## Selective Scattering of Slow Neutrons

In addition to the experiments described in the foregoing letter we have investigated the scattering of slow neutrons from various scatterers using In and Rh detectors. The Rh detector used was 0.1 mm thick (0.122 g/cm$^2$), the In detector 0.15 mm (0.109 g/cm$^2$), while the Ag detector was 0.1 mm (0.105 g/cm$^2$).

Complete scattering curves were run, with a Rh detector, for the scatterers Ni, C, and Zn while a sufficient number of points was observed on the curve for Fe to show the trend of the curve. Typical results are shown in Fig. 1 where the full curves give the scattering with Ag detector and the dashed curves that for the Rh detector. In addition, single points were obtained with the Rh detector for the metals Pb, Cu, Al and Bi. Because of the long period of In no curves were run with this detector, but points were taken showing the scattering for the metals Fe, Ni, Pb, and Cu. In Table I are shown the relative cross section for scattering for the Ag and Rh detectors for scatterers for which these data are available. Table II gives the comparative scattering (in percent) for the various detectors at specified thickness of the various scattering materials. It will be seen that large differences exist between the measured scattering from a single element by using different detectors. Similar results have been obtained by Tillman[1] on the scattering of slow neutrons by using Cu, Ag, and I, as detectors. Furthermore, the absorption coefficient of various metals has been found by several authors[2] to depend on the detector. In discussing the results it should be noted that each detector contained approximately the same number of g/cm$^2$ and, on account of the closeness in atomic weights of the three metals, about the same number of atoms cm/$^2$ (to within 15 percent). Let us consider Ag and Rh, since more data exist for these elements. Several explanations are possible. (1) Neutrons which are absorbed by Rh are not scattered back by the various scatterers in such great numbers as those absorbed by Ag. (2) The absorption *vs.* velocity curve may be of such a form that in the region of a most probable velocity for absorption it is steeper and narrower in the case of Rh than in the case of Ag, so that a larger proportion of neutrons having the necessary energy to activate Rh strongly are absorbed in the first passage through the metal than in the case of silver. Probably some combination of the two explanations is actually the real one. In favor of (1) the authors have shown[3] that, by using an Ag detector and filtering the neutrons through 0.65 mm Cd, a smaller cross section for the scattering by ions was obtained than with unfiltered neutrons.

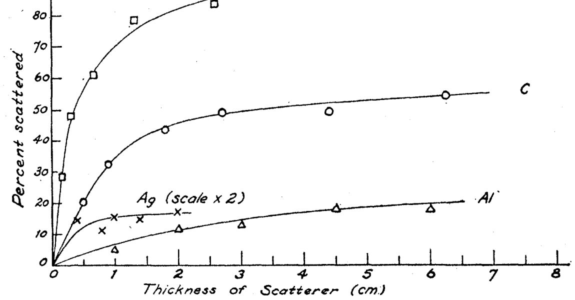


FIG. 1. Percent scattering of slow neutrons from Ni and C.

TABLE I. *Relative scattering cross sections, Ag and Rh detectors.*

| SCATTERER | $\sigma^2\times10^{24}$cm$^2$ Ag DETECTOR | $\sigma^2\times10^{24}$cm$^2$ Rh DETECTOR |
|---|---|---|
| C | 3.2 | 2.2 |
| Fe | 9.9 | 4.3 |
| Ni | 17 | 7.2 |
| Zn | 3.4 | 2.9 |

TABLE II. *Comparison of various detectors (percent scattering).*

| SCATTERER / DETECTOR | 1 cm Fe | 0.65 cm Ni | 1 cm Pb | 1.3 cm Cu | 2.1 cm Sn | 5 cm Al | 2 cm Bi | 1 cm C | 1 cm Zn |
|---|---|---|---|---|---|---|---|---|---|
| Ag | 59 | 60.5 | 25.0 | 45.0 | 22.0 | 18.0 | 35 | 35.0 | 20.0 |
| Rh | 32.8 | 42.0 | 26.8 | — | 19.6 | 18.7 | 26.1 | 21.0 | 19.0 |
| In | 51.0 | 51.0 | 18.2 | 40.2 | — | — | — | — | — |

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[1] J. R. Tillman, Nature **137**, 107 (1936).
[2] Moon and Tillman, Nature **135**, 904 (1935); Tillman and Moon, Nature **136**, 66 (1935); Ridinour and Yost, Phys. Rev. **48**, 383 (1935); Szillard, Nature, **136**, 950 (1935).
[3] A. C. G. Mitchell and E. J. Murphy, Phys. Rev. **48**, 653 (1935).

## Disintegration of the Deuteron by Gamma-Rays

The cross section for photoelectric disintegration of a deuteron by gamma-rays on the assumption of a short range interaction force between neutron and proton, was found by Bethe and Peierls,[1] to be of the order of $7\times10^{-28}$ cm$^2$ for $h\nu=2.62$ MEV. This appears to be in satisfactory agreement with the experimental result $5\times10^{-28}$ cm$^2$ of Chadwick and Goldhaber,[2] who allow a factor two for experimental uncertainties.

However, it now seems possible with this experimental accuracy, or with accuracy only slightly improved over this, to set an upper limit on the range of the proton-neutron interaction. The argument is something as follows:

The Bethe-Peierls result for the cross section $\sigma$ may be considered an exact evaluation if the interaction occurs only over a distance $r_0$, where $r_0$ tends to the limit zero. But if $r_0$ is in the neighborhood of $1.5\times10^{-13}$ cm, in accordance with the idea of various writers, changes occur which tend to increase $\sigma$ substantially over the value $7\times10^{-28}$ cm$^2$. These changes were studied for several types of $n-p$ interaction, including a potential hole of width $r_0$ and depth $V_0$, and the exponential function $V=-V_0\exp(-r/r_0)$. In all cases the effect was a fractional increase in $\sigma$ of amount somewhat greater than $r_0E^{\frac{1}{2}}$, where $E$ is the mass defect of deuterium in MEV (about 2.14 MEV), and $r_0$ is the interaction distance in units of $6.35\times10^{-13}$ cm ($r_0=0.237$ for an interaction extending to $1.5\times10^{-13}$ cm). For the potential hole, and an $r_0$ corresponding to $1.5\times10^{-13}$ cm, the correction is 42 percent, which gives $\sigma=10\times10^{-28}$ cm$^2$. Similar results hold for other types of interaction. For $r_0$ about $1.0\times10^{-13}$ cm the correction is $(2/3)(0.42)=28$ percent, or $\sigma=9\times10^{-28}$ cm$^2$.

Considerations based on the WKB method seem to indicate that the effect of any reasonable potential function $v(r)$ will lead to the same essential result, namely, an increase in $\sigma$ for a finite range of interaction.

These results for $\sigma$ are just on the verge of the upper limit allowed by Chadwick and Goldhaber, and hence definite conclusions are to be avoided. It is only suggestive that with slightly improved experimental technique, an upper limit may be fixed for $r_0$.

It seems unlikely that any experiment of this kind can offer definite information about the shape of the interaction in the light of present ideas, since $\sigma$ is so insensitive to the particular form of interaction chosen.

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[1] Bethe and Peierls, Proc. Roy. Soc. **A148**, 146 (1935).
[2] Chadwick and Goldhaber, Proc. Roy. Soc. **A151**, 479 (1935).

## The Scattering of Protons by Protons

We have examined the scattering of protons by protons at 5° intervals from 15° to 45° and at voltages from 320 to 980 kilovolts, using a linear amplifier connected to an ionization chamber which, with its attached slit system, can be oriented at will with respect to a narrow proton beam in a scattering chamber containing palladium-purified hydrogen at 12.0 mm pressure. From 100 to 2000 scattered protons were observed at each point. The angular definition is about 2°. Voltages are held constant to one percent and measured to two percent by a corona-free high resistance voltmeter (1000 ten-megohm resistors). Range limitations prevent observations at the highest angles for voltages below 600 kilovolts.

Data taken at fixed voltages (630, 696, 740, 830, 922, and 980 kilovolts at scattering volume) with variable angle are consistent and in agreement with independent observations at fixed angles (15, 20, 25, 35, and 40 degrees) and variable voltage. All comparisons are made *on an absolute basis*, the largest error (10 to 20 percent) arising from difficulties connected with the continuous absolute determination of the primary proton current, which cannot be measured with an ordinary Faraday cage due to ionization in the hydrogen gas. Our observations do not confirm White's report[1] that the scattering varies with angle from one through one-quarter to nine times Mott's values for proton-energies of 600 to 750 kilovolts. For this voltage range most of our values lie within 25 percent of those predicted by Mott's formula, although at 740 kilovolts and 45° our value is approximately 50 percent higher than Mott's. As the voltage is increased, consistently larger deviations are in evidence at high angles, our values at 980 kilovolts reaching 5.2 and 7.5 times the Mott values at 40° and 45°, respectively.

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[1] M. G. White, Phys. Rev. **47**, 573 (1935).

## The Ionization Probability of $He^{++}$

At a meeting of the American Physical Society in 1932 some results were presented on the probability of producing doubly charged helium at a single electron impact.[1] No other publication has been given for this work, but in view of a large number of inquiries concerning these results we thought it worth while to repeat the measurements on a different instrument and present them in this journal.

The shape of the probability function, Fig. 1, was found by setting the mass spectrograph on the $m/e=2$ peak and varying the electron velocity. A small impurity of molecular hydrogen was present but at about 79 volts an abrupt rise in the curve began which can only be interpreted as $He^{++}$. At 300 volts the current due to this ion is 1.1 percent of that ascribed to $He^+$ which means that at this point only 0.55 percent of the ions are doubly charged. The absolute values may be determined by referring to the data of Smith[2] on the singly charged ion.

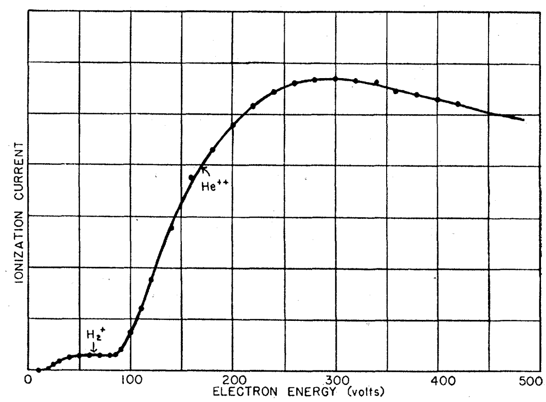


FIG. 1.

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[1] W. Bleakney, Phys. Rev. **43**, 378 (1933).
[2] P. T. Smith, Phys. Rev. **36**, 1293 (1930).
[3] We wish to make acknowledgment of financial assistance from the Penrose fund of the American Philosophical Society.