distance L. It was connected in anticoincidence with the coincidence output of the first two counters so as to count directly the number of particles removed from the beam. Thin scatterers (of 90–95 percent beam transmission) were placed directly after the second crystal counter.

The variable distances L between the thin scatterer and the anticoincidence counter determined the minimum angle θ, by which a proton (and any secondary charged particles) would have to be deflected from the forward direction in order to allow an anticoincidence event to register. The angle θ was varied in each case over a range of small angles, but no angles were used which were so small as to introduce any large effect from Coulomb scattering. Corrections were applied to the results from measurements at the smallest values of θ for the Coulomb scattering. The corrected experimental values were plotted against θ, and in each case lay on a straight line. These straight lines were extended to $\theta=0$ to obtain the total cross sections.

For the determination of the total cross section of liquid hydrogen, the transmission was measured for laboratory angles of 1.5° to 6°. The straight line drawn through the experimental points showed a steep slope in the case of hydrogen, due to the deuterons formed in pion production. These deuterons have about 4-Mev energy in the baricentral system, and of the order of 200 Mev in the laboratory system. Consequently they all come forward within an angle of 8° to the beam giving rise to the observed increase of counting rate with decreasing angle of the large counter. An angular dependence of $0.2+\cos^2\theta$ was assumed for the deuteron production in the baricentral system. The corresponding effect on counting rate calculated as a function of angle (assuming 2 mb for the deuteron production cross section) accounted for most of the slope of this line. The data were corrected for deuteron production and plotted against θ; the line through the corrected points was extrapolated to zero angle, and the assumed deuteron cross section was added to the intercept to give a total hydrogen cross section of 24 mb. This number is insensitive to the quantity assumed for the deuteron production cross section, the final result of 24 mb being obtained for choices of 2, 3, or 4 mb.

For Li, Be, and C, θ was varied from 3.5° to 14° and for D_2O and H_2O, from 2.5 to 8°. In no case was the Coulomb correction more than a few percent. The straight lines determined by the corrected transmissions plotted *versus* θ were extended to $\theta=0$, to give the total cross section for 408-Mev protons not including Coulomb scattering. The values so obtained are as follows:

$$\sigma(\mathrm{H})=24.0\pm1 \text{ mb (liquid hydrogen)}$$
$$\sigma(\mathrm{Li})=194\pm8 \text{ mb (lithium metal)}$$
$$\sigma(\mathrm{Be})=242\pm6 \text{ mb (beryllium metal)}$$
$$\sigma(\mathrm{C})=285\pm14 \text{ mb (graphite)}$$
$$\sigma(\mathrm{D-H})=\tfrac{1}{2}[\sigma(\mathrm{D_2O})-\sigma(\mathrm{H_2O})]=31.6\pm2 \text{ mb}$$
$$\sigma(\mathrm{O})=\sigma(\mathrm{H_2O})-2\sigma(\mathrm{H})=406\pm3 \text{ mb}$$
$$\sigma(\mathrm{D})=\sigma(\mathrm{D-H})\pm\sigma(\mathrm{H})=55.6\pm2.2 \text{ mb.}$$

These total cross sections for 408-Mev protons are closely equal to the corresponding total cross sections for 400-Mev neutrons,[1] in agreement with the hypothesis of charge symmetry. The (p,p) cross section, however, is significantly lower than the (n,p) cross section at the same energy. In order to compare this transmission cross section with (p,p) scattering cross sections it must be corrected for a sizeable meson production, which may be as much as 2 millibarns. The scattering cross section implied here is therefore in agreement with the Berkeley value[2] of 3.5±0.4 mb/sterad at 340 Mev, and with one-half the Carnegie Institute of Technology value[3] of 45±10 mb at 435 Mev. (The factor ½ is needed to allow for the definition of scattering cross section in the case of identical particles.)

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Gamma Radiation from Inelastic Scattering of 2.7-Mev Neutrons

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We have performed some preliminary observations of gamma radiation arising from bombardment of various materials with 2.7-Mev neutrons produced by the $D(d,n)He^3$ reaction. A scatterer, made of the material of interest, was placed 25 cm from the accelerator target and in line with the deuteron beam. Gamma radiation was detected by a Compton spectrometer placed about 10 cm from the scatterer. Some shielding of the spectrometer crystals was provided by a lead bar placed between the accelerator target and spectrometer. The spectrometer crystals were arranged such that the angle of scattering of the incident quanta was 135 degrees. With this arrangement the resolution was about 12 percent full width at half-maximum. Calibration was performed with standard sources of Na^{22}, Cs^{137}, and Co^{60}. Experiments indicated that the energy calibration was essentially independent of the position of the sources from points within the volume normally occupied by the scatterer.

Pulse-height distributions were taken first with the scatterer in position and then removed. The accelerator rate was held constant during the runs so that the neutron yield was the same during both source and background runs. The net counting data in counts per channel per neutron monitor count is plotted in the accompanying figures. Sample probable errors are indicated at a few points. Generally the error was large for small pulse heights due to a large accidental rate produced by neutrons penetrating the spectrometer shield.

Figure 1 shows pulse-height distributions produced by bombardment of a copper scatterer as well as a typical Co^{60} calibration curve. Ordinates, for the latter, are in counts per second per chan-

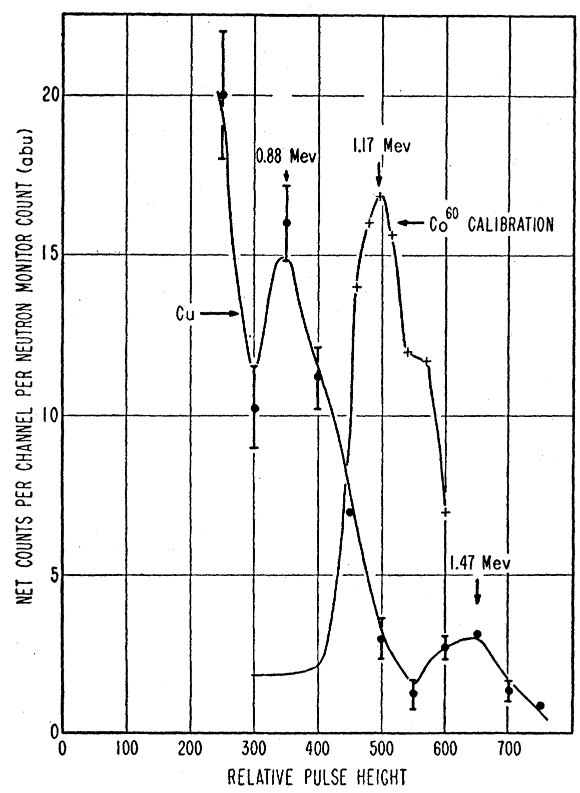

Fig. 1. Compton spectrometer pulse-height distribution produced by gamma rays arising from neutron bombardment of copper.

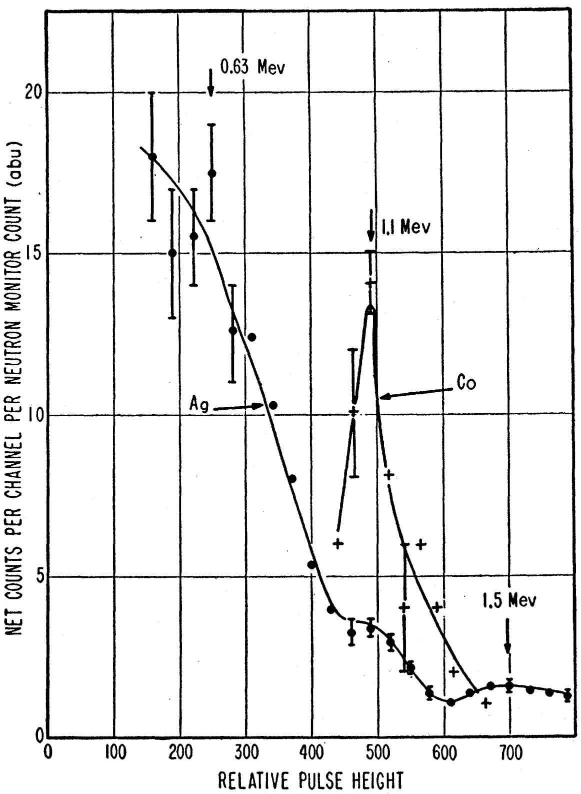

FIG. 2. Compton spectrometer pulse-height distribution produced by gamma rays arising from neutron bombardment of silver and cobalt.

nel. The copper spectrum shows gamma rays at 0.88 Mev as well as a broad smear near 1.47 Mev. The silver pulse-height distribution, shown in Fig. 2, indicates gamma rays at 1.1 and 1.5 Mev. Further data indicate a repeatable maximum near 0.63 Mev, although statistics are too poor on data shown here to definitely establish a gamma ray at that energy. A cobalt scatterer produced the pulse-height distribution also shown in Fig. 2, in which a strong 1.1-Mev gamma ray is quite apparent.

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Interpretation of $0+xp$ Type Stars in Photographic Emulsions

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A NUMBER of observers[1–7] have reported stars in photographic emulsions which are produced by a fast singly charged particle and are remarkable for having a number of shower tracks without any accompanying heavy particles. The primary particle has generally been interpreted as a proton, and there has been a tendency to believe that the stars are the result of a single nucleon-nucleon interaction and that they demonstrate the possibility of the multiple production of mesons.

However, there are a number of features of these stars which argue against this interpretation. In the first place, the stars are produced by primaries of a very wide range of energy (~10 Bev to several thousand Bev) and there is no significant correlation of multiplicity with primary energy. Secondly, almost equal numbers are found with odd and even numbers (n_s) of shower particles. While it is possible to interpret those of even n_s as proton-proton interactions, the law of conservation of charge forbids such an explanation of those of odd n_s. Moreover there are serious difficulties in the way of believing that these latter are the result of the interactions of a primary proton with a peripheral neutron of a nucleus in the photographic emulsion. For, if a single neutron is removed from any of the main stable isotopes of C, N, O, Ag, and Br, the remaining nucleus is radioactive to β decay with a half-life of a few minutes and a β energy of ~1 Mev.[8] Such an electron should easily be observed in the emulsion but none of the events published have recorded its presence.

Thus we may conclude that events of odd n_s are not p-n encounters and we may then either suppose that events of odd and even n_s are due to completely different causes or that neither type of event represents in general, a nucleon-nucleon encounter. The latter hypothesis is obviously the more satisfactory particularly as it seems reasonable to suppose that a struck nucleus may return to equilibrium without the emission of any charged particles. Indeed for excitation energies of less than ~100 Mev this is the normal process.[9] Such an hypothesis at once explains the roughly equal numbers of stars of odd and even n_s and suggests the possibility that the shower particles are due to normal cascading through the nucleus.

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New Evidence Concerning Extreme Energy Interactions in Heavy Nuclei

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EXTENDING work with copper targets,[1] Kaplon, Ritson, and Walker (KRW) have now investigated[2] stars produced in lead and in emulsion by $10^{12}\cdots 10^{13}$ ev primaries. We wish to discuss their results in relation to our theory (RM) of the extreme energy cascade.[3] The new evidence may be used to decide which of the two multiplicity functions [RM Eqs. (49) and (54)] and [RM Eq. (55)] or other such functions is the right one.

For primary energies $E'\gtrsim 16A$ (in Bev, A denoting the atomic weight of the target[3]) the jet will develop within an almost cylindrical tunnel. For a given target, the length of the tunnel s depends upon the impact parameter. Measured in nucleon diameters, the median $\bar{s}\approx A^{\frac{1}{3}}$. If the semi-empirical multiplicity function (RM-49 and 54) is approximately correct, one should find experimentally $\bar{n}\propto s^{4/5}\propto {}^{4/15}$. If, on the other hand, (RM-55) is the more correct multiplicity function, one should find $\bar{n}_s\approx A^{\frac{1}{3}}+\exp[2A^{\frac{1}{3}}/3]$.

Table I shows the mean multiplicities inferred from observation and the predicted multiplicities including extrapolations for carbon and hydrogen. We have estimated the median tunnel length to be expected in Ilford G-5 emulsion and find it to correspond to that of a nucleus with $A=49$.

The trend of (RM-49 and 54) fits the experimental results very well. By contrast, (RM-55) seems to be ruled out by the observations for lead.

The observed trend of multiplicities and (RM-49 and 54) both demand a (slow) *decrease* of dn_s/ds with s. It seems that no theory based on "plural" production alone can give this, that is make d^2n_s/ds^2 negative for all (even for small) s. (A purely plural theory could make d^2n_s/ds^2 negative for large s, if reabsorption of mesons is taken into account.) An argument which might be