Furthermore there is good evidence for the proton group at an excitation of 8.2 Mev (see Fig. 2).

I am indebted to Professor E. C. Pollard, who suggested the investigation, for many helpful discussions.

* Assisted by the joint program of the ONR and the AEC.

[1] Bleuler and Rossel, Helv. Phys. Acta **20**, 445 (1947).
[2] Bleuler, Scherrer, Walter, and Zunti, Helv. Phys. Acta **20**, 96 (1947).
[3] Guggenheimer, Heitler, and Powell, Proc. Roy. Soc. **190**, 196 (1947).
[4] A. B. Martin, Phys. Rev. **72**, 378 (1947).
[5] Flugge and Mattauch, Physik. Zeits. **44**, 181 (1943).

Ionization Measurement of $He^3(np)$ and $N^{14}(np)$ and the Neutron-Hydrogen Mass Difference

W. Franzen,[1] J. Halpern, and W. E. Stephens
University of Pennsylvania,[2] Philadelphia, Pennsylvania
May 25, 1949

A cylindrical ionization chamber with a fine axial wire collector was filled with a highly purified mixture of two atmospheres of argon, one-tenth atmosphere of nitrogen and one-half atmosphere of helium enriched in He^3. The pulse size distribution arising from electron collection of the ionization produced by the reactions $He^3(np)H^3$ and $N^{14}(np)C^{14}$ induced by slow neutrons was observed. With a model 100-linear amplifier, modified to have a "rise time" of 16 microseconds, a "clipping time" of 5 microseconds and using an input capacity of 16 micro-microfarads, it was possible to achieve a noise equivalent to 8 kev of ionization in argon (corresponding to an r.m.s. input voltage of 2.3 microvolt). Pulses were recorded by photographing an oscillograph tube. The linearity of the system was checked by means of a precision pulser and an electronic discriminator. The system was calibrated with alpha-particles from a thin polonium source mounted on a platinum foil which could be positioned at the chamber wall or retracted.

The absence of electron capture in the gas was checked by observing the dependence of pulse height on collecting voltage. Saturation was complete at 100 volts with less than one percent variation in pulse height as the applied potential was increased from 100 to 1000 volts.

Figure 1 displays the pulse size distribution obtained from $He^3(np)$ and $N^{14}(np)$ observed simultaneously and from polonium alpha-particles observed in the same gas mixture. The observed distributions agree closely with the distributions expected for a ratio of 400 between outer and inner radii of the ionization chamber and disintegration tracks short compared to the diameter of the chamber.[3] The alpha-particle distribution is narrower due to the localization of the source. On the high energy side, all the distributions fall off sharply, the rate of fall being limited mainly by amplifier noise. This sharp cut-off and the similarity of the curves allow a precise comparison of the ionizations.

If a linear relation between energy and ionization is assumed in argon, in accordance with the results of Jesse,[4] then the energy equivalents of the total ionization produced in $He^3(np)$ and $N^{14}(np)$ are 764 ± 10 kev and 628 ± 4 kev, respectively, when a direct comparison is made with polonium alpha-particles (assumed to have an energy of 5298.4 kev).[5] A correction of -0.3 percent has been applied to these values to account for the effect of the presence of one-tenth atmosphere nitrogen. This correction is derived from the results of a separate experiment in which the total ionization due to $N^{14}(np)$ was studied as a function of nitrogen concentration in purified nitrogen-argon mixtures.

The difference in the energy values for $N^{14}(np)$ and $He^3(np)$ checks closely with the difference between the end-points of the beta-spectra of C^{14}, 156 ± 1 kev,[6] and H^3, 18 ± 1 kev,[7] and their ratio agrees with the ratio of the total ionizations of the two reactions considered independently. This agreement supports the assumption of a constant average energy per ion pair in argon. The errors quoted on the energy values are based on internal consistency and the uncertainty due to statistics alone and do not take into account any systematic errors arising from the method of calibration.

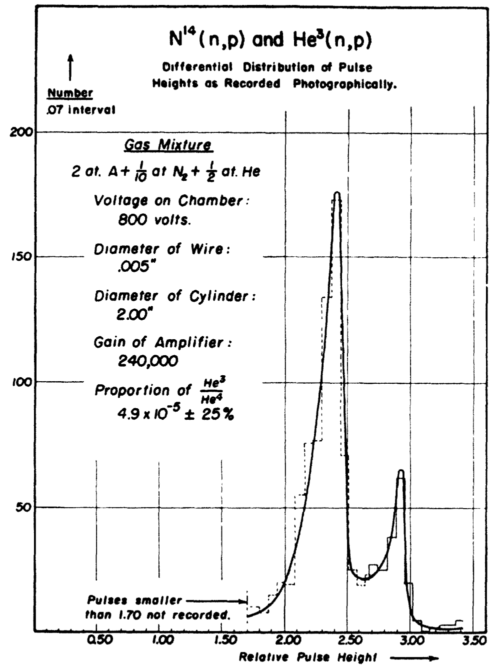

Fig. 1A. Distribution of pulse heights due to $N^{14}(np)$ and $He^3(np)$.

The energies obtained agree well with the thresholds for the inverse (pn) reactions, 620 ± 9 kev[8] and 764 ± 1 kev,[9] respectively, and an ionization determination of $N^{14}(np)$ using total ion collection, 630 ± 10 kev.[10] Assuming zero neutrino mass, our results lead to a neutron-hydrogen mass-difference of 783 ± 4 kev. This value is higher than previously supposed,[11] but agrees well with a value of 789 ± 6 kev deduced from the $D[(dn)(dp)\beta^-]$ cycle.[12] However, it is smaller than the value of 804 ± 5 kev obtained by Bell and Elliott[13] from measurement of $H(n\gamma)$ and the HH−D mass doublet.

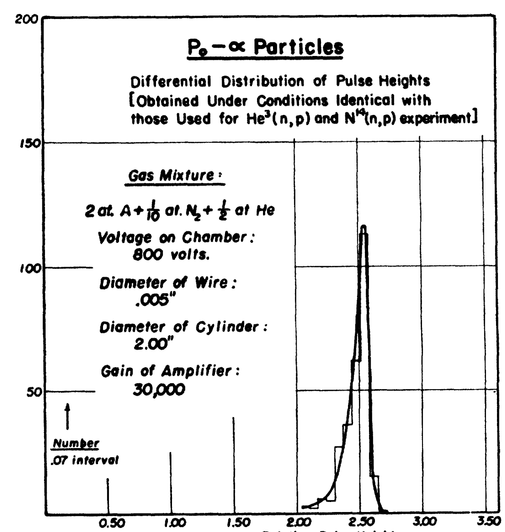

Fig. 1B. Distribution of pulse heights due to polonium alpha-particles emitted by wall source.

The helium used in this experiment had been enriched to a ratio of $He^3/He^4 = 4.9\times 10^{-5}$ and was supplied by Professor A. O. C. Nier of the University of Minnesota to whom we are indebted for his kind cooperation.

[1] Mary Amanda Wood Research Associate.
[2] Supported in part by a joint program of the ONR and AEC and aided by a grant from the Committee on Advancement of Research of the University of Pennsylvania.

[3] P. G. Koontz and T. A. Hall, Rev. Sci. Inst. **18**, 643 (1947).
[4] W. P. Jesse and H. Forstat, Phys. Rev. **74**, 1259A (1948). W. P. Jesse and J. Sadauskis, Phys. Rev. **75**, 1110 (1949).
[5] M. G. Holloway and M. S. Livingston, Phys. Rev. **54**, 18 (1938).
[6] Cook, Langer, and Price, Phys. Rev. **74**, 548 (1948).
[7] G. C. Hanna and B. Pontecorvo, Phys. Rev. **75**, 983 (1949); Curran, Angus, and Cockroft, Phil. Mag. **40**, 53 (1949).
[8] Shoupp, Jennings, and Sun, Phys. Rev. **75**, 1 (1948).
[9] Taschek, Jarvis, Argo, and Hemmendinger, Phys. Rev. **75**, 1268 (1949).
[10] P. Huber and A. Stebler, Phys. Rev. **73**, 85 (1948).
[11] W. E. Stephens, Rev. Mod. Phys. **19**, 19 (1947).
[12] Tollestrup, Jenkins, Fowler and Lauritsen, Bull. Am. Phys. Soc. **24**, no. 4, abst. T2 (1949).
[13] R. E. Bell and L. G. Elliott, Phys. Rev. **74**, 1552 (1948).

Angular Distribution and Multiplicity of Neutrons Associated with Local Cosmic-Ray Showers

G. Cocconi and V. Cocconi Tongiorgi
Laboratory of Nuclear Studies, Cornell University, Ithaca, New York

May 27, 1949

PRELIMINARY experiments have been performed at Ithaca (260-m elevation) to study some aspects of the local production of neutrons associated with local showers of ionizing particles. The following topics have been investigated: (a) angular distribution of neutrons, (b) multiplicity of the neutron production in lead.

The thirty Geiger-Müller counters in tray A (see Fig. 1) were connected to a discriminator that selected the events in which one and no more than one counter was struck (event 1A). The twelve counters under lead, each separated from its neighbors by 1 cm of lead, were connected in three groups, B, C and D of four counters each. Fourfold coincidences $S=1A+B+C+D$ were assumed to represent mostly showers of three or more ionizing particles produced in the lead Σ. All Geiger-Müller counters were $\frac{1}{2}$ inch$\times$10 inches.

Twenty neutron counters (1 inch$\times$19 inches proportional counters filled with enriched BF_3) were embedded in the paraffin block (38 inches$\times$26 inches$\times$26 inches) surrounding the Geiger-Müller assembly, and connected in two groups of ten counters each, N_1 and N_2, as indicated in Fig. 1. The neutrons that our detector was able to record have energies from $\sim$1 to $\sim$15 Mev. The over-all efficiency ϵ of the two neutron recording systems (paraffin plus 10 neutron counters) was estimated as close to 0.09.

Coincidences S, delayed 7 microseconds and shaped in a 200 microsecond square pulse, were put in coincidences with pulses N_1 and N_2. Coincidences S, $S+N_1$, $S+N_2$ and $S+N_1+N_2$ were registered.

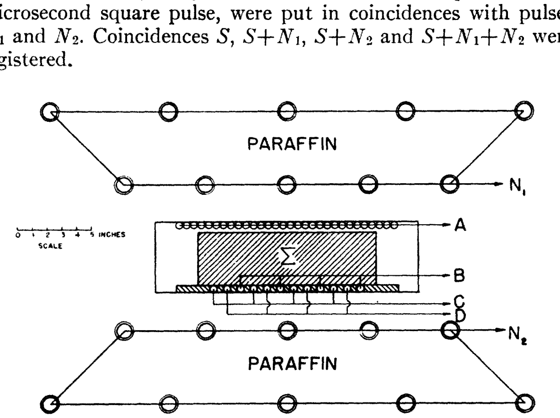

Fig. 1. Arrangement of counters and absorbers.

Measurements have been taken with thicknesses of the lead Σ ranging from $\frac{1}{4}$ inch to 3.5 inches. When the thickness of the lead Σ was smaller than 3.5 inches, the absorber was built with several lead plates evenly placed in 3.5 inches.

Table I. Results of the measurements.

1 Thickness of the lead Σ (inches)	2 S (h^{-1})	3 $S+N_1$ (h^{-1})	4 $S+N_2$ (h^{-1})	5 $S+N_1+N_2$ (h^{-1})	6 $\frac{S+N_1}{S+N_2}$	7 ν
3.05	4.83	0.73 ± 0.06	0.76 ± 0.07	0.40 ± 0.05	0.96 ± 0.12	22 ± 4
2.25	8.02	0.76 ± 0.07	0.86 ± 0.07	0.40 ± 0.05	0.88 ± 0.11	20 ± 4
1.00	17.03	0.49 ± 0.06	0.62 ± 0.06	0.24 ± 0.04	0.80 ± 0.14	16 ± 4
0.75	23.04	0.53 ± 0.06	0.51 ± 0.06	0.14 ± 0.03	1.05 ± 0.17	10 ± 3
0.50	27.00	0.37 ± 0.04	0.42 ± 0.04	0.11 ± 0.02	0.87 ± 0.12	10 ± 2
0.25	31.05	0.20 ± 0.03	0.27 ± 0.03	0.06 ± 0.02	0.73 ± 0.13	10 ± 3
0	18.00	0.06 ± 0.04	0.06 ± 0.04	0	$1.0\ \pm0.80$	——

The results are given in Table I. In column 6 the ratio $(S+N_1)/(S+N_2)$ is given, which represents the ratio of the showers containing neutrons traveling in forward directions to showers containing neutrons traveling in backward directions. The fact that this ratio is found close to unity indicates that the neutrons are produced fairly isotropically. This directly confirms what has been previously suggested,[1] namely that the observed neutrons are produced in evaporations of excited nuclei.

On the basis of the observed isotropy of the neutron production, the comparison of the rates $S+N_1+N_2$ (column 5) with the average $S+N$ of the rates $S+N_1$ and $S+N_2$ (columns 3 and 4) enables us to compute the average multiplicity ν with which the neutrons are produced, i.e., the average number of neutrons simultaneously produced in the energy range to which our detector was sensitive. The multiplicity ν can be deduced from the expression:

$$\frac{S+N_1+N_2}{S+N}=1-\exp\frac{[(\nu-1)\cdot(\omega/4\pi)\cdot\epsilon]}{l}$$

where ϵ is the over-all efficiency and $\omega=0.4\times4\pi$ is the solid angle at the lead Σ subtended by the paraffin in which each group of neutron counters was embedded. The results are given in column 7 of Table I. Though the statistical errors are very large, the results indicate that the multiplicity depends upon the thickness of the lead in which the events originate, decreasing as the thickness is decreased.

It is clear that different kinds of events are selected by the coincidences S when the thickness of the lead Σ is varied. With $\Sigma=3.5$ inches most of the coincidences S are due to penetrating showers, while the great majority of the showers recorded with smaller thicknesses are due to the soft component. However, the fact that the rates of coincidences $S+N_1$ and $S+N_2$ steadily decrease when the thickness Σ decreases and are extremely small for $\Sigma=0$, while electron showers generated in the lead between the counters, in the paraffin, etc. are still very frequent, indicates that the association of neutrons with electron showers, if it exists, is very small. We are therefore led to interpret the coincidences $S+N_1$ and $S+N_2$ as revealing mostly events induced by the nucleonic component. If this is the case, the average energy of the ionizing particles created in the showers, hence the average energy involved in the events, decreases with decreasing the thickness of the lead. The fact that the multiplicity also decreases shows that the number of the neutrons produced in nuclear events decreases with decreasing the energy involved in the process.

While the coincidences $S+N_1$ and $S+N_2$ registered with high thicknesses of lead are mostly due to penetrating showers, stars are likely the predominant processes recorded with small thicknesses. However the distinction between the two kinds of phenomena is merely formal, as a continuous transition from one phenomenon to the other probably occurs, when the energy involved in the nuclear processes varies.