

is a superconductor.³

In an earlier paper,⁴ the question was raised whether an electronic configuration favorable to superconductivity might also be favorable to ferromagnetism. The experimental data by which we tried to illustrate this question started with the demonstration that while the germanides of most of the rare earths were either ferromagnetic or superconducting, all investigated silicides with the exception of PrSi₂, were neither ferromagnetic nor superconducting. We have now found that this dualism can also be illustrated by forming the AB₂ Laves phase compounds. If B is ruthenium then for A=Sc, Y, La, Ce we find superconductivity and for A=Pr...Gd...we have ferromagnets. In Table I the corresponding transition temperatures are listed.

Table I. Transition temperatures of ruthenides.

Compound	Behavior	T _c
ScRu ₂	superconducting	1.67°
YRu ₂	superconducting	1.52°
LaRu ₂	superconducting	1.63°
CeRu ₂	superconducting	4.9°
PrRu ₂	ferromagnetic	40°
NdRu ₂	ferromagnetic	35°
ErRu ₂	ferromagnetic	13°

It appears rather remarkable that the compound CeRu₂, containing an element with a 4f electron, should be superconducting. However, the lattice constant reveals that in this compound at least 25% of the 4f electron has been squeezed into the outer shells.⁵ In this way, the magnetic moment is reduced, and the number of valence electrons (hence the superconducting transition temperature) is raised considerably.

In summary, we wish to point out that there seems to be a correlation between the Curie points in certain alloys and compounds which include the rare earth elements and the superconducting transition temperatures of other closely related alloys and compounds.

Finally, we would like to thank P. W. Anderson and J. K. Galt for many helpful discussions.

¹ T. H. Van Vleck, Magnetic and Electric Susceptibilities (Oxford University Press, Oxford, 1932), pp. 243, 244.

² F. H. Spedding, Progress of Low-Temperature Physics (North-Holland Publishing Company, Amsterdam, C. Zener, Phys. Rev. **81**, 440, (1951); S. V. Vonsorsky, J. Exptl. Theoret. Phys. U.S.S.R. Vol. II, p. 391; 981, (1946).

³ Calculations by C. Herring, to be published in a

subsequent paper, make this idea plausible.

⁴ Matthias, Corenzwit, and Zachariasen, Phys. Rev. (in press).

⁵ We want to thank Professor W. H. Zachariasen for his help and discussion with respect to these matters.

F AND V CENTERS THERMOLUMINESCENT RECOMBINATION*

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In the course of experiments on thermoluminescence of alkali halides, to be published in the near future,¹ the writers have found that current theories, all treating the process as a first-order one,² do not allow an easy interpretation of all the experimental features. It was decided, therefore, to investigate a particular case of thermoluminescence in which the nature of the electronic traps was known so that the task of setting up a model which could undergo quantitative examination would be greatly facilitated. X-rayed NaCl was chosen, in which F centers can give rise to thermoluminescence, as is well known.

Using an idea previously advanced by Johnson³ and by Hill and Schwed,⁴ a second-order process was considered and a phenomenological theory of F center thermoluminescence was carried out, starting from the equation

$$-dN_i/dt = p_i \exp(-E/kT) N_i(N_i - N_{i0} + n_0). \quad (1)$$

This equation is based on the hypothesis that there are present in the crystal, together with the F centers, also some kinds of "luminophor" centers L_i . The electrons are supposed to be able to escape from the F-center ground level, with a thermal activation energy E , to reach some higher, excited level (perhaps in the conduction band) from which they can undergo a radiative transition to the L_i levels, with probability factors p_i . N_i means the luminophor center concentration, n the F-center concentration, the index 0 identifying the initial values at the beginning of the i th peak of the "glow curve" considered.

This way of reasoning can interpret satisfactorily many experimental features, and, moreover, it contains the following implications:

(a) The analysis of the glow curves must give a unique E value for all the peaks,⁵

(b) The light of each peak must have its own wavelength.

(c) The temperatures of the maxima of the glow curves are by no means characteristic of the trap depth, not even when the warming speed is held constant; on the contrary, they depend on the value of n_0 (in contradiction to the results of Randall and Wilkins' calculations²).

Experiments have been performed to test these points, with satisfactory results. It has been found: $E=0.72$ ev for all the peaks,⁶ and $p_1=5.10^{-10}$, $p_2=9.10^{-8}$, $p_3=2.10^{-5}$ cm³ sec⁻¹.

In connection with point (b), we succeeded, through the use of interference filters, in proving that the wavelengths quoted by Hill and Schwed,⁴ namely 3620, 4180/4320, and 5250 Å, belong, respectively, to the first, second (doublet), and third peak.

The principal problem appeared then to be the identification of the L_i centers.

The following facts support the idea that L_i centers are V centers, introduced by irradiation at the same time as F centers.

First of all, it is well known that the relative amount of the different species of V centers is strongly influenced by the thermal history of the specimen, or by the irradiation temperature, and the same sensitivity is shown by the relative intensity of the thermoluminescence peaks. A much more important argument of a quantitative nature is that, if each L_i center is a V_i center, this means that when the radiative thermoluminescent transition takes place, the excited electron annihilates the V_i center, by recombination with the hole belonging to the V_i center. It can then easily be seen that the energy of the photon released in such a process is given by

$$(\hbar\nu)_i = \epsilon - (\hbar\nu)_{V_i} \quad (2)$$

where ϵ means the energy gap between the excited level of the electron and the valence band, and $(\hbar\nu)_{V_i}$ means the energy belonging to the V_i absorption band. Consequently, in Eq. (2), ϵ must have the same value for every thermoluminescence peak.

Since the $(\hbar\nu)_i$ and $(\hbar\nu)_{V_i}$ values can be found in the literature,^{4,7} it has been possible to test our idea, and the results are given in Table I.

Table I shows that, with the exception of the first peak, our predictions are surprisingly well confirmed; and, in fact, the value found for ϵ is very near to the value of the energy gap of NaCl (about 9 ev).^{8,9} The ϵ corresponding to the first peak deviates sensibly, but it is a pleasure to

acknowledge here a kind private communication by Professor P. Pringsheim, who pointed out that the V_1 band energy value given in reference 7 was probably unreliable.

Table I. Values of ϵ calculated through $(\hbar\nu)_i$ and $(\hbar\nu)_{V_i}$.

i	1	2/3	4
$(\hbar\nu)_i$	3.425	2.966/2.870	2.362
$(\hbar\nu)_{V_i}$	3.594	5.570	5.904
ϵ	7.019	8.536/8.440	8.266

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¹ See also Bonfiglioli, Brovotto, and Cortese, Technical Notes No. 1b, 2b, 3b under Contract AF 61(514)-1333 of the ARDC European Office.

² F. Urbach, Akad. Wiss. Wien., Ber. (2A), 139, 363 (1930); J. T. Randall and M. H. F. Wilkins, Proc. Roy. Soc., (London) A184, 366 (1945).

³ R. P. Johnson, J. Opt. Soc. Am. 29, 387 (1939).

⁴ J. J. Hill and P. Schwed, J. Chem. Phys. 23, 652 (1955).

⁵ As a matter of fact, the peaks found in our experiments are three, but the second is a doublet rather poorly resolved.

⁶ Hill and Schwed's value is 1.28 ev.⁴ This discrepancy has not been explained so far.

⁷ Castler, Pringsheim, and Yuster, J. Chem. Phys. 18, 887 (1950).

⁸ N. F. Mott and R. W. Gurney, Electronic Processes in Ionic Crystals (Oxford University Press, Oxford, 1940), p. 97.

⁹ It is to be remarked that values for $(\hbar\nu)_i$ and $(\hbar\nu)_{V_i}$ in Table I are not obtained through measurements performed at the same temperature: $(\hbar\nu)_i$ are thermoluminescent temperature values, whereas $(\hbar\nu)_{V_i}$ are low temperature values. This point could be worth some discussion, but, nonetheless, the agreement obtained definitely proves our aim.

SHAPE AND POLARIZATION OF THE BETA SPECTRUM OF RADIUM E[†]

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The shape of the beta spectrum of RaE (Bi²¹⁰) has long been known to be nonallowed, even though it is a $\Delta I=1$ (yes) transition in a heavy