used by Umeda and Tomishima[7] in extending the Thomas-Fermi-Dirac method to nonzero temperatures.[8]

These applications were confined to low temperatures, but in principle Zirin's table now allows this distribution function to be used for all temperatures. For, choosing kT/ϵ_0 and ϵ_j/ϵ_0, we can obtain the free energy F as a function of τ, using Stoner's tables[9] to find the kinetic energy and entropy terms and Zirin's table to find the exchange energy. Then τ can be chosen to minimize the free energy and hence β can be found.

Unfortunately, however, in practice the accuracy of the calculations is limited by the nature of Zirin's table, since the free energy curve is very flat near the minimum, and it is not possible therefore to determine τ at all precisely. Thus the broken curve 3 in Fig. 1 is more of an estimate than the result of a precise calculation, for particularly in the neighborhood of $kT/\epsilon_0=1$ the possible errors are large. Nevertheless, it is possible to conclude that whereas Zirin's curve considerably underestimates β for $\epsilon_j/\epsilon_0=1$, Lidiard's work leads to values which are too great, particularly for $kT/\epsilon_0>1$. Curve 3 will certainly give a better approximation than either of these, but until a more accurate table than Zirin's is available it does not seem possible to be more precise than this.

In conclusion, it seems worthwhile to point out that though Lidiard's work does not lead to a very good approximation to the exchange energy, the free energy, which is the important quantity in most applications, for example in the calculation of specific heat,[3] ferromagnetic properties,[4] and spin paramagnetism,[10] is much less in error. This is shown quite clearly in Fig. 2, from

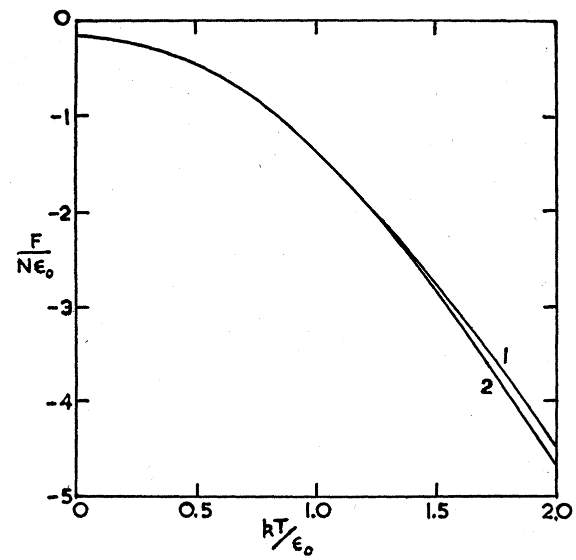

FIG. 2. Free energy as function of temperature for $\epsilon_j/\epsilon_0=1$. Curve 1: Lidiard approximation. Curve 2: Improved approximation.

which it can be seen that the free energy is insensitive to the choice of distribution function, and that, as we would expect, the function given by (3) is everywhere a better approximation than that used in Lidiard's first paper.[4]

1 H. Zirin, Phys. Rev. 90, 795 (1953).
2 H. Koppe, Z. Naturforsch. 2A, 429 (1947).
3 E. P. Wohlfarth, Phil. Mag. 41, 534 (1950).
4 A. B. Lidiard, Proc. Phys. Soc. (London) A64, 814 (1951).
5 A. B. Lidiard, Phil. Mag. 42, 1325 (1951).
6 I. Yokota, J. Phys. Soc. Japan 4, 82 (1949).
7 K. Umeda and Y. Tomishima, J. Phys. Soc. Japan 8, 360 (1953).
8 See also N. H. March, Phil. Mag. 44, 346 (1953).
9 E. C. Stoner, Phil. Mag. 28, 257 (1939).
10 N. H. March and B. Donovan (unpublished calculations).

Ionization Loss in Nuclear Emulsions*

JOHN R. FLEMING AND J. J. LORD
Department of Physics, University of Washington, Seattle, Washington

(Received July 22, 1953)

A STUDY has been made of the relationship between the velocity of singly charged particles and the resultant grain density produced in an Ilford G-5 emulsion. A single 2 in.×2 in., 400-micron thick place was exposed successively to slow negative muons (for their decay electrons) and to 227, 122, 81, and 31 Mev negative pions from the Chicago cyclotron.[1] The plate was rotated 45° after each exposure so that the tracks of particles of differing energies could be distinguished. This also made it possible to make grain and blob density measurements of tracks over a restricted portion of a single plate.

TABLE I. Data on grain counting.

Particle	Energy (Mev)	Total track length (microns)	Blob mean (100 μ)	Normal blob mean	Grain mean (100 μ)	E/Mc^2
e^-	34 ± 10	40 400	30.44 ± 0.08	0.983	41.9 ± 0.1	66.6
π^-	224 ± 5	112 500	27.78 ± 0.08	0.897	37.1 ± 0.1	1.61
π^-	121 ± 5	24 600	31.69 ± 0.08	1.023	43.6 ± 0.6	00.87
π^-	80 ± 4	34 900	36.71 ± 0.15	1.185	52.0 ± 0.3	00.58
π^-	24 ± 2	40 800	45.16 ± 0.11	1.458	75.7 ± 0.4	00.173

Since the cyclotron meson beams contain 5 to 10 percent muons and electrons,[1] it was necessary to insure that only pion tracks were measured by selecting the tracks of particles which produced nuclear disintegrations in the emulsion. Each track was then followed back to the point where it entered the emulsion so that the average energy of the pion could be determined for the interval measured. The average energies of the pions in the measured portions of the tracks are given in Table I. The errors given for the pion energies in Table I include both the spread of energy of the incident pions and the variations of the path lengths of the pions in the emulsion. In the case of the electrons, the spread in energy is due to the natural muon decay energy spectrum.

All grain and blob counting was made by a single observer whose reproducibility was found to be 2.5 percent for grain and 0.5 percent for blob counting. The plate was calibrated for the variation of blob and grain densities with depth below the surface and the measured mean track density corrected accordingly. This was the largest single correction applied and amounted to −0.9, +2.59, +1.34, +2.14, and +1.50 percent for, respectively, the electrons, and the pions of 224, 121, 80, and 24 Mev. The track densities of the randomly distributed electrons were found to be independent of the azimuthal angle indicating the absence of any effects due to a possible preferential alignment of the AgBr crystals of the emulsion.

The corrected mean values for the grain and blob densities are given in Table I. These data for the blob densities are plotted in Fig. 1 together with theoretical curve for the restricted energy loss of electrons and heavy particles in AgBr for energy exchanges less than 5 kev. The data were normalized so that the point representing the average value of the decay electron blob density lies on the theoretical curve. This curve was obtained from the calculations of Sternheimer[2] based on the methods of treatment given by Fermi and Halpern and Hall.[3] The data (Fig. 1) agree reasonably well with this theory except for the point at $E/Mc^2=0.173$. This is due to the saturation of blob density which occurs in this range of high track densities. The close agreement of the data with the theory, which gives a 14.0 percent relativistic increase, implies that nearly all of the energy exchanges less than 5 kev go into the formation of grains.

Since Pickup and Voyvodic[4] first established the relativistic rise of track density in photographic emulsions, there have been a number of experimental investigations undertaken to establish these features.[5] The data reported herein were taken in order to give very precise information under more controlled conditions.

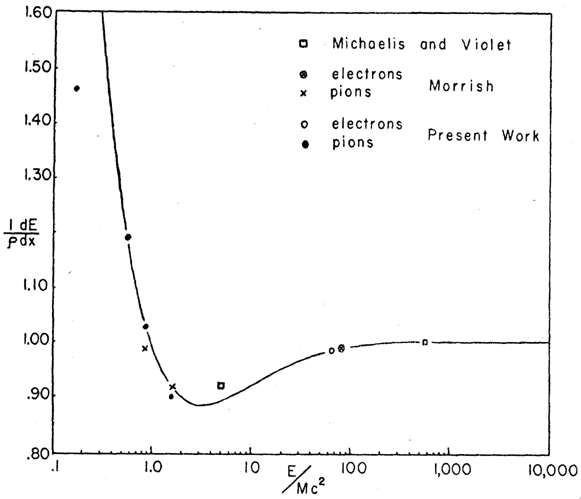

FIG. 1. Theoretical curve of energy loss in AgBr in Mev per gram per cm^2 as a function of E/Mc^2. Blob densities are plotted and normalized to the curve at the points for the decay electrons in the present investigation and that of Morrish. The data of Michaelis and Violet are normalized to the curve for their point at $E/Mc^2=580$.

Similar type experiments over restricted portions of the curve have been made at Berkeley[6] and by Morrish,[7] and these data have been included in Fig. 1. The points, Fig. 1, appear to be in reasonable agreement with the theoretical curve; however, the agreement between both the theory and the different observers would be quite good if all statistical errors were doubled. It is probable that this is due to some systematic errors, the nature of which are not known at present.

We would like to thank Professors Marcel Schein and H. L. Anderson for the photographic plate and the cyclotron exposure. It is also a pleasure to thank Professors E. A. Uehling and S. H. Neddermeyer for very helpful discussions.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Anderson, Fermi, Martin, and Nagle, Phys. Rev. **91**, 155 (1953).
[2] R. M. Sternheimer, Phys. Rev. **88**, 851 (1952); **91**, 256 (1953).
[3] Enrico Fermi, Phys. Rev. **56**, 1242 (1939); O. Halpern and H. Hall, Phys. Rev. **73**, 477 (1948).
[4] E. Pickup and L. Voyvodic, Phys. Rev. **80**, 89 (1950).
[5] Daniel, Davies, Mulvey, and Perkins, Phil. Mag. **43**, 753 (1952); M. M. Shapiro and B. Stiller, Phys. Rev. **87**, 682 (1952).
[6] R. P. Michaelis and C. E. Violet, Phys. Rev. **90**, 723 (1953).
[7] A. H. Morrish, Phys. Rev. **91**, 423 (1953).

Negative μ-Meson Capture in Carbon*

T. N. K. GODFREY
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
(Received September 1, 1953)

WE are studying experimentally the behavior of cosmic-ray μ mesons stopped in carbon. Bell and Hincks[1] have shown that the mean life of negative μ mesons in carbon differs from the mean life of positive μ mesons. They compute the nuclear capture rate for negative μ mesons in carbon to be $A=(5.5\pm1.5)\times10^4$ sec^{-1}. The fraction of stopped negative μ mesons which are captured, $F=A/(A+1/\tau)$, is 0.11 ± 0.03, where τ is the mean life of positive μ mesons. The possible end products of the capture reaction are bound states of B^{12} or groups of fragments such as B^{11} plus a neutron. The object of our investigation is a determination of the probability for the end product to be B^{12} in its ground state. We present here a brief description of the method and some preliminary results.

The μ mesons to be studied are stopped in an organic liquid scintillation counter. The counter has a sensitive volume of 4 in.$\times 4\frac{1}{2}$ in.$\times$5 in. viewed by two RCA type C7157 photomultipliers. The pulses from the counter are presented on an oscilloscope and photographed. An arrangement of coincidence and anticoincidence Geiger counters selects events and triggers the oscilloscope sweep. Details of the presentation scheme and of the means used to eliminate spurious events will be presented in a subsequent paper.

Two types of events are investigated. In the first, the pulse from the arriving μ meson is followed by a pulse with a 2 μsec mean delay, indicating that the meson decayed. In the second type of event, the arriving μ-meson pulse is followed by a pulse with a 39 millisecond mean delay, indicating that a C^{12} nucleus captured the meson, forming a B^{12} nucleus which subsequently decayed by β emission back to C^{12}.[2] The end product of the capture reaction in the second type of event is B^{12} in either the ground state or a bound excited state. (An unbound excited state would decay by neutron emission and a B^{12} β particle would never be observed.) A bound excited state would promptly decay by γ emission to the ground state and later a β particle would be emitted. With the present apparatus, the γ ray would in general not be detected, and the event would have the same appearance as if the ground state had been formed in the original capture reaction.

Let D be the number of events observed in which a negative meson decays, as determined from the total number of decays, corrected by the data of Bell and Hincks and by the known positive excess. Let C be the number of capture events observed. Then $P=C/D\tau$ is the rate of the μ-meson capture reaction that results in a B^{12} nucleus in the ground state or in a bound excited state. P is thus also an upper limit on the rate of the reaction whose end product is B^{12} in the ground state. Our preliminary result is that $P=(5\pm2)\times10^3$ sec^{-1}.

The ratio P/A is 0.09 ± 0.05. This indicates that only about a tenth of the capture reactions result in B^{12} in a bound state. If the unbound states of B^{12} usually break up into B^{11} plus a neutron, then from the low value of P/A one would expect the multiplicity of the neutrons emitted in the capture of μ mesons in carbon to be near unity. Although the neutron multiplicity has been measured[3] for the capture of μ mesons in several elements, it has not yet been done for carbon.

A full report will be published upon completion of this investigation.

* Supported by the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.
† National Science Foundation Predoctoral Fellow.

[1] W. E. Bell and E. P. Hincks, Phys. Rev. **88**, 1424 (1952).
[2] J. E. Brolley, Jr., *et al.*, Phys. Rev. **83**, 990 (1951).
[3] M. F. Crouch and R. D. Sard, Phys. Rev. **85**, 120 (1952); A. M. Conforto and R. D. Sard, Phys. Rev. **86**, 465 (1952); M. Widgoff, Phys. Rev. **90**, 891 (1953).

Liquid Scintillation Counting of Natural C^{14}†

F. N. HAYES, D. L. WILLIAMS, AND BETTY ROGERS
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico
(Received May 8, 1953; revised manuscript received September 2, 1953)

DURING an investigation of the natural C^{14} content of liquid scintillation solvents, samples of *p*-cymene were obtained which gave very different counting rates. A consistently high rate resulted from material whose primary origin, via certain trees, was contemporary atmospheric carbon dioxide[1] and an equally consistent low value was derived from samples synthesized entirely from petroluem chemicals.[2]

Accurate knowledge of these two counting rates and the accompanying backgrounds, along with careful standardization of the C^{14} detection efficiencies during the experiments, has allowed easy realization of a number which is the specific activity of natural C^{14} in *p*-cymene and in the constituents of turpentine from which it is derived.