plication in a very large shower-star as evidence for photons from the decay of neutral mesons whose number was comparable with the number of charged mesons.[3] Our shower-stars do not show such striking multiplication, perhaps because the energies involved are lower. Some of the shower particles from stars may be electrons produced in the plates by photons from neutral mesons

In Table I 45 showers are listed which do not have two or more heavy tracks. Some of these are probably immediate products of nuclear explosions which have only one or no slow fragments emerging from the plate, but since some show the typical form of small electron cascades it is unlikely that all are formed in this way. We estimate that about 16 of these showers originate at the point of a nuclear explosion and about 29 do not. If these showers were caused by a primary electronic component, which was even 10 percent as numerous as the proton component,[4] the number of energetic showers observed in our cloud chamber would be approximately equal to the number of nuclear explosions caused by protons. There are actually about 25 of the latter (including "showers" which we estimated to have unobserved heavy tracks concealed in the plates) and one or two energetic electron showers. We conclude that primary electrons are rare, or non-existent, as is generally considered to be the case, and that the small showers observed must arise in some way from the nuclear interactions of the primary protons. One expansion showed two small showers coming from the second plate which project back to a common point in the first (carbon) plate, the angle between them being 40°, a type of event which suggests the neutral meson hypothesis.

* Work performed at Brookhaven National Laboratory under the auspices of the AEC.

[1] Flights were made by General Mills, Inc., Project Skyhook, sponsored by the ONR.

[2] The cloud chamber has been described by Shutt, Johnson, and Thorndike, Rev. Sci. Inst. **20**, 398 (1949).

[3] Camerini, Coor, Davies, Fowler, Lock, Muirhead, and Tobin, Phil. Mag. **40**, 1073 (1949). Kaplon, Peters, and Bradt, Phys. Rev. **76**, 1735 (1949). P. Freier and E. P. Ney, Phys. Rev. **77**, 337 (1950).

[4] Janossy, Rossi, and Hulsizer, Nature **163**, 246 (1949).

Erratum: X-Ray and Gamma-Ray Reflection Properties from 500 X Units to Nine X Units of Unstressed and of Bent Quartz Plates

[Phys. Rev. **77**, 475 (1950)]

D. A. LIND, W. J. WEST, AND J. W. M. DUMOND
California Institute of Technology, Pasadena, California

ON p. 482, column 1 of the text the statement is made that $t=w_1=w_4$. This should read: $t=w_1=w_2$. The text material is otherwise correct.

Equation (18), p. 485, is not complete as it stands. It should read:

$$\exp[\mu_0 l_0/\gamma_0]R'=r_0 d_H(|F_H|/V)\lambda/2\cos\theta_B \cdot\left[\frac{1+\cos^2 2\theta_B+2l_0^2(1+\cos^4 2\theta_B)}{1+\cos 2\theta_B+l_0^2(1+\cos^3 2\theta_B)}\right]. \quad (18)$$

On p. 485, bottom of column 1, the words *electron vector* should read *electric vector*.

In Fig. 3, the boxes represent the *maximum* spread in the experimental data, and not the probable errors as stated in the text.

The Thermal Rayleigh Disk in Liquid He II*

JOHN R. PELLAM
National Bureau of Standards, Washington, D. C.
AND
PHILIP M. MORSE
Massachusetts Institute of Technology, Cambridge, Massachusetts

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DURING early discussions regarding the validity of formulas for radiation pressure[1] and associated properties of second sound, it became apparent that a Rayleigh disk[2] experiment might constitute an additional crucial test of the two-fluid hypothesis[3-5] for liquid He II. Measurements of this nature are being conducted at the Cryogenics Laboratory of the National Bureau of Standards and the positive effects observed thus far have been in full conformity with the currrent concepts[3,4] of the second sound mechanism. In addition to allowing a more detailed examination of the quantum hydrodynamics of liquid He II, the Rayleigh disk method provides an absolute measure of second sound intensity, dependent only upon such fundamentals as the kinetic energy and the geometry.

The singular feature of second sound in liquid He II is of course the basically thermal nature of the propagation. Ordinary acoustical sources cannot generate second sound waves, nor can ordinary microphones detect them; thermal methods are customarily employed instead.[6] This situation may be rationalized on the basis of the current two-fluid hypothesis for He II. Whereas the oppositely directed momenta (and particle velocities) of the component fluids logically constitute zero net momentum,[4,5] the internal mass transport establishes a net heat flow with an associated temperature fluctuation.

Although detectors of the microphone class (either pressure or velocity type) cannot recognize this process, the mechanical device known as the Rayleigh disk can and does resolve the existent internal convection. This disk can detect second sound as well as ordinary (sound) because it responds to particle velocity squared, rather than to mere particle velocity. The disk accordingly recognizes the existence of a kinetic energy density within the second sound as pictured on the two-fluid basis.

A thin circular mirror ($\frac{1}{2}$-in. diam.) has been suspended vertically within the second sound field by a thin torsion wire. The mirror orientation was adjusted for equilibrium conditions (in the absence of second sound) to make a 45° angle with the axis of wave propagation. The second sound field was then set up within a horizontally oriented cavity, and the mirror deflections observed for conditions of resonance. The sharp response of the mirror disk (and deflection of a reflected light beam) as the system was tuned through resonance verifies the internal mass flow and its associated kinetic energy density.

The wave velocity determined in this manner from critical resonance frequencies (half-wave-length fixed) is in essential agreement as a function of temperature with the results of earlier purely thermal methods.[6,7] Measurements can be extended quite close to the λ-point where velocities of less than 1 m/sec. have been observed.

The maximum torque set up at resonance can be measured directly, knowing the torsion constant of the system (from the observed period of free oscillation). Since, furthermore, the resonance response is regular and symmetrical, band width determinations are practicable. The associated reinforcement factor Q combined with the known periodic heating rate (introduced uniformly over one end-wall of the cavity) leads to an estimate of the actual heat flow density at the location of the disk.

By comparison of the observed dependence of the torque on the temperature with theoretical predictions based on modifications of the classical Rayleigh formula,[2] the individual roles of normal fluid and superfluid in deflecting the disk can be examined. Space does not permit giving expressions for the separate torques, but should *both* fluids contribute it can be shown that the resultant torque τ would be

$$\tau=(4/3)a^3\rho(\rho_n/\rho_s)[\dot{H}^2/(\rho ST)^2]. \quad (1)$$

Here a is the radius of the disk. The properties of liquid He II enter through the entropy S and total density ρ; also ρ_n is the density of the normal fluid, ρ_s that of the superfluid. T denotes the ambient absolute temperature and $\dot{H}$ the heat flow density. A similar expression holds for the contributions by each individual fluid component.

Thus far Eq. (1) has been checked only near the λ-point, but there the agreement seems complete. The significance of this verification however is that *superfluid is providing the predominant*

torque in this temperature region [since near the λ-point $\rho_s \ll \rho_n$, making the superfluid particle velocity (squared) relatively large]. Whether the normal fluid is contributing its share awaits extension of the measurements to the lower temperature range where the condition $\rho_n < \rho_s$ holds.

Otherwise stated, the results thus far substantiate a form of the Bernoulli equation now generalized to suit the quantum hydrodynamics of He II

$$\tfrac{1}{2}\rho(\rho_n/\rho_s)[\dot{H}^2/(\rho ST)^2]+\tfrac{1}{2}\rho V^2+\rho gh+p=\text{const.} \qquad (2)$$

Here the additional first term represents the contribution of pressure due to heat flow density $\dot{H}$. The derivation of (2) will be given more completely in a later discussion.

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Extension of Alpha- and Beta-Decay Systematics of Protactinium Isotopes*

W. W. MEINKE† AND G. T. SEABORG
Radiation Laboratory and Department of Chemistry, University of California, Berkeley, California
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As part of our program for obtaining data to extend the scope of the systematics of alpha-radioactivity[1] and to obtain more data pertaining to the energy surface in the heavy region of elements, we have made some pertinent new measurements on protactinium isotopes.

The heaviest isotope of protactinium hitherto reported is that of mass 234 and hence it would be of interest to know the beta-emission properties of heavier isotopes in order to tie them in with the known radioactive data in this general region. Since low energy deuteron bombardment of U^{238} might be expected to lead to Pa^{235} and Pa^{236} by $(d,\alpha n)$ and (d,α) reactions and proton bombardment to Pa^{235} by the (p,α) reaction, these irradiations were made in the 60-in. cyclotron at energies of 19 and 9.5 Mev, respectively.

The protactinium was chemically separated following the bombardment of natural uranium by a procedure which involved a number of manganese dioxide cycles coupled with extractions of protactinium from aqueous into organic solvents. The manganese dioxide cycles consisted in precipitating this compound from the solution of uranium in nitric acid, followed by centrifugation, dissolution of the solid with hydroxylamine solution, dilution, and reprecipitation. The dissolved precipitate from the last cycle was acidified, salted with ammonium nitrate, and the protactinium extracted with diisopropyl ketone, several washings with salted solutions being made to insure good separation from fission products. The protactinium was then washed back into a low acidity aqueous solution and after acidification was extracted into a benzene solution of thenoyltrifluoroacetone which forms a complex ion with the protactinium. This solution was then evaporated to dryness on a platinum counting plate leaving a weightless deposit of protactinium.

The protactinium from the 19-Mev deuteron bombardment contained 23.7±0.5 min. and 27-day beta-particle emitters. The cross section for the formation of the former is about 2×10^{-27} cm² on the assumption that it is formed from U^{238} while that for the latter is about 4×10^{-27} cm² on the assumption that it is due to Pa^{233} produced in the reaction $U^{235}(d,\alpha)Pa^{233}$. Small amounts of two intermediate periods were present but these most probably can be attributed to a small amount of zirconium and niobium fission product contaminants. The 23.7-min. activity was also found in the protactinium fraction from the bombardment of U^{238} ($U^{238}/U^{235}=2300$) with 9.5-Mev protons in a yield corresponding to a cross section of about 3×10^{-29} cm². These observations are consistent with the assignment of the 23.7-min. activity to Pa^{235}, produced in the reactions $U^{238}(d,\alpha n)Pa^{235}$ and $U^{238}(p,\alpha)Pa^{235}$.

An aluminum absorption curve taken on this 23.7-min. activity shows that the beta-particles have a range of about 600 mg corresponding to an energy of about 1.4 Mev according to the Feather relationship.[2] Gamma-rays are either absent or are present in amounts too small to be detected by absorption experiments.

If one closes a decay cycle involving Pu^{239}, Np^{239}, Pa^{235}, and U^{235} using the values 0.7 Mev for the beta-disintegration energy[3] of Np^{239}, 5.24 Mev for the alpha-disintegration energy[3] of Pu^{239}, and 4.6 Mev for the estimated alpha-disintegration energy[1] of Np^{239}, a beta-disintegration energy of 1.34 Mev is obtained for Pa^{235}. This measurement, therefore, gives added weight to the somewhat uncertain measured beta- and estimated alpha-disintegration energies of Np^{239}, and hence adds to the reliability of the data needed for the construction of the energy surface in this region.

We also were interested in determining the partial half-life of Pa^{230} for alpha-disintegration. A half-life of some hundreds to thousands of years would be predicted from the alpha-systematics by obtaining the alpha-disintegration energy from mass number *versus* energy plots (5.5 Mev) and taking into account the prohibition introduced by the presence of two odd nucleons in determining its alpha-disintegration rate.[1] In this experiment the alpha-particles of the Pa^{230} were not measured directly but its half-life for alpha-disintegration was inferred by measuring the equilibrium amount of its alpha-disintegration product, the beta-particle emitting 29-hr. Ac^{226}, on the assumption that the predicted negligible branching decay of Ac^{226} by electron capture is correct. (The half-life of Ac^{226}, originally reported as 22 hr.,[3] has been more recently determined to be 29 hr.[4])

The actinium was chemically separated from a sample containing a large amount of Pa^{230} and the Ac^{226} was identified and the amount measured through an alpha-pulse analysis in which the alpha-particles of its daughters, 30-min. Th^{226} and daughters, were measured. In a bombardment of a thick thorium target with 60-Mev deuterons for 10μa-hr. in the 184-in. cyclotron a sample of Pa^{230} corresponding to 1.3×10^6 negative beta-disintegrations/min. (as determined by alpha-pulse analysis of the daughter U^{230} decay chain) was chemically isolated as described above. The actinium was chemically separated from this protactinium fraction by carrying it on lanthanum and cerium fluorides which were redissolved and reprecipitated several times and further purified after dissolution by removing thorium through repeated zirconium phosphate precipitations. At the end of the procedure, the cerium (III) was oxidized to cerium (IV) with sodium bismuthate, the cerium (IV) removed on a zirconium phosphate precipitate, and the actinium activity precipitated with a small amount of lanthanum fluoride. After dissolution in hydrochloric acid, the soluble chloride of the carrier when evaporated on platinum gave a thin plate suitable for alpha-pulse analysis.

The actinium fraction from the protactinium containing 1.3×10^6 beta-disintegrations/min. of Pa^{230} contained 300 alpha-disintegrations/min. of Th^{226} which decayed with the 29-hr. half-life of its beta-emitting Ac^{226} parent. Correcting for chemical yield (as determined by 10.0-day Ac^{225} tracer) and taking into account the fact that Pa^{230} has a half-life of 17 days[5] and also decays by electron capture in a ratio of 10 as compared to its decay by negative beta-particle emission,[6] these data lead to a partial half-life for alpha-emission of about 1400 yr.±20 percent. This corresponds, as in the case[1] of the analogous nucleus Pa^{228}, to a prohibition by a factor of about 100 in the alpha-decay, presumably due to the presence of two odd nucleons.

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