Conservation of the Number of Nucleons*

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THE conservation of the number of nucleons in the sense that they do not decay spontaneously nor are destroyed or created singly in nuclear collisions is generally assumed. The validity of this conservation law was tested experimentally in 1954 with the conclusion[1] that a bound nucleon has a mean lifetime $>10^{22}$ years. We report here an improvement on this number which is made possible by the use of a delayed-coincidence technique in conjunction with a giant liquid scintillation detector array placed about 200 ft underground at Los Alamos.

The experimental arrangement is sketched in Fig. 1 and shows the target material between the large-slab liquid scintillation detectors.[2] This array is shielded against local radioactivity by blocks made of boron and paraffin. The electronics are adjusted to select a delayed coincidence which had a first pulse of energy $\geqslant 5$ Mev occurring in the top and/or bottom tank. If the pulse was followed in 20 microseconds by a second one which registered between 1.5 and 6 Mev in each tank with the sum restricted to $3\leqslant E\leqslant 10$ Mev, a delayed coincidence was registered, a two-beam oscilloscope sweep was triggered, and a film recording of the event was made. Rates were recorded in the first and second pulse gates so as to allow the calculation of accidental coincidences. The system was energy-calibrated by using cosmic ray μ mesons which traversed the scintillator.

The experiment consisted in measuring as a function of target material the delayed coincidence rate determined from an analysis of the film records. The use of film recording enabled the rejection of electrical noise and an arbitrary selection of the time interval (10 μsec) between the events we chose to consider. The delayed coincidence was supposed to arise from a pair of pulses, the first of which came from the decay of a charged nucleon, the second from the capture of a neutron emitted by the residual nucleus. An uncharged nucleon might conceivably also give rise to charged products or

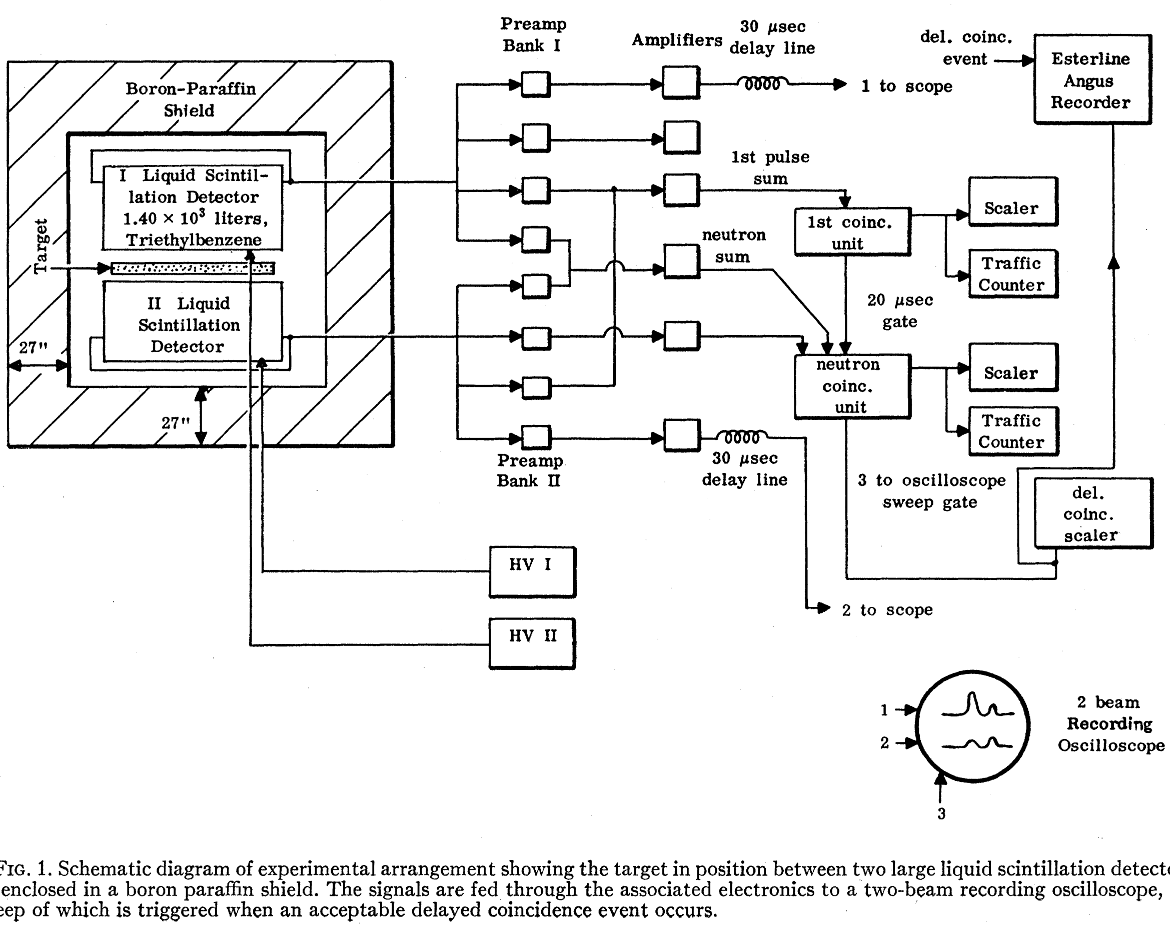

Fig. 1. Schematic diagram of experimental arrangement showing the target in position between two large liquid scintillation detectors, all enclosed in a boron paraffin shield. The signals are fed through the associated electronics to a two-beam recording oscilloscope, the sweep of which is triggered when an acceptable delayed coincidence event occurs.

TABLE I. Summary of experimental data, containing information on "target" nuclei, run lengths, and count rates.

Target	Number of atoms H	D	O	Cd	Cl	Run length (hr)	Counts	Rate (hr^{-1})	Calculated acc. bkgd. (hr^{-1})
1	4.0×10^{27}	3.6×10^{27}	3.8×10^{27}	1.5×10^{26}	3.1×10^{26}	112.2	313	2.79 ± 0.16	0.23
2	1.1×10^{28}	...	5.5×10^{27}	...	...	72.0	173	2.40 ± 0.18	0.24

detectable gamma rays but we do not consider this possibility further here. Two experiments, one with an H_2O target and one with a target containing Cd to capture and detect the neutron by means of its capture gamma rays, were performed to enable a measurement to be made of the postulated neutron-associated delayed coincidences. The targets chosen were 165 kg of H_2O and 168 kg of a mixture of H_2O, D_2O, and $CdCl_2$. Table I shows the pertinent data from these two experiments. The neutron detection efficiency for the system with Cd is about 0.3 and charged particles emanating from the target should be seen with an efficiency approaching 100% since edge effects are small. Without Cd the neutron efficiency is effectively zero.

From the table it is seen that the net neutron-associated rate $=0.39\pm0.24\ hr^{-1}$ ($<0.63\ hr^{-1}$). Although a partial cosmic-ray anticoincidence blanket in the form of liquid scintillation detectors was placed above the detectors it was not possible to rule out nucleon modes of decay which would not trigger the anticoincidence. The observed rate is not inconsistent with that expected from cosmic rays at the detector location. It seems quite conservative to assume that at most one-half of the events are due to nucleon decay. We interpret the data by assuming that less than half the neutron-associated rate (i.e., $<0.32\ hr^{-1}$) is due to the reaction

$$D\rightarrow n+\text{decay products},$$

where the choice of decay products is limited by the laws of conservation of electrical charge and mass-energy-momentum. The nucleon lifetime based on this reaction is in excess of 4×10^{23} yr.

In view of the enormously great lifetimes under discussion, pions are assumed to be excluded as decay products by virtue of their strong interaction with nucleons, an assumption which precludes consideration in these estimates of the other nuclei comprising the target. This follows because the assumption makes improbable an interaction between the residual nucleus and the decay products and the consequent emission of a neutron which could give rise to a delayed coincidence. An estimate of the nuclear excitation produced by the sudden, noninteracting removal of a nucleon based on considerations of nuclear compressibility indicates that only a fraction of a Mev is available. This conclusion also rules against the possibility of neutron emission due to nucleon decay of the other nuclei which make up the target.

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[1] Reines, Cowan, and Goldhaber, Phys. Rev. **96**, 1157 (1954).
[2] These detectors designed for the free-neutrino studies are pictured in an article by F. Reines and C. L. Cowan, Phys. Today **10**, No. 8, 12 (1957).

Relations between the Hyperon Polarizations in Associated Production*

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In view of the recent discovery of a large up-down asymmetry in $\Lambda^0\rightarrow p+\pi^-$,[1] we report in this note on some results on the polarizations of the produced hyperons, which will be useful in the interpretation of the experiments. We first show that in the decay $\Sigma^0\rightarrow\Lambda^0+\gamma$ from a polarized Σ^0 the Λ^0 is longitudinally polarized in the Σ^0 rest frame, and the value of its polarization is the same, except for having opposite sign, as the component of the Σ^0 polarization along the Λ^0 line of flight. It is assumed that both Λ^0 and Σ^0 have spin $\frac{1}{2}$, but the result is independent of their relative parity. Denoting by $\mathbf{u}$ the unit vector along the direction of emission of the Λ^0 in the Σ^0 rest frame, and by $\langle\boldsymbol{\sigma}\rangle_\Sigma$ and $\langle\boldsymbol{\sigma}\rangle_\Lambda$ the polarizations of the Σ^0 and of the Λ^0, one finds, after summing over the photon polarizations,

$$\langle\boldsymbol{\sigma}\rangle_\Lambda=-(\langle\boldsymbol{\sigma}\rangle_\Sigma\cdot\mathbf{u})\mathbf{u}. \quad (1)$$

The angular distribution of the pion emitted in the subsequent Λ^0 decay is given by

$$W(\mathbf{v})=1+\alpha(\langle\boldsymbol{\sigma}\rangle_\Lambda\cdot\mathbf{v})=1-\alpha P_\Sigma(\mathbf{n}\cdot\mathbf{u})(\mathbf{u}\cdot\mathbf{v}), \quad (2)$$

where $\mathbf{v}$ is the unit vector along the direction of emission of the π^- from Λ^0 decay in the Λ^0 rest frame, α is the asymmetry parameter for $\Lambda^0\rightarrow p+\pi^-$, and we have written $\langle\boldsymbol{\sigma}\rangle_\Sigma=P_\Sigma\mathbf{n}$, where, in a two-body production process, such as $\pi^-+p\rightarrow\Sigma^0+K^0$, $\mathbf{n}$ is a unit vector normal to the production plane. If α is known,[2] from