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The Diffraction of X-Rays by Liquid Na-K Alloy in a Magnetic Field

C. W. HEAPS, *The Rice Institute*

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Because magnetoresistance is found in the liquid Na-K alloy there is reason to expect that a magnetic field might modify the x-ray diffraction curve of the liquid. Experiment indicates that the diffraction is not changed by as much as two percent in a field of 2700 gauss. A test made to detect magnetostriction in the alloy indicates no volume change per unit volume greater than 3×10^{-7} in a field of 7800 gauss. The cause of magnetoresistance in the liquid does not, therefore, appear to lie in changes of molecular grouping caused by a magnetic field.

THE liquid alloy of sodium and potassium has recently been found to increase its resistance when placed in a magnetic field.[1] It also shows a fairly large Hall effect. The discovery of these galvanomagnetic effects in a liquid is a matter of some importance; it would now seem that a molecular lattice structure is not necessary for the production of the effects, although this structure has occasionally been suggested as fundamental in the phenomena. The empirical fact has been, heretofore, that strongly crystalline substances of low degree of symmetry (e.g., Bi, Sb, graphite) have the largest values of magnetoresistance. The Sommerfeld theory as developed by Houston[2] assumes the resistance of a metal to be due to deviations of the lattice from symmetry, such deviations being caused by impurities or thermal motions. If a magnetic field in any way affects the regularity of lattice structure we might expect magnetoresistance to appear.

There is at present a considerable body of evidence in favor of the view that liquids possess characteristic molecular structures. G. W. Stewart's idea[3] is that large numbers of molecules may be cooperating at any one instant of time to form temporary lattice arrangements in the liquid. Although this viewpoint is not necessary in order to explain x-ray diffraction curves for liquids there are a number of reasons why it is a plausible hypothesis. If it is accepted we might expect a magnetic field to affect either the number of molecules which at any one time are cooperating, the time of their cooperation, or the orientation (crystalline axis) of the group. Hence, following the general lines of Houston's theory, the field might be expected to change the resistance of the liquid. If the field produces any of the suggested effects on molecular grouping, the x-ray diffraction curve of the liquid would be modified, provided the effects are large enough. It seemed worth while, therefore, to investigate the effect of a magnetic field on the x-ray diffraction curve of the liquid Na-K alloy.

EXPERIMENT

The x-ray spectrometer was equipped with Soller slits and an ionization chamber made of seamless steel tubing filled with argon at about 20 atmospheres pressure. A celluloid window

[1] Fakidow and Kikoin, Physik. Zeits. d. Sowjetunion **3**, 381 (1933); J. E. Armstrong, Phys. Rev. **47**, 391 (1935).

[2] W. V. Houston, Zeits. f. Physik **48**, 449 (1928).

[3] G. W. Stewart, Rev. Mod. Phys. **2**, 116 (1930).

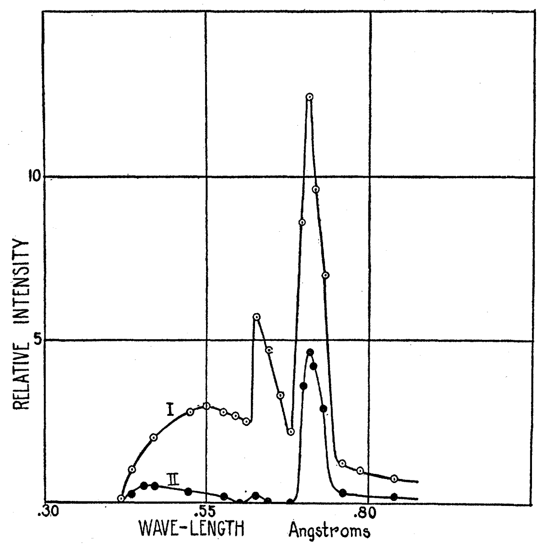

FIG. 1. Effect of filter on the x-ray spectrum of Mo. Curve I, no filter; curve II, with ZrO_2 filter.

admitted the rays. The ionization current was measured by the use of a Western Electric D-96475 electrometer tube in an amplifying circuit as described by Harnwell and Van Voorhis.[4] The sensitivity was adjusted to be about 40,000 divisions per volt and an input resistance of 10^{10} ohms was used. The circuit was carefully shielded and readings were not taken until about two hours after the filament current had been turned on. Under these conditions the galvanometer drift was negligible and random fluctuations were seldom more than two mm.

The x-rays were produced by a Coolidge tube with water-cooled molybdenum target. A potential of about 30 kv was used. The tube was enclosed in a lead box provided with a small hole through which the x-ray beam could pass. A filter of ZrO_2 placed over this hole produced approximate monochromatization of the beam. Fig. 1 shows the spectrum of the rays obtained with a calcite crystal, with and without the filter.

The liquid alloy contained approximately 35 percent sodium, this proportion having been found by Armstrong to give an alloy with fairly large magnetoresistance. The cell for holding the alloy was about 1 mm thick. It was made by bending a thin glass rod into suitable contour and cementing thin mica plates to both sides of this framework. The scattering of the empty cell was small; however it was carefully measured for the various angles and subtracted from the total scattering after the cell was filled. This difference was assumed to be the scattering of the alloy. To fill the cell it was placed mouth downward in an evacuated tube. The alloy, in a side bulb, was now decanted into the tube. When air was admitted the alloy was forced up into the cell. This cell was mounted on the spectrometer table between the poles of an electromagnet.

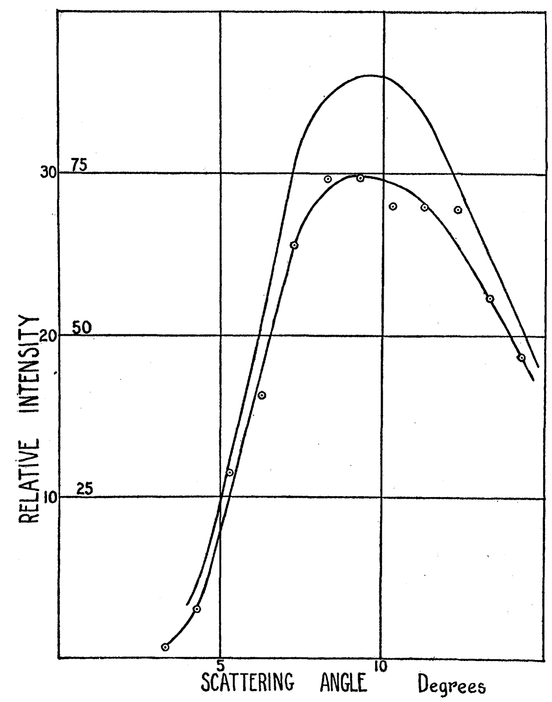

FIG. 2. Scattering by Na-K alloy. For the upper curve obtained without filter, the right-hand scale of ordinates is to be used. For the lower curve, obtained with filter, the left-hand scale is used. The experimental points all refer to the lower curve.

Fig. 2 shows the scattering curves obtained with and without the filter. The points are averages of a number of observations taken with random distribution. A magnetic field of 2700 gauss produced no measurable effect on the form of either curve. In testing the effect of the magnetic field the following procedure was adopted. The galvanometer zero was first noted, then a lead shutter was opened to admit the x-ray beam through the Soller slits to the specimen. The

[4] G. P. Harnwell and S. N. Van Voorhis, Rev. Sci. Inst. 5, 244 (1934).

scattered beam passed through the second set of slits into the ionization chamber and produced a definite deflection of the galvanometer. The magnetic field was now switched on and careful observation made to see whether the deflection changed. Then the field was switched off, the shutter closed, and the galvanometer zero checked again. In no case could any effect of the magnetic field be detected. Tests were made at 1° intervals for both curves of Fig. 2, a field of 2700 gauss being used. An effect as large as two percent could have been detected in the case of the largest deflections.

Discussion of Results

The diffraction of x-rays by Na-K alloys has been investigated previously by K. Banerjee,[5] who used the Mo $K\alpha$ radiation and a photographic method. Banerjee finds a maximum at 11° 28′. In the present work the maximum is at about 9.5°. The scattering of the points at the maximum in Fig. 2 appears to be rather too large for high accuracy; however, repeated trials indicated a definitely smaller angle for the maximum than was found by Banerjee. The reason for the discrepancy is not evident. It may be mentioned, however, that thin, flattened, glass tubes, such as Banerjee used to contain his alloy, could not be used in the present work because their scattering was comparable to that of the alloy. Using the Bragg formula the spacing of diffracting centers in the liquid turns out to be 4.3 Angstrom units, according to the present data, instead of 3.5 as given by Banerjee.

The absence of any effect of a magnetic field indicates that no appreciable modification of molecular groupings is produced. Hence the magnetoresistance of the alloy cannot be explained on these grounds. The possibility remains that certain structural changes may occur which are too small to be detected by the x-ray method. Ferromagnetic crystals when magnetized give an unchanged x-ray spectrum although definite structural changes occur, as is evidenced by the presence of magnetostriction.

An attempt was made to detect magnetostriction in the Na-K alloy. A quantity of the material under oil in a glass bulb was placed bebetween the poles of an electromagnet and subjected to a field of 7800 gauss. The oil meniscus in a fine capillary tube connected to the bulb was observed under a microscope. It was estimated that if any magnetostriction occurred the volume change per unit volume must have been less than 3×10^{-7}, the limit of accuracy of the experiment. This is a smaller volume change than is found to exist in ferromagnetic materials.

The conclusion appears to be that in this alloy a magnetic field does not produce a resistance change by modification of any molecular groupings or spacings in the liquid. The main cause of magnetoresistance is thus to be sought in the Lorentz forces which modify the electron free paths.

[5] K. Banerjee, Ind. J. Phys. 3, 399 (1928).

SEPTEMBER 15, 1935 PHYSICAL REVIEW VOLUME 48

The Transmutation Functions for Some Cases of Deuteron-Induced Radioactivity[1]

Ernest O. Lawrence, Edwin McMillan and R. L. Thornton, *Radiation Laboratory, Department of Physics, University of California, Berkeley*

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When nuclei are bombarded with deuterons, a commonly observed type of reaction is that resulting in proton emission and the conversion of the nuclei into isotopes of mass number one unit greater. Many such reactions give beta-radioactive products. The variation of the transmutation cross section with deuteron energy has been studied for the radioactivity thus produced in Na, Al, Si and Cu, with deuteron energies ranging from 0 to 3.6 MV. In all these cases it is found that the excitation curve is too flat to be explained by the Gamow theory, while it is fitted very well by a theoretical curve derived by Oppenheimer and Phillips. This is based on the idea that the nucleus can capture the neutron from the deuteron without requiring the penetration of the deuteron through the nuclear Coulomb barrier. The form of the theoretical curve depends on the binding energy of the deuteron; a value between 2.0 and 2.4 MV is required by the experimental results.