that the p.p. are produced, partly at least, in the absorbers and in groups. In the alternative hypothesis that the p.p. are nearly all produced in the air, they should be associated in very narrow showers arising not far from our apparatus. In Table II the association between the events of the same set is given as an example.

(c) Within the limits of statistic fluctuations, we have observed the same frequency and distribution of penetrating events in the two sets X and Y (Table II). In agreement with several authors,[2-4] our measurements indicate that the p.p. are produced with a cross section proportional to Z^2, provided that production takes place in the absorbers by the soft component. It may be noted, however, that in the intermediate hypothesis of a production in the air, as well as in the absorbers, the exponent of Z might be less than two.

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Range of Nuclear Forces in the Neutron-Proton Triplet Interaction

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MEASUREMENTS of the coherent scattering of neutrons by hydrogen[1] permit the evaluation of the scattering amplitudes characteristic of the two spin states of scattering, *viz.*, when the neutron and proton spins are parallel or antiparallel. Such evaluation also permits a determination of the range of nuclear forces present in the triplet interaction.

It can be shown that the coherent scattering amplitude for hydrogen in a crystal is given by

$$f_H = 2[\tfrac{3}{4}a_1 + \tfrac{1}{4}a_0], \quad (1)$$

where a_1 and a_0 are the triplet and singlet scattering amplitudes of a free proton when the spins of the proton and the incident neutron are, respectively, parallel and antiparallel. Also, the total scattering cross section of a free proton can be expressed as

$$\sigma_f = 4\pi[\tfrac{3}{4}a_1^2 + \tfrac{1}{4}a_0^2]. \quad (2)$$

Equations (1) and (2) permit evaluation of a_1 and a_0. From neutron diffraction experiments on hydrogen containing crystals, the coherent scattering amplitude has been determined to be

$$f_H = +0.472 \pm 0.040 \times 10^{-12}\ \text{cm}.$$

Using this value of the coherent scattering amplitude and Hanstein's[2] value of 21×10^{-24} cm^2 for the total scattering cross section for a free proton, one obtains for the triplet scattering amplitude

$$a_1 = -0.498 \pm 0.025 \times 10^{-12}\ \text{cm}.$$

The singlet scattering amplitude determined by this procedure is dependent almost completely upon the value of the free proton cross section and turns out to be $+2.44 \times 10^{-12}$ cm.

Hamermesh and Schwinger[3] have discussed the relationship between the scattering amplitudes and the range of nuclear forces, and when the above values are inserted into their calculations, the range of the neutron-proton triplet interaction becomes

$$r_0 = 1.2 \pm 0.4 \times 10^{-13}\ \text{cm}.$$

This value is definitely smaller than the value 2.8×10^{-13} cm ascribed to the singlet proton-proton interaction and is slightly smaller than that found by Sutton, Hall, and others[4] from the scattering of neutrons by *ortho-* and *para-hydrogen*, namely 1.5×10^{-13} cm. This latter difference is, however, within the suggested error of the diffraction result.

Further details on the neutron diffraction experiments will be published in the near future.

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Cross Section for the Reaction $C^{12}(n, 2n)C^{11}$ at 90 Mev

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THE formation of C^{11} by high energy particle impact on C^{12} has been studied extensively in this laboratory;[1-3] it has been found that the cross sections for its formation by deuterons, helium ions, and protons become constant above a certain bombarding energy, and this constant absolute cross section in the latter case has been found to be 0.073×10^{-24} cm^2. We have no information on the excitation curve in the case of neutron activation, but an extension of the theory would indicate that it should be flat above about 60 Mev as it is for protons. Whether or not there may be a peak between 20 and 60 Mev depends on the relative importance of "intermediate nucleus" processes compared to non-capture processes. However, such a peak of moderate size would not seriously affect the measurements reported here because of the small number of neutrons in this energy range. Theoretically, the yield on the flat part of the excitation curve should be less for neutrons than for protons if exchange collisions occur, because a (p, n) exchange can lead to C^{11} by evaporation of a proton, while an (n, p) exchange cannot lead to C^{11}.

The measurements reported here were made in a neutron beam produced by stripping deuterons[4,5] in a $\frac{1}{2}$ in. thick Be target in the 184-in. cyclotron, and collimated into a width of $2\frac{1}{2}$ in. by passing through an aperture in the cyclotron shield. The mean neutron energy is 90 Mev, and the width of the distribution at half-maximum is about 27 Mev; these theoretical figures now have some experimental support. The neutron flux was measured by apparatus set up by one of us (H.F.Y.) for examining the angular distribution in neutron-proton scattering; since it will be described in full when that work is published, only an outline is given here. A thin scatterer of paraffin was put in the neutron beam at 52 feet from the source, and the recoil protons detected by a line of four proportional counters in coincidence. The solid angle for accepting protons was accurately defined by a hole in a copper plate, and an absorber between the counters limited the protons counted to those corresponding to neutron energies above 66 Mev. Protons coming from the carbon were eliminated by making another count with pure carbon in place of the paraffin. Then, knowing the counting rate at a given angle, the angular distribution of the protons (as found with this apparatus and in Dr. Wilson Powell's cloud chamber) and the total neutron-proton cross section,[6] the neutron flux can be computed. The neutrons whose energy lies below 66 Mev were not counted, and a 6 percent correction based on the fraction theoretically expected below this energy has been made. The neutron fluxes determined in the three runs made were 38, 8.5, and 8.8×10^4 neutrons cm^{-2} $sec.^{-1}$. At full beam intensity the flux would have been about 10^6 neutrons cm^{-2} $sec.^{-1}$ at 52 feet from the target, which from the known angular distribution would correspond to a total yield of 2×10^{11} neutrons per sec. for a deuteron current of the order of 1 microampere.

The rest of the measurement consisted of a determination of the C^{11} activity induced in the paraffin scattering blocks during the above experiments. The counting rate due to the paraffin was compared with that of a uranium standard, then in a separate experiment these blocks and a 5-mil polystyrene sheet were exposed simultaneously to a stronger beam, and the ratio of their counting rates was observed. Using the latter ratio, the activity that the polystyrene would have acquired in the weaker beam (which would have been too weak for accurate measurement) could be computed, and from this the disintegration rate free of self-absorption corrections. These disintegration rates per carbon atom in the polystyrene combined with the neutron fluxes lead to activation cross sections of 0.021, 0.024, and 0.022×10^{-24} cm^2 in the three runs. The mean value, with an estimate of the over-all error, is $(0.022\pm0.004)\times10^{-24}$ cm^2.

Thus it is seen that the high energy cross section for the (p, pn) reaction is greater than that for the $(n, 2n)$ reaction in carbon as expected from the action of exchange collisions. The experimental ratio of these cross sections is 3.3. Another interesting comparison is with the total cross section of carbon for 90-Mev neutrons,[6] which is 0.55×10^{-24} cm^2. If the total proton cross section is assumed to be the same, and half of these cross sections is assumed to be due to diffraction, then activation to C^{11} is caused by 27 percent of the proton impacts and 8 percent of the neutron impacts. A theoretical basis for treating these reactions has been given by Serber,[7] and detailed computations leading to results in reasonable agreement with experiment have been made by Heckrotte and Wolff.[8]

Another experiment was made in an attempt to measure the ratio of the proton activation to the neutron activation directly. One carbon block was put in the neutron beam and another in a position to intercept protons from the same target; these were exposed simultaneously and the cross section ratio computed, assuming equal neutron and proton yields from the target and the theoretical angular and energy distributions for both particles. The ratios found were 2.5 using a $\frac{1}{2}$-in. Be target, 4.0 using a $\frac{1}{16}$-in. Cu target, and 2.9 using a 0.05-in. U target. Since this method is not very precise, the differences of these values from each other and from the value of 3.3 given above are probably not significant, but the rough check indicates that no gross error has been made in the various assumptions underlying this comparison.

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A Nuclear Evaporation Recorded in an Emulsion Near Sea Level

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DISINTEGRATIONS of component nuclei in thick layered emulsions by cosmic radiation have been recorded in plates exposed at high altitudes. At sea level the probability of this occurrence is very low and has been estimated at 10^{-9} event per ml per sec.[1] From available reports[2-4] only four evaporations have been observed in the microscopic survey of plates exposed near sea level. The event described in Fig. 1 and Table I was recently

TABLE I. Analysis of recorded track lengths.

Track	Length* microns	Direction	Number of grains**	Mean grain spacing	Particle	Probable energy (Mev)
A	39.1	air	72	0.55	alpha	(10)***
B	53.0	glass	36	1.52	proton	6.9
C	17.0	air	16	1.13	proton	5.4
D	56.5	glass	57	1.01	proton	5.0
E	24.1	glass	12	2.19	proton	8.9
F	42.3	glass	33	1.32	proton	6.2
G	2.0	emulsion		0	recoil(?)	

* Corrected for dip and gelatin contraction.
** Counted at 1250 × under oil immersion and transmitted light.
*** Portion of track recorded corresponds to 7.2 Mev.