electrons in the primary radiation, since the latitude effect[4] shows that no singly charged particles with momentum larger than 4.5 Bev/c are present.

We wish to emphasize that it is not necessary to postulate the existence of any electrons or photons in the primary radiation since cascade showers have been observed to be produced in lead by penetrating particles believed to be high energy protons.[5]

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The Effect of Non-Central Forces on the Collisions of High Energy Neutrons with Protons

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As it is now possible to investigate experimentally[1] the collisions of high energy (~100 Mev) neutrons with protons, it is important to have detailed information about the effects to be expected on the assumption of different types of interaction between neutron and proton. Camac and Bethe[2] have already taken the first step in this direction by calculating the angular distributions of projected protons for various incident neutron energies, assuming central interactions of spherical well type. As, however, the quadrupole moment of the deuteron shows that a strong non-central component of the interaction exists, it is necessary to carry out such calculations with this component included. This is particularly important because for neutrons with energies of 50–100 Mev the scattering of the d component of the incident waves is quite strong. The non-central admixture is therefore likely to have a much greater influence than in phenomena involving neutrons of lower energy. In this note we wish to report the results of the first cases investigated in pursuance of this program.

Following Rarita and Schwinger[3] three forms of the neutron-proton interaction $V(r)$ were assumed:

$$I.\quad V(r)=\tfrac{1}{3}\tau_1\cdot\tau_2\left\{1+\tfrac{1}{2}g(\sigma_1\cdot\sigma_2-1)+\gamma\left(\frac{3\sigma_1\cdot r\sigma_2\cdot r}{r^2}-\sigma_1\cdot\sigma_2\right)\right\}D\cdots r<a$$
$$=0\qquad\cdots r>a.$$

σ_1, σ_2 are the spin and τ_1, τ_2 the isotopic spin operators of the two nucleons, r their relative position vector. In the present calculation the constants a, g, γ, and D were taken the same as those used by Rarita and Schwinger, namely, $a=2.8\times10^{-13}$ cm, $g=0.0715$, $\gamma=0.775$, and $D=13.8$ Mev.

TABLE I.

Type of interaction	Central forces ratio $I_{180°}/I_{90°}$	Non-central forces ratio $I_{180°}/I_{90°}$
I	159*	9.56
II	234	3.80
III	9.7**	0.58

* We have calculated the angular distribution for central forces only in the case of interactions *II* and *III*. For interaction *I* the value quoted is that given by Camac and Bethe (see reference 2).
** The value for $I_{180°}/I_{90°}$ obtained by us with central forces and interaction *III* is almost exactly one-tenth of that given in Table III of Camac and Bethe's paper. Our value appears to follow from the constants given in Table II of their paper, however.

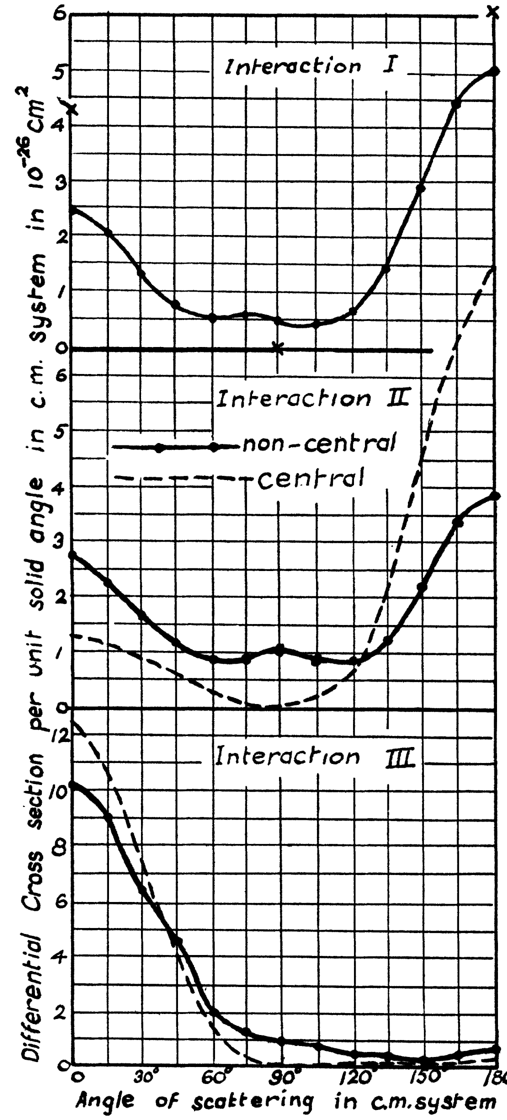

FIG. 1. Comparison of angular distribution of scattered neutrons in the c.m. system for non-central and central forces, and for the three interaction types. The total incident neutron energy assumed is 83 Mev. The circles shown on the curves represent actual calculated values.
In the case of central forces, interaction *I*, the crosses represent points calculated by Camac and Bethe.

This is an interaction of the same exchange type as that given by symmetrical meson theory.

II. As for *I* but with $\frac{1}{3}\tau_1\cdot\tau_2$ replaced by $\frac{1}{2}(1+\tau_1\cdot\tau_2)$. In this case the exchange operator is of the same form as that given by charged meson theory.

III. As for *I* but with $\frac{1}{3}\tau_1\cdot\tau_2$ replaced by -1. This is an interaction without exchange characteristics.

Angular distributions per unit solid angle, in the center of gravity system, for the scattering of 83 Mev-neutrons by protons initially at rest were calculated for each of the three assumed interactions and are illustrated in Fig. 1. The corresponding distributions for central interactions with the same exchange operators and range of the spherical well are also given for comparison.

Apart from the usual feature that the scattering maximum occurs at 180° for the exchange interactions *I* and *II* instead of at 0° as for the ordinary interaction *III*, it will be seen that the variation with angle, particularly for interaction *II*, is much less rapid for the exchange interactions. This is a marked feature only of non-central interactions, as may be seen from Fig. 1 and from the following table which gives the ratio $I_{180°}/I_{90°}$ of the differential cross section at 180° and 90° in the center of gravity system for the three types of interaction in the central and non-central cases for neutrons of energy 83 Mev.

From the preliminary reports of measurements made at Berkeley[1] it would appear that they already rule out a non-central force of type *III* but are not in marked contradiction with predictions based on a non-central force of type *II* with range near 2.8×10^{-13} cm.

The total elastic collision cross sections for collisions of 83-Mev neutrons with protons are found to be in units of 10^{-26} cm^2:

non-central interaction	*I*	14.10
	II	15.77
	III	23.38
central interaction	*I*	11.1 (Camac and Bethe)
	II	13.2 (Authors)
	III	19.5 (Authors)

In the case of central forces we have not calculated the total cross section for interaction *I*. The value 11.1×10^{-26} cm^2 is that given by Camac and Bethe. Actually the calculations of these writers is for a neutron energy of 80 Mev, while our calculations have been made for a neutron energy of 83 Mev, but the difference would not be expected to be significant.

Measurements of the total cross section for 90 ± 13 Mev neutrons scattered by protons, reported recently from Berkeley,[4] have given the value $(8.3\pm0.4)\times10^{-26}$ cm^2.

Calculations are now in progress for non-central forces of other ranges and also with radial variation other than of spherical well form.

We are indebted to Miss K. Blunt for assistance in certain of the numerical calculations.

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Self-Delayed Coincidences with Scintillation Counters*

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It is possible to measure time intervals between two ionizing events by studying the distribution of pulses from a single detector provided the dead time of the detector is smaller than the interval to be measured. A possible method consists in recording the coincidences between the signals from two separate channels, both activated by the same detector pulse, but designed so that the first produces an immediate signal of duration τ_1 and the second gives a signal of delay T and duration τ_2 (*self-delayed coincidences*). Provided $T>2\tau_1$, we obtain a count for detector pulses whose interval in time is between $T-\tau_1$ and $T+\tau_2$. The smallest time intervals which can be measured with this method is $\sim10^{-4}$ sec. for Geiger counters. However, with scintillation counters[1] which supposedly have a very short dead time, the method of self-delayed coincidences should be capable of measuring very short intervals, and has the advantage of requiring only one amplifier.

To test this point a source of Hf^{181} (known to decay into Ta^{181*} of 22-μsec. half-life[2]) was located close to a clear anthracene[3] sample ($\sim0.5\times1\times2$ cm); on the opposite side, at a distance of 0.3 cm, was the glass wall of a 1P21 photo-multiplier tube, operating at 60 volts per stage. The pulses from this tube, after amplification, were fed to a self-delayed coincidence circuit as described above. With this arrangement it was possible to measure the half-life of Ta^{181*}, obtaining a value in good agreement with previous determinations.

Though no special effort was made to realize maximum efficiency (the efficiency can be increased by moving the anthracene closer to the tube and by placing the source between the tube and the anthracene sample), the efficiency of the present arrangement is almost equal to that of the old instrument involving two thin mica window Geiger counters at $\sim$50 percent geometry.

In the following table counting rates (counts/min.) of single counts and delayed coincidences (for the same source and with same delay and resolving times) are shown.

TABLE I.

	Geiger counters	Anthracene counters
Background (single counts)	20	150
Single counts from source	9600	7200
Delayed coincidences	230	130

This indicates that anthracene scintillation counters are highly efficient, not only for the main radiation from Hf^{181}, but also for the radiation of Ta^{181*}, which consists of electrons and gammas of around 100 kev. Despite the fact that the photo-multiplier was used at room temperature, the background corresponding to this efficiency is not too high.