[14]V. Alles-Borelli *et al.*, Nuovo Cimento 7A, 331 (1972).

[15]The cross sections probed by elastic scattering are at least 1 order of magnitude smaller than the corresponding inelastic cross sections in the region of our measurement.

Baryon-Conservation Limit*

F. Reines
Department of Physics, University of California, Irvine, California 92664

and

M. F. Crouch
Department of Physics, Case Western Reserve University, Cleveland, Ohio 44106
(Received 17 January 1974)

An improved lower limit of $>2\times10^{30}$ yr against baryon-conservation-violating nucleon decay has been obtained for modes which produce $\mu\to e$ decays. The detector, employing a 20-ton large-area (180 m^2) liquid scintillator, was operated deep underground (3.2 km) to eliminate stopping muons from cosmic rays, leaving only the background from muons produced by atmospheric neutrinos. A run length of 2.7 yr was required to achieve the sensitivity quoted.

In view of recent interest in the possibility that baryon conservation may not be an absolute principle,[1] we present improved limits obtained incidental to the now completed Case Western Reserve University–University of Witwatersrand–University of California at Irvine deep-underground neutrino program.[2] The best published limit for nucleon stability is $>2\times10^{28}$ to $>8\times10^{29}$ yr,[3] depending on the decay mode assumed. In order to discriminate against penetrating muons from cosmic rays, Gurr *et al.*[3] based their results on those particles which passed through their scintillation hodoscope at zenith angles ranging from 45 to 90°. In the present paper the distinctive delayed coincidence produced by a muon stopping and decaying in the scintillator is used to set a new limit on baryon conservation as revealed by the conservation of nucleons. Five such events were seen during the course of the experiment.[4] The observed number can be accounted for[2] by neutrino-produced muons originating in the rock surrounding the detector, or in the detector itself, and then decaying in the scintillator. Muons produced in the atmosphere, and penetrating the 3.2 km of earth from the surface, are both rare and energetic and so give rise to $<\frac{1}{10}$ the observed decay rate. Although it is not possible to rule out nucleon decay completely as a source of muons which in turn decayed in our detectors,[5] it seems prudent to interpret the signal so as to yield a lower limit on nucleon lifetime.

The following table lists the run times, detector masses, nucleon content, and number of decay events for the two experiments involved:

Expt.	Detector mass (metric tons CH_2)	Number of nucleons	Run length (yr)	Muon decays observed
1	19	1.1×10^{31}	1.7	4
2	21	1.2×10^{31}	0.9	1

In order to interpret the data of the table in terms of nucleon stability, we consider decay modes in which one particle, a muon, is produced either directly or by the decay of a pion. Since our detectors were not thick (~20 MeV) compared with the muon range (~200 MeV), the effective number of nucleons under observation is approximately given by the stopping power per gram of the scintillator (CH_2) relative to that of the surrounding rock (SiO_2) times the number of nucleons in the scintillator. The π or μ range in the scintillator is ~20% shorter than in the surrounding rock[3] so it is conservative to take the effective number of nucleons to be equal to the number of nucleons in the scintillator.

It remains to estimate the detection efficiency for the muon-decay electron. The detector consisted of 54 elements (Expt. 1) or 60 elements (Expt. 2), each measuring $12.7\times55\times500$ cm^3 and containing liquid scintillator ($\rho=0.87$ g/cm^3). Since the electron detection threshold was 10 MeV and the slab ~20 MeV thick, the geometrical efficiency for electrons >10 MeV depositing at least 10 MeV in a detector element was ~0.8. The 10-MeV threshold resulted in ~30% loss of decay electrons and the finite oscilloscope display time further reduced the detection efficiency by ~40%. Combining these factors yields an overall decay-electron detector efficiency

$$\eta = 0.8\times 0.7\times 0.6 = 0.34.$$

The limit on the nucleon decay rate τ_N is obtained from

$$\tau_N = \frac{N}{dN/dt} = \frac{1.1\times 10^{31}\times 0.34}{5/2.6} = 1.9\times 10^{30}\ \mathrm{yr}.$$

The number of decays seen is not inconsistent with that expected from ν-produced muons, so that it is reasonable to state the limit for decay modes which result in muons as

$$\tau > 2\times 10^{30}\ \mathrm{yr}.$$

It is useful in planning an improved experiment to contemplate the rate associated with the present equipment,

$$R = \frac{5}{20\times 2.6\times 0.34} = 0.3/\mathrm{ton\ yr}.$$

The overall detector efficiency can be raised to ~100%, and any case of $\pi\to\mu$ decay observed as well, by employing a detector of linear dimensions larger than the range of the charged nucleon decay products sought. Such a detector with 100 tons of scintillator would enable an order-of-magnitude increase in sensitivity to nucleon decay. Further it should be possible from the total energy associated with the first pulse (or pulses) of the delayed coincidence to discriminate to some extent against the neutrino-produced muons and in favor of the lower-energy muons expected from nucleon decay.

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[1]J. C. Pati and A. Salam, Phys. Rev. Lett. 31, 661 (1973), and International Centre for Theoretical Physics Report No. IC/73/85, 1973 (unpublished).

[2]F. Reines, W. R. Kropp, H. W. Sobel, H. S. Gurr, J. Lathrop, M. F. Crouch, J. P. F. Sellschop, and B. S. Meyer, Phys. Rev. D 4, 80 (1971), and to be published.

[3]H. S. Gurr, W. R. Kropp, F. Reines, and B. S. Meyer, Phys. Rev. 158, 1321 (1967).

[4]Four of these events are listed in the published paper of Ref. 2 under the category "type 5"; the fifth was recorded in the as yet unpublished paper of that reference.

[5]Since ν_μ reactions produce muons directly and the Pati-Salam scheme suggests some baryon decay modes with a pion product, a detector with time resolution $\lesssim 10^{-8}$ sec could see $\pi\to\mu$ decay and so distinguish ν_μ reactions from nucleon decay.

Electron's Anomalous Moment and Its Spin-Precession Frequency Shift

S. B. Lai, P. L. Knight, and J. H. Eberly
Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627
(Received 26 December 1973)

We derive the anomalous moment of the electron from the quantum-electrodynamic equations of motion for the electron spin precession.

The anomalous moment of the electron[1] occupies a special place in quantum electrodynamics. Unlike the Lamb shift, it is a property of the free electron interacting only with the electromagnetic field and uncomplicated by problems of binding. Despite this, and despite the excellent agreement between the theoretical predictions and experimental determinations of the moment anomaly, it is widely remarked[2] that the usual methods of perturbative calculation do not provide clear physical insights into the origin of the anomaly or allow an intuitive understanding of even the sign of the lowest-order correction to the moment.

Existing quantitative treatments[1,3] of the moment anomaly are almost universally based on a point of view which has elementary electron-photon scattering events at the root of the effect. As an alternative, it is possible to construct a qualitative and intuitive treatment by considering the