A type A-19 advance wire strain gauge[4] with an effective length of $\frac{1}{16}$ in. was cemented onto the top surface of the crystal. This gauge is then made the active arm of a Wheatstone bridge in which all other arms are similar strain gauges and placed very near the crystal so as to minimize temperature and other effects. The detector is a Perkin-Elmer d.c. amplifier the output of which is connected to an Esterline-Angus d.c. milliampere recorder. The crystal was mounted in a unit which permits rotation of the crystal in the magnetic field. The change in magnetostrictive strain in a direction fixed relative to the crystal axes is then measured as the direction of magnetization is varied. The magnetic field employed is 4000 oersteds; thus the sample is always saturated and only differences in strain as a function of the direction of magnetization are measured. This eliminates the need for making any assumptions concerning the demagnetized state. The results are shown in Fig. 1 in which the strain in a fixed direction is plotted against the angle made by this direction with the applied field. The strain when the gauge is perpendicular to the field is arbitrarily set at zero. From this data, the constants in Becker's expression for the magnetostriction as a function of the direction cosines of the direction of strain and the direction of magnetization[5] can be obtained. In our case four terms in the series are required. Using Becker's notation we obtain for the magnetostriction in the principal crystal directions:

$$\lambda_{[100]}=1.5\times10^{-5}, \quad \lambda_{[111]}=8.5\times10^{-5}.$$

An extension of these measurements to other compositions is currently in progress. We are indebted to Mr. H. Plotkin for helpful assistance in making the x-ray measurements and to Professor Smoluchowski for discussions.

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[2] R. Becker, Zeits. f. Physik **87**, 547 (1934); also W. J. Carr, Jr. unpublished dissertation, Carnegie Institute of Technology (1950). We are indebted to Mr. Carr for discussions on this point.

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[5] Becker-Doring, *Ferromagnetismus* (Verlag. Julius Springer, Berlin, 1939), p. 275.

Theory of Magnetic Anisotropy in Alnico V

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ALNICO V is the name given to an alloy of iron, cobalt, nickel, aluminum, and copper, which when cooled in a magnetic field shows unusual magnetic properties in the direction of the field. The energy product, $(BH)_{max}$, of an alloy treated in this manner is increased by a factor of three when a field is present during cooling. The composition is particularly critical with respect to cobalt and aluminum content; i.e., changes greater than two percent in either direction destroy the effect of the field almost completely. Recently it has been demonstrated that with proper thermal treatment a preferred grain orientation in Alnico V can be obtained and then a preferred domain distribution can be produced by cooling in a magnetic field. The result is a further improvement in the magnetic properties.

Kittel, Nesbitt, and Shockley[1] have recently discussed the origin of the anisotropic properties of Alnico V and have interpreted the effect of the heat treatment in terms of a preferred direction of nucleation of the precipitated phase arising from the extra magnetostatic energy when the magnetization of the precipitate differs appreciably from that of the matrix, with a resulting preferred shape anisotropy. Although it is not specified whether the precipitate has a greater or smaller magnetization than the matrix, it is apparent that it must be smaller in their theory, for otherwise it would require very large fields to saturate the alloy in directions other than the direction of the field present during the anneal. Specifically, a plate-like precipitate of the dimensions suggested by KNS with a magnetization *ca.* 1700 c.g.s. units requires a field of 15,000 oersteds to saturate it in a direction normal to the plate. It follows that in a direction perpendicular to the cooling field for reasonable volumes of precipitate compatible with the known saturation magnetization of the alloy (p in KNS notation), a field of the order of 10,000 oersteds would be required to attain saturation contrary to experimental evidence. On the other hand, to suppose thus that the precipitate is the more weakly magnetic constituent is contrary to the observations of Bradley and Taylor[2] and Dannohl[3] for FeNiAl, recently confirmed by Geisler[4] and by Went[5] for Alnico V. Moreover, the theory of KNS does not explain the unusual sensitivity of the Alnico V effect to small changes in composition[6] nor does it suggest a reason for the significant improvement obtainable by means of directional grain growth.

We propose to explain the Alnico V effect by considering the anisotropy of the elastic energy which accompanies the formation of nuclei of the precipitate during annealing in a magnetic field. This elastic deformation is due to magnetostriction of the strongly magnetic precipitate. The elastic anisotropy causes preferential growth of nuclei of given orientation. As shown below, this picture not only explains quantitatively the magnetic properties of Alnico V but also the sensitivity to composition and to grain orientation of the matrix. The very existence of the nuclei in the form of platelets in this and many other non-magnetic alloys reflects the influence of elastic strain at the temperature of nucleation.[7]

Alnico V differs from Fe_2NiAl (app. Alnico III) in the addition of cobalt and increased iron content. If one makes the plausible assumption that cobalt behaves as iron in solid solution, calculation shows that the precipitate is an iron-cobalt alloy containing approximately 30 percent cobalt. Comparison of the saturation moment and remanence of Alnico V with the moments of the assumed phases and of Alnico III confirms this assumption. (An extreme assumption that all the cobalt goes into precipitate does not alter the subsequent results significantly; any other assumption would be highly improbable.) It has been shown[8] that for an alloy of this composition, the magnetostriction is smallest in the cubic direction: $\lambda_{[100]}=1.5\times10^{-5}$, $\lambda_{[111]}=8.5\times10^{-5}$. Therefore, the elastic deformation due to magnetostriction is smallest when the nucleus is oriented with the [100] in the direction of the field. Such nuclei will, therefore, have a somewhat lower free energy and will grow preferentially. There will thus be a preponderance of volume of recipitate with a direction of easy magnetization ([100] axis) making a small angle with the field direction. According to our picture, therefore, the Alnico V effect which is essentially an increase in remanence is associated with the crystalline anisotropy of the precipitated magnetic phase and is consistent with recent results obtained by Geisler[4] with the electron microscope on single crystals of Alnico V. It appears, as Dr. Kittel has pointed out to us, that the orientational energy due to demagnetization is much greater than that due to magnetostriction. This is certainly true especially since ΔI appears to be about three times as great as the minimum value of 500 assumed by KNS. To be sure, this may influence the shape of the precipitate but, as indicated above, cannot alone explain the remanence or the field required to saturate in a direction perpendicular to the annealing direction.

On the basis of this theory we can now account for the unusual sensitivity of the Alnico V effect to composition. If the cobalt content is decreased, the Curie temperature of the precipitate is rapidly decreased to below the proper nucleation temperature. If the cobalt content is increased, the crystalline anisotropy of the precipitate is rapidly decreased and reverses its sign at a composition of 45 percent cobalt in the precipitate itself. Similarly, a decrease in aluminum content causes more nickel to go into the precipitate and reduce its Curie temperature.[9] An increase in aluminum content would tend to make cobalt enter the Ni-Al matrix with a similar effect on the Curie temperature of the precipitate.

We are indebted to Dr. Geisler and Drs. Kittel and Shockley for making available to us the results of their investigations in advance of publication.

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On the Temperature Variations in Alcohol-Argon Filled G-M Counters

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RECENTLY Tanyel[1] has noticed an improvement in plateau of a xylene-argon filled counter with rest period after filling. This is believed to be due to the formation of a continuous film on the cathode. The partial removal of the film, on heating the counter at 120°C and then cooling it slowly, produced an increase in slope of the plateau, which improved again with time. The effect, which the author[2] reported, in the case of ethyl alcohol-argon filled counters has also been attributed to the alteration of the film. However, our recent experiments, at even higher temperatures than those reported in the previous case, do not seem to confirm the above view, at least, in the particular case of alcohol-argon filled counters.

Counter B of the previous communication was successively raised to higher temperatures through 20° steps (up to 180°C) in a thermostat (±0.5°C) and kept at each temperature for 2 to 3 hr. Counting rate-voltage curves were obtained (Fig. 1) at different high temperatures and soon after each heating (within 30 min.) when the counter came to the room temperature. The curves obtained at room temperature before and after heating come out to be practically similar. A very large increase in counting rate and slope of the plateau is observed at high temperatures. Finally the plateau disappears. This is not in accord with the view of Tanyel in that he finds a semipermanent increase in slope which improves with time. If we consider the effect which we reported to be due to the partial removal of the film, then we must assume that either (a) this does not occur within the temperature range investigated or (b) the film removed on heating is restored soon after cooling.

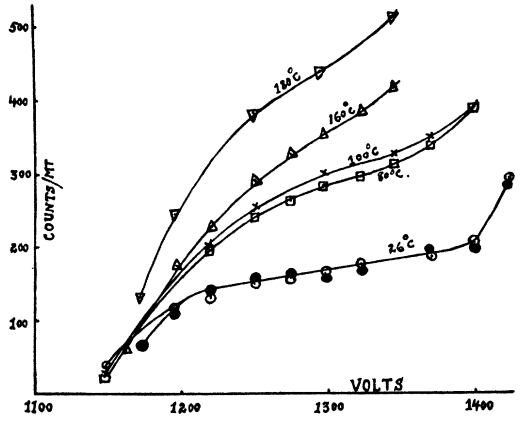

FIG. 1. Counting rate *vs.* voltage curves for counter B at different temperatures. Curves (●) before heating and (⊙) after heating at 26°C are exactly similar. Other repetitions have been omitted.

The large counting rate and greater slope at higher temperatures, together with the fact that there is a "residual slope"[3] always present with self-quenching G-M counters, may occur because of the spurious pulses which arise due to the positive ions[4] striking the cathode. If we assume that the secondary emmission from the cathode by the positive polyatomic ions is negligible at ordinary and even higher (?) temperatures, then the positive ions responsible for spurious pulses, and hence for the above-mentioned effects, may be of mercury. That mercury vapor can produce spurious pulses is not unexpected, since mercury has a low ionization potential (10.4 v) with the result that some ions are able to reach the cathode. (It may be mentioned that mercury vapor is always present in the counters owing to the mercury manometers, etc., which are connected with the filling apparatus.) However, the mercury ions are probably less effective at ordinary temperatures[5] but more important at high temperatures[6] and this explains the mentioned effects. Simpson[7] has recently reported an increase in slope in neon-argon counters from 0.035 to 0.11 percent per volt with mercury contamination and organic vapor impurities from greases. This supports the above view and further shows the effect of mercury vapor even at ordinary temperatures. The author's observations, therefore, seem to be a temperature effect rather than the cathode film effect. Detailed work on temperature effects in counters with and without mercury vapor contamination will be reported.

Thanks are due Dr. H. R. Sarna, Director of the Punjab University Physics Laboratories, for providing facilities for this work.

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Multiple Scattering of Fast Electrons in Nuclear Emulsions*

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IN view of the increasing importance of multiple scattering in nuclear emulsion work[1] some preliminary scattering measurements on 115±5-Mev electrons in Ilford G-5 plates will be of interest. For each of 50 tracks the y-coordinate was measured with a calibrated eyepiece scale at 50μ-intervals along the x-coordinate. The angle between successive chords drawn between the ends of the intervals is given by $\alpha=D/X$ where D is the second difference $(2y_n-y_{n-1}-y_{n+1})$ and X is the interval length. The mean angle $\langle\alpha(X)\rangle_{Av}$ between chords for interval lengths X of 50, 100, 200, 300, and 400μ has been computed and is shown in Table I. The corresponding mean angle $\langle\alpha(100)\rangle_{Av}$ for a 100μ-interval (computed by assuming α proportional to $X^{\frac{1}{2}}$) is shown for each interval. For short intervals the measured mean angles

TABLE I. Second difference $\langle D(X)\rangle_{Av}$ and mean angle $\langle\alpha(X)\rangle_{Av}$ between successive chords for interval of length X. Also corresponding mean angle $\langle\alpha(100)\rangle_{Av}$ for a 100μ-interval.

X	$\langle D(X)\rangle_{Av}$	$\langle\alpha(X)\rangle_{Av}$	$\langle\alpha(100)\rangle_{Av}$
50μ	0.24μ	0.28°±0.01°	0.40±0.01
100	0.46	0.26 ±0.01	0.26±0.01
200	0.97	0.28 ±0.02	0.20±0.02
300	1.61	0.31 ±0.03	0.18±0.02
400	2.26	0.32 ±0.03	0.16±0.02