Note on the Broadening of X-Ray Lines of Cold-Worked Aluminum

In the course of an investigation of internal strains in metals now in progress, the authors thought it advisable to check the experiments of van Arkel,[1] Dehlinger,[2] and others with regard to the reported impossibility of broadening the Hull-Debye-Scherrer lines of aluminum by cold-deformation, inasmuch as the effect of temperature of working seems to have been generally neglected in the work reported in the literature which has come to the authors' attention. In view of the kinetic nature of inner-strain-relief, the effect of working temperature seemed of theoretical interest, as the metals lead, tin, zinc and aluminum, which were reported to show no broadening of lines also have low recrystallization and melting temperatures.

A number of specimens of 99.97 percent pure aluminum were severely cold-worked by compression under similar conditions with the exception of temperature. The first group was compressed at room temperature, while the second was compressed in a bath of dry ice in acetone at −75°C.

The diffraction pictures, taken at room temperature, were completed within two hours after compression of the specimens, in order to minimize annealing effects. Moll microphotometer records were made of the (440) Fe $K\alpha$ doublet lines and the ratio of the maximum α_1 ordinate to the ordinate of the minimum between α_1 and α_2 was used as a measure of the sharpness of resolution. This ratio is 2.9 for the samples worked at room temperature, and 1.5 for those compressed at −75°C. Diffraction pictures of annealed specimens of aluminum have ratios for this doublet similar to that of the samples worked at room temperature. These results indicate that broadening of the x-ray lines of aluminum may be obtained by cold-working at −75°C.

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April 7, 1933.

[1] A. E. van Arkel, Physica 5, 208 (1925).
[2] U. Dehlinger, Zeits. f. Krystallographie 65, 615 (1927).

Discontinuities of Magnetoresistance

According to current theories of magnetism a ferromagnetic body consists of small elements each magnetized to a saturation intensity J. The body as a whole will be unmagnetized unless a preponderance of the J vectors point in a given direction. An external field may magnetize the body by two possible processes: (A) reversal of the directions of those J vectors which oppose the external field, (B) rotation of the J vectors into the direction of the applied field. Process A is considered to be irreversible and process B is, in the main, reversible.[1] Barkhausen discontinuities of magnetization being irreversible, are on this view interpreted in terms of process A.

It has been found[2] that the magnetoresistance of nickel does not become very large (as the magnetic field is increased) until the magnetization curve of the nickel has passed the knee. Where the slope is greatest and where large Barkhausen jumps occur, the magnetoresistance is small and does not vary rapidly. W. Gerlach, therefore, supposes that process A does not affect the electrical resistance; magnetoresistance is due entirely to process B. He suggests[3] that "the irreversible phenomena are without influence on the electrical resistance, and therefore on the phenomena which exist in a rotation of Forrer's magnetic elementary bodies." Apparently these "irreversible phenomena" are the strikingly large jumps of magnetization discovered by Forrer.[4] An experimental test of this idea has been made as follows.

A nickel wire, 5 cm long, 0.01 cm in diameter, was bent into the arc of a circle and then thrust into a short length of capillary tubing. It was thus held straight but in a state of elastic strain. The tube and wire were then inserted in a small coil of about 3000 turns, connected through a three stage amplifier to a loudspeaker. When a permanent magnet was brought up slowly towards one end of the nickel wire the loudspeaker indicated the existence of one large magnetic discontinuity followed by several smaller ones. The search coil was now removed and the nickel wire connected in series with a rheostat and dry cell. The low-resistance side of a microphone transformer was put in parallel with the nickel wire, and the output side of the transformer connected to the amplifier and loudspeaker. With this arrangement a change, dS, in the resistance of the nickel will produce a change dI, in the current through the transformer, given by $dI=ERTdS/(RS+RT+ST)^2$, where E is the e.m.f. of the dry cell, R the resistance of cell and rheostat, T the resistance of primary of transformer, and S the resistance of the nickel wire. With a given nickel wire and transformer the condition for a maximum of dI is $R=ST/(S+T)$. This condition was approximately satisfied by adjusting the rheostat. When the permanent magnet was moved towards one end of the nickel wire in this circuit a sharp click was heard in the loudspeaker, followed by several smaller ones. These clicks were due to sudden changes of resistance corresponding to the magnetic discontinuities previously observed. (Unless some care is taken to adjust resistances and secure high amplification these clicks are of weak intensity. Also, the permanent magnet must not be brought too near the transformer or the Barkhausen effect of the transformer core will be heard.) Ordinary nickel or iron wire, when substituted for the strained nickel in the electric circuit produced noises in the loudspeaker very similar to the noise of the Barkhausen effect as picked up by the search coil.

We conclude, therefore, that discontinuities of resistance are associated with discontinuities of magnetization. It seems entirely reasonable that process A, mentioned above, should not produce any resistance change, because the resistance of a wire is unchanged by a mere reversal of its saturated magnetism. For a similar reason it is hard to see why process A should produce any resultant magnetostriction. Since the Barkhausen discontinuities are found to be associated with both resistance jumps and magnetostrictive jumps[5] we must conclude that process A is not the main feature in the Barkhausen effect.

A third type of change which the J vector may undergo has been suggested.[6] This third process consists of a sudden swing of the J vector through 90° (in an unstrained cubic crystal) from one crystalline axis to another. If the Barkhausen effect is due to this kind of process it could have magnetoresistance and magnetostriction associated with it. Also, if process B is influenced by strains in the material it alone could give rise to jumps of magnetization, resistance, and magnetostriction in a manner previously described.[7]

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April 7, 1933.

[1] W. Gerlach, Ann. d. Physik **12**, 894 (1932).
[2] L. W. McKeehan, Phys. Rev. **36**, 948 (1930).
[3] W. Gerlach, Proc. Phys. Soc. **42**, 418 (1930).
[4] R. Forrer, J. de Physique **7**, 109 (1926).
[5] C. W. Heaps and A. B. Bryan, Phys. Rev. **36**, 326 (1930).
[6] W. L. Webster, Proc. Phys. Soc. **42**, 431 (1930).
[7] C. W. Heaps, Phys. Rev. **42**, 108 (1932).

Radiation Reaction Forces and the Expanding Universe

More than a year ago[1] the author pointed out that in a star that had just broken up, the reacting forces due to the asymmetrical radiation of mass would add momentum and kinetic energy to it, and it would be propelled through space much like a skyrocket.

An analysis of the motions imparted to a star as the result a deep seated thermal asymmetry resulting from fission shows that the kinetic energy W of an average star increases at a rate given by

$$\frac{dW}{dt}=\frac{Mf^2c^2b^2}{2}\left(\frac{1}{M}\frac{dM}{dt}\right)^2 t, \tag{1}$$

where M is the mass of the star, c the velocity of light, t the time and f and b are characteristic constants. A secular and statistical increase in the kinetic energies of all the stars implies an expansion of the system, and we have been able to work out, with sufficient completeness, the rate of expansion.

It is found that the radius of gyration of the galaxy is subject to a "uniform" acceleration (a) given by

$$a=\frac{2fbc}{[6/(1-q)]^{\frac{1}{2}}}\left(\frac{1}{M}\frac{dM}{dt}\right), \tag{2}$$

where q and dM/Mdt are supposed to be nearly constant. Now if G is the radius of gyration of a uniformly expanding system, then the velocity of recession V_r of a point at a distance R from an observer is

$$V_r=(dG/Gdt)R \tag{3}$$

and because of the form of Eq. (2) this becomes, to a first approximation

$$V_r=2R/\tau, \tag{4}$$

where τ is the interval of time since the Universe was comparatively dense. Putting Eq. (4) in terms of observed quantities we can show that

$$V_r=\frac{2^{\frac{1}{2}}fb(dM/Mdt)}{\Delta V/c}R. \tag{5}$$

The numerator can be evaluated from the masses, luminosities, etc. of the stars in the galaxy and the denominator determined from the observed differences in velocity ΔV between early and late type stars. With data that we believe to be correct, Eq. (5) becomes

$$V_r=10^{-17}R \tag{6}$$

and hence stars in our own galaxy must be statistically receding from us and at a rate proportional to their distance. The form of the equations show why the early type stars are observed to recede at the greatest velocity.

The mechanisms developed and applied to the galaxy are, with certain restrictions, applicable to nebulae. Eq. (6) is, of course, *identical in form and numerical constant with Hubble's observed relation.*

Our results indicate that the expansion is a slow evolutionary process and that the initial rate of expansion was probably small. The age of the Universe and galaxy approximates to 10^{10} years. We note particularly that we have not assigned special properties to space. Further, the expansion is real and results necessarily from radiation processes which take place in stars and nebulae that have suffered fission. Calculations show that except immediately after fission, the radiation reaction forces acting on a star are small compared to gravity and thus the motions of a star over short time intervals are adequately described by gravitational theory. But the mechanism slowly adds kinetic energy to the system and in describing the motions of stars over long periods of time, radiation reaction forces are perhaps of as great importance as the gravitational forces.

The complete papers should appear shortly.

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Naval Research Laboratory,
April 8, 1933.

[1] R. Gunn, Phys. Rev. **39**, 130 (1932).