Measurement of the neutron half-life

L. N. Bondarenko, V. V. Kurguzov, Yu. A. Prokof'ev,
E. V. Rogov, and P. E. Spivak

I. V. Kurchatov Institute of Atomic Energy

(Submitted 28 July 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **28**, No, 5 328–333 (5 September 1978)

A neutron beam from the IRTM reactor was used to measure the neutron half-life by the proton registration method. The value obtained was $T_{1/2} = 10.13 \pm 0.9$ min. The calculated ratio is $G_A'/G_V' = 1.279 \pm 0.006$.

PACS numbers: 13.30.Ce, 14.20.Cg

The presently known most accurate value of the neutron half-life, $T_{1/2} = 10.61 \pm 0.16$, was obtained in Ref. 1. In that reference, using a detector in a geometry close to 4π, they registered the electrons produced in the neutron decay. Another method of determining the neutron half-life, based on the measurement of the proton counting rate, was used in an earlier study.[2] It is now obvious to us that the overestimate $T_{1/2} = 11.7 \pm 0.3$ min obtained in that paper was due to the fact that the residual pressure in the apparatus, along the path of the protons between the bounding diaphragms, was 10–20 times higher than that measured by the authors near the vacuum pump. The large charge-exchange cross section ($\sim 2 \times 10^{-15}$ cm^2) should have led to neutralization of about 10% of the decay protons.

For all that, in our opinion, the method used in Ref. 2 can eliminate considerable difficulties faced by a correct determination of the effectiveness and magnitude of the background components, which are capable of introducing errors in the results.

We present in this communication the main results of measurements of the neutron half-life by the indicated method.

Figure 1 shows the schematic diagram of the setup. The stainless steel chamber was outgassed and evacuated by oil-free pumps. The residual-gas pressure measured at the region of passage of the protons between the diaphragms D_1 and D_2 did not exceed $(2\text{–}3) \times 10^{-8}$ Torr. The decay protons, after passing through the diaphragm D_2, were accelerated to 25 keV and focused on the detector window.

The decay constant λ is connected with the measured proton counting rate by the equation

$$N_p C \equiv f_p = \lambda \iint q(\mathbf{r})\, d\Omega\, dV \;\ldots, \tag{1}$$

where f_p is the proton flux incident on the diaphragm D_2 and $q(\mathbf{r})$ are the absolute values of the neutron-beam density.

This equality can be represented in the form

$$f_p = \lambda\, Q_S\, \epsilon, \tag{2}$$

where Q_S is the absolute value of the integral density of the neutrons over the beam cross section, and $\epsilon = \int\int \rho(\mathbf{r}) dV d\Omega / \int \rho(\mathbf{r}) dS$ and $\rho(\mathbf{r})$ is the distribution of the neutrons over the beam cross section.

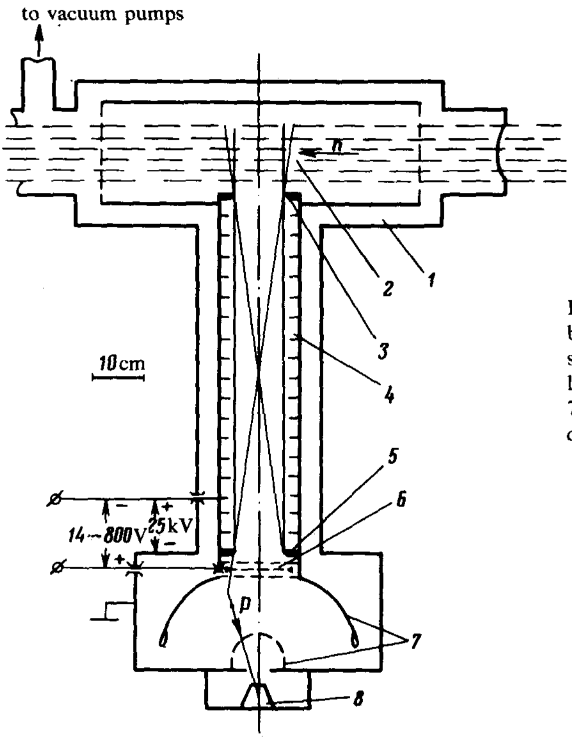

FIG. 1. 1—Vacuum chamber; 2—neutron beam; 3—limiting diaphragm D_1; 4—screen that bounds the field-free space; 5—limiting diaphragm D_2; 6—retarding grid; 7—focusing electrodes; 8—proton detector.

The measurement of the proton counting rate N_p was made with a proportional drift counter filled with CH_4 to a pressure 8 mm. The counter window, of 17 mm diameter, was covered with an organic film of thickness 20 $\mu g/cm^2$. Control measurements of the distribution of the proton intensity over the counter window have shown that 90% of the intensity is concentrated in a diameter of 10 mm with a decrease to a 0.15% level at diameter of 13 mm.

The measurement procedure consisted of alternating measurement of the background at a potential 800 V on the grid 6 (Fig. 1) and of the combined effect and background at a potential 14 V on the same grid. The potential 800 V applied to the grid 6 blocks all the protons and changes neither the fundamental background component due to the fast neutrons nor the intensity or spectrum of the electrons, which were detected with a counter in the first channels of the analyzer. Figure 2 shows the measurement results. The extrapolated value of the proton counting rate turned out to be 0.848 sec^{-1} with an error $\pm 0.23\%$. Several corrections were introduced in this quantity: one of them takes into account the backscattering of the protons incident on the counter-window film (control measurements with an H_1^+ source have shown that this correction amounts to $0.25 \pm 0.15\%$); the other correction takes into account the results of control experiments with a neutron beam blocked with a Cd shutter (a certain excess was observed in the counting rate, amounting to $(0.27 \pm 0.2)\%$ of the expected intensity corresponding to the measured density of the neturons behind the Cd).

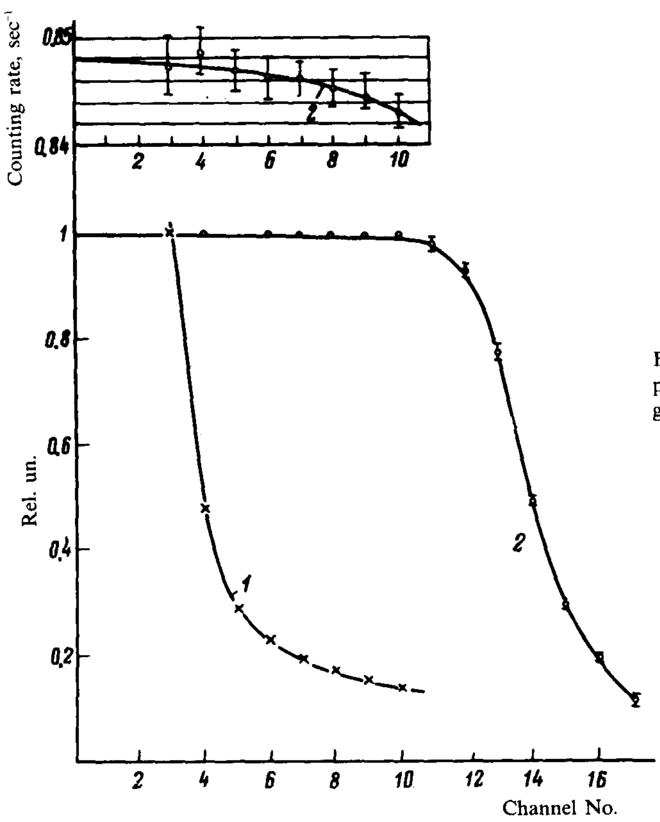

FIG. 2. Integral spectrum of pulse amplitudes: 1—background; 2—decay protons.

The coefficient C, which connects the proton flux f_p with the measured counting rate N_p of the protons, takes into account the loss of part of the protons (0.36%) with energy less than 14 eV, and the absorption of the protons in the grids, the transparency of which, measured by a shadow method with the aid of an α-particle source, turned out to be 0.8716 ± 0.0025.

The integral neutron density Q_S was measured by the method of activation of thin gold foils ($\sim$ 14 mg/cm^2) that overlapped fully the neutron beam. It is known that this method is presently the most exact one and is used to calibrate other neutron-density indicators, whose efficiencies and target-atom numbers are quite difficult to measure.

Control experiments have shown that the methodological errors that arise when account is taken of the past-the-cadmium effect and of the correction for the deviation of the cross section from the $1/v$ law did not exceed $\pm 0.5\%$. The absolute activities of the irradiated foils were measured with a calibrated $\beta\gamma$ coincidence setup. The measurement error, $\pm 0.3\%$, was close to the error of reference measurements of the activity of a thin gold layer by the $4\pi\beta\gamma$ coincidence method. The value of ϵ was calculated with a computer by the Monte Carlo method on the basis of the measured distribution of the density of the neutrons and of the geometric parameters of the installation. The error ϵ incorporates the calculation error itself, the errors in the knowledge of the coordinates of the beam elements relative to the limiting diaphragms,

TABLE I.

f_p, sec^{-1}	0,976 ±0,004
Q_S, 10^5 cm^{-1}	1,0025 ±0,0065
ϵ, 10^{-3}cm	8,538 ±0,0024

and the error in the measurement of the diameters of the diaphragms and of the distances between them.

Subtitution of the values listed in Table I in the equation $T_{1/2} = \ln 2/(f_p 60 Q_S \epsilon)$ yields a neutron half-life $T_{1/2} = 10.13 \pm 0.09$ min.

TABLE II.

Method	λ	Reference	Year
Ft of neutron and of $0^+ \to 0^+$ transition	1,279 ±0,006	Present work	1978
	1,244 ±0,011	[1]	1972
Electron-spin correlation	1,258 ±0,015	[6]	1975
	1,261 ±0,012	[7]	1977
Electron-neutrino correlation	1,250 ± 0,036	[8]	1975

Table II gives the values of $|\lambda| = G_A/G_V$, obtained by various methods. The present data were calculated by the method of Ref. 3 using the latest values $Ft_{0^+ \to 0^+} = 3086.6 \pm 3.5$[4] and $f_{(n)} = 1.693 \pm 0.002$[5]; the data of Ref. 1 were recalculated by us in the same manner.

The authors are grateful to P.N. Orlov for participating in the construction of the apparatus, to A. Yu. Kulikov for development of the electronic apparatus, as well as to Yu. V. Gaponov and V.N. Tikhonov for useful discussions of the results.

The authors thank V.N. Chernyshev and to the entire crew of the IRTM reactor of our Institute for help with this work, which spanned a number of years.

[1] C. Christensen, A. Nielsen, A. Bahnsen, W. Brown, and B. Rustad, Phys. Rev. D **5**, 1628 (1972).

[2] A.N. Sosnovskiĭ, P.E. Spivak, Yu. A. Prokof'ev, I.E. Kutikov, and Yu. P. Dobrynin, Zh. Eksp. Teor. Fiz. **35**, 1059 (1958) [Sov. Phys. JETP **8**, 739 (1959)].

[3] R.J. Blin-Stoyle and J.M. Freman, Nucl.Phys. A **150**, 369 (1970).

[4] H. Vonach *et al.*, Nucl. Phys. A **278**, 189 (1977).

[5] B.S. Dzhelepov, L.N. Zyryanova, and Yu. P. Suslov, Beta-protsessy (Beta Processes), Nauka, 1972.

[6] V. Krohn and G. Ringo, Phys. Lett. B **55**, 175 (1975).

[7] B.G. Erozolimskiĭ, A.I. Frank, Yu. A. Mostovoĭ, S.S. Arzumanov, and L.R. Voĭtsik, Tochnoe izmerenie koeffitsienta korrelyatsii spin-élektron v raspade polyarizovannykh neĭtronov i opredelenie otnosheniya G_A/G_V (Exact measurement of the Spin–Electron Correlation Coefficient in the Decay of Polarized Neutrons, and Determination of the Ratio G_A/G_V), Preprint IAE-2963.

[8] R. Dobrozemsky *et al.*, Phys. Rev. D **11**, 510 (1975).