THE HALF-LIFE OF THE FREE NEUTRON

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A measurement of the half-life of the free neutron yields $T_{\frac{1}{2}} = 10.80 \pm 0.16$ min.

The neutron half-life has been remeasured at the DR-3 reactor at the Risø Laboratory. Two flat plastic scintillators were positioned on opposite sides of an essentially γ-free well-collimated thermal neutron beam [1], perpendicular to a homogeneous magnetic field passing through the scintillators and beam (fig. 1). As electrons are constrained to follow helical paths along the field lines, neutron-decay β particles originating in the volume defined by the field and scintillators must strike one or the other of the two scintillator plates. This geometry therefore constitutes a 4π β spectrometer with an accurately defined neutron source volume. The total number of neutrons in the sensitive volume is obtained through measurement of the neutron density. The neutron half-life is calculated from the β-decay

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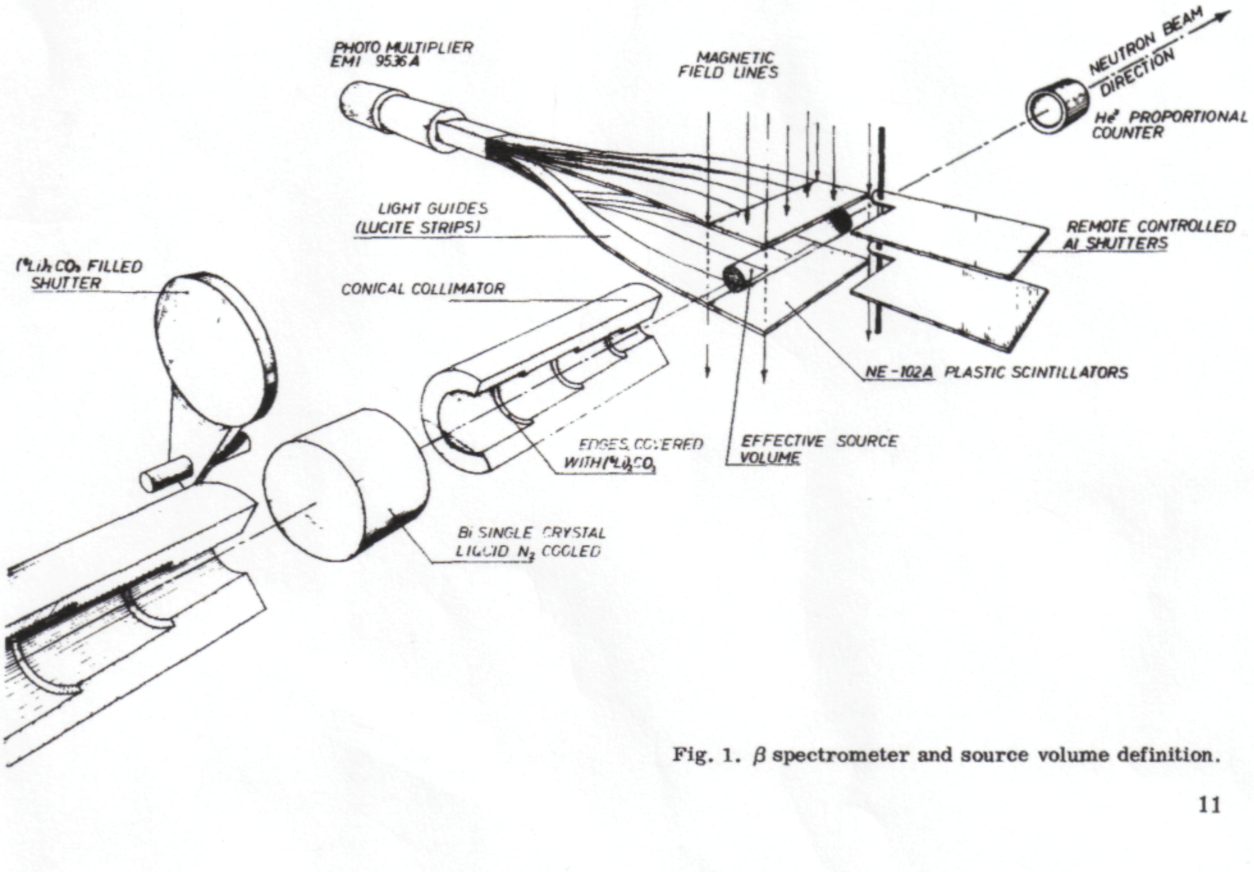
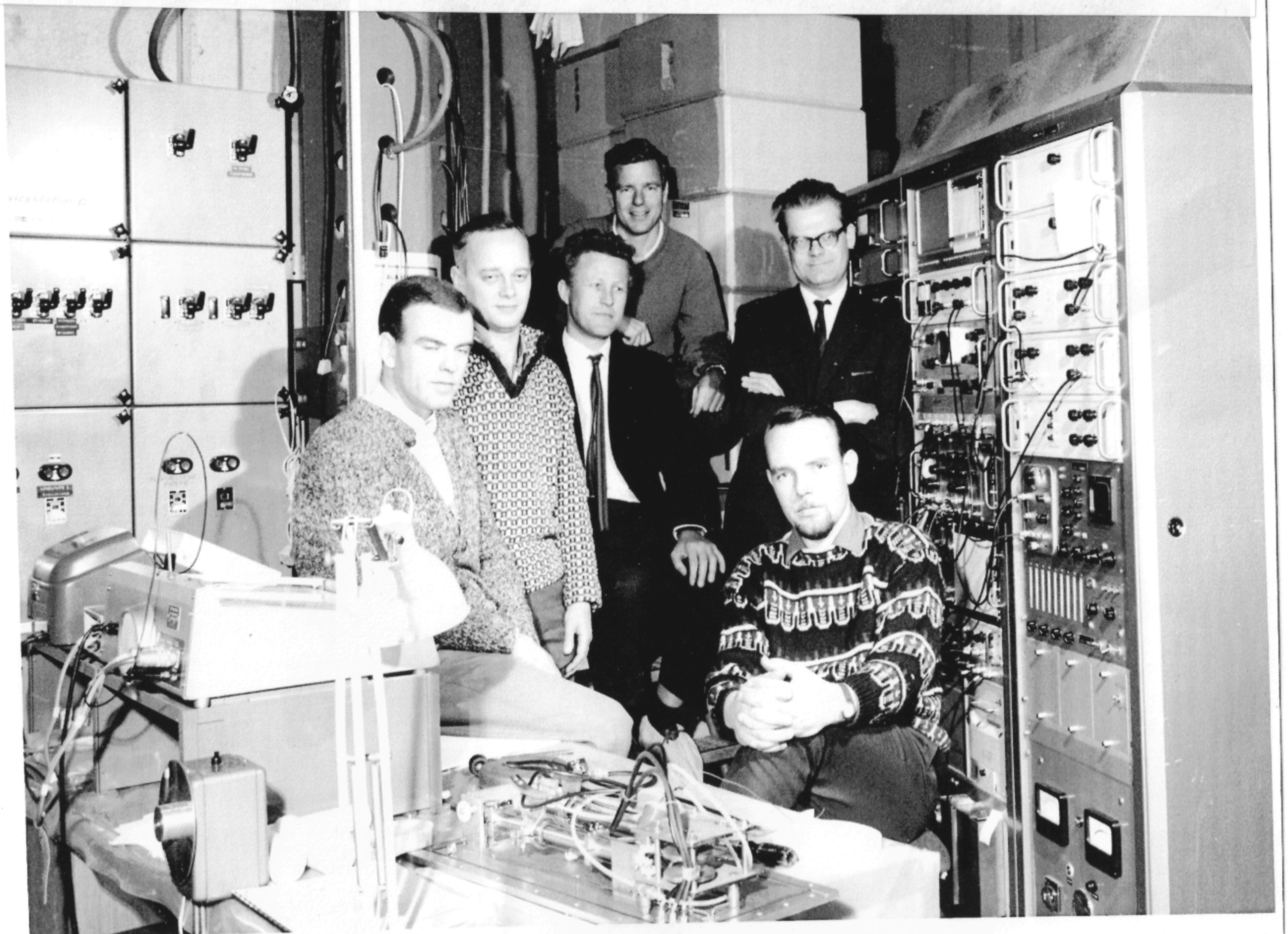


Fig. 1. β spectrometer and source volume definition.



Joergen Stroemstad Poul Andersen Arne Nielsen Bill Carl-Joergen Finn Hansen rate given by the integral of the measured β-decay spectrum.

The count rate, C, of neutron decay β particles is related to the neutron half-life $T_{\frac{1}{2}}$ by

$$C = \epsilon \Omega L n_z \ln 2 / T_{\frac{1}{2}} \qquad (1)$$

where ϵ is the detection efficiency of the scintillators (NE-102), Ω is the fractional solid angle (here = 1), L is the scintillator length in the beam direction and n_z is the linear neutron density (volume density integrated over the beam area). It is measured by a ^{3}He proportional counter accepting the whole beam [2].

The length L is the physical length (10 cm) plus a small correction to account for β particles detected at the 3 mm thick ends of the scintillator plates. A calculation checked by measurement with a small, movable, gold foil β source yielded L = 10.25 cm ± 0.5%. The scintillators were made sufficiently wide to prevent β particles of the highest energy (E_{max} = 782 keV) from escaping around the side edges. Light passes through one edge of each scintillator through lucite strips to one magnetically shielded photomultiplier (EMI 9536A). Pulses are registered by a 256-channel analyzer and a discriminator-scaler system.

The system is calibrated with conversion electron sources. As the geometry eliminates the backscattering problem, the pulse height distribution is Poissonian. In this spectrometer the f.w.h.m. is 20%-25% at 1 MeV and proportional to $E^{-\frac{1}{2}}$. The observed β spectrum is fitted with a spectrum derived by folding the resolution function with the theoretical spectrum. The detector efficiency is determined from this theoretical spectrum as a function of E. As the spectrum is inevitably affected by background at lower energies, an energy must be chosen above which the fit is in good agreement. The integral of the observed spectrum from this energy up yields C, which is used in eq. (1) with the corresponding ϵ. We have chosen this lower limit to be 0.4 mc^2 (204.4 keV). This crucial procedure was checked by measuring the absolute source strength of thin ^{198}Au sources. These sources were also measured in a $4\pi\beta$-γ coincidence set-up, and comparison showed agreement to ± 1%. The deviation is statistical and presumably caused by the inaccuracy of the calibration procedure. A gold source measured by the National Bureau of Standards in Washington D.C., with 2% accuracy differed by 1.5% from our measurements (ours being high). This corresponds to a 10 keV error in the calibration. Fig. 2 shows the β spectra of ^{198}Au and of neutron decay.

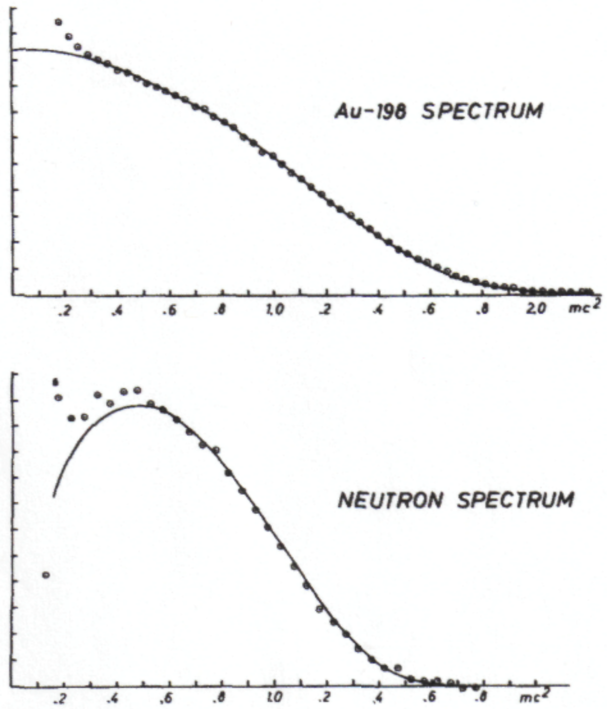


Fig. 2. β spectra of ^{198}Au and neutron decay. Points are experimental and solid curves are calculated predictions of experimental spectra.

To determine C, background must also be taken into account. The neutron-decay rate in the spectrometer is approximately 5 s^{-1} and is typically accompanied by 5 counts s^{-1} room background. This background can be subtracted through a beam-off measurement using a thin ^{6}Li carbonate plate as shutter. The approximately 0.5 counts s^{-1} beam background from fast neutrons and γ rays represents no problem because the counts are essentially unaffected by the shutter and are subtracted together with the room background.

The most serious background contribution is from capture γ rays in the collimating system (~ 0.2 counts s^{-1}). The ^{6}Li shutter is placed far back in the beam and thus shuts off the capture γ rays along with the decays. To take care of this problem a pair of aluminium plates between the beam and detectors can shut off the neutron decays without affecting the capture γ rays. It is estimated that a beam-on, beam-off experiment measured this capture γ-ray contribution to better than 30%.

To avoid capture γ-ray background from the ^{3}He counter windows, this counter was inserted into the beam only at intervals and removed while accumulating β-spectrum data. In order to compensate for possible background variation, the density and various decay and background measurements were made in a cyclic pattern. Also included in the cycle was a ^{207}Bi source to check gain stability. Statistical treatment of the spectra showed that this sampling procedure is effective and that the fluctuations do indeed cancel out.

The following half-lives and estimated uncertainties were obtained from 5 separate measurements:

Run	1	2	3	4	5
Half-life (min)	10.5	11.0	11.4	10.8	10.9
Neutron decay count rate (%)	± 0.9	± 1.4	± 3	± 1	± 1
Neutron density (%)	± 0.5	± 1.0	± 1	± 1	± 1
Decay counter efficiency (%)	± 1	± 1	± 1	± 1	± 1
Total statistical (%)	± 1.4	± 2	± 3.5	± 1.6	± 1.6

The weighted average mean half-life is 10.78 min with a standard deviation of 0.8%.

A χ^2 test on the 5 runs gives $\chi^2 = 7.8$ and $P = 0.1$ which shows a reasonable reproducibility.

The following possible systematic errors on the half-life must be taken into account:

scintillator length	± 0.5%,
neutron density	± 0.5%,
capture γ-ray corrections	0% to -1.5%,
decay counter efficiency	0% to +1.5%.

If all of these errors are treated as standard deviations for independent statistics variables, we may add the errors and in this way obtain $\sqrt{(0.8^2+0.5^2+0.5^2+0.75^2)}\% = 1.5\%$. The final result is thus 10.80 ± 0.16 min.

This value is not consistent with the result of Sosnovsky et al. [3] of 11.7 ± 0.3 min.

It is interesting to compare the g_A/g_V as determined from our experiment with other available numbers:

present work + $ft(^{14}O)$	-1.23±0.01,
Sosnovsky et al. [3] + $ft(^{14}O)$	-1.18±0.02,
electron-neutrino correlation; neutron decay [4]	-1.33±0.15,
electron asymmetry in decay of polarized neutrons [5,6]	-1.25±0.05,
mirror nuclei + $0^+ \rightarrow 0^+$ [7]	-1.11±0.03.

Apart from the disagreement between the two half-life results, the mirror transition determination seems to be definitely in error.

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