earth. Further, this is the energy liberated in thermonuclear reactions; such is essentially the origin of the energy radiated by the sun and stars, and from which, in the final analysis, come all the energy resources of modern technology.

These simple considerations make it possible to give a general answer to the question of the cause of thermodynamic irreversibility. At present nuclear processes accompanied by liberation of energy very often take place in the universe surrounding us, and as far as we know reverse processes accompanied by an increase in internal nuclear energy almost never take place. A gradual dissipation of nuclear energy on a very large scale is therefore taking place around us. It is just to this quite specific process that thermodynamics refers. The law of entropy increase characterizes its directional nature.

If the general equations of mechanics are entirely reversible, irreversibility can be due only to the initial conditions. In reality such an initial condition is, on the one hand, the existence of decaying heavy nuclei and, on the other hand, the possibility of further thermonuclear synthesis. Both these phenomena lead to the continual production of particles with enormous kinetic energies which are then gradually dissipated among all the degrees of freedom of the surrounding macroscopic molecular systems. All physical kinetics is a description of various stages of this extremely complex process.

We shall not consider here the possible reasons for the fact that nuclear energy is much more often liberated around us rather than absorbed. There can be no doubt in this, of course, as an observed experimental fact. We wish only to indicate the possibility of explaining thermodynamic irreversibility by well-established experimental facts which are completely independent of thermodynamics and statistical mechanics.

Translated by E. J. Saletan
161

MAGNETIC PROPERTIES OF COBALT FLUORIDE IN THE ANTIFERROMAGNETIC STATE

D. N. ASTROV, A. S. BOROVIK-ROMANOV, and M. P. ORLOVA

All-Union Institute of Physico-Technical and Radiotechnical Measurements

Submitted to JETP editor June 20, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 812-815 (September, 1957)

THE antiferromagnetism of cobalt fluoride was established in neutron diffraction experiments by Erickson,[1] from whose data it follows that the transition temperature of CoF_2 lies in the neighborhood of 50° K. Calorimetric measurements by Stout and Catalano[2] indicated the existence of a peak in the specific heat at a temperature of 37.7°K.

We have investigated several CoF_2 samples prepared of ChDA material which was dried in a vacuum by the method suggested by Birk and Biltz.[3] The magnetic susceptibility was measured by the Faraday method. The experimental error in the temperature was no greater than ± 0.5° at liquid hydrogen temperatures, and about ± 0.1° at higher temperatures. The error in the absolute measurements of the susceptibility was no greater than ± 5%, and in the relative ones it was no greater than ± 2%.

The results obtained are shown in Fig. 1. The inverse of the susceptibility has a minimum at T_C = 38° K, which is in good agreement with the temperature of the discontinuity in the specific heat.[2] Above 55° of the curve obeys the Curie-Weiss law $\chi_m = C_m/(T - \Theta)$ with $\Theta = -50$ and $C_m = 0.875$ (per mole). The magnetic susceptibility is field independent in the field interval we investigated (900 — 4000 oersteds).

Stout and Matarrese[4] have measured the difference between the principal molar susceptibilities $(\chi_\parallel - \chi_\perp)$ in CoF_2 single crystals. It is of interest, for comparison with theory, to find the temperature dependence of the absolute values of $\chi_\parallel$ and $\chi_\perp$. Stout and Matarrese used the results of experiments with a polycrystalline sample[5] in 1939, combining them with their data to construct temperature-dependence curves for $\chi_\parallel$ and $\chi_\perp$. The curves obtained in this way are difficult to explain on the basis of existing concepts of antiferromagnetism; the value of $\chi_\perp$ increases greatly instead of remaining constant,

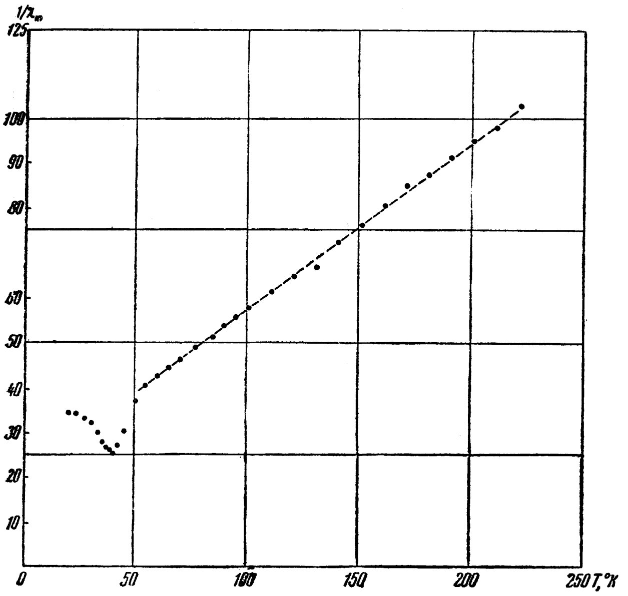

FIG. 1. The reciprocal of the molar magnetic susceptibility $1/\chi_m$ of CoF_2 as a function of temperature.

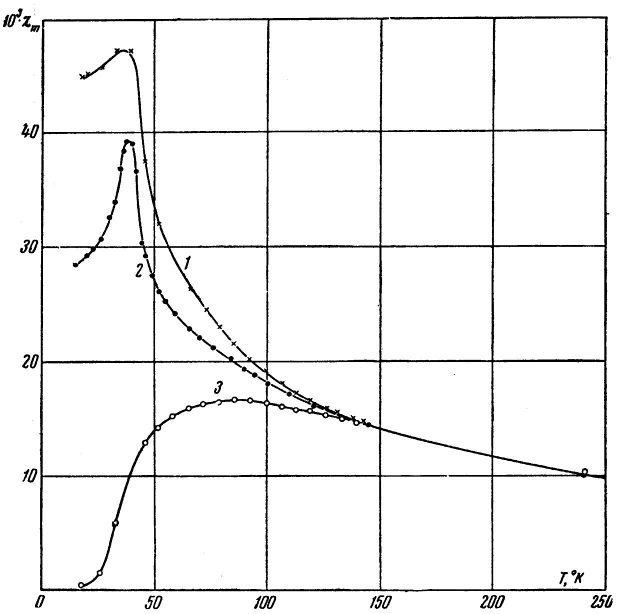

FIG. 2. The temperature dependence of the molar magnetic susceptibility of CoF_2. (1) temperature dependence of the "perpendicular" susceptibility, on the basis of our data and that of Stout and Matarrese;[4] (2) temperature dependence of the magnetic susceptibility of the powder, according to our measurements; (3) temperature dependence of the "parallel" magnetic susceptibility, based on our measurements and the data of Stout and Matarrese.[4]

and after passing through a maximum at about 65° K, $\chi_{\parallel}$ decreases not to 0, but to 40% of its maximum value.

Entirely different but also anomalous curves were obtained by Bizett and Tsai,[6] who compared their new results for a polycrystalline sample with the data of Stout and Matarrese. According to them $\chi_{\perp}$ increases greatly, and $\chi_{\parallel}$ varies in a complex way with a maximum at 50° K, a minimum at about 23° K, and a strong increase at lower temperatures. In our opinion the low-temperature increase they obtain for the susceptibility of polycrystalline CoF_2 is due to their sample being not sufficiently baked out and containing some of the paramagnetic hydrated salt $CoF_2 \cdot 4H_2O$.

Figure 2 shows curves of the temperature dependence of $\chi_{\parallel}$ and $\chi_{\perp}$ obtained by combining our data with the anisotropy data of Stout and Matarrese. At the transition point $\chi_{\perp} = 4.8\ \chi_{\parallel}$. Below the transition point $\chi_{\perp}$ remains practically constant, and $\chi_{\parallel}$ decreases rapidly approaching 0 as $T \rightarrow 0$. The fact that no anomalies are observed on the $\chi_{\parallel}$ curve at the transition point may be explained by the chance coincidence of the nature of the anisotropy change in the paramagnetic and antiferromagnetic regions, as well, perhaps, by the insufficient accuracy in the measurement of $(\chi_{\parallel} - \chi_{\perp})$ in the intermediate temperature range, when the measurements were performed while heating the apparatus.

It is thus seen that the temperature dependence of the principal magnetic moments $\chi_{\parallel}$ and $\chi_{\perp}$ of CoF_2 below the transition point is of the same general character as it is for other antiferromagnetic substances. A particular property of CoF_2 is the strong anisotropy of the Co^{++} ion in the paramagnetic state, which causes $\chi_{\perp}$ to be much greater than $\chi_{\parallel}$ at the transition point.

The authors express their deep gratitude to P. G. Strelkov for constant interest in the work.

---

[1] R. A. Erickson, Phys. Rev. 90, 779 (1953).

[2] I. W. Stout and E. Catalano, Phys. Rev. 92, 1575 (1953).

[3] E. Birk and W. Blitz, Z. anorg. u. allgem. Chem. 153, 121 (1926).

[4] I. W. Stout and L. M. Matarrese, Revs. Modern Phys. 25, 338 (1953).

[5] W. J. de Haas and B. H. Schultz, Physica 6, 481 (1939).

[6] H. Bizett and B. Tsai, Conference de Physique des basses temperatures, (Paris 2 — 8 September, 1955).

Translated by E. J. Saletan