energy, about 3 scatterings will be necessary to give Bernardini's result. But if the scattering cross section per nucleon is only a few millibarns, such repeated scattering would be most unlikely.

Further experimental evidence on meson scattering, especially by protons and deuterons, is clearly needed.

[1] M. Camac *et al.*, Phys. Rev. **82**, 745 (1951).
[2] A. Shapiro, private communication. See also Bull. Am. Phys. Soc. **26**, No. 4, 10 (1951).
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[4] The *increase* of diffraction scattering due to the refractive index can be calculated by expansion of the formula of Fernbach and others which yields

$$D=\frac{\sigma_d(\lambda, k_1)}{\sigma_d(\lambda, k_1=0)}-1=4(k_1\lambda)^2\left(1-\frac{1}{18}\left(\frac{R}{\lambda}\right)^2+\cdots\right).$$

For carbon, $R/\lambda\approx 1$ so that the second term is only a small correction. The simplified formula, $D=4(k_1\lambda)^2$, was found by numerical calculation to hold within 5 or 10 percent for opacities up to 0.9 and $k_1\lambda$ up to about 1.
[5] This value follows from the energy difference between mirror nuclei which seems to us the most accurate determination of the nuclear radius. The mirror nuclei may be chosen in the neighborhood of carbon.
[6] Shutt, Miller, Thorndike, and Fowler (private communication).
[7] Chedester, Isaacs, Sachs, and Steinberger, post-deadline paper at the Washington meeting of the Am. Phys. Soc.
[8] This cross section was used by Brueckner, Serber, and Watson (Phys. Rev., to be published) to separate the total collision cross section of mesons in nuclear matter, $1/\lambda$, into scattering and star formation. The cross section thus obtained for star formation is shown by them to be in good agreement with detailed balancing arguments, but this agreement would not be substantially changed if the scattering were reduced to essentially zero because even Steinberger's cross section is only one-third of the total interaction cross section of 40 mb.
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Ranges of High Energy Electrons in Water

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(Received June 11, 1951)

RANGE measurements of high energy electrons in various media have customarily been made with Geiger counters or cloud chambers as detectors. With the high intensity homogeneous electron beam available from the betatron, ionization measurements are employed to determine the distribution of dissipated energy in various materials. Such ionization measurements that can be interpreted to supply information on the ranges of high energy electrons in water are reported here.

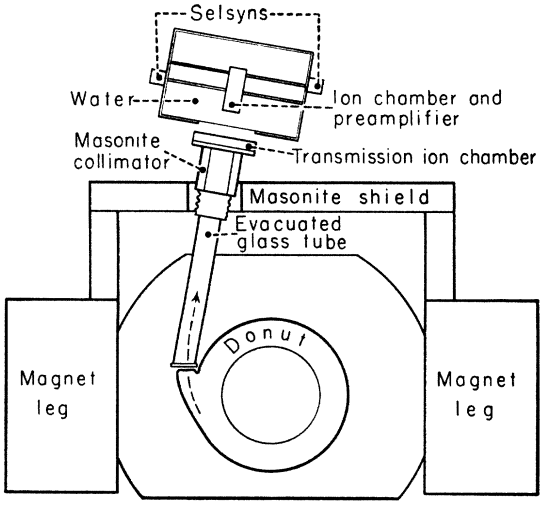

FIG. 1. Top view of betatron and apparatus for measuring ionization as function of depth in water. A parallel beam of electrons passes through transmission monitor chamber (Nylon walls) before entering water tank through thin window.

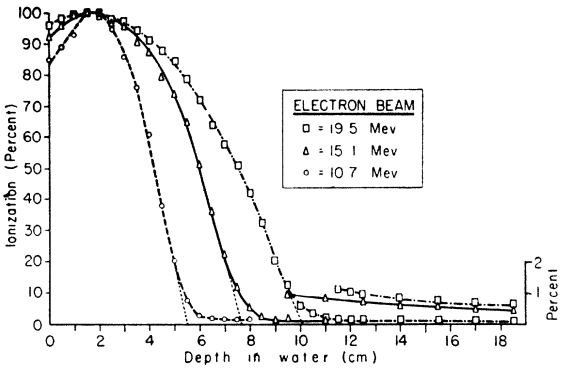

FIG. 2. Relative distribution of ionization as function of depth in water. Extrapolated ranges are indicated. Ionization produced in absorption of the bremsstrahlung was measured with increased amplification and is plotted against ordinate scale at right.

The energy of the electron beam can be varied continuously from 5 Mev to 22 Mev. The energy is determined by controlling the time at which the electrons are "expanded" from their orbit. The expansion timing circuit was calibrated directly against electron energy with known electrodisintegration thresholds. Thin foils of copper (10.9 Mev) and polythene (carbon, 18.7 Mev) were employed with the direct electron beam for this calibration.

A schematic diagram of the apparatus arrangement is shown in Fig. 1. The electron beam emerged from a thin window in the doughnut and passed in an evacuated tube through the fringing field of the magnet. Different field sizes and lengths of evacuated extension tubes were employed, but in all cases the electrons were in a parallel beam at the measuring apparatus. The ionization was measured in a small ion chamber (0.381 cm³) immersed in a water tank. Its position could be accurately varied by remote control. The inside diameter and height dimensions of the chamber were 5 mm. It was mounted on a stem on a preamplifier leading to a dc amplifier. Details of this measuring apparatus have been described elsewhere.[1,2]

Typical distributions of ionization as a function of depth in water produced by a 6-cm diameter electron beam are shown in Fig. 2. The increase in ionization beyond the surface which is due to multiple scattering is less marked with increasing energy. The ionization distribution can be made proportional to the number of electrons by correcting for the specific ionization of the electrons as a function of energy. Brode's plot of specific ionization against energy[3] was used to correct distributions such as those in Fig. 2 to a plot of number of electrons *versus* depth in water. This correction did not prove to be important, and the

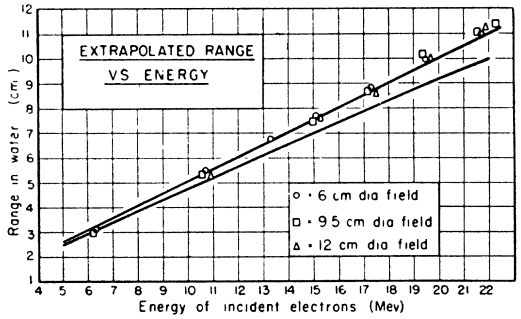

FIG. 3. Experimental points are the extrapolated ranges obtained from data plots such as those in Fig. 2. The maximum experimental uncertainty in the points is ±0.2 Mev in energy and ±2 mm in range. The upper curve represents maximum ranges predicted on the basis of Halpern and Hall's equation including density effects. The lower curve represents the predictions of the Bethe-Bloch equation ignoring density effects.

extrapolated ranges obtained from the corrected number plots were not significantly different from those obtained from the original ionization distribution data.

These extrapolated ranges should correspond to the "practical maximum range" defined by Bleuler and Zünti.[4,5] The "absolute maximum range" is greater but is not as easily determined experimentally. In Fig. 3 the extrapolated ranges determined from plots similar to those in Fig. 2 are plotted as a function of the kinetic energy of the electrons. The extrapolated ranges appear to be independent of field size. The "absolute maximum ranges" would be a few millimeters longer.

Fermi[6] and Halpern and Hall[7] have discussed the polarization effect of materials in a condensed state on the energy loss of electrons. The upper curve in Fig. 3 is a plot of the ranges to be expected on the basis of Halpern and Hall's[7] treatment of density effects in water. This curve was constructed from their results for water by numerical integration. The lower curve was constructed in a similar manner from the predictions of the Bethe-Bloch formula as represented by Halpern and Hall.[7] The calculated ranges which include density effects approach the experimental ranges more closely. The experimental "absolute maximum ranges" would, moreover, be slightly greater than the extrapolated range points shown.

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Low States of F^{17} and Neutrons from $O^{16}+D$

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A THIN (<80-kev) tungsten oxide target, (prepared by electrolysis) was bombarded by 3.083-Mev deuterons from the Wisconsin electrostatic generator. The resultant neutron spectrum was observed by means of Eastman NTA nuclear emulsions, 100 microns thick, mounted 10 cm from the target and at angles of 0°, 10°, 20°, 30°, and 90° to the direction of the beam. A total of 1700 tracks have been measured. Both the criteria[1] for the measurement of the proton recoil tracks and the range-energy relation[2] have been discussed elsewhere. The data, plotted in 50-kev intervals, and corrected for geometry[3] and for variation of the neutron-proton scattering cross section,[4] are shown as Fig. 1.

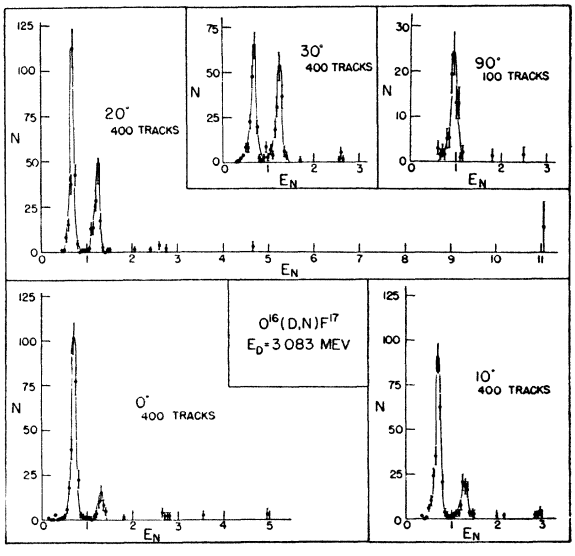

FIG. 1. Neutrons from the deuteron bombardment of O^{16} at 0°, 10°, 20°, 30°, and 90° to the incident beam. N is the relative number of neutrons per 50 kev, and E_n is the neutron energy in Mev.

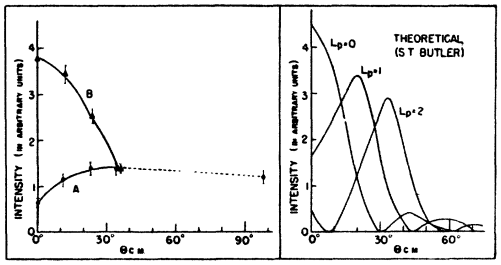

FIG. 2. $O^{16}(d,n)F^{17}$ angular distributions in the center-of-mass system. Curve A is for formation of F^{17} in the ground state, and curve B is for the 536-kev excited state. Butler's theoretical curves for high energy deuterons on O^{16} (see text) are shown for purposes of comparison.

Neutron groups corresponding to a first excited state of F^{17} at 536±10 kev are observed. These groups occur at approximately 0.7 Mev for the 0° to 30° data. The group at 90° corresponding to this first excited state would have an energy less than 0.5 Mev, and no tracks due to neutrons of energy less than 0.6 Mev were measured at that angle. The neutrons of energies 2.5 to 3 Mev at the various angles are possibly from carbon contamination (ground-state neutrons from the $C^{12}(d,n)N^{13}$ reaction). Neutrons from the first excited state of N^{13} would appear well below the lower limit of observation.

Figure 2 shows the relative intensities of the ground-state neutron groups (curve A) and of the 536-kev excited state neutron groups (curve B) as a function of angle in the center-of-mass system. Figure 2 also shows Butler's[5] theoretical curves for angular distributions resulting from a stripping process. These curves are for deuteron energies above the coulomb barrier which for oxygen is about 2.5 Mev. Hence, it is interesting to compare the shape of the experimental intensity *vs* angle curve for the 536-kev level of F^{17} with the $L_p=0$ curve of Butler. If the comparison is valid, this leads to the assignment of $S_{\frac{1}{2}}$ to the first excited state of F^{17}. Burrows, Gibson, and Rotblat[6] have bombarded O^{16} with 8-Mev deuterons, and they have interpreted the angular distribution of the protons from the 0.88-Mev level of O^{17} by means of Butler's theory. This led to their assignment of $S_{\frac{1}{2}}$ to this first excited state of O^{17}. Hence, it appears that the 0.536-Mev level of F^{17} and the 0.88-Mev level of O^{17} are the mirror levels expected from the equality of n-n and of p-p forces.

Alder and Yu[7] have assigned $D_{5/2}$ to the ground state of O^{17} on the basis of a nuclear induction experiment. By mirror nuclei arguments, the ground state of F^{17} should also be $D_{5/2}$. The shape of the experimental intensity *vs* angle curve for the ground state of F^{17}, as shown on Fig. 2, is not inconsistent with such an assignment if it is remembered that for our low deuteron energy compound nucleus formation might be expected to compete appreciably with the stripping process. Compound nucleus formation would probably tend to make the angular distribution more isotropic.

The author is extremely grateful to Professor H. T. Richards for suggesting this experiment, for his aid in the exposure of the plates, and for many helpful discussions. She also wishes to acknowledge the generous assistance of D. R. M. Williamson, and of D. J. Donahue, R. E. Benenson, and D. S. Craig in the running of the generator.

* Supported by the AEC and the Wisconsin Alumni Research Foundation.

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