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SUPERCONDUCTIVITY AND FERROMAGNETISM OF URANIUM COMPOUNDS

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Résumé — L'uranium forme cinq composés intermétalliques supraconducteurs, et un nombre beaucoup plus grand de composés ferro- et antiferromagnétiques.

Tous ces composés illustrent la position de Zwitter de l'uranium dans le système périodique. La position analogue dans la série 4 f est celle du cérium. Une comparaison du comportement des composés supraconducteurs et magnétiques de ces deux éléments montre de manière très décisive la différence fondamentale entre les électrons 4 f et 5 f.

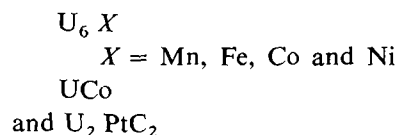
Abstract — Uranium forms five superconducting intermetallic compounds, but a much greater number of ferro- and antiferromagnetic compounds.

All these illustrate the Zwitter position of uranium in the periodic system. The analogous position in the 4 f series is that of cerium. A comparison of the behavior of the superconducting and magnetic compounds of these two elements shows in a very decisive way the fundamental difference between 4 f and 5 f electrons.

From a magnetic point of view, cerium and uranium are two exceptional elements whose positions in the periodic system are analogous to each other. They both mark the beginning of the 4 f and 5 f series. This is a very fortunate situation since it at least permits a comparison between these two elements. However, as with all beginnings, their f electron configurations are at this time somewhat uncertain, vacillating and still affected considerably by external factors. As such, the precise f electron character varies a great deal with temperature, pressure and alloy formation, and hence their magnetic behavior at very low temperatures covers the whole gamut from ferromagnetism to superconductivity. But apart from the similarity of these general features, with a closer look one finds that well defined differences in characteristics between U and Ce begin to appear. The existence of these dissimilar characteristics further illuminates the comparison between them and for the first time shows what the differences between 4 f and 5 f electrons really are.

For instance, under pressure both cerium and uranium become superconducting at temperatures above 1 °K. It takes more than 50 kbars of pressure for cerium while in the case of uranium 2-10 kbars are already sufficient [1, 2].

Superconducting compounds of these two elements are not very numerous, but do exist and usually occur, strangely enough, only with magnetic or superconducting elements. For U they are :



and for Ce



In order to understand U_2PtC_2 , a ternary compound, it is necessary to decompose it into two binary compounds UC_2 and UPt . And from this the ferromagnetism of UPt could be predicted and was then also found experimentally. This close link between superconductivity and magnetic phases illustrates the rather complex nature of the superconducting mechanism in these compounds, and also indicates that the electron-phonon interaction may not be the dominant cause for superconductivity in this instance.

There is now an entirely different correspondence between cerium and uranium which is however not strictly limited to these two elements but extends as well to their neighboring elements in the periodic system. This analogous behavior is a depression of their melting points from the values one would have extrapolated, had no f electrons or their proximity interfered. It has been known for some time³ that any sdf hybridization, however weak, will lead to rather substantial depressions of the melting temperature. This is sensible in view of the fact that the bonding nature of f electrons, if at all, is rather weak. The melting temperatures of both cerium and uranium is now only about 50 % of the values extrapolated in the periodic system.

The real difference between the two elements is however best seen in figure 1 and figure 2. In these figures essentially all superconducting and magnetic Ce and U compounds, known today, are plotted [4]. Magnetic ordering temperatures appear at the bottom and the superconducting ones at the top. In both, superconductivity will give way to magnetism once the average interatomic distance exceeds a certain critical value.

And while again this critical value is not too different for both elements, once magnetic ordering sets in,

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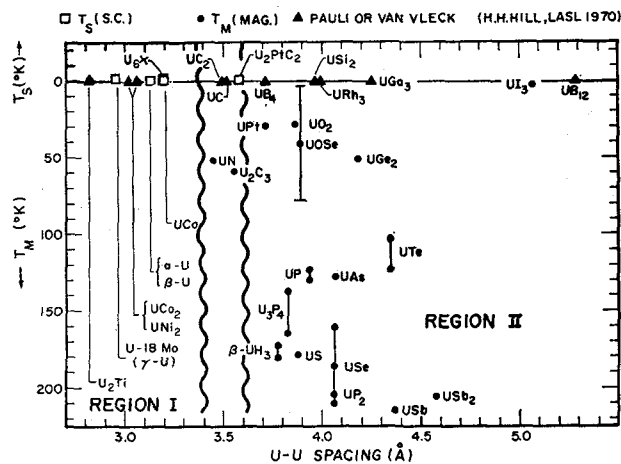


FIG. 1. — Superconductivity and ferromagnetism of uranium compounds.

the crucial difference between 4 f and 5 f electrons becomes evident. Generally the 5 f magnetic ordering temperatures are far above those of the 4 f ones. The

cause for this behavior should now be looked for in the much smaller localization of the 5 f electrons as compared to 4 f electrons. And, therefore, as H. H. Hill has already pointed out, 5 f states are somehow the magnetic intermediate situation between 4 f and 3 d configurations.

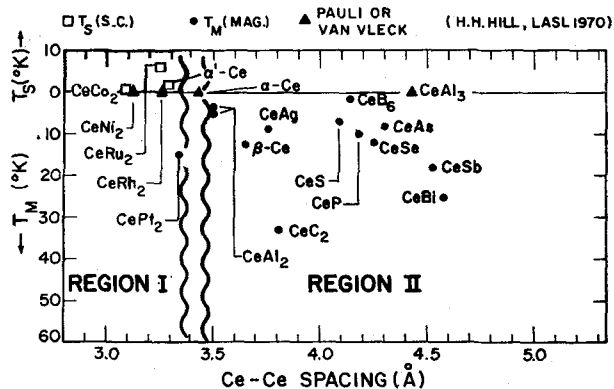


FIG. 2. — Superconductivity and ferromagnetism of cerium compounds.

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