These results are preliminary to more extensive investigations of the matter.

The writers take pleasure in acknowledging helpful discussions with Professors W. H. Newhouse and K. Rankama of the Geology Department and A. J. Dempster and E. Fermi of the Physics Department of the University of Chicago.

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On the Negative Proton*

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August 24, 1949

THE possible existence of negative proton has been speculated on by various investigators.[1] The initial and final nuclei involved in the delayed neutron emission (or preferably the β–n decay process) are the same as that for a hypothetical process of negative proton emission. Equations (1), (2) and (3) illustrate this point and also yield a value of the reaction energy for the negative proton emission.

$$ {}_{Z}X^{A}={}_{Z+1}Y^{A-1}+\beta^{-}+{}_{0}n^{1}+Q_{1}, \tag{1}$$

$$ {}_{Z}X^{A}={}_{Z+1}Y^{A-1}+{}_{-1}H^{1}-2e+Q_{2}, \tag{2}$$

$$ Q_{2}=Q_{1}+1.826 \text{ in Mev.} \tag{3}$$

Equation (3) is obtained on the assumption that the negative proton has the same mass as the positive proton.

For a process that involves delayed neutron emitters, Q_1 is always positive. Q_2, then, is also positive which means that reaction (2) is possible, at least from energy considerations. The emission of negative protons if further favored on account of the negative potential barrier involved.

The delayed neutron emitter, N^{17}, was first discovered by the University of California group.[2] It was produced by bombarding oxygen or elements immediately above it in atomic number with 200-Mev deuterons. The group at Westinghouse Research Laboratories and the University of Pittsburgh have induced the reactions, $C^{14}(\alpha,p)N^{17}$, by means of 16 to 30 Mev α-particles, and $O^{17}(n,p)N^{17}$ by means of the cyclotron-produced fast neutrons on the O^{17} in natural water.[3,4] The reaction energy for the β–n decay of N^{17} was measured by Alvarez[5] to be 4.58 Mev. This yields reaction energy of 6.41 Mev for the emission of a negative proton from N^{17}.

It is possible to produce N^{17} in the order of one millicurie strength from the large California cyclotron[6] or from the University of Pittsburgh cyclotron by the $C^{14}(\gamma,p)N^{17}$ method, if a few hundred millicurie of C^{14} are used.

It should not be difficult to detect negative proton emission with a cloud chamber in a magnetic field even if the probability of negative proton decay is only one in 10^7. A cyclotron producing 200-Mev deuterons would be particularly suitable for this experiment. Because of the high penetrating power of deuterons, N^{17} may be made inside a cloud chamber. If the intense ionizations from other radioactive products cause difficulty in the cloud-chamber operation, a magnetic spectrometer with a proportional counter as the detector may be used.

An alternative way of detecting the presence of negative protons is to observe the annihilation radiations which should be present. If a pair of γ-rays is produced for each annihilation, their energy would be about 10^9 ev. These may be detected by observing showers produced by the powerful γ-rays in a cloud chamber or in some device composed of lead sheets and Geiger counters. This method is convenient to be carried out because the N^{17} or other delayed neutron emitters may be produced in a separate container from that of the detecting device, and also because a thick target may be used in the production of N^{17}. Since intense delayed neutron emitters can also be produced in a fission reactor, this method may also be easily applied.

It is, perhaps, also advisable to look for mesons in N^{17} or other delayed neutron emitters, since it has been postulated[7] that mesons may be produced during the annihilation process.

* Assisted by the Joint Program of the ONR and the AEC.
[1] See for examples, L. Rosenfeld, *Nuclear Forces, I* (1948), p. 8, and G. Gamow, *Structure of Atomic Nuclei and Nuclear Transformations* (1937), p. 14.
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Erratum: The Chi-Square Test as a Criterion for Testing Halogen-Filled Geiger Tubes

[Phys. Rev. 75, 1461 (1949)]

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THE second sentence in the abstract should read: "Many of the early halogen-quenched tubes exhibited slopes of six percent or more, although Liebson* has reported that it is possible to produce tubes with one or two percent slopes."

Since the time of this report Lieutenant Commander F. W. Brown III of this laboratory has also obtained halogen-quenched tubes with slopes of a few percent.

* S. H. Liebson, Rev. Sci. Inst. **19**, 303 (1948).

Spontaneous Decay Rate of Heavy Mesons. II

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September 6, 1949

IN a recent note of the same title,[1] it was shown that either a coupling between heavy (π) and light (μ) mesons or a coupling between μ-mesons and nucleons can lead to both the observed rate of π–μ-decay and the observed rate of capture of negative μ-mesons by nuclei. It was also shown that neither a coupling between π-mesons and electrons (e) nor a coupling between electrons and nucleons can lead to rates of both π–e decay and nuclear beta-decay in agreement with observation. It was assumed there that π-mesons are scalar particles, μ-mesons, electrons, neutrinos (ν), neutrons (N), and protons (P) are all Dirac particles, and that all couplings are of the scalar type that involve the Dirac β-operator. A divergent integral that appears in the calculation

$$ I=\int_{0}^{\infty} P^{4}dP/(P^{2}+M^{2}c^{2})^{\frac{3}{2}}, \tag{1}$$

where M and P are the nucleon mass and momentum, was interpreted both by taking the upper limit to be roughly equal to Mc, and by setting the self-energy of the π-meson (which involves I) equal to mc^2. The two interpretations of I give approximately the same values, the latter being

$$ I=3\pi m^{2}c^{2}, \tag{2}$$

when the π–N coupling constant has the magnitude

$$ |G|=(4\pi\hbar c^{3}/3)^{\frac{1}{2}}$$

obtained from the strength of nuclear forces.

Steinberger[2] has attempted to resolve the discrepancy noted above by using Pauli's regulator formalism[3] to so interpret the integral (1) that it is negligibly small in comparison with the value (2). Since this application of regulators to an integral that is not even conditionally convergent makes it so small that the sum over intermediate states characteristic of second-order perturbation theory ceases to have any meaning, it seems worth while to consider other possibilities. Thus if the existence of anti-nucleons is denied, I is identically zero since the intermediate nucleon states do not occur. Then agreement with experiment could be attained by assuming appropriate values for the π–μ- and N–e coupling constants.[2] Alternatively, nuclear beta-decay could perhaps be explained in terms of a very short-lived intermediate meson of much greater mass ($\sim 1000 m_e$) that is strongly coupled to nucleons, which might then also be responsible for initiating soft cosmic-ray showers.

Another possibility, investigated here, assumes both π–e and N–e couplings, so that there is interference between first- and second-order processes in both π–e decay and nuclear beta-decay. The pertinent interaction terms in the Hamiltonian are

$$G\int \psi_\pi(\psi_P{}^*\beta\psi_N)d\tau+\gamma\int \psi_\pi(\psi_e{}^*\beta\psi_\nu)d\tau$$
$$+g_e\int(\psi_\nu{}^*\beta\psi_e)(\psi_P{}^*\beta\psi_N)d\tau+\text{c.c.}$$

Then the ratio of the rate of π–e decay to the rate of free neutron decay is

$$\frac{w_{\pi e}}{w_{Ne}}=\frac{45\pi}{8f(\Delta/m_e)}\left(\frac{m}{\Delta}\right)^5\left|\frac{1-(G\bar{g}_e/\gamma)(I/\pi^2\hbar^3c)}{1-(G\bar{g}_e/\gamma)(3m^2c/4\pi\hbar^3)}\right|^2, \qquad (3)$$

where

$$f(x)\equiv\left(1-\frac{9}{2x^2}-\frac{4}{x^4}\right)\left(1-\frac{1}{x^2}\right)^{\frac{1}{2}}+\frac{15}{2x^4}\ln(x+(x^2-1)^{\frac{1}{2}}),$$

and Δ is the neutron-proton mass difference. The experimental upper limit for this ratio is roughly $10^7/6\times10^{-4}$, so that the squared bracket in (3) is less than about 0.02. This is so small that the quantity $G\bar{g}_e/\gamma$ must be mainly real and positive with not more than a small imaginary part, if the evaluation (2) for I is assumed. Then $|g_e|$ must have about one-third the value usually assumed to account for nuclear beta-decay, and the ratio $|\gamma/G|$ of π–e to π–N coupling constants is approximately equal to 1.3×10^{-7}.

It is interesting to note that the magnitude of the π–μ-coupling constant required to explain π–μ-decay as a pure first-order process is very nearly equal to the value of $|\gamma|$ obtained above.

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A Note on the Infra-Red Spectra of the Deutero-Ammonias

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August 29, 1949

MIGEOTTE and Barker[1] measured the fundamental vibration-rotation bands of the ND_3 molecule but were bothered some by contaminations of ND_2H and NDH_2, as well as CO_2 and possibly D_2O. An attempt has been made to remeasure these bands at higher resolution with the vacuum grating spectrometer of the laboratory. However, the gas obtained was not of sufficiently high purity to make an accurate analysis of the ND_3 fundamental bands, but was found to contain a considerable amount of the mixed ammonias. During the course of these measurements, high resolution data were recorded from about 790 cm^{-1} to 1800 cm^{-1} and in the region 2350–2600 cm^{-1} and several Q-branches were observed which undoubtedly belong to the mixed ammonia molecules. This data is included as part of a dissertation by the author.[2]

Howard[3] calculated the fundamental frequencies for the various ammonia molecules on the basis of valence forces using values of the force constants which gave the proper values of ν_3 and ν_4 for NH_3. By a comparison with these calculated frequencies, the various Q-branches observed have been assigned in Table I.

TABLE I. Observed and calculated fundamental frequencies in cm^{-1} for the ammonia molecules.*

Molecule		ν_2	ν_4	ν_1	ν_3
NH_3	calc.	1010	1631	3355	3470
	obs.	966 933	1631	3335.9 3337.5	3407
NH_2D	calc.	1025	1385*a* 1600*s*	3400	2510*s* 3470*a*
	obs.	894** 874**	1592		
NHD_2	calc.	925	1230*s* 1460*a*	2455	2565*a* 3435*s*
	obs.	818** 808**	1234 1464	2418	2556
ND_3	calc.	840	1180	2405	2565
	obs.	749.2** 745.8**	1191.2	2420.4	2555.6

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* The letter, *a* or *s*, after a frequency of NH_2D or NHD_2 indicates that it corresponds to a vibration which is antisymmetric or symmetric, respectively, with respect to reflection through a plane passing through the figure axis and the hydrogen isotope differing from the other two.

** Values obtained from data of Migeotte and Barker (see reference 1).

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On the Latitude Dependence of the Absolute Neutron Intensities in Cosmic Radiation*

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August 25, 1949

THIS is a preliminary report on some of the results obtained on the study of the latitude dependence of slow neutron intensities in the free atmosphere carried out by means of a B-29 plane. Two identical proportional counters filled with boron trifluoride of 96 percent B^{10}, similar to those employed in our earlier experiments,[1] were placed in the pressurized cabin of the tail gunner's compartment of the plane. They were suspended two feet apart near the center of the cabin with all hydrogenous material and heavy equipment removed from the compartment and its vicinity. Furthermore, the plastic bubble was replaced by a thin Duralumin plate. Thus the counters would not be appreciably affected by their surroundings in the plane and should measure essentially the slow neutron intensity in the free atmosphere. This conclusion is borne out by the fact that the measurements obtained in the plane agree well with our free balloon results for the absolute intensity.[2]

Each counter output was fed directly to a cathode follower which was placed inside one end of the counter shield. Both counter shields were pressurized to prevent corona. The output leads from the cathode followers as well as the high voltage cable from the counters were fed through a long pressurized duct to the rear compartment of the plane where all the electronic circuits and high voltage supplies were located. The rear compartments was located about 35 feet away from the counters.

Figure 1 shows the results of the flight from McArthur Field,

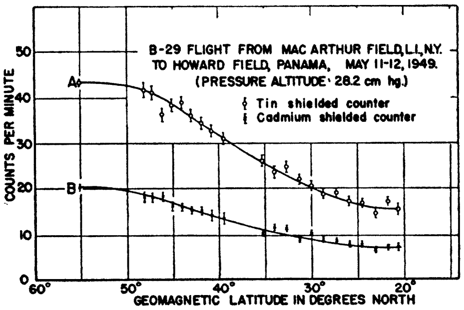

FIG. 1. Counts per minute as a function of geomagnetic latitude obtained at an altitude of 25,000 feet, with a tin-shielded counter (upper curve), and with a cadmium-shielded counter (lower curve).