small meteoroids may be increased by a large factor (up to $10^2$) and the time for the formation of the observed helium contents in small meteorites decreased correspondingly.

There are other observations, in addition to those of Fig. 1, that will give us valuable evidence for or against the proposed process: (1) determination of the ratios $He^3:He^4$ for the helium from meteorites, (2) determination of any radial variation in the helium content of meteorites, (3) measurement of the helium, uranium, and thorium contents of both the iron and stone portions of stony-iron meteorites, (4) investigation to detect any cosmic-ray radioelements (such as $C^{14}$).

I wish to express my sincere appreciation to Drs. S. C. Brown and B. Rossi of M.I.T., and to Drs. E. M. Purcell and F. L. Whipple of Harvard for valuable discussions and suggestions.

[1] F. Paneth, Nature **149**, 235 (1942).
[2] The masses are from: H. H. Nininger, *Our Stone-Pelted Planet*, Appendix; A. D. Nininger, Pop. Astron. **45**, 449 (1937); **47**, 209 (1939); **48**, 555 (1940), and F. C. Leonard, Pop. Astron. **51**, 161 (1943). For the two crater-producing meteorites a somewhat low estimate of the mass has been adopted.
[3] W. E. Hazen, Phys. Rev. **65**, 67 (1944); M. M. Shapiro, Rev. Mod. Phys. **13**, 58 (1941); H. Wambacher, Sitzungsberichte Akad. Wiss. Wien **149**, 2a (Nos. 3–4), 157 (1940); **149**, 2a (Nos. 5–6), 231 (1940).
[4] H. Bridge and B. Rossi, Phys. Rev. **71**, 379 (1947).
[5] For $E=3$ Bev the equation $N=(7\times10^{-10}/E^{1.9})/\text{cm}^3$ leads to $J=2.6/\text{cm}^2\text{-sec}$.

## Erratum: On the Alleged Gamma Ray of $N^{13}$

[Phys. Rev. **71**, 906 (1947)]

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The Editor regrets that Fig. 1 of the above Letter to the Editor was badly distorted in reproduction. Its correct appearance is as follows:

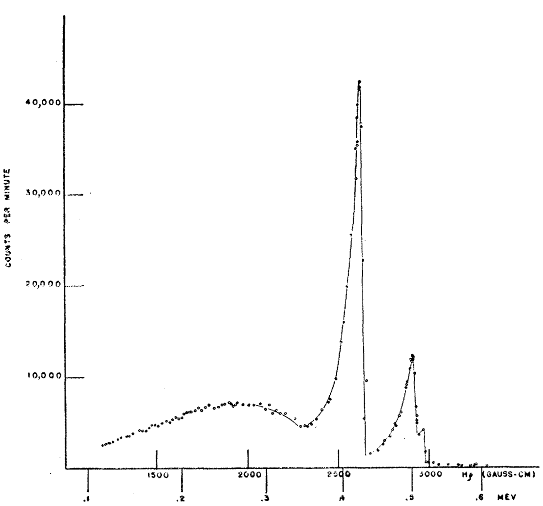


Fig. 1. Momentum distribution of photo and Compton electrons ejected from a Pb radiator by the radiation from $N^{13}$.

## On the High Energy Neutron-Proton Scattering

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June 23, 1947

In a previous paper,[1] we calculated the cross section for the inelastic scattering of neutrons by protons with production of isobars, according to the point of view of the meson field theory of nuclear forces with strong coupling. The cross section depends on the isobar energy $E_j$ of a nucleon; the value that we assumed for $E_j$ was 45 Mev, as indicated by Wentzel's[2] attempt to adjust the theory to Amaldi's measurements of the angular distribution of 14 Mev neutrons scattered by protons. Recently, however, Villars[3] showed that if the theory with strong coupling is to give the correct energy levels of the triplet and singlet states of the deuteron, then $E_j$ should be larger[4] than 200 Mev. In this case, the production of isobars is possible only if the kinetic energy $E_0$ of the bombarding neutrons is larger than 400 Mev in the laboratory system. In Table I

Table I. Cross sections of the inelastic and elastic $n-p$ scattering at high energies.

| $E_j$ | $E_0$ | $\sigma_{\text{in}}(\text{cm}^2)$ | $\sigma_{\text{el}}(\text{cm}^2)$ | $R$ |
|---|---|---|---|---|
| 100 Mev | 250 Mev | $1.05\cdot10^{-27}$ | $1.44\cdot10^{-25}$ | 0.007 |
| 150 | 350 | $0.40\cdot10^{-27}$ | $1.03\cdot10^{-25}$ | 0.004 |
| 200 | 450 | $0.24\cdot10^{-27}$ | $0.80\cdot10^{-25}$ | 0.003 |
| 250 | 550 | $0.84\cdot10^{-28}$ | $0.66\cdot10^{-25}$ | 0.001 |
| 300 | 650 | $0.50\cdot10^{-28}$ | $0.55\cdot10^{-25}$ | 0.0009 |
| 350 | 750 | $0.33\cdot10^{-28}$ | $0.48\cdot10^{-25}$ | 0.0007 |
| 400 | 850 | $0.15\cdot10^{-28}$ | $0.42\cdot10^{-25}$ | 0.0003 |

we give the values of the inelastic cross section $\sigma_{\text{in}}$ on the symmetrical Møller-Rosenfeld theory with strong coupling,[5] corresponding to several high values of the isobar energy. For comparison we also give the values of the elastic cross section $\sigma_{\text{el}}$ as derived from the same theory with weak coupling, i.e., from the potential:

$$V=(\boldsymbol{\tau}_I\cdot\boldsymbol{\tau}_{II})\{g_1^2+g_2^2(\boldsymbol{\sigma}_I\cdot\boldsymbol{\sigma}_{II})\}e^{-\mu r}/r,$$

where the symbols have the usual meaning and $g_1^2=0.05$, $g_2^2=0.09$. Both cross sections were evaluated in the first Born approximation; $R$ is the ratio $\sigma_{\text{in}}/\sigma_{\text{el}}$.

It is seen that $\sigma_{\text{in}}$ decreases more rapidly than $\sigma_{\text{el}}$ with increasing energy; the ratio $R$ is already very small for $E_0=250$ Mev. Our results show that such high values of the isobar energy make it still more difficult to check the strong coupling theory directly, at least with a nucleon-nucleon collision experiment. In the same paper,[1] it was stated that the triplet cross section of the elastic scattering of neutrons by protons as calculated by Hulthén[6] in the pseudoscalar theory was not correct. Hulthén's formula is, however, correct[4] and agrees with ours except for a factor 3 by which our formula has to be divided if we use the usual expression:

$$\sigma=\tfrac{1}{4}\sigma_s+\tfrac{3}{4}\sigma_{\text{tr}}.$$

The elastic cross section in this theory is $0.18\cdot10^{-24}$ cm² for 100 Mev neutrons; also $R=0.16$ and not 0.05, for $E_j=45$ Mev, as was indicated in our paper.

Calculations are being carried out for high energy proton-proton scattering and will be published elsewhere.


[1] J. Leite Lopes, Phys. Rev. **70**, 5 (1946).
[2] G. Wentzel, Helv. Phys. Acta **18**, 430 (1945).
[3] F. Villars, Helv. Phys. Acta **19**, 323 (1946).
[4] I am indebted to Dr. L. Hulthén for having called my attention to this point.
[5] Ref. 1, section 5.
[6] L. Hulthén, Arkiv. Mat. Astr. Fysik **31A** [15] (1944).


## Quantitative Alpha-Particle Counting by the Emulsion Technique


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EXPERIMENTS with weighed thin films of radiochemically pure $U_3O_8$ exposed to fine grained emulsions[1] show that the rate of disintegration $\delta$ can be computed accurately by microscopic evaluation of the number of alpha-particle tracks $n_r$ recorded by the emulsion. For films having an equivalent air thickness $\tau$ emitting alpha-particles of average range $\bar{R}$;

$$\delta = 2n_r/[1-(\tau+2l)/2(\bar{R}-e)] = n_r k_w.$$

When the distance between the source and the emulsion $l$ is less than 0.05 cm, about 98 percent of the tracks are confined to an area on the emulsion equal to that of the source, and $n_r$ can be evaluated by counting tracks in sampled portions of this area with a precision of 2 percent. At magnifications exceeding 500×, employing dark field illumination, the tracks of alpha-particles striking the emulsion at normal incidence are readily discernible from the background fog (Fig. 1). Measurements with a collimated source of polonium alpha-particles reveal that the minimum residual air range $e$ recorded in the emulsion as a distinct track is 0.84 air cm. The equivalent air thickness of the source $\tau$ is computed from its atomic composition with the aid of the Bragg-Kleeman stopping power law. For films of $U_3O_8$, $\tau = 0.2288w$, where $w$ is the film thickness in mg per sq. cm. The track-disintegration conversion factor

A B C

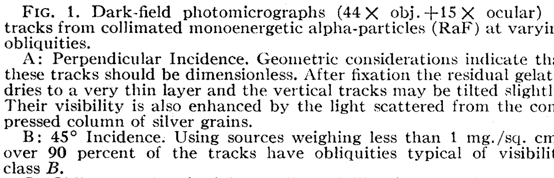

FIG. 1. Dark-field photomicrographs (44× obj.+15× ocular) of tracks from collimated monoenergetic alpha-particles (RaF) at varying obliquities.

A: Perpendicular Incidence. Geometric considerations indicate that these tracks should be dimensionless. After fixation the residual gelatin dries to a very thin layer and the vertical tracks may be tilted slightly. Their visibility is also enhanced by the light scattered from the compressed column of silver grains.

B: 45° Incidence. Using sources weighing less than 1 mg./sq. cm., over 90 percent of the tracks have obliquities typical of visibility class *B*.

C: Oblique tracks of minimum discernibility ($e$ = 0.84 air cm.) produced by alpha particles which spent 80 percent of their energy in traversing the source and air gap.

TABLE I. Rate of disintegration in $U_3O_8$ films.*

| Film | $w$ | $k_w$ | Track count | $\delta$ per g of U per sec. |
|---|---|---|---|---|
| *A* | 0.61 | 2.12 | 6604 | $2.51\times10^4$ |
| *B* | 0.75 | 2.14 | 11,600 | 2.48 |
| *C* | 1.43 | 2.23 | 13,500 | 2.37 |
| *D* | 2.32 | 2.36 | 13,874 | 2.34 |
| | | | average: | $2.43\pm.07\times10^4$ |
| Comparative determinations: | | | | |
| Geiger and Rutherford,** from scintillations | | | | $2.37\times10^4$ |
| Kovarik and Adams,*** alpha-pulses | | | | 2.48 |
| Schiedt,† alpha-pulses | | | | 2.53 |
| Kovarik and Adams,†† alpha-pulses | | | | 2.50 |

* The $U_3O_8$ was isolated and purified from a sample of Great Bear Lake pitchblende containing 51.0 percent U, 0.005 percent Th and 10.1 percent Pb. The Pb/U ratio of 0.198 indicates that the specimen (U. S. Nat. Mus. R6736) is probably of the same age ($1.3\times10^9$ yr) as found in the investigations of Marble[5] and Nier.[3] The measurements of Rutherford and Kovarik were made on uranium oxide isolated by Boltwood from Norwegian uraninite of similar geologic age,[3] $1.1\times10^9$ yr.
** H. Geiger and E. Rutherford, Phil. Mag. (6) **20**, 691 (1910).
*** A. F. Kovarik and N. I. Adams, Jr., Phys. Rev. **40**, 718 (1932).
† R. Schiedt, Sitz. Akad. Wiss. Wien, Math.-naturw. Kl. Abt IIa **144**, 175–211 (1935).
†† A. F. Kovarik and N. I. Adams, Jr., J. App. Phys. **12**, 296 (1941).

$k_w$ was evaluated for an air gap of 0.05 cm, using 2.93 cm for $\bar{R}$ (the weighted average of the mean ranges of the alpha-particles emitted by U*I*, U*II* and AcU based on the measurements of Rayton and Wilkins[2] and the activity ratios of Nier).[3]

Preliminary results on sources of varying thickness prepared by the ether-sedimentation method are recorded in Table I. The average on the four films corresponds to a disintegration rate of $2.43\pm0.07\times10^4$ alpha-particles per sec. per g of U. This is in good agreement with other experimental determinations of this constant and indicates the general validity of the method as a quantitative tool. Track counts from electrolytically deposited extra-thin films of uranium may lead to a more precise determination of the value of this fundamental constant.

The principal applications of the method reside in the estimation of low levels of alpha-ray activity, the track population increasing linearly on extended exposure until the fading of the latent image[4] of the older tracks becomes pronounced. Preliminary experiments on an exposure identical with *B* of Table I, but whose development was delayed for 10 days, gave a track count 9.2 percent lower than that of the undelayed control. With the brief exposures of 25 to 10 minutes employed in conjunction with sources *A* to *D* this factor is entirely negligible. However, in the analysis of a radiochemically purified carrier containing only 0.01 percent uranium, a 10 day exposure is desirable, and the track count would be about 5 percent low as a result of partial fading of the older tracks. Experiments on the mechanism and rate of fading in progress at present are expected to yield data on the fading factors covering exposures of 100 days duration for alpha-particles of diverse energy. A comprehensive report covering the technical details of the method is in preparation.

[1] Eastman fine grain alpha-particle emulsion No. 340,388 was employed. Our analyses indicate a composition of 84 percent silver halide and 16 percent gelatin. Their stopping power relative to air is 1680 for alpha-particles of 4.7 to 6.9 Mev. The value of $e$ is dependent on the emulsion composition and must be determined for each lot of plates.


[2] W. M. Rayton and T. R. Wilkins, Phys. Rev. **51**, 818 (1937).
[3] A. O. Nier, Phys. Rev. **55**, 150–163 (1938).
[4] H. Yagoda and N. Kaplan, Phys. Rev. **71**, 910 (1947).
[5] J. P. Marble, J. Am. Chem. Soc. **58**, 434 (1936).