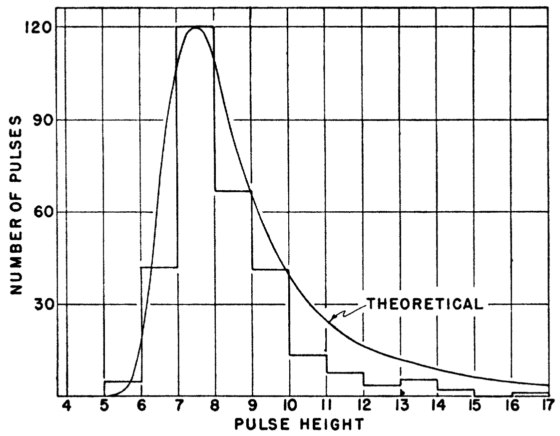

FIG. 2. Theoretical (smooth curve) and experimental pulse distributions.

Critchfield has pointed out to us that because the large pulses come from high energy δ-rays, all of which would not stop in the liquid, the experimental curve should drop off faster on the high energy side than the theoretical curve. The statistics of the data are not good enough to decide this point.

Two types of end-window photo-multipliers are suitable for use in this type of counter; the English Electrical and Musical Industries VX5031 and the R.C.A. 5819. The E.M.I. tube which we used was preferred, because its signal to noise ratio was about 10 times better than that of any of the 5819 tubes which we tried.

We are indebted to Professor Walter Lauer for supplying us with pure pyrene.

* Assisted by the joint program of the ONR and AEC.

[1] L. Landau, J. Phys. U.S.S.R. 8, 201 (1944).

[2] K. Symon, Ph.D. thesis, Harvard University (1948).

[3] W. L. Whittemore and J. C. Street, Phys. Rev. 76, 1786 (1949).

A Scintillation Counter Measurement of Heavy Nuclei*

E. P. Ney and D. M. Thon
University of Minnesota, Minneapolis, Minnesota
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A SCINTILLATION counter telescope of the type described in the previous latter[1] was flown on October 4, 1950, to an altitude of 105,000 ft on a "Skyhook" balloon. The residual atmosphere above the balloon was less than 10 g/cm^2 for a period of 5 hr.

The scintillation pulses from the counter were displayed on oscilloscopes in the balloon gondola whenever a coincidence count occurred in the Geiger telescope. Pulse amplitudes over a range of 200 to 1 could be recorded. The oscilloscopes on which the pulses were displayed were photographed continuously, and at one-minute intervals the reading of a Wallace and Tiernan low pressure barometer and a "total count" recorder were also photographed. During the flight approximately 30,000 pulses were recorded.

Because of the stage of development of the scintillation counter at the time of the flight, the resolution of the equipment did not approach the Landau statistical limit. It was not possible, therefore, to resolve adjacent atomic numbers in this flight because of the poor resolution and the fact that at 55°N latitude the cut-off energy imposed by the earth's magnetic field is so low that slow particles of low atomic number can suffer a greater energy loss in the scintillation counter than relativistic particles of higher atomic number.

The energy loss in the scintillation counter is proportional to Z^2/V^2, where Z is the atomic number and V is the particle velocity. A differential pulse amplitude distribution would, therefore, have a scale of abscissas proportional to Z^2. We have changed the scale in Fig. 1 so that we obtain a frequency distribution of pulses as a function of atomic number. The dotted curve in Fig. 1 gives the distribution obtained during the ascent from 500 g/cm^2 to 100 g/cm^2. The difference between the curves shows clearly the contribution of multiply charged primaries at the top of the atmosphere. Since one knows the shape of the curve corresponding to singly charged particles, it is possible by successive subtraction to estimate the number of pulses in each interval of atomic number. These results are shown in Table I. The actual number of pulses is included to show the magnitude of the statistical errors.

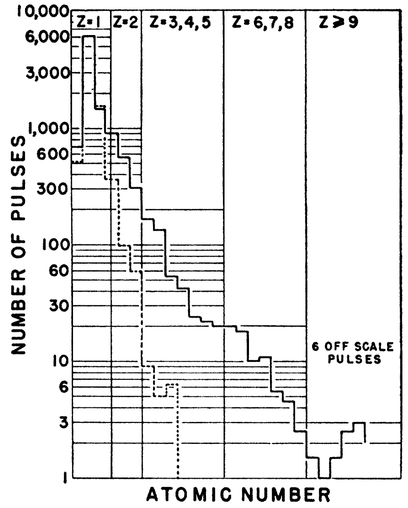

FIG. 1. Atomic number histogram.

TABLE I. Measured abundancies of nuclei.

Element	Number of pulses	Flux (particles/cm^2-sec-steradian)
H	8740	1.9×10^{-1}
He	1257	2.8×10^{-2}
Li, Be, and B+Stars	387	8.4×10^{-3}
C, N, O+Stars	76	1.6×10^{-3}
$Z\geqq9$+Stars	20	4.3×10^{-4}

The total flux of 0.23 parts/cm^2-sec-steradian is in reasonable agreement with the results of Winckler and Stroud.[2] The hydrogen-helium ratio of 7 is higher than that previously reported.[3–5] The last three groups in the table must include pulses arising from stars produced by primary protons in the scintillator. Emulsion work leads one to believe that most of these stars would give pulses in the region of the lithium, beryllium, boron group. The energy of such a star would be about 150 Mev. If we assume that all the pulses in the lithium, beryllium, boron region are due to stars, we can calculate the product of $\eta\sigma$, where η is the efficiency of the counter telescope for triggering on a star produced in the scintillator, and σ is the cross section for star production by primary protons. On this assumption, if η is 1, then σ would be half geometric cross section. The abundance of carbon, nitrogen, and oxygen and of $Z\geqq9$ agrees well with the values obtained in photographic plates.[3, 5, 6] This leads us to believe that stars do not contribute appreciably in this region of pulses.

During the period of the flight there was a variation with time in the frequency of large pulses. This variation seems statistically significant and appears to be further evidence for a change in the flux of heavy nuclei either as a diurnal effect or because of solar activity. At the same time that the heavy nuclei increased, the pulse distribution in the proton—α-particle region indicated the presence of more α-particles. These results are indicated in Fig. 2

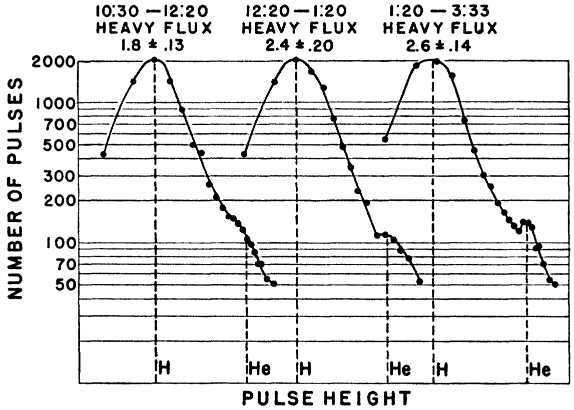

FIG. 2. Distribution of the proton and α-particle pulses during the day.

and Table II. The proton flux was constant within statistics throughout the day.

Further experiments are now in progress with high resolution equipment which will be flown at a latitude of 30° N.

TABLE II. Frequencies of pulses *vs* time.

Time	Frequency of pulses of magnitude greater than 16 times the average proton pulse (pulses/min)	Frequency of proton pulses (pulses/min)
10:30 to 12:20 A.M.	1.8±0.13	78±0.8
12:20 to 1:20 P.M.	2.4±0.2	76.5±1.4
1:20 to 3:30 P.M.	2.6±0.14	79±0.8

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* Assisted by the joint program of the ONR and AEC.

[1] E. P. Ney and D. M. Thon, Phys. Rev. **81**, 1068 (1951).

[2] J. R. Winckler and W. G. Stroud, Phys. Rev. **76**, 1012 (1949).

[3] Freier, Lofgren, Ney, and Oppenheimer, Phys. Rev. **74**, 1818 (1948).

[4] M. A. Pomerantz and F. L. Hereford, Phys. Rev. **76**, 997 (1949).

[5] H. Bradt and B. Peters, Phys. Rev. **77**, 54 (1950).

[6] P. Freier, Ph.D. thesis, University of Minnesota (1949).

Non-Equilibrium Thermodynamics of Two-Fluid Models

S. R. DE GROOT, L. JANSEN, AND P. MAZUR
Institute for Theoretical Physics, The University, Utrecht, The Netherlands
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TWO-FLUID models have been proposed for the explanation of the properties of liquid helium II and for superconducting metals.[1] In both cases the existence of two kinds of particles has been assumed: in liquid helium II *normal* (*n*) and *superfluid* (*s*) atoms, and in superconducting metals *normal* (*n*) and *superconductive* (*s*) electrons. It is supposed that the "chemical reaction" $n \rightleftarrows s$ is possible. In these systems occur further the phenomena of heat conduction, diffusion of electrical conduction, and various cross-effects.

The thermodynamics of irreversible processes, based on the Onsager reciprocal relations,[2] can be used to treat these models mentioned above by means of the general methods, including the entropy balance equation, the phenomenological relations, and the theory of stationary states.[3]

Among the results for helium[4] we note a connection between the fountain effect and the mechano-caloric effect. The fountain effect is the pressure difference, ΔP, which arises in the stationary state when a fixed temperature difference, ΔT, exists between two reservoirs, containing liquid He II, which are connected by a capillary. The mechano-caloric effect is the heat, Q transferred by the unit of mass from one reservoir to the other in the state of fixed ΔP and $\Delta T=0$ (uniform temperature). An application of the Onsager relations gives the connection

$$v\Delta P/\Delta T=-Q^*/T. \tag{1}$$

Between the two effects (v is the specific volume) we can derive Gorter's relation

$$Q^*=-Tx(\partial s/\partial x)_{P,T}, \tag{2}$$

(with x is the fraction of normal atoms and s the specific entropy) as a special case, if we accept the following assumptions, which are generally made for He II: first, immediate "chemical equilibrium" of the reaction $n \rightleftarrows s$ under all circumstances, and second, only superfluid atoms can pass through a sufficiently narrow capillary.

In a recent work,[5] I. Prigogine and one of the authors (P. M.) have obtained Gorter's equation of motion for the normal- and the super-fluid, by deriving a new set of "hydrothermodynamical" equations for systems of several components, with the assumption of a negligible transfer of impulse between the components, and by applying these equations to the two-fluid model by liquid helium II.

For superconductive metals, work is still in progress, but it already can be said that new terms arise in the expression for heat conductivity and probably also in the expression for the thermoelectric homogeneous effect, as compared with the results for ordinary metals.

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[1] See e.g., for helium, C. J. Gorter *et al.*, Physica **15**, 285 and 523 (1949); **16**, 113 (1950); for superconductivity, C. J. Gorter and H. B. G. Casimir, Physica **1**, 305 (1934).

[2] L. Onsager, Phys. Rev. **37**, 405 (1931); **38**, 2265 (1931). H. B. G. Casimir, Revs. Modern Phys. **17**, 343 (1945).

[3] S. R. de Groot, *Thermodynamics of Irreversible Processes* (Interscience Publishers, New York, 1951).

[4] de Groot, Jansen, and Mazur, Physica **16**, 421 and 691 (1950).

[5] I. Prigogine and P. Mazur, Physica (to be published).

Field Variation of Superconducting Penetration Depth

J. BARDEEN
Bell Telephone Laboratories, Murray Hill, New Jersey
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IN a recent article of the same title, Pippard[1] has shown that there is only a small dependence of penetration depth, λ, on the applied magnetic field. Pippard's observations are based on changes of the reactive component of the skin impedance of superconducting tin at 3.2 cm with applied field. The over-all change in λ is no more than 3 percent at the critical field strength. From an application of the Gorter-Casimir two fluid theory, he estimates the size of the regions over which order must exist.

Pippard's argument is briefly as follows. With an increase in applied field, one might expect a decrease in concentration of superconducting electrons near the surface so as to increase the penetration depth and decrease the magnetic energy. The fact that this occurs only to a small degree indicates that the size of the regions over which order exists and which must be considered as a unit in the transition must be at least as large as 10^{-4} cm. The very sharp resistance transition in pure tin is given as further evidence of an order existing over regions of this size. This result appeared to be difficult to reconcile with observations on thin films[2,3] and on colloidal mercury[4] that there is very little change in transition temperature with dimensions, even when the film thickness or particle size is as small as 5×10^{-6} cm; i.e., less than the penetration depth.

These apparently contradictory results both follow from the lattice-vibration theory[5] of superconductivity and may be taken as evidence that the general approach, which is the one anticipated by London, is along the correct lines. London[6] had previously shown that the phenomenological equations follow if it is assumed that the wave functions of the electrons are not changed very much by the magnetic field. The fact that the penetration depth is independent of field is good evidence that the wave functions are not altered; for if they were, one would expect the penetration to change.