

The thermal conductivity of three samples is shown in Fig. 1. Due to the small size and irregular nature of the flakes, the absolute magnitudes are only approximate. The relative values are good to 5–10 percent. The maxima of the conductivity occur at around 80°K. Previously measured samples have maxima above room temperature. From this fact or from the actual conductivities at low temperatures, it is found that the mean free path, when boundary limited, is about 100 times that of any previous sample and slightly less than the crystallite size mentioned previously. The important fact, however, is that all three samples show a  $T^2$  dependence at low temperatures. This leads to the conclusion that the intrinsic conductivity does have a  $T^2$  dependence and substantiates the two-medium explanation of the higher exponent previously measured.

\* This report is based on studies conducted for the U. S. Atomic Energy Commission.

<sup>1</sup> R. Berman, Proc. Phys. Soc. (London) **A65**, 1029 (1952).

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<sup>3</sup> A. W. Smith, Phys. Rev. **93**, 952 (1954).

<sup>4</sup> W. DeSorbo and W. W. Tyler, Phys. Rev. **21**, 1660 (1953).

<sup>5</sup> P. G. Klemens, Australian J. Phys. **6**, 405 (1953).

<sup>6</sup> Obtained from J. C. Bowman of the National Carbon Company.

### Paramagnetic Resonance Absorption in Sodium Plutonyl Acetate\*

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WE have observed paramagnetic resonance absorption in pure single crystals of  $\text{NaPuO}_2 \times (\text{C}_2\text{H}_3\text{O}_2)_3$  at 4°K and at a frequency of  $2.3 \times 10^{10}$  sec<sup>-1</sup>. The magnetic field was varied from 0 to  $1.4 \times 10^4$  gauss.

The Pu is contained in the four linear triatomic  $\text{PuO}_2^{++}$  molecules which are located on the body diagonals of the cubic unit cell of this compound.<sup>1</sup> Measurements have been made on three crystals. Each was rotated about an axis which was parallel to the  $\gamma f$  field. The three axes of rotation were the 112, 111, and 100 axes of the cube. Observations have been made of peak positions for 21 different orientations of the  $\text{PuO}_2^{++}$  axis ranging from  $\theta=0.108$  to  $\theta=0.425$ . A number of the angles were checked on more than one crystal. The positions are given very closely by  $g=5.92 \times |\cos\theta|$ , where  $g$  is  $\hbar/\beta$  times the ratio of frequency to field strength at maximum absorption and  $\theta$  is the angle between the  $\text{PuO}_2^{++}$  axis and the magnetic field. This corresponds to  $g_{11} \cong 5.9$ ,  $g_{12} \cong 0.0$ .

This behavior is that to be expected for an electronic structure of  $\text{PuO}_2^{++}$  in which the two electrons not in closed shells are  $f$  electrons.<sup>2</sup> In the strong axial electric field of  $\text{PuO}_2^{++}$ , the two electrostatically interacting  $f$  electrons will be in states with  $M=\pm 3$  and  $M=\pm 2$ . The spin, 1, will interact with the state  $M=5$  so that  $L_z+2S_z=\pm 3$  for the lowest doublet and hence the magnetic splitting will be  $6\beta H$  when  $H$  is parallel to the molecular axis and zero when it is perpendicular. Under these assumptions or taking the trigonal character of the field into account there would be no observable resonance absorptions because of the vanishing of the matrix elements of magnetic moment between the split states. Slight departures from the ideal symmetry apparently permit the observation of the transition.

The powder susceptibility would be given to first order at low temperatures by

$$\chi = \frac{N\beta^2}{kT} \left( \frac{g_{11}^2 \pm 2g_{12}^2}{12} \right) = \frac{1.09}{T},$$

corresponding to  $3\chi kT/N\beta^2=2.95$ . This is to be compared with the measured value 2.83<sup>3</sup> for  $\text{PuO}_2^{++}$  and 3.17<sup>4</sup> for the presumably isoelectronic  $\text{NpO}_2^+$ .

The resonance data offer convincing evidence that the two unpaired electrons in the plutonyl compound are  $f$  electrons.

A 2 percent solution of  $\text{NaPuO}_2(\text{C}_2\text{H}_3\text{O}_2)_3$  in the isomorphous diamagnetic  $\text{NaUO}_2(\text{C}_2\text{H}_3\text{O}_2)_3$  has been investigated and the nuclear hyperfine structure has been observed. In one orientation a doublet (the nuclear spin of Pu is  $\frac{1}{2}$ )<sup>5</sup> with a spacing of 430 gauss was found. The hyperfine structure data have not yet been interpreted.

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<sup>2</sup> The theory of resonance in such ions is discussed in detail by J. Eisenstein and M. H. L. Pryce in a forthcoming paper. We wish to thank them for communicating their results to us in advance of publication. Various models of the situation resulting from crystalline field and spin-orbit perturbations of heavy metal ion electronic states have been discussed by R. J. Elliott, Phys. Rev. **89**, 659 (1953) and by D. M. Gruen and C. A. Hutchison, Jr., reference 4.

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