theoretically only 4 percent above the classical $1/T$ curve.[8] This point was used to fix the relative position of the Fermi-Dirac curve and the $1/T$ curve. Possible error in the measurements should not exceed 10 percent, even in the gas where the signal is weakest. It is impossible, however, to ascertain from these results whether the gas point shows the 4 percent degeneracy expected of an ideal Fermi-Dirac gas.

Nuclear magnetic resonance in He^3 has already been observed by Anderson[9] in the gas at room temperature. In the present

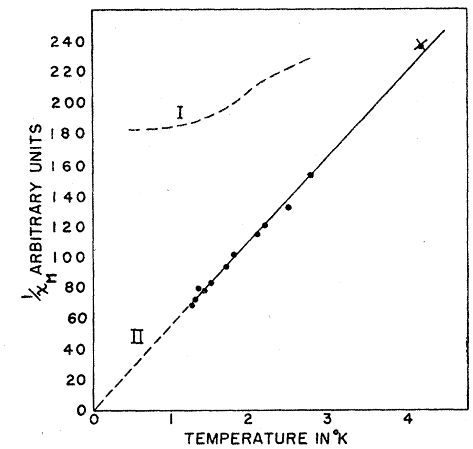

FIG. 1. Graph of the reciprocal of the molar nuclear susceptibility χ_M of He^3 *vs* the absolute temperature. Curve I including the x at 4.2°K represents the curve for an ideal Fermi-Dirac gas of the same density as the He^3. The dots represent the experimental points in the liquid below 2.8°K and in the gas at 4.2°K and 900-mm pressure.

experiment He^3, in a field of about 10 000 gauss, was condensed inside a coil which formed part of the resonant circuit for the input to a 30 mc/sec receiver.[10] The signal was displayed on a scope and the amplitude was measured from photographs of the scope trace. The He^3 sample, 20 cc of He^3 gas at S.T.P., was obtained from the Stable Isotope Division of the Oak Ridge National Laboratory and was concentrated by us by fractional distillation to better than 99 percent purity as determined by vapor pressure measurements. The temperature of the He^3 was determined directly from its vapor pressure and checked against the temperature of the bath.

Under the conditions of the experiment, the amplitude of the nuclear magnetic resonance signal, corrected for its small effect on the Q of the coil, was proportional to the nuclear volume susceptibility.[11] The line width was observed to remain constant, being determined only by the inhomogeneity of the external magnetic field. From relaxation time measurements it was ascertained that equilibrium had always been reached between the nuclei and the lattice motions before a measurement was taken. The radio-frequency signal was kept small enough to avoid appreciable disturbance of this equilibrium. The coil was always kept full of He^3.

To obtain the molar susceptibility the Los Alamos density values were used for the liquid below 2.8°.[12] At 4.2° the density of the gas was measured experimentally and found to agree within the possible error of 5 percent with that calculated using the theoretical second virial coefficient.[13]

The nuclear spin lattice relaxation time was observed to be 60 sec in the gas at 4.2°K and 900-mm pressure, 135 sec at the critical point and 200 sec in the liquid at 2.2° and 1.2°K. The relatively short relaxation time in the gas may possibly be accounted for by a layer of absorbed oxygen on the walls of the container.

The susceptibility measurements are being continued to lower temperatures. We wish to express our appreciation to Dr. F. London for many helpful discussions which contributed materially to the conception of this experiment. We also wish to thank Mr. T. C. Chen and Dr. R. S. Smith for help with the theoretical details of the experiment and for aid in taking the measurements.

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[1] I. Pomeranchuk, J. Exptl. Theoret. Phys. (U.S.S.R.) **20**, 919 (1950).
[2] L. Goldstein and M. Goldstein, J. Chem. Phys. **18**, 538 (1950).
[3] E. M. Lifshitz, J. Exptl. Theoret. Phys. (U.S.S.R.) **21**, 659 (1951).
[4] K. S. Singwi, Phys. Rev. **87**, 540 (1952).
[5] Weinstock, Abraham, and Osborne, Phys. Rev. **89**, 787 (1953).
[6] T. C. Chen and F. London, Phys. Rev. **89**, 1038 (1953).
[7] Hammel, Laquer, Sydoriak, and McGee, Phys. Rev. **86**, 432 (1952).
[8] J. McDougall and E. C. Stoner, Trans. Roy. Soc. (London) **A237**, 67 (1938).
[9] H. A. Anderson and A. Novick, Phys. Rev. **73**, 919 (1948).
[10] B. V. Rollin and J. Hatton, Proc. Roy. Soc. (London) **199**, 222 (1949).
[11] Bloembergen, Purcell, and Pound, Phys. Rev. **73**, 679 (1948), Eq. 8 and Appendix.
[12] Grilly, Hammel, and Sydoriak, Phys. Rev. **75**, 1103 (1949).
[13] de Boer, van Kranendonk, and Compaan, Physica **16**, 545 (1950).

Example of a V^+ Decay*

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IN view of the current interest in the heavy charged unstable particles,[1] it seems worthwhile to report a V^+ decay, film R-112 shown in Fig. 1, which permits detailed analysis. A heavily ionizing particle (1), of momentum 270±10 Mev/c, apparently enters the chamber from the right and decays in flight to produce a secondary (2) of minimum ionization. The estimate of the primary mass from ionization and momentum is less uncertain than the average case since the proximate meson track (3) of momentum 67±4 Mev/c is heavily ionizing and may be used for comparison. If the meson (3) is assumed to be a pion, its ionization can be computed from the known momentum, and the projected

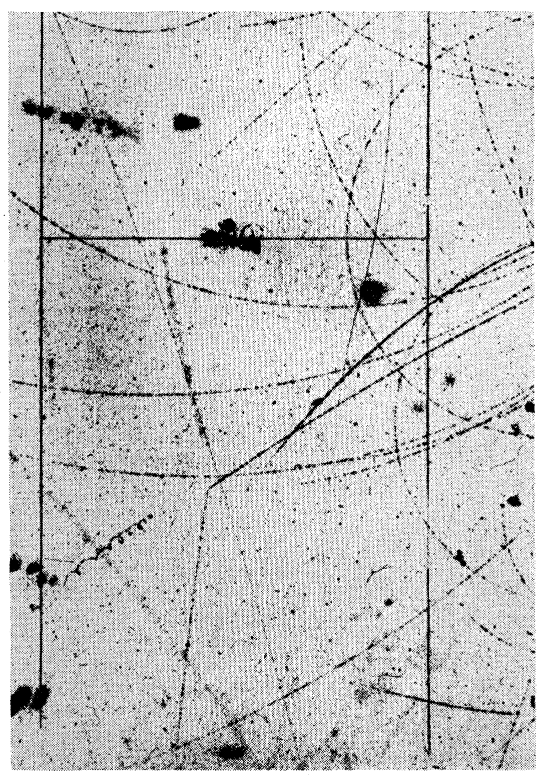

FIG. 1. Right-eye view of event R-112. The lower ⅔ of the chamber is shown.

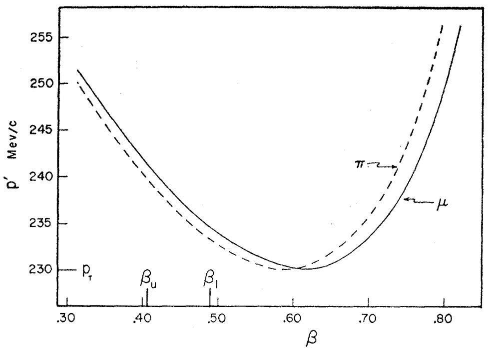

FIG. 2. The dependence of p' on β, the secondary assumed to be a muon or pion. Note that the range of ordinate scale is only $230 < p' < 250$ Mev/c, whereas the corresponding range on the abscissa is approximately $0.3 < \beta < 0.8$. Thus the uncertainty in p' due to uncertainty in β is practically negligible.

ionization[2] on each stereoscopic negative can then be found from the orientation of the track in space. The projected ionization of the primary (1) appears to be distinctly less than that of the meson (3) on all three films, so that an upper limit for the primary mass is obtained by assumption that the projected ionizations on each film are equal, etc. The upper limits thus obtained independently from the three films differ slightly since the orientations of the films with respect to the tracks differ. The lowest upper limit is obtained from the right eye and gives $M < 1200m_e$. Assumption that the meson (3) is a muon clearly leads to a lower upper limit.

On the other hand, a lower limit for the mass of the primary can be obtained from the transverse component of momentum p_T of the secondary. Unfortunately, the secondary track is of intermediate quality only. Furthermore, although the values of the spatial radius of curvature deduced from the left and central eyes agree (to 5 percent, the left eye, of better quality, being the lower), the value from the right eye is somewhat higher. The reason for this discrepancy is not known.[3] Therefore, since we wish to set a lower limit for the mass of the primary, we report the momentum from the left eye, namely 300_{-20}^{+60} Mev/c, where the error on the upper side is sufficient to include the value from the right eye. Since the ionization is probably less than twice minimum, an upper limit of $740m_e$ is obtained for the mass of the secondary.

The angle between the secondary (2) and the continuation of the primary (1) is, after the dilation correction, 49.2 ± 0.2 degrees, giving $p_T = 230_{-15}^{+45}$ Mev/c. The lower limit for the primary mass, under assumption that the secondary is a muon[1] and that no rest mass is associated with the recoil momentum, is then $M > 940m_e$. A higher lower limit is obtained for a pion secondary. If one or more neutral particles have nonzero rest mass, the lower limit on M is raised; or alternately, an upper limit for the sum of the masses of the neutral particles $\Sigma m_0 < 550m_e$ is obtained. It is thus unlikely, for example, that the neutral fragments in this case include a V_4^0 particle ($m = 971m_e$).[4]

If the secondary (2) is assumed to be a muon (or pion), its momentum p' in the center-of-mass system can be computed for various values of β, the velocity of the primary. The result, shown in Fig. 2, indicates a broad minimum at $p' = p_T$, which corresponds to emission at 90° in the center-of-mass system The values β_l and β_u indicated on the abscissa correspond to the lower and upper limits of the primary mass, respectively. These values of β lie just to the left of the minimum, which means that the momentum in the center-of-mass system is very nearly equal to p_T and is highly insensitive to β. The variation of p' with β as illustrated in Fig. 2 has been discussed in connection with the question of propagation of error in the determination of Q values of V_1^0 particles.[5]

The possibility that the event represents the decay of a negatively charged particle (2) which entered the chamber from below can be fairly well excluded on energetic grounds. The possibility that the event represents the decay of a V^0 particle which entered the chamber from above (4) is not suggested by the presence of other tracks from that general direction, but cannot, of course, be excluded. However, in this interpretation the V^0 decay would involve a negative fragment of intermediate mass and a $Q(\pi^+, \tau^-)$ value of 225 Mev, somewhat higher than that reported in the literature.[6]

We wish to acknowledge the help of Mr. L. R. Etter in the operation of the equipment and the reduction of the data.

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[1] G. D. Rochester and C. C. Butler, Nature **160**, 855 (1947); H. S. Bridge and M. Annis, Phys. Rev. **82**, 445 (1951); C. O'Ceallaigh, Phil. Mag. **42**, 1032 (1952). Much of the recent work on this subject is described in the Proceedings of the Bagneres Congress (to be published).

[2] It seems that the projective corrections to the estimate of ionization have not been taken into account in a quantitative way in some of the work described in the literature.

[3] Such a discrepancy may have been caused by damage to the right-eye film during processing.

[4] Thompson, Buskirk, Etter, Karzmark, and Rediker, Phys. Rev. **90**, 1122 (1953).

[5] Thompson, Karzmark, and Cohn, Phys. Rev. **87**, 182 (1952).

[6] Leighton, Wanlass, and Anderson have reported a decay $V_3^0 \rightarrow \pi^+ + (\tau^-$ or $\kappa^-) + 60$ Mev. See Phys. Rev. **89**, 148 (1953).

The Nuclear Stability Curve

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IN the usual explanation[1,2] of the relation between mass number A and atomic number Z for stable nuclei, the minimizing condition $(\partial E/\partial Z)_A = 0$ applied to a semi-empirical expression for the total nuclear energy $E(Z,A)$ yields the stability relation

$$Z = A/(2 + 0.0146A^{\frac{2}{3}}), \tag{1}$$

which is known to be in good agreement with observation. It will be shown here that a relation of this form results from the Fermi-Dirac degenerate-gas model[3] on the assumption that nucleon interactions are, apart from ordinary Coulomb forces, independent of charge state.

The potential energy for a proton is taken to be just that for a neutron with the Coulomb energy eV superposed.[4] Beta stability requires that the available levels for the two charge states be filled to the same total energy. Thus at a given radius r the maximum kinetic energy, which in the degenerate gas is proportional to the $\frac{2}{3}$ power of the local particle number density, is μ for neutrons and $(\mu - eV)$ for protons. Accordingly, the ratio of proton density ρ_p to neutron density ρ_n is

$$\rho_p/\rho_n = (1 - eV/\mu)^{\frac{3}{2}}, \tag{2}$$

the proportionality factors cancelling owing to the practical equality of the neutron and proton masses. The ratio (2) must be such a function of r as to yield the observed uniform nucleon density, $\rho = \rho_p + \rho_n$. With the approximation $eV/\mu \ll 1$, which later proves self-consistent, we find

$$\rho_p \approx (\rho/2)(1 - 3eV/4\mu). \tag{3}$$

From Mattauch's value of the nuclear radius, $a = 1.42 \times 10^{-13} A^{\frac{1}{3}}$, the Coulomb energy at the surface of the nucleus may be written as

$$eV_a = Ze^2/a \approx Z/A^{\frac{1}{3}} \text{ Mev}. \tag{4}$$

Were all the protons on the surface, the potential energy would have this constant value throughout the nucleus; on the other hand, if the proton density were uniform,

$$V/V_a = [3 - (r/a)^2]/2. \tag{5}$$

For either of these extremes, the potential involves r only in the ratio $\xi = r/a$. It thus appears reasonable to ascribe this same behavior to the actual potential: $V/V_a = f(\xi)$; moreover, since this function is to appear in an integrand, the final result is rela-

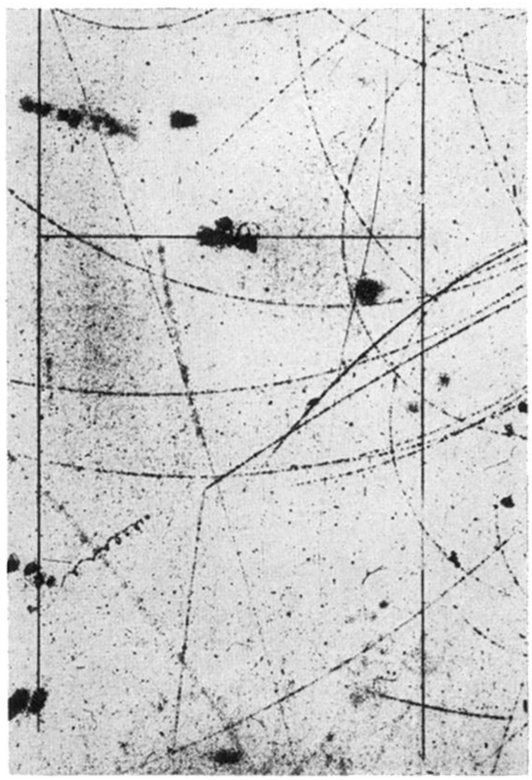

FIG. 1. Right-eye view of event R-112. The lower ⅔ of the chamber is shown.