Neutron physics

Half life defies measurement

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THE β-decay of a free neutron into a proton, electron and neutrino[1] is an extremely rare event compared with other subnuclear reactions. The first measurement[2] of the neutron lifetime, a parameter of wide theoretical significance, gave the quite precise value $\tau = 1{,}013 \pm 26$ s. Subsequent experiments (Fig. 1) failed to sustain confidence in this result, revealing discrepancies and uncertainties in the data which have been scrutinized theoretically[3] and experimentally[4]. Thus a new redetermination of τ_n reported by J. Last *et al.* from the Institut Laue-Langevin at Grenoble[5], which proposes the value $\tau_n = 876 \pm 21$ s, arouses great interest, not only because it seems to confirm the consistent decline over many years in the measured values of τ_n, but also because it lays claim to no significant improvement in accuracy compared with its immediate predecessors. Although it can hardly be contemplated that the longevity of neutrons is less today than in former times, it is evident that τ_n has been seriously overestimated in the past, and it is interesting to enquire why this is so, and whether the latest measurement is any more reliable.

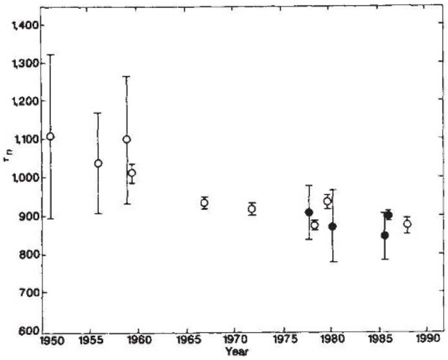

Fig. 1 The decrease in measured values of neutron lifetime τ_n. Open circles, estimates based on the flux of decay particles from neutron decays in neutron beams. Closed circles, estimates based on number of surviving neutrons in magnetic or material bottles.

The neutron lifetime is of crucial importance for theories of the nuclear weak interaction, astrophysics and cosmology. In the context of weak interactions, precise measurements of the weak polar-vector (g_V) and axial-vector (g_A) coupling constants that govern nuclear β-decay can be made only by the study of free-neutron β-decay, which is independent of nuclear structure. Furthermore, because an independent value of g_V can be derived from the measured rate of superallowed pure Fermi β-transitions in which nuclear-structure effects are minimal and calculable, the possibility exists for a fundamental cross-checking of current theory[6]. The basic proton–proton cycle of energy generation in the Sun proceeds at a rate which is proportional to g_A^2 with obvious implications for the solar-neutrino problem[7]. In cosmology, τ_n is closely related to the rate at which helium is formed in the early Universe, and is important in the determination of the number of distinct types of light neutrino[8].

To illustrate the imprecision of our knowledge of the neutron lifetime, we may compare the existing accuracy of about 2.5 per cent with the corresponding figures of 1.8×10^{-3}, 0.09 and 0.8 per cent for the muon, pion and the lambda particles respectively. Like the lambda, the neutron is one of seven baryons closely related to the proton whose decay parameters are all connected by Cabibbo's theory of weak interactions[9], but whose lifetimes, excluding τ_n, are about 10^{-10} s. The fact that the neutron lives 10^{13} times longer than any of its partners (except the stable proton) is solely a reflection of the near identity of the neutron and proton masses.

The truth is that β-decay is a very rare event in the career of a neutron, and it is precisely because of this that τ_n is extraordinarily difficult to measure with any accuracy. No more than one neutron will decay per second per centimetre cubed in the neutron flux from a typical reactor, and unless elaborate precautions are taken, the demise of this one unlucky neutron is very difficult to detect against the intense radiation background generated when the surviving neutrons are captured locally in strong nuclear reactions. As a result it is very easy to lose sight of genuine neutron decays in the confusion of spurious background events, with the consequence that τ_n is overestimated.

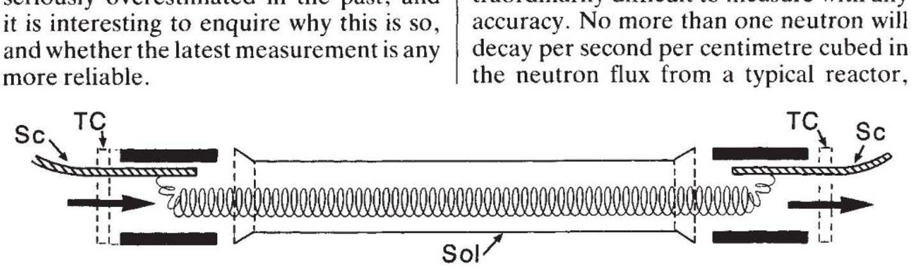

Fig. 2 Schematic of the experiment of J. Last *et al.*[5]. A pulsed beam of cold neutrons (arrows) passes through the superconducting solenoid (Sol). Electrons emitted in β-decays follow helical paths around the magnetic field lines to the scintillators (Sc) where they are detected. The shaped field tapers towards the scintillators to prevent the magnetic-mirror effect which would trap electrons. Timing information can identify events in which an electron is back-scattered from one scintillator to be detected a second time by the other, and the event is counted just once at the first detection. TC, magnetic trim coil.

Two quite different methods have been used in the past to determine τ_n (ref. 4). The first makes use of ultracold neutrons of energy less than 10^{-7} eV stored in magnetic or material bottles, and τ_n is determined by recording the number $N_n(t)$ of neutrons surviving to time t, and applying the exponential law of radioactive decay $N_n(t) = N_n(0) \exp (t/\tau_n)$. The second method, which is used in the new measurement by Last *et al.*[5], relies on the differential form of the decay law $dN_n(t)/dt = -N_n(t)/\tau_n$. In the new experiment, $-dN_n/dt$ is determined by counting electrons of energy in the range 0–0.78 MeV created by neutron decays within a 2.1-m length of beam containing N_n neutrons. These electrons are confined to move in helical paths of less than 0.5 cm orbit radius by a 1.6-tesla longitudinal magnetic field, so shaped that electrons are channelled into one of a pair of plastic scintillators located at each end of, but outside, the neutron beam (Fig. 2). This system provides a counter for all the decay events that occur within the specified active volume.

The use of a pulsed rather than a continuous neutron beam is a novel feature of this experiment. This technique eliminates the spread of neutron velocities from the equation, because all the neutrons in the pulse are contained within a 1.5-m length of beam and the number N_n of neutrons in this active volume is determined by absorbing the whole pulse in thick ^{59}Co or ^{197}Au targets. The resultant

100 years ago

THE following incident is from the trial of the great patent case, Edison and Swan Electric Light Company *v.* Holland and others, now proceeding in the High Court of Justice. On May 16, Prof. James Dewar was under examination. A small crucible was produced and handed to the witness, who said: In the crucible I have, with Mr. Gimingham, carbonized filaments in the precincts of the court, using no packing and no luting of any description. Sir Horace Davey urged that this did not arise out of the cross-examination. Mr. Justice Kay said it should have been produced in the examination-in-chief.

Mr. Justice Kay: I am very much disgusted. I am here trying all I can to understand the case, and this is clearly an attempt to mislead. I am greatly disgusted.

Prof. Dewar: I have no desire to mislead your lordship. I have stated that this was a mere experiment. I did not produce it. It was put to me.

Mr. Justice Kay: You may stand down.

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