$$\overline{G_i(\mathbf{r}_1 t_1)\,Q_k(\mathbf{r}_2 t_2)} = 2kT\left\{\rho D\left[\frac{\partial}{\partial c}\left(\frac{Z}{\rho T}\right)k_T - T\frac{\partial}{\partial T}\left(\frac{Z}{\rho T}\right)\right]\Big/\frac{\partial}{\partial c}\left(\frac{Z}{\rho T}\right)\right\}\delta_{ik}\delta(\mathbf{r}_1-\mathbf{r}_2)\,\delta(t_1-t_2).$$

The fluctuations of the hydrodynamical parameters can be found by expressing them in terms of the "outside" quantities with the aid of the hydrodynamical equations.

In conclusion we note that the equations for fluctuations of the quantities **Q** and **g** will also apply, naturally, to solutions of ordinary (non-superfluid) liquids.

I would like to thank L. D. Landau and E. M. Lifshitz for allowing me to become acquainted with their manuscript before publication.

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*The thermodynamic identity has the form

$$d\epsilon = T\,dS + \mu\,d\rho + Z\,dc + (\mathbf{v}_n - \mathbf{v}_s)\,d(\mathbf{j} - \rho\mathbf{v}_s).$$

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Translated by W. M. Whitney
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CAUSES OF THERMODYNAMIC IRREVERSIBILITY

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THE statistical interpretation of the second law of thermodynamics was given by Boltzmann more than eighty years ago. In spite of this long period of time, there is no clear explanation for the experimentally observed fact of macroscopic irreversibility.

The laws of elementary mechanics, both classical and quantum, are entirely reversible. This fact causes the general laws of statistical mechanics to be also reversible. Indeed, the Liouville equation is reversible just as is the equation of motion of the density matrix for a mixed state in quantum mechanics. Therefore with any mechanical process developing in time there can always be associated an analogous process moving in the opposite direction. This is accomplished by replacing all the velocities or momenta by their negatives. Thus if the entropy is increasing in time in any process, the reverse process in which the entropy decreases may always exist in principle. One cannot, therefore, assign to the second law of thermodynamics the same universal meaning as to the first law, the conservation of energy. In small-scale events, in fact, one often observes fluctuation phenomena due to the decrease of entropy with time.

It is on the basis of such concepts that Boltzmann arrived at his fluctuation hypothesis. This hypothesis, however, is of a merely speculative nature, being based on no experimental facts other than those it attempts to explain. As is known, it did not achieve recognition.

In order to find genuine reasons for thermodynamic irreversibility, one must first clarify the origin of those statistical anomalous states which approach thermal equilibrium in an irreversible way.

The sources of all the thermal energy with which we deal are nuclear processes. This is above all the energy liberated in radioactive decay; such is, for instance, the source of heat in the interior of the 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.

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MAGNETIC PROPERTIES OF COBALT FLUORIDE IN THE ANTIFERROMAGNETIC STATE

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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,