carbon-14 atoms now found in modern wood are 8000 years old on the average, the integrated cosmic-ray flux seems to have been essentially constant for the last 12 000 years.

Unfortunately this takes us back only to the end of the last great glacial period. A method was devised to show constancy from the present back to about the maximum of the last phase of the Wisconsin glaciation (estimated at 30 000–40 000 years ago). This span of recent earth history displays about one-half of the greatest mean annual temperature fluctuation since the Cambrian period (500 000 000 years ago). Thus if the cosmic-ray flux was constant in this interval, and if it is related in any way to the total energy received by the planet, the integrated cosmic-ray flux would appear to have remained constant over most of geologic time.

An attempt was made to determine the possible variation in the cosmic-ray flux by dating layers of mud in a deep sea core by both the carbon-14 and ionium[4] ($_{90}Th^{230}$) methods. For the ionium ages, the radium concentration in homogeneous cores as a function of depth was obtained. For the carbon-14 ages, the carbon in the precipitated calcium carbonate of the same core was used.

Figure 1 shows the results of both methods obtained for several of these deep sea core samples as well as some of the carbon-14 ages on specimens whose age could be determined by written history. The errors are indicated by the size of the box or, in the case of the historical samples, by the length of the line. Although these errors are rather large, it seems certain that the cosmic-ray flux has not varied by more than 10–20 percent over the last 35 000 years. A hypothetical curve shows the relation if the cosmic-ray flux was half of its present value during the ice age. The errors in the carbon-14 ages are large because the samples were very small. Additional cores of much larger diameter will be taken next summer on one of the scientific cruises under the direction of Professor Maurice Ewing. This should make it possible to reduce considerably the probable error of these measurements.

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Angular Distributions of Elastically Scattered 1-Mev Neutrons*

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FESHBACH, Porter, and Weisskopf[1] have accounted for the observed regular variations of total fast neutron cross sections with energy and atomic weight[2] by using a model in which nuclear matter is assigned a fixed refractive index and absorption coefficient. Since this theory should also predict angular distributions of elastically scattered neutrons, differential cross sections for the elastic scattering of 1-Mev neutrons were measured for several elements in order to obtain a further check on the theory.

1-Mev neutrons with an energy spread of about 100 kev were produced by bombarding a Li target with protons from an electrostatic accelerator. In order to distinguish between elastically and inelastically scattered neutrons a biased recoil counter was used as a detector. It was operated at two biases, one to give a threshold of about 750 kev, the other about 850 kev. After correction for energy loss of the neutrons in elastic collisions, results obtained at the two biases showed no significant differences. It was, therefore, assumed that only elastically scattered neutrons were detected. Differential cross sections were measured at 15° intervals from 30° to 150° scattering angles with an angular resolution of about 15°.

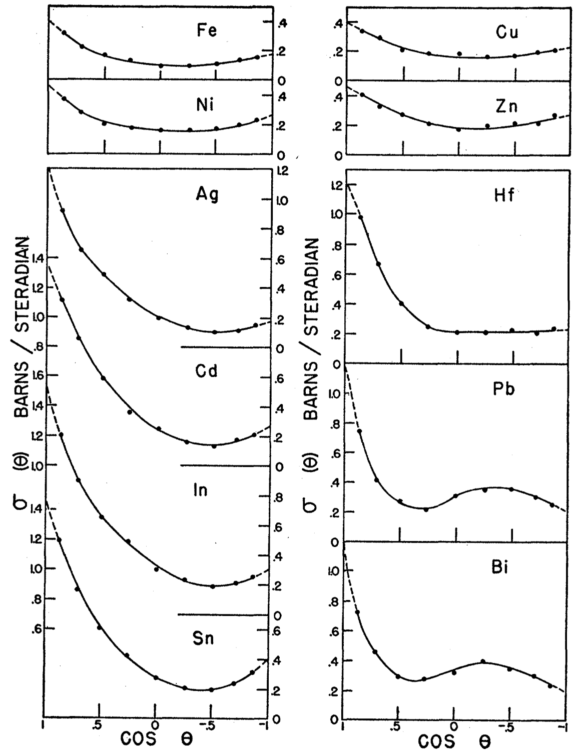

FIG. 1. Differential cross sections for the elastic scattering of 1-Mev neutrons as a function of the cosine of the scattering angle in the laboratory system. The data are still subject to a correction for multiple scattering.

The results of the measurements are shown in Fig. 1. It may be noted that the angular distributions of neutrons scattered by neighboring elements are similar, while the angular distributions for elements in different parts of the periodic table have varying characteristic shapes. Such a behavior might be expected on the basis of Weisskopf's theory.

Since the scattering samples had thicknesses comparable to a mean free path, the data have to be corrected for the attenuation of the primary neutron beam in the sample, and for multiple scattering. The cross sections shown in Fig. 1 have been corrected for the attenuation of the primary neutrons in the sample but not for multiple scattering. A calculation of the multiple scattering effect is in progress and will tend to increase both the anisotropy and the areas under the curves.

The difference between the total cross section and the integral over all angles of the elastic scattering cross section is the inelastic collision cross section. Preliminary values of these cross sections are shown in Table I. In the last column tentative values of the

TABLE I. Preliminary values (in barns) of elastic and inelastic collision cross sections for 1-Mev neutrons.

Element	Total cross section	Area under curves in Fig. 1	Difference between two preceding columns	Estimate of inelastic collision cross section
Fe	2.5	2.0	0.5	0.4
Ni	2.9	2.8	0.1	0.1
Cu	3.2	2.9	0.3	0.3
Zn	3.6	3.3	0.3	0.3
Ag	6.6	4.2	2.4	2.1
Cd	6.9	5.2	1.7	1.4
In	6.7	6.1	0.6	0.4
Sn	6.8	6.0	0.8	0.7
Hf	7.2	4.7	2.5	2.1
Pb	4.9	4.6	0.3	0.3
Bi	4.9	4.8	0.1	0.1

inelastic collision cross sections are given, based on an estimate of the effect of multiple scattering. The accuracy of the integrated elastic cross sections shown in the third column is about fifteen percent apart from the effects of multiple scattering. The estimate of the inelastic collision cross section is, therefore, uncertain by at least fifteen percent of the values given in the third column.

The observed angular distributions are in qualitative agreement with results obtained with pile neutrons.[3]

Measurements on other elements are in progress, and final results will be reported after the calculations of the corrections are completed.

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The Elastic Scattering of Pions in Deuterium*

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RECENT experiments by Arase, Goldhaber, and Goldhaber[1] on the elastic scattering of pions in deuterium have shown a considerable discrepancy with the results of a straightforward application[2] of the impulse approximation[3] to the problem. It is the purpose of this note to show that inclusion of the effects of the multiple scattering of the mesons by the two nucleons in the deuteron leads to a considerable improvement of the agreement of experiment with theory. The method used has been developed in a recent paper[4] (to be referred to as I) by the author and there applied to the evaluation of the total cross section. The results obtained can be easily extended to the determination of the elastic cross section.

The approximations made in I were (a) the usual impulse approximation[3] of neglecting both the binding effects in the deuteron on the scattering matrices and the off-the-energy-shell dependence of the scattering matrices; (b) the adiabatic approximation for the treatment of the nucleon motion, i.e., treating the nucleons as very heavy.[5] It was not necessary, however, to make the additional approximation of neglecting the rescattering of the outgoing meson waves from one nucleon by the other nucleon in the deuteron. The coupled algebraic equations obtained could be solved exactly by straightforward methods to give the cross sections. The result for the total cross section for π^+ mesons on deuterons was

$$\sigma_{\text{total}} = 4\pi\lambda\!\!\!^{-} \,\mathrm{Im}\int f_R(0)\,|\psi_D(R)|^2 d\mathbf{R}. \quad (1)$$

The elastic cross section is given by[6]

$$\frac{d\sigma_{\text{elastic}}}{d\Omega} = \left|\int f_R(\theta)\,|\psi_D(R)|^2 d\mathbf{R}\right|^2. \quad (2)$$

In both of these results $f_R(\theta)$ is the scattered amplitude into the isotopic spin singlet state with the two nucleons at a separation R. In I, $f_R(\theta)$ was evaluated for P-wave scattering with isotopic spin dependence; for scattering in the isotopic spin state 3/2 state alone, which is a quite good approximation to the experimental results for scattering on free nucleons,[7] $f_R(\theta)$ is given by

$$f_R(\theta) = \frac{2b\lambda\!\!\!^{-}}{1-b^2f^2}\Big\{\cos\theta\big[e^{i(\mathbf{k}_0-\mathbf{k})\cdot\frac{1}{2}\mathbf{r}} + e^{i(\mathbf{k}_0+\mathbf{k})\cdot\frac{1}{2}\mathbf{r}}\big] + \frac{(\mathbf{k}\cdot\mathbf{R})(\mathbf{k}_0\cdot\mathbf{R})}{R^2}\lambda\!\!\!^{-2} bg\big[b(f+h)e^{i(\mathbf{k}_0-\mathbf{k})\cdot\frac{1}{2}\mathbf{r}} - (1+b^2fh)e^{i(\mathbf{k}_0+\mathbf{k})\cdot\frac{1}{2}\mathbf{r}}\big]\Big\}$$
$$+\text{a term in which } \mathbf{R} \text{ is replaced by } -\mathbf{R}, \quad (3)$$

where $b = e^{i\delta}\sin\delta$, $f = (1/x)(d/x)(e^{ix}/x)$, $g = xdf/dx$, $h = f+g$, and $x = R/\lambda\!\!\!^{-}$. The neglect of multiple scattering is equivalent to the retention of terms linear in b only.

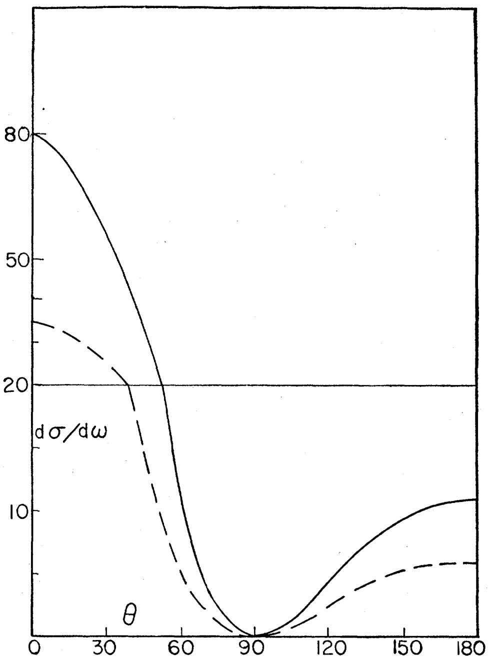

FIG. 1. Elastic P-wave scattering of pions by deuterons at 140 Mev for a phase shift of 45°. The solid curve gives the impulse approximation neglecting multiple scattering; the dashed curve includes the effects of multiple scattering. The curves are in the center-of-mass system for the meson and one nucleon. Note the change in scale at $d\sigma/d\omega = 20$ mb/steradian.

The differential cross sections calculated from Eqs. (2) and (3) are given in Figs. 1 and 2, together with the result obtained if the multiple scattering is neglected. In evaluating the integrals over the deuteron wave function, the Hulthén wave function has been used. The cases given are for phase shifts of 45 degrees at 140

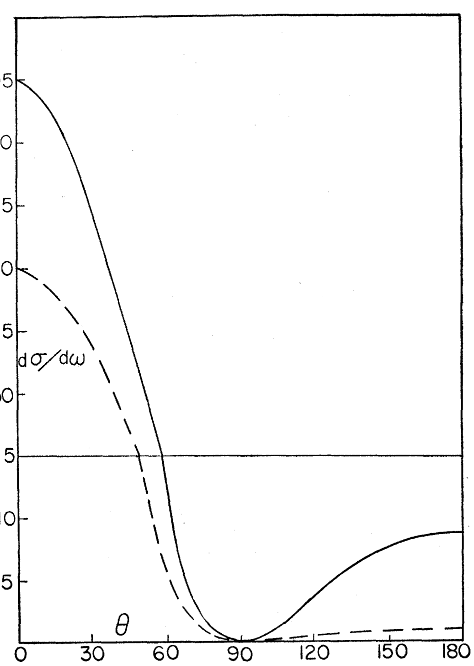

FIG. 2. Elastic scattering at 200 Mev for a phase shift of 90°. The notation is the same as in Fig. 1. Note the change in scale at $d\sigma/d\omega = 15$ mb/steradian.