Hall Effect in Lu, Yb, Tm, and Sm†

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The Hall effect in Lu, Yb, Tm, and Sm has been studied as a function of temperature for the temperature range 40°K to 320°K in a magnetic field of 5500 oe. The Hall coefficient for Yb is positive, while the Hall coefficients for Lu and Tm are negative. Sm has a negative Hall effect at room temperature, but at lower temperatures the sign apparently changes.

INTRODUCTION

THE Hall effect of a metal furnishes some information about the conduction of the metal. The rare earths are in general trivalent and their principal variation is in the number of $4f$ electrons per atom. The $4f$ electrons are presumably highly localized around each ion and hence do not contribute directly to the conduction process. They may, however, have an important effect on the mobilities and the populations of the conduction bands.

Hall effect data presented here have been analyzed where possible for each of the metals on the basis of a simple one-band model to obtain an effective number of carriers per atom. It is quite evident that this is almost certainly an incorrect description. The number has been calculated, however, to aid in the discussion of the data. A more probable description of the data would be on the basis of a two-band model as proposed by Mott[1] and developed by Sondheimer.[2]

The Hall effects of several other rare earth metals have been examined previously by Kevane *et al.*[3] The apparatus used for the present investigation was described in that paper. This method employs an alternating current through the sample which was placed in a steady magnetic field. The polycrystalline samples were cut from castings and filed to the dimensions $2.5\times0.5\times0.1$ cm. The maximum magnetic field used was 5500 oe.

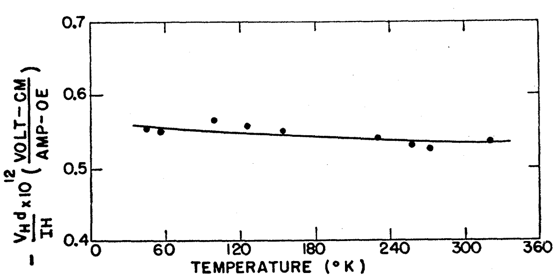

FIG. 1. Hall coefficient of Lu as a function of temperature.

RESULTS

1. Lutetium

The Hall coefficient $R=V_Hd/IH$ (where V_H=Hall voltage, d=room temperature thickness, I=primary current, and H=applied magnetic field) as a function of temperature for Lu is shown in Fig. 1. The Hall coefficient for Lu is nearly independent of temperature within the precision of the experiment over the temperature range from 40°K to 320°K. The coefficient has a value of about -0.535×10^{-12} volt cm/amp oe at room temperature. This value corresponds to 3.5 effective negative carriers per atom if one were to apply a one-band description. Lu has the hexagonal close-packed structure according to Spedding *et al.*[4] The $4f$ shell is completely filled, as magnetic measurements at this laboratory indicate.[5] Thus there are three conduction electrons per Lu atom.

2. Ytterbium

The Hall coefficient as a function of temperature for Yb is shown in Fig. 2. The coefficient has a value of 3.77×10^{-12} volt cm/amp oe and is independent of temperature for the temperature range from 80°K to 300°K. This value for R corresponds to 0.69 effective positive carriers per atom on the one-band model. Yb has the face-centered cubic structure.[4] Magnetic measurements by Lock[6] indicate that the $4f$ shell for Yb is filled, at least for this temperature range, as it is for Lu. This means there are just two electrons per atom available for the conduction process in Yb.

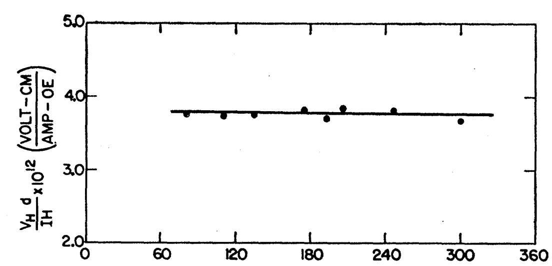

FIG. 2. Hall coefficient of Yb as a function of temperature.

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[1] N. F. Mott, Proc. Roy. Soc. (London) **A153**, 699 (1936).

[2] E. H. Sondheimer, Proc. Roy. Soc. (London) **A193**, 484 (1948).

[3] Kevane, Legvold, and Spedding, Phys. Rev. **91**, 1372 (1953).

[4] Spedding, Daane, and Herrmann, Acta Cryst. **9**, 559 (1956).

[5] W. C. Thoburn (private communication).

[6] J. M. Lock, Proc. Phys. Soc. (London) **70**, 476 (1957).

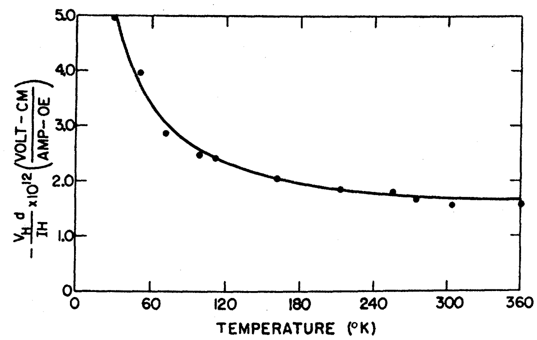

FIG. 3. Hall coefficient of Tm as a function of temperature.

3. Thulium

The Hall coefficient as a function of temperature for Tm is shown in Fig. 3. The increase at lower temperatures is attributed to the extraordinary effect. The coefficient has a value of -1.8×10^{-12} volt cm/amp oe at higher temperatures. This value of R corresponds to 1.1 effective negative carriers per atom on the one-band model. Tm has the hexagonal close-packed structure.[4] According to the magnetic measurements of Rhodes *et al.*,[7] there are two holes per atom in the $4f$ shell, which means that three electrons are available for the conduction process. These same measurements indicate a Néel temperature of 51°K. A slight field dependence of the Hall coefficient was noted for the lower two points.

4. Samarium

The Hall coefficient as a function of temperature for Sm is shown in Fig. 4. This is a rather unusual case. The coefficient is negative at room temperature and decreases in magnitude rather rapidly with decreasing temperature. At 150°K the effect seemed slightly positive, but was not of sufficient magnitude to be determined quantitatively. At 100°K the effect was positive, but showed a pronounced field dependence and no value of R was determined. Magnetic measurements by Lock[8] also indicate that Sm behaves rather strangely. However, no field dependence of the magnetic susceptibility was observed in this temperature region. Sm has a close-packed hexagonal structure with the c-axis parameter four and one-half times the normal value.[9]

[7] Rhodes, Legvold, and Spedding, Phys. Rev. **109**, 1547 (1958).

DISCUSSION

On the basis of a one-band model we find there are 3.5 effective negative carriers per atom for Lu, 1.1 effective negative carriers per atom for Tm, and 0.69 effective positive carriers per atom for Yb. Something more complicated than the one-band model is obviously necessary to explain these results. An interpretation in terms of the two-band model mentioned earlier is not possible because this model involves the population of each of the conduction bands and the ratio of their mobilities. We have been unable to assign numbers to the unknown quantities which would give reasonable results and be consistent with the electrical resistivities.

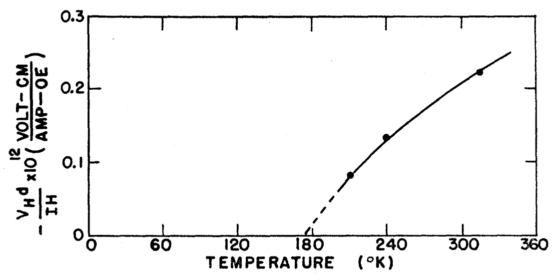

FIG. 4. Hall coefficient of Sm as a function of temperature.

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[8] J. M. Lock, Proc. Phys. Soc. (London) **70**, 566 (1957).

[9] Daane, Rundle, Smith, and Spedding, Acta Cryst. **7**, 532 (1954).