2.29 ± 0.12 and 3.48 ± 0.12 Mev. These results are in complete agreement with the energy levels in N^{13} found by the $C^{12}(p,\gamma)$ reaction, which is a strong indication that there are no additional levels in N^{13} below 3.8 Mev.

It is of theoretical interest to compare these energy levels of N^{13} to those of the mirror nucleus C^{13}. The first three levels of C^{13} known at present are at 0.9 ± 0.2 Mev,[9–11] 3.098 ± 0.008 Mev[5], and 3.91 Mev.[12] The existence of the lowest level is not yet firmly established. However, it is evident that the energy levels of these mirror nuclei do not correspond, as would be expected for equal neutron-neutron and proton-proton forces.

The author is indebted to Professor W. W. Buechner and to Dr. John Blatt for their invaluable guidance, and to A. Sperduto for the measurement of the energy of elastically scattered protons.

* This work has been supported by the Joint Program of the ONR and the AEC.

[1] W. A. Fowler and C. C. Lauritsen, Phys. Rev. **76**, 314 (1949).
[2] W. F. Hornyak and T. Lauritsen, Rev. Mod. Phys. **20**, 191 (1948).
[3] W. E. Bennett and H. T. Richards, Phys. Rev. **71**, 565 (1947).
[4] R. E. Bell and L. G. Elliot, Phys. Rev. **74**, 1552 (1948).
[5] Buechner, Strait, Sperduto, and Malm (to be published shortly).
[6] Taschek, Argo, Hemmendinger, and Jarvis, Phys. Rev. **76**, 325 (1949).
[7] Hornyak, Dougherty, and Lauritsen, Phys. Rev. **74**, 1727 (1948).
[8] J. C. Grosskreutz, Phys. Rev. **76**, 482 (1949).
[9] R. R. Roy, Phys. Rev. **75**, 1775 (1949).
[10] O. Merhaut, Physik. Zeits. **41**, 528 (1940).
[11] W. Jentschke, Physik Zeits. **41**, 524 (1940).
[12] Heydenberg, Inglis, Whitehead, and Hafner, Phys. Rev. **75**, 1147 (1949).

On the Double Beta-Process

MARK G. INGHRAM AND JOHN H. REYNOLDS
University of Chicago and Argonne National Laboratory, Chicago, Illinois

August 31, 1949

A STUDY has been made of the isotopic constitution of xenon extracted from a pre-Cambrian tellurium ore, in order to determine the half-lives of the double beta-transitions $Te^{128} \rightarrow Xe^{128}$ and $Te^{130} \rightarrow Xe^{130}$. In this ore, measurable amounts of these two isotopes of xenon should have accumulated during geological time if the transitions take place at a rate comparable to that reported by Fireman[1] for the similar transition $Sn^{124} \rightarrow Te^{124}$. The importance of double beta-studies lies in the fact that the half-lives calculated from the Majorana theory of the neutrino[2] and the Dirac theory of the neutrino[3] differ by a large factor. Table I gives half-lives so calculated; the energies available for the transitions have been estimated from the decay schemes of the intermediate nuclei and from considerations of the nuclear energy surface[4] and are conservative.

TABLE I. Theoretical half-lives for allowed double beta-disintegrations.

Transition	$Te^{128} \rightarrow Xe^{128}$	$Te^{130} \rightarrow Xe^{130}$
Atomic mass difference in Mev	0.5	1.6
Majorana half-life in years	2×10^{16}	6.0×10^{14}
Dirac half-life in years	3×10^{27}	1.1×10^{24}

The ore used for this study was the mineral tellurobismuthite (Bi_2Te_3) in andalusite and sericite rock blasted from an outcrop in Mångfallberget, near Boliden, Sweden. This telluride deposit has been described in detail by Grip and Ödman.[5] A rough estimate by Dr. K. Rankama places the age of the original sulfide mineralization at 1500 ± 500 million years.

TABLE III. Measured minimum half-lives based on crystal age of 1.5×10^9 years.

Transition	$Te^{128} \rightarrow Xe^{128}$	$Te^{130} \rightarrow Xe^{130}$
Max. no. radiogenic xenon atoms per atom of Xe^{134}	0.07	0.014
Max. no. radiogenic xenon atoms in sample	3.0×10^{12}	5.0×10^{11}
No. of parent atoms in sample	3.8×10^{22}	4.2×10^{22}
Minimum half-life in years	1.3×10^{19}	8.0×10^{19}

The sample (430 grams containing 6 percent tellurium) was crushed in an iron mortar and transferred to a quartz bottle which was then evacuated and heated to well above the melting point of Bi_2Te_3. The gas evolved was collected and purified in an apparatus patterned closely after that of Epstein and co-workers[6] in their experiments with fission xenon. The final rare gas mixture was analyzed in a conventional 60° single-focusing mass spectrometer. By calibrating with artificially prepared mixtures of argon and xenon, it was possible to measure both the chemical composition and the isotopic constitution of the gas.

The mixture was found to consist of $1.3 \pm 0.3 \times 10^{-5}$ cc S.T.P. xenon plus $1.3 \pm 0.3 \times 10^{-2}$ cc S.T.P. argon. The results of the isotopic analysis are represented in Table II together with Nier's values[7] for normal xenon. All abundances are referred to mass 134. It will be noted that the only evidence for the presence of radiogenic xenon occurs at mass 130. For this minute sample of xenon, however, the accuracy of the measurements is such that the apparent excess xenon at this mass can only be viewed as intriguing (even though a measurement of normal xenon immediately thereafter checked Nier's value of 0.386 exactly). At masses 124, 126 and 128 the recorder peaks were so close to background level that only upper limits for these abundances can be given.

These data can be used, however, to place lower limits on the half-lives of the double beta-transitions. The results are presented in Table III. A corresponding calculation for the energetically questionable transition $Te^{126} \rightarrow Xe^{126}$ gives a minimum half-life of 6×10^{19} years.

On comparison with the half-lives presented in Table I, it appears that these results support the Dirac antineutrino theory. However, the values are subject to qualification on two counts. First, the possibility exists that radiogenic xenon may have escaped from the crystals of ore since the time of the original mineralization, either by simple diffusion or during later alteration of the mineral. Considering the retentivity of helium by various minerals,[8, 9] it appears that the former possibility is remote. A hydrothermal alteration of the telluride, on the other hand, would certainly result in loss of xenon, and this possibility cannot be dismissed for the present ore. If this has occurred, the accumulation of daughter xenon dates only from the time of alteration and the half-lives in Table III must be reduced in proportion. Secondly, the theoretical half-lives presented in Table I are essentially minimum values; favorable forms of the interaction terms have been assumed and the calculations have been made for completely allowed transitions. As a result, the Majorana half-lives may be longer in the particular transitions we have investigated, due, for example, to a possible difference in parity between the ground states of Te^{130} and Xe^{130}. That these two effects, acting in combination, could overpower the factor of 10^5 by which the measured minimum half-life exceeds the calculated Majorana half-life in the transition at mass 130 is improbable, but it must be admitted as a possibility.

TABLE II. Relative abundances of the xenon isotopes.

Mass	124	126	128	129	130	131	132	134	136
Present study	<0.015	<0.018	<0.25	2.47 ±0.03	0.394 ±0.004	2.00 ±0.02	2.55 ±0.02	1.000	0.847 ±0.008
Normal xenon*	0.0089	0.0083	0.180	2.49	0.386	2.009	2.558	1.000	0.849

* See reference 7.

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.

[1] E. L. Fireman, Phys. Rev. **75**, 323 (1949).
[2] W. H. Furry, Phys. Rev. **56**, 1184 (1939).
[3] M. G. Mayer, Phys. Rev. **48**, 512 (1935).
[4] E. Feenberg, Rev. Mod. Phys. **19**, 239 (1947).
[5] E. Grip and O. Ödman, Sveriges Geologiska Undersökning **36**, No. 4 (1942).
[6] S. Epstein, Proc. Conf. on Nuclear Chem., McMaster University, pp. 108–116 (May 1947).
[7] A. O. Nier, Phys. Rev. **52**, 933 (1937).
[8] P. M. Hurley and C. Goodman, Bull. Geol. Soc. Am. **54**, 305 (1943).
[9] N. B. Keevil, Proc. Am. Acad. **73**, 311 (1940).

On the Negative Proton*

Kuan-Han Sun
Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania
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.

$$_ZX^A = {}_{Z+1}Y^{A-1} + \beta^- + {}_0n^1 + Q_1, \quad (1)$$

$$_ZX^A = {}_{Z+1}Y^{A-1} + {}_{-1}H^1 - 2e + Q_2, \quad (2)$$

$$Q_2 = Q_1 + 1.826 \text{ in Mev.} \quad (3)$$

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.
[2] Knable, Lawrence, Leith, Moyer, and Thornton, Phys. Rev. **74**, 1217 (1948).
[3] Sun, Jennings, Shoupp, and Allen, Phys. Rev. **75**, 1302 (1949).
[4] Charpie, Sun, Jennings, and Nachaj, Phys. Rev. (to be published).
[5] L. W. Alvarez, Phys. Rev. **75**, 1127 (1949); E. Hayward, Phys. Rev. **75**, 917 (1949).
[6] L. W. Alvarez, private communication at Washington Meeting of the American Physical Society, 1949.
[7] J. McConnell and L. Janossy, Nature **159**, 335 (1947).

Erratum: The Chi-Square Test as a Criterion for Testing Halogen-Filled Geiger Tubes

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

A. B. Willoughby
Naval Radiological Defense Laboratory, San Francisco, California

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

L. I. Schiff and D. L. Weisman
Stanford University, Stanford, California
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

$$I = \int_0^\infty P^4 dP/(P^2 + M^2c^2)^{\frac{3}{2}}, \quad (1)$$

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

$$I = 3\pi m^2 c^2, \quad (2)$$

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 per-