is improved considerably. Therefore, it was considered worthwhile to present the results in spite of their lack of completeness.

The energy spectra of the protons at the emission angles of 45°, 90°, and 135° are shown in Table I together with the previously reported[1] data for the deuteron. The values are corrected for the nuclear absorption of protons in the absorbing material. To make the numbers comparable in the deuteron and alpha-particle cases, they are normalized to the number of protons in the nucleus concerned. The data available in the helium case are less complete than those in the deuteron case.

In the 45° case, there seems to be a fairly well-defined cutoff at energy almost equal to the cutoff energy of the deuteron, which is approximately 200 Mev. The yield corresponding to a proton energy of about 160 Mev is nearly equal in both cases. In the case of helium, the yield of protons below 140 Mev increases more steeply with decreasing energy than in the case of the deuteron, indicating the existence of more low energy protons.

In the 90° case, the cutoff energy is again nearly the same in both cases. The energy distribution curve below the cutoff energy in the helium case shows a steady increase of the number of protons with decreasing energy, leaving no plateau below the cutoff, indicating again the larger number of protons below about 140 Mev.

In the 135° case, the energy spectrum extends up to about 130 Mev, which is higher than the cutoff energy of the deuteron case.

The conclusions one can draw from these data might be as follows. The fact that the cutoff energies of the spectra of protons at 45° and 90° are approximately the same as in the case of the deuteron, seems to indicate that the high energy protons, at least in the 45° case, are produced by the absorption of a photon in a two-nucleon system. The existence of protons of energy higher than the cutoff energy of the deuteron in the 135° case might be due to an absorption process in which the energy and momentum of a photon is taken up by three or four nucleons. The fact that there are more protons below, say, 140 Mev at the emission angles of 45° and 90° in the helium case than in the deuterium case, might also be explained by the three- or four-nucleon process mentioned above. The lack of protons above the cutoff energy for the two-nucleon process in the 45° and 90° cases and the lack of protons of energy above about 130 Mev in the 135° case, seem to indicate that the cross section for a process such as $\mathrm{He}+\gamma\rightarrow\mathrm{T}+p$ is small compared to the two-nucleon process. They also indicate the small probability for a process such as $\mathrm{He}+\gamma\rightarrow 2p+2n$ or $\mathrm{He}+\gamma\rightarrow\mathrm{D}+p+n$, in which the proton gets more energy than allowed by the two-nucleon process.

The present results, together with the previous results on the deuteron, should help to provide a fundamental basis for interpreting the photodissociation of nuclei in general by high energy gamma-rays.

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V^0 Particles and Isotopic Spin*

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RECENT experiments and interpretations on the scattering of mesons by protons[1,2] have suggested that the isotopic spin T is a good quantum number for meson-nucleon systems. It is therefore of interest to consider the implications of this quantum number for the unstable cosmic-ray particles. As an example the V^0 will be considered as a nucleon in an excited state, a generic term that includes any heavy fermion. Similar considerations are applicable to bosons without essential novelty.

The most remarkable feature of the V^0 particle is its stability against decay by π- and γ-emission. As a first approximation, we inquire under what conditions it could be absolutely stable. Let $\mathbf{t}$, $\boldsymbol{\tau}$, and $\mathbf{T}$ be the respective isotopic spin vectors of the nucleon, π-meson, and total system. The interaction energy is $H_0\sim(\mathbf{t}\cdot\boldsymbol{\tau})$, with corresponding selections rules for single meson emission

$$\Delta t,\ \Delta t_z=0,\ \pm 1, \tag{1a}$$

$$\Delta T,\ \Delta T_z=0. \tag{1b}$$

The emission of a real meson requires at least 140 Mev, so that by (1) an excited nucleon will be stable against π-decay to its ground state ($t=\frac{1}{2}$) if its excitation energy E and isotopic spin satisfy the relation

$$E<(t-\tfrac{1}{2})\ 140\ \text{Mev}. \tag{2}$$

Since the V^0 ultimately emits one π-meson, it must have $E>140$ Mev, which is charge forbidden only if $t>\frac{3}{2}$. The simplest choice is $t=5/2$, $140<E\lesssim 280$ Mev, with an eventual Q value for π-emission of $0<Q\lesssim 140$ Mev. There is of course no difficulty about the production of states with large t values in a high energy nuclear event where many particles are present in strong interaction.

This stability against π-emission is independent of the magnitude of H_0, which is not true of the stability against γ-emission. In the isotopic spin formalism the photon interaction term is of the form $H\sim a+bt'$, where t' is the isotopic spin of whatever particle is involved. The selection rule accordingly depends on whether the V^0 is in a single-nucleon state or a virtual state of nucleon plus meson,

$$\text{single}-\text{nucleon}\quad H_\gamma\sim A+BT_z,\quad \Delta T=\Delta T_z=0 \tag{3a}$$

$$\text{nucleon}+\text{meson}\quad H_\gamma\sim a+\alpha+bt_z+\beta\tau_z,\quad \Delta T_z=0,\ \Delta T=0,\ \pm 1. \tag{3b}$$

The rule (3b) requires $b\neq\beta$, which is generally true; it is this type of process that occurs in the decay of a π^0 meson ($T=1$) into two photons, each of isotopic spin $T=0$.

If isotopic spin is to be made the basis of γ-stability, (3a) indicates that the V^0 must have $t>\frac{1}{2}$. On the other hand, (3b) shows that the V^0 must also be stable against virtual π-meson emission, for otherwise it could decay rapidly by emitting $(t-\frac{3}{2})$ photons and one π. Thus isotopic spin considerations alone cannot account for both π- and γ-stability but only for one of the two: If γ-emission can be "turned off," π-stability can be achieved, or if some external postulate ($g^2/\hbar c\sim 10^{-12}$) is introduced to give π-stability, isotopic spin restrictions can provide equally good γ-stability without additional assumptions.

Therefore, if isotopic spin is to help account for V^0 stability, a model must be chosen in which $t\geq\frac{3}{2}$ for the V^0. This would imply the existence of a number of companion particles, including at least V^- and V^{++}, which decay in a similar fashion to $n+\pi^-$ and $p+\pi^+$. The V^+ particles would exist for any value of t, and their modes of decay should provide some information on t of the initial state. For $\pi-V$ coupling of the type H_0 the relative frequencies of decay $(V^+\rightarrow n+\pi^+):(V^+\rightarrow p+\pi^0)=2:1$ or $1:2$ according as $t=\frac{1}{2}$ or $\frac{3}{2}$. For higher values of t, $(t-\frac{3}{2})$ quanta must accompany the π-decay if the $\pi-V$ coupling is of type H_0; if it is of type H_γ, the decay will divide in comparable proportion among processes accompanied by $(t-\frac{1}{2})$, $(t-\frac{3}{2})$, $(t-5/2)$ quanta. The decay lifetime increases by order $1/\alpha\sim 10^2$ per quantum.

Thus the following conclusions are reached: The apparent failure to observe V^{++} and other companion particles with frequencies comparable to V^0 suggests that the V-particle wave functions have some (or all, if T is a good quantum number) components with $t<\frac{3}{2}$. This would mean that independent principles must be found to explain both the π- and γ-stability of these particles without help from isotopic spin considerations, which could have eliminated one type of instability. A direct check of t for the V^+ particles is in principle possible from a determination of the $(n+\pi^+):(p+\pi^0)$ ratio. The presence of V^- particles in the face of an established absence of corresponding V^{++} would suggest failure of T as a good quantum number.

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The Absorption Rate of Cosmic-Ray Neutrons Producing C^{14} in the Atmosphere

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ANDERSON and Libby,[1] who determined the average number of disintegrating C^{14} atoms per cm^2 of the earth surface, found an approximate agreement of this number with the average integrated absorption rate of atmospheric neutrons computed from Yuan's measurements.[2] Since Yuan's more recently published value of this absorption rate[3] is nearly twice as large and since improved neutron cross sections have been published in the meantime,[4] a recalculation seems necessary.

The measurements of Yuan on January 8, 1949, integrated over the atmosphere up to 102,000 feet at Princeton's geomagnetic latitude (51° 46′ N), give for the tin-shielded boron counter $I_t=\int n_t dp=834$ counts-g/cm²-sec and for the cadmium-shielded boron counter $I_{cd}=\int n_{cd}dp=394$ counts-g/cm²-sec. By taking the difference of these values one can eliminate the background of "secondary" counts b due to stars produced in the shields or to recoils etc.; and by multiplying this difference by the ratio A/Σ_c, where $A=0.0545$ cm²/g is the absorption of one gram of air and $\Sigma_c=12.5$ cm² is the effective absorption cross section of the counter,[5] both for thermal neutrons, one obtains as the total number of absorbed neutrons up to 0.4 ev (the cut-off energy of the cadmium-shield) $(I_t-I_{cd})A/\Sigma_c=1.92$/cm²-sec. An upper limit for the absorption rate up to 0.4 Mev is $I_tA/\Sigma_c=3.64$/cm²-sec, since I_t is uncorrected for the unknown background effect $I_b=\int bdp$ and since the cross sections for nitrogen and for boron follow the $1/v$ law; but above 0.4 Mev nitrogen has some resonance absorptions for the (n, p) as well as for the (n, α) reaction. On the other hand, the corrected neutron absorption rate can be obtained approximately from the cadmium-difference counts by using the "slowing-down theory" of neutrons.[6] If $q(E)$ is the "slowing down density past the energy E," then

$$q(E_2)/q(E_1)=\exp\left[-\frac{1}{\xi}\int_{E_2}^{E_1}\frac{\sigma_a}{\sigma_a+\sigma_s}\frac{dE}{E}\right]=S(E_2, E_1).$$

With $E_1=0.4$ Mev and $E_2=0.4$ ev, $\xi=6/(3A+2)=0.132$ one obtains by numerical integration

$$q(0.4\text{ ev})/q(0.4\text{ Mev})=(I_t-I_{cd})/(I_t-I_b)=1/1.77;$$

therefore,

$$(I_t-I_b)A/\Sigma_c=(I_t-I_{cd})A/\Sigma_c\times S(E_1, E_2)=3.4/\text{cm}^2\text{-sec}$$

is the absorption rate up to 0.4 Mev neutrons.[7] To compute the absorption rate of neutrons of higher energy, the energy distribution $f(E_p)$ of the neutrons as they are "evaporated" from cosmic-ray stars has to be taken into account. The integrated number of all neutrons absorbed by the $N(n, p)C$ reaction in the atmosphere at 52°N will then be

$$Q=q(E_1)\int_0^\infty f(E_p)dE_p\bigg/\int_{E_1}^\infty f(E_p)\times S(E_1, E_p)dE_p,$$

with $E_1=0.4$ Mev and $E_p>E_1$. The cross section $\sigma_a(n, p)$ is measured up to 3.6 Mev where it is only 1/100 barn, and is approximately known[8] at 14 Mev. Using the function[9] $f(E_p)=E_p\times\exp(-E_p/3)$ one obtains Q (up to 14 Mev) $=3.4\times1.2=4.2$/cm²-sec. But this result should be taken as tentative, inasmuch as the function $f(E_p)$ and some of the cross sections (including that of the counter) are somewhat uncertain and as the neutron flux at high latitudes fluctuates due to changes of the activity of the sun.[10] On account of the strong latitude dependence of atmospheric neutrons[11] one obtains finally for the averaged value over the earth's surface[12] (including neutron energies up to 14 Mev) $\bar{Q}=0.58\times4.2=2.4$/cm²-sec. Anderson and Libby's value for the average number of disintegrating carbon atoms is 2.23/cm²-sec. Their conclusion, that apparently no considerable change in the cosmic-ray intensity has occurred over the past several thousand years is, therefore, corroborated so far by the present recalculations.

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[6] See, e.g., H. Soodak and E. C. Campbell, *Elementary Pile Theory* (John Wiley and Sons, Inc., New York, 1950); also see reference 1 and the references given there.
[7] The "true cadmium ratio" $(I_t-I_b)/(I_{cd}-I_b)=R_0=1/[1-S(E_2, E_1)]=2.3$, so that with $R=I_t/I_{cd}=2.12$ the relative background $I_b/I_t=[(R_0/R)-1]/(R_0-1)$ was only 7 percent in the present case.
[8] According to private information from T. W. Bonner, Dr. A. Lillie found, at 14 Mev, $\sigma_H=0.040$b (disintegration of N into H^1, H^2, and H^3); and according to information from E. O. Salant σ_{total} at 14 Mev is (1.7 ± 0.1)b for N and (1.64 ± 0.04) for O.
[9] See S. Fluegge, *Cosmic Radiation* (John Wiley and Sons, Inc., New York, 1946), p. 154. The rather different energy distribution of neutrons found by D. M. Skyrme and W. S. C. Williams [Phil. Mag. **42**, 1187 (1951)] when bombarding carbon with 171-Mev protons gives essentially the same result.
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The Production Rate of Cosmic-Ray Neutrons and C^{14}†

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A REPORT of measurements made by one of us,[1] and containing references to calculations made by the other, deduced the low energy capture rate of cosmic-ray neutrons to be 7.1 per second per square centimeter of the earth's surface at Princeton. These results were based on the assumption of what seemed at the time to be the best values of the scattering and absorption cross sections of nitrogen and oxygen. Now, the predicted experimental cadmium ratio of the $1/v$ detectors used depends strongly upon the values of the cross sections assumed (actually, upon the average value of their ratio in the energy region where most of the capture occurs). This can be seen from the approximate theoretical expression for this ratio:

$$R=1-\exp[-2B/(\sigma_s\xi\sqrt{E_c})],\tag{1}$$

where ξ is the logarithmic decrement of the energy for neutrons in air, σ_s is the mean scattering cross section of air, the capture cross section of an air atom is $B/(E)^{\frac{1}{2}}$, and E_c is the cadmium cutoff of the counters used.

We have decided that, because the cross sections used were not correct, it would be wise to review the conclusions of (1), so that a