *Phil. Mag.*, p. 29, August, 1923.

11 Bohr, "The Theory of Spectra and Atomic Constitution," p. 74, 1922.

12 Hull, *Phys. Rev.*, p. 540, 1919.

13 Perrier and Onnes, Proc. Roy. Acad. Amsterdam, 16, 901, 1914.

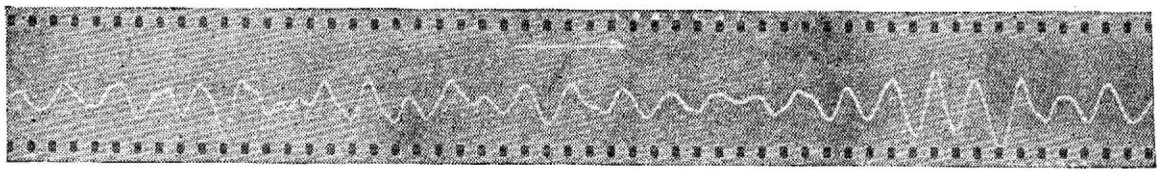

FIG. 1. Oscillogram of Barkhausen Effect.—Arrow indicates direction film moved.—Distance from one perforation to the next indicates 1/509 of a second.

tionship of the electronic orbits in internuclear and intermolecular space must still yield very valuable contributions to our knowledge of atomic structure.

In applying the quantum theory to magnetic phenomena it appears that an atom possessing a magnetic moment and subjected to a magnetic field is not able to orient itself into any position but only at certain definite inclinations, such that the cosine of the angle between the magnetic axis of the atom and the direction of the applied field will have one of certain specified values.[14] Gerlach's[15] work with a ray of silver atoms projected through a magnetic field with an extremely steep field gradient seems to confirm this. If such a point of view is correct would it not indicate that the process of the magnetization of iron, for example, would not be a continuous process but stepwise? An oscillographic study[16] of the Barkhausen[17] effect shows that the magnetization process does proceed by irregular steps and not continuously. The elementary magnets appear to jump in groups, sometimes a great many and at others a few only (see Fig. 1). Is the Barkhausen effect another confirmation of the applicability of the quantum theory to magnetic phenomena? It is an interesting avenue of approach to the study of magnetic phenomena.

Not only will these four specific lines of research in magnetic phenomena be illuminating to the whole field of atomic structure, but the fundamental principle enunciated in the beginning becomes itself a program of research along the same line that must challenge many because of the numerous problems which it suggests.

There are a few items which should be emphasized in connection with research in magnetism. As far as possible the same specimens should be used in all the magnetic tests which may be applied to any substance. For instance, if the magneto-mechanical effects of a steel rod are studied, the same rod should be used in studying the Barkhausen effect in magneto-acoustics, the change in resistance in the next group, its magnetic induction, the effects due to heat and the Kerr effect in the other groups. *The importance of making as many tests as possible on the same specimen can not be overestimated.* Here, if anywhere in scientific research, there must be cooperative action, for the program of research as outlined above will lead into the fields of physics, chemistry, both physical and chemical metallurgy and mineralogy. A group of physicists, mineralogists expert in X-ray analysis, chemists and metallurgists cooperating in the study of magnetic phenomena could make a wonderful contribution to this field. Helmholtz is quoted as having said that "the disgrace of the nineteenth century is its ignorance of the subject of magnetism." Will the twentieth bring knowledge?

There has been a prodigious amount of labor performed in the field of magnetic research. Knowlton[18] counted the papers on the subject of magnetism which had been reviewed in *Science Abstracts* for the decade 1900–1910 and there were about five hundred, exclusive of technical contributions and papers on electromagnetism. *Sustained research, both coordinated and cooperative, is needed in the fields of magnetic phenomena.*

A great deal of work has been done on materials whose chemical properties were not known, to say nothing of the previous physical history which is so important in correlative studies. There is real need to go back and review the experimental data and where possible correlate one set of facts with another, and where no knowledge of the physical and chemical history exists repeat the experiments as far as possible with standard or known conditions. *Modern methods of pyrometry, microphotography, chemical and X-ray analysis give no excuse for ignorance of the character of the materials used in magnetic investigations.*

The magnetic analysis of the physical and chemical properties of matter will lead into many fields that at present are almost wholly unexplored. This is illustrated in that work which has rather recently been undertaken, *viz.*, the study of the mechanical properties of steel by magnetic analysis. In the case of diamagnetic substances the magnetic forces are so feeble that they may be investigated only by very delicate methods. *This difficulty will disappear as the technique of the problem is developed.*

A general study as thus outlined would lead to two very distinct goals: first, it would develop methods of

[14] Darrow, *Bell System Tech. Jour.*, October, 1923.
[15] Gerlach, *ZS.* f. Physik., 9, pp. 349–355; 1922.
[16] Williams, *Phys. Rev.*, p. 526, November, 1923.
[17] Barkhausen, *Phys. ZS.* 20, 401–403, 1919.
[18] Knowlton, *Terres. Mag.*, p. 3, March, 1910.

analysis of immense value to the industrial arts and sciences, and secondly, of even greater significance, a furtherance of our present concept of the structure of the atom.

Now why have I brought to you, my fellow teachers, this rather specialized discussion of research work? In the first place, because it is typical of all modern research work in the physical sciences, it is concerned with the problem of atomic structure in which we are all interested. Secondly, and most important of all, you hold a very strategical position in the program of research in this country in the fields of physics and chemistry. It is given to you, the unique honor of introducing very many of our future research chemists and physicists to their first formal knowledge of the fundamental sciences of chemistry and physics. To you is given the opportunity to inspire these embryo scientists with a love and enthusiasm for the fields of knowledge in which we are so interested. Every hour in the class-room or laboratory is one of golden opportunity to instill in their minds a desire for more knowledge in these fields. We may erect on the highway of knowledge along which these young people travel signboards bearing the words "On to College." That wisdom may be shown in whom we recommend for college and that the proper college be urged to these students needs to be emphasized. Our zeal in recruiting should not run riot. The slogan "On to College" is for those servants which have more than one talent. Beyond the college lies the graduate school. To only a gifted few is the invitation, "Enter thou into the joy of creative scholarship." In the matter of pushing a favorite college it should not be from the standpoint of its being our Alma Mater, unless we are sure that these young people will be furthered on in the divine life of scientific knowledge. They must be recommended to a college which is known for its equipment and scholarly and enthusiastic teachers and not because it happens to have a winning football or other athletic team.

Isn't this hope of being able to contribute to the development of future great physicists and chemists a stimulus to do our own work just a little better than ever before as thus we help young men and women to find their life work? I believe it is.

S. R. WILLIAMS

OBERLIN COLLEGE

EXPERIMENTAL BIOLOGY AND THE WORK OF THE MOSCOW INSTITUTE*

ZOOLOGY of to-day differs greatly from the zoology of the nineteenth century. Two points are characteristic in modern zoological research. First, the chief method of zoology is now experimental and we call our science a branch of experimental biology. Second, during the period of the last ten years all branches of the natural sciences have come to need organization, and experimental biology requires organization more than any other science. The organization of science must be national in the sense that every country will coordinate its own researchers, who must work under the particular conditions which their country may afford, but the work of these national organizations can of course be regulated by international meetings.

I wish to offer many thanks to the American Zoological Society and the Genetics Section for their kind invitations to take part in the meeting at Cincinnati. I am very sorry that circumstances have not allowed me to take part in it personally, as had been my wish, and that I have been compelled to send the report, which I intended to read.

Some of the American biological laboratories have been devoted to determined special purposes. So, for instance, the celebrated laboratory of Jacques Loeb pursues the fundamental problems of the application of physical chemistry to biology, and T. H. Morgan's laboratory is especially devoted to the genetics of Drosophila. But it would be very interesting to unite these two scientific tendencies in the same institution. In every science the best results are to be obtained when the same theme is treated with two quite different methods belonging to two different scientific branches. Therefore, I have tried to put together in my Moscow Institute of Experimental Biology many different sections, such as cytological, biochemical, physiological, behavioristic, genetic and eugenic sections. Sometimes two or more of these sections work on the same subject, but every section investigates the problem from its own point of view and with its own methods.

I

The chief problem of our cytological section is that of the cell-skeleton. In 1905, when studying the structure of the sperm of different crayfishes[1] I came to the conclusion that every cell whose external form differs from the spherical one ought to consist of a drop of liquid protoplasm (hydrosol) and of a hard protoplasmic skeleton (hydrogel), whose form determines the external form of the cell. The rôle of this skeleton is played by the hard cell membranes or by the organic fibers which lie in the outer layer of the protoplasm and define the form of the liquid proto-

* Address sent to the convention of the American Society of Zoologists, upon invitation of the society.—ED.

[1] N. K. Koltzoff, "Studien ueber die Gestalt der Zelle." Th. I, *Archiv für Micr. Anat.*, Bd. 67; Th. II and III, *Archiv für Zellforschung*, Bd. II and VII.