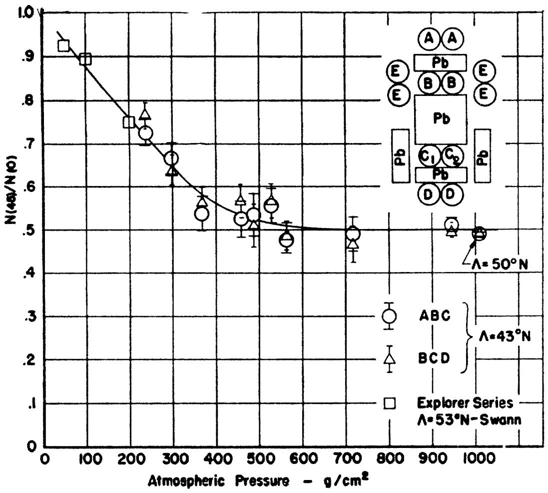

FIG. 1. Variation of the ratio of counting rates at zenith angles 45° and 0° with atmospheric pressure.

The variation with atmospheric pressure of the ratio of the penetrating particle counting rate at zenith angle setting 45° to that of 0° for the telescopes *ABC* and *BCD* is shown in Fig. 1, and this ratio is seen to be essentially the same for these two telescopes. The counting rate used for the numerator of this ratio was the average of the counting rates in the north, east, south, and west directions. The vertical bars indicate the statistical probable error of each point. The over-all correction made for counter dead-time, resolving time, counter efficiency, and recording circuit efficiency was less than 1 percent for the highest counting rate. The percentage of multiple particle events subtracted was the same for the case where the zenith angle setting was 0° as for the case where it was 45° for each of the two telescopes. These events accounted for from 1 percent at sea level to 18 percent of the net counting rate at 36,000 feet in the case of the *ABC* telescope and from 1 percent at sea level to 24 percent of the net counting rate at 36,000 feet in the case of the *BCD* telescope. Similar data, multiple particle events not excluded, obtained with narrow angle, non-leaded telescopes in the Explorer Balloon Flight Series[2] are shown for comparison.***

It is interesting to note the agreement between the zenith angle dependence of the total flux (Explorer Series) and that of the hard component (present work) at 200 g/cm^{-2}.

The assumption of a cosine power law variation of directional flux with zenith angle is suggested by the well-established $\cos^2\theta$ zenith angle dependence of the hard component flux at low altitudes.[3] Thus, if it is assumed that the directional flux, $J(\theta)$ (particles cm^{-2} sec.$^{-1}$ steradian^{-1}), at zenith angle θ, independent of azimuth, has the form:

$$J(\theta)=J(0)\cos^n\theta,\quad 0\leqq\theta\leqq\pi/2,$$
$$J(\theta)=0,\quad \pi/2<\theta\leqq\pi;$$

then from consideration of Fig. 1, the exponent, n, must vary with altitude.

To find the manner in which the exponent, n, varies with altitude, the ratio of the counting rates of these telescopes in the 45° and vertical positions, N(45°)/N(0°), has been calculated after the method of Greisen[3] for various assumed values of the exponent, $0\leqq n\leqq 2$, from the expression for the directional counting rate given in terms of the directional flux, the solid angle and the area of the telescope

$$N(\theta)=\eta\int_\sigma\int_\Omega J(\theta)d\Omega d\sigma \text{ sec.}^{-1},$$
$$J(\theta)=J(0)\cos^n\theta,\quad 0\leqq\theta\leqq\pi/2,$$
$$J(\theta)=0,\quad \pi/2<\theta\leqq\pi,$$

where η is the over-all efficiency of the system. In making this calculation, proper account has been taken of the spread of zenith angles within the acceptance angle of the composite telescopes *ABC* and *BCD*.

The values of n which gave a calculated ratio, N(45°)/N(0°), equal to the experimental one at each atmospheric pressure are plotted as a function of atmospheric pressure in Fig. 2. These values of the exponent are independent of the experimental arrangement. Again the points from the Explorer Balloon Flight

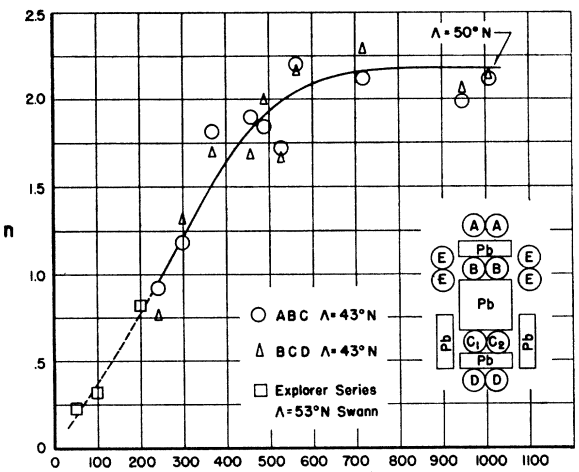

FIG. 2. Variation of n with atmospheric pressure assuming $J(\theta)=J(0)\cos^n\theta$.

Series are included and are seen to follow the same trend, even though they correspond to the total rather than the hard component of the flux.

* This work was supported by the Navy Bureau of Ordnance under Contract NOrd 7386.

[1] M. Schein and V. C. Wilson, Rev. Mod. Phys. 11, 292 (1939).

** In particular:

$$ABC_{\text{net}}=[ABC-ABC_1C_2-ABCE+ABC_1C_2E],$$
$$BCD_{\text{net}}=[BCD-BC_1C_2D-BCDE+BC_1C_2DE].$$

[2] W. F. G. Swann, Rev. Mod. Phys. 11, 242 (1939).

*** It is to be noted that the present experimental measurements have been made at only two zenith angles; therefore, they do not establish the form of the zenith angle law.

[3] K. I. Greisen, Phys. Rev. 61, 212 (1942) and references therein.

Angular Correlation of Delayed Radiations

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THE energy-lifetime relation of nuclear transitions and the internal conversion coefficient in the case of gamma-ray emission do not always lead to unique assignments of spin and relative parity values to excited energy levels of nuclei. It is therefore fortunate when two transitions follow each other in cascade, since, then, observation of the relative direction of emission of the two radiations frequently yields the necessary spectroscopic information. With coincidence circuits the method has been applied to transitions following each other in instantaneous succession.[1] The major experimental difficulties are in this case due to scattering effects and the presence of annihilation radiation.

We have extended the method of radiations which are delayed with respect to each other. Using delayed coincidence circuits, angular correlations can at present be measured when the lifetime of the intermediate state lies between about 10^{-8} and 10^{-2} sec. This state may be a metastable energy level or a short-lived alpha-

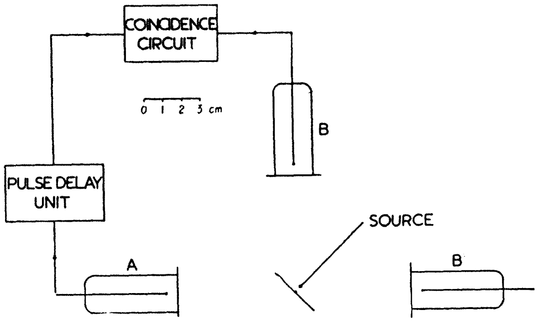

FIG. 1. Schematic diagram of experimental arrangement for measuring directional correlation of delayed radiations.

particle emitter. Since instantaneous coincidences are not recorded, the difficulties mentioned are ruled out. The major experimental difficulty is, in this case, due to the competition of the random with the genuine delayed coincidences. One should endeavor to make the efficiency of the detectors (Geiger-Müller counters) as large as possible and still keep the angular resolution high. Furthermore, the individual counting rates should be kept at a minimum, determined by the maximum practical time of the experiment. For half-lives shorter than about one μsec. the random coincidences are less troublesome. However, when the lifetime is shorter than 10^{-7} sec., the fluctuations in the time lag between the entrance of the ionizing radiation into the Geiger counter and the recording of the corresponding electrical pulse impose a limitation to the accuracy of the result.

With the experimental arrangement of Fig. 1 we have recorded delayed coincidences from a Hf^{181} source at angles 90° and 180° between the counters. The delay introduced in channel A was 2 μsec., while the sum of the effective pulse lengths in the two channels was 1.9 μsec. The Geiger counters in the A and B channels had mica windows of 3 and 1.6 mg/cm^2, respectively. The angular resolution was about $\pm 9°$.

It has been shown that the β^--decay of Hf^{181} leads directly to a 20-μsec. metastable state in Ta^{181}.[2] The β-transition is once-forbidden,[2] and the maximum energy is 0.405 Mev.[3] The Σ-radiation emitted in the decay of the metastable state has an energy of 0.130 Mev and is highly internally converted. It is probably a mixed electric octopole and magnetic quadrupole radiation.[2] Further internally converted γ-rays follow the 0.130-Mev transition, but they are probably of less importance in this experiment.

It is apparent that the observed delayed coincidences are mainly due to β-particles entering counter A and conversion electrons (chiefly from the 0.130-Mev transition) entering counter B. The genuine delayed coincidence rates were found to be 0.018 ± 0.0017 (p.e.) min.$^{-1}$ and 0.02 ± 0.0029 min.$^{-1}$ in the 90° and 180° positions, respectively, before the experiment had to be discontinued for some months. The random coincidence rate amounted to one-fourth of the genuine coincidence rate. A possible deviation from isotropic distribution must therefore certainly be less than 15 percent. It is, of course, quite probable that the distribution actually should be symmetrical owing to the following reason: In our delayed coincidence experiment we have selected the transitions in which the nuclei, decaying by β-emission to the metastable state, remain in this state for between two and four μsec. During this time an originally existing anisotropy could have been removed by external fields which may be acting on the magnetic moment of of the nucleus. The most likely effects would be the coupling between the nucleus and the atomic electrons, or the influence of other fields existing within the crystals or molecules in the source material.[4] On the other hand, if any appreciable alignment of the nuclear magnetic moments with respect to these fields occur, the relaxation time for the process may be rather long. It is therefore our purpose presently to measure angular correlations of the radiations preceding a short-lived state (e.g., Ta^{181*}, Te^{121*}, $Tm^{169* \text{ or } 171*}$, Re^{187*}, Po^{213*}, RaC'^*, ThC'^*, etc.) and the radiations emitted from this state after the lapse of different time intervals. This can easily be achieved by introducing a variable delay in channel A (Fig. 1). It should then be possible to get an indication of the relaxation time for the alignment process, which further may give us some information about the fields acting on the nucleus.

By applying a magnetic field to the sample under low temperature it may even be possible to influence the angular distribution by external means. The corresponding relaxation times may then be studied.

[1] Kikuchi, Watase, and Itoh, Zeits. f. Physik **119**, 185 (1942); R. Beringer, Phys. Rev. **63**, 23 (1943); W. M. Good, Phys. Rev. **70**, 978 (1946); E. L. Brady and M. Deutsch, Phys. Rev. **72**, 870 (1947); A. H. Ward and D. Walker, Nature **163**, 168 (1949).
[2] A. Lundby, Phys. Rev. (to be published). See also S. DeBenedetti and F. K. McGowan, Phys. Rev. **74**, 728 (1948); Bunyan, Lundby, Ward, and Walker, Proc. Phys. Soc. **61**, 300 (1948).
[3] K. Y. Chu and M. L. Wiedenbeck, Phys. Rev. **75**, 226 (1949).
[4] G. Goertzel, Phys. Rev. **70**, 897 (1946).

On the Polarization of Slow Neutrons

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RECENT measurements[1] of Bloch's polarization cross section, p, for thermal neutrons in cold-rolled iron yield a value $p = 3.1$ barns, about a factor of 3 larger than the latest previous theoretical value,[2] and one might think that there is a serious disagreement here, requiring some drastic correction in the magnetic interaction law. It has been pointed out, however,[3] that a critical revision of some factors entering the theory leads to a different conclusion. It is the purpose of this note to give a more detailed account of this work.

We are concerned here with an analysis of the "single transmission experiment." A beam of slow neutrons is detected after passing through a slab of iron. The experiment is performed alternately with the iron unmagnetized, and magnetized in a direction perpendicular to the neutron beam. For unmagnetized iron the scattering cross section for both spin orientations of the neutrons is the same. However, when the iron is magnetized, there is an additional contribution from the scattering of the neutrons on the magnetically active d electrons, which is of opposite sign for the two spin orientations: $\sigma_+ = \sigma + p$; $\sigma_- = \sigma - p$. If a neutron beam of intensity I_0 passes through a slab of unmagnetized iron d cm thick, with N atoms per cubic cm, it will emerge with intensity $I_u = I_0 e^{-Nd\sigma}$. When the iron is then magnetized, the transmitted intensity increases:

$$I_m = I_0/2[e^{-Nd\sigma_+} + e^{-Nd\sigma_-}] = (I_0/2)e^{-Nd\sigma}[e^{+Ndp} + e^{-Ndp}],$$
$$I_m/I_u = \cosh Ndp.$$

The experiment therefore measures p.

The theoretical determination of p, which is somewhat complicated by crystal effects, has been carried out by Halpern, Hamermesh, and Johnson.[4]

For saturated iron:

$$p = \left(\frac{\sigma_{\text{coh}}}{4\pi}\right)^{\frac{1}{2}} \frac{e^2}{mc^2} \mu_n \mu_e \left(\frac{\lambda}{2a}\right)^2 \sum_{l<2a/\lambda} \frac{N(l)}{l}\left(1 + \frac{l^2\lambda^2}{4a^2}\right) F(l), \quad (1)$$

where

σ_{coh} = coherent scattering cross section of the iron nucleus,
μ_n = neutron magnetic moment in nuclear magnetons,
μ_e = magnetic moment of all unpaired electrons, in electronic magnetons,
= 2.18 for iron,
λ = de Broglie wave-length of the neutrons,
a = lattice constant of the iron = 2.86×10^{-8} cm,

$$F(l) = (a/2\pi l)\int_0^\infty \sin(2\pi l r/a)\varphi^2 r dr \bigg/ \int_0^\infty \varphi^2 r^2 dr,$$

φ = wave function of d electrons (electrons with unpaired spin).