Determining the half-life of Ba–137 m

Recording and evaluating the decay curve with CASSY

Objects of the experiments

- Elution of the metastable Ba–137 m isotopes from a Cs–137 preparation.
- Measuring the activity of the eluate as a function of time and determining the half-life of Ba–137 m.

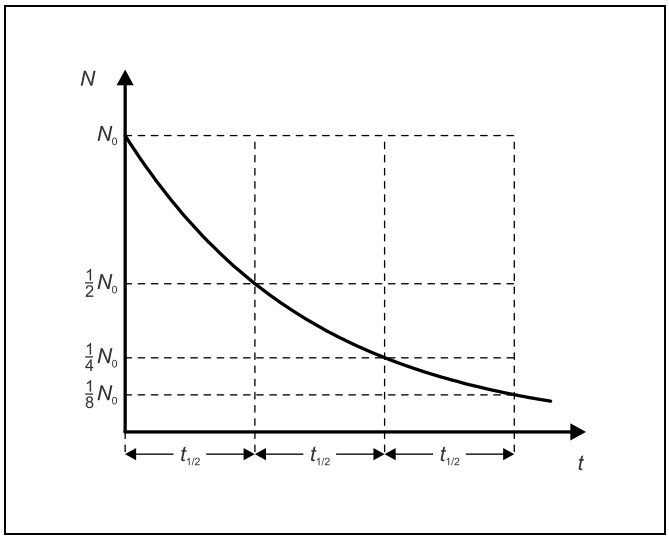
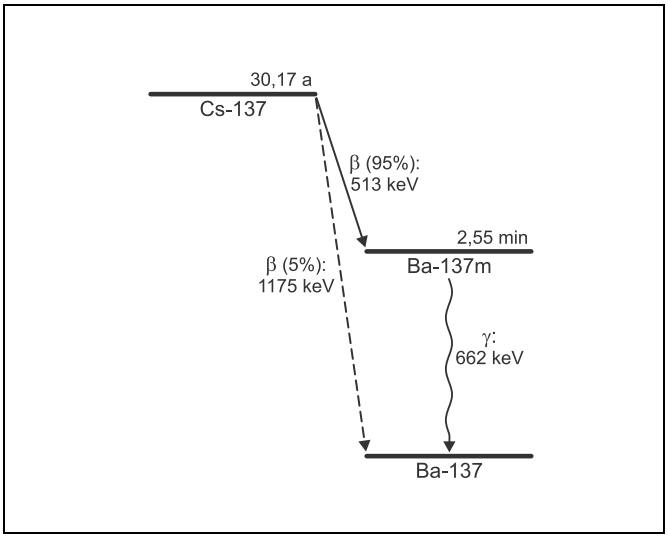


Fig. 1 Radioactive decay: the number *N* of radioactive nuclei as a function of the time *t*.

Fig. 2 Simplified decay scheme of Cs–137



Principles

If there are radioactive nuclei of a certain kind in a sample, the decay probability is the same for each nucleus. However, the instant at which an individual nucleus decays cannot be predicted. If no further radioactive nuclei are supplied, the number *N* of a particular kind of nuclei decreases during the subsequent time interval *dt* by

$$dN = -\lambda \cdot N \cdot dt \quad \text{(I)}.$$

λ: decay constant

The decay law for the number *N* therefore reads

$$N(t) = N_0 \cdot e^{-\lambda \cdot t} \quad \text{(II)}.$$

N_0: number of radioactive nuclei at the time $t = 0$

This law states, among other things, that each time when the half-life

$$t_{½} = \frac{\ln 2}{\lambda} \quad \text{(III)}$$

has passed, there is only half the number of radioactive nuclei left (see Fig. 1). For the activity of the sample, i.e., the number of decays per unit time

$$A(t) = \lambda \cdot N(t) \quad \text{(IV)}$$

applies. From this it follows that

$$A(t) = A_0 \cdot e^{-\lambda \cdot t} \text{ with } A_0 = \lambda \cdot N_0 \quad \text{(V)},$$

i.e., the activity $A(t)$ is also halved each time when the half-life has passed.

In this experiment, the decay curve of the metastable state Ba–137 m of the isotope Ba–137 is recorded and the half-life is determined. Ba–137 is a decay product of the long-lived parent substance Cs–137, whose half-life is approx. 30 years. Cs–137 decays into Ba–137 whereby β radiation is emitted. In 95 % of the decays, this is a transition into the metastable state Ba–137 m (see Fig. 2), which passes into the ground state of Ba–137 via γ decay with a half-life of only 2.551 min.

The parent substance is stored in a Cs/Ba–137 m isotope generator. The metastable isotopes Ba–137 m produced in the β decay of Cs–137 are eluated from the isotope generator with an acidified sodium chloride solution at the beginning of the experiment. Then the activity of the eluate is recorded.

Apparatus

1 Cs/Ba–137 m isotope generator	559 815
1 end-window counter	559 01
1 GM box	524 033
1 Sensor CASSY	524 010
1 CASSY Lab	524 200
1 stand base, V-shape, 20 cm	300 02
1 stand rod, 47 cm	300 42
2 Leybold multiclamps	301 01
2 universal clamps, 0 ... 80 mm dia.	666 555
1 set of 10 test tubes, 16 × 160 mm	664 043
1 beaker, 250 ml, ss, hard glass	664 103

additionally required:

1 PC with Windows 95 / 98 / NT or higher version

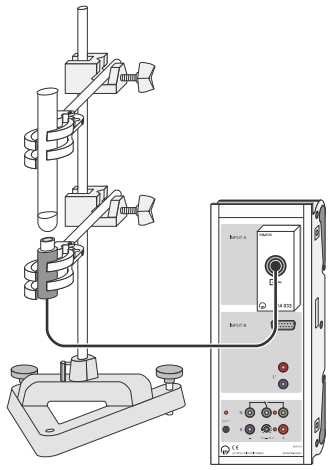


Fig. 3 Experimental setup for recording the decay curve of the metastable Ba–137 m with CASSY.

Safety notes

When radioactive preparations are handled, country specific regulations must be observed such as the Radiation Protection Regulation (StrSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the Cs/Ba–137 m isotope generator by unauthorized persons.
- Before using the Cs/Ba–137 m isotope generator make sure that it is intact.
- For the purpose of *shielding*, keep the Cs/Ba–137 m isotope generator in a cupboard.
- To ensure *minimum exposure time* and *minimum activity,* take the Cs/Ba–137 m isotope generator out of the safety container only as long as is necessary for the elution of the Ba–137 m. Always carry protective gloves during the elution of the Ba–137 m.

After approx. 30 min, the activity of the Ba–137 in the eluate is a thousandth of the initial activity. The contamination of the eluate with Cs–137 is less than 50 Bq/ml.

- Before disposing of the eluate by disposal to sewers, wait approx. half an hour.

Setup

The experimental setup is illustrated in Fig. 3.

– Attach the universal clamps to the stand rod with a distance of approx. 6 cm.
– Clamp the end-window counter in the lower universal clamp so that it is directed upwards and remove the protective cap.
– Clamp a test tube in the upper universal clamp so that its distance from the entrance window is approx. 0.5 cm.
– Connect the Sensor-CASSY to a serial input of the computer (e.g. COM1), plug the GM box in, and connect the end-window counter.

Carrying out the experiment

Setting the measuring parameters:

– Call the CASSY Lab software, and click “Update Setup” in the register “CASSY” of the dialog window “Settings”.
– Click the display of the GM box, and select the following settings:

  Measurement quantity: “Rate RA1”, Measuring range: “100 1/s”,
  Gate time: 12 s

– Select in the register “Display” of the dialog window “Settings”:

  x-axis: t, y-axis: RA1

– Select the measuring parameters:
– “Automatic Recording”, “Interval: 100 ms”

Elution of Ba–137 m:

– Put a piece of plastic tubing on the syringe, take approx. 2–3 ml of eluting solvent into the syringe, and remove the plastic tubing.
– Unscrew the protective cap at the threaded stub of the Cs/Ba–137 m isotope generator (blue name plate) and screw the tip of the syringe on the stub (see Fig. 4).
– Remove the protective cap from the outlet stub of the Cs/Ba–137 m isotope generator, and hold the discharge opening over the clamped test tube.

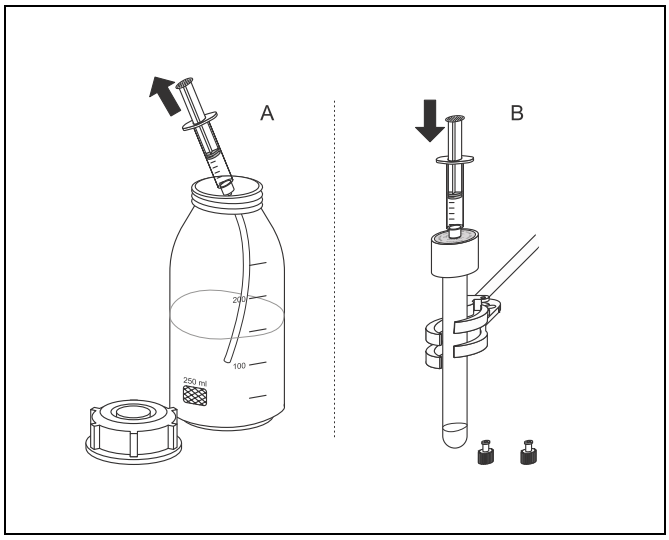


Fig. 4 Elution of the Ba–137 m from the Cs/Ba–137 m isotope generator.

– Press the eluting solvent through the Cs/Ba–137 m isotope generator by carefully pressing the piston of the syringe.

  The elution should be finished after 10–20 s.

Recording the measured values:

– Start recording the measured values by pressing the button or the key F9, and stop after about 700 s.

– Store the measurement with or F2 (use a filename that allows you to recognise the file).

Remark:

The radioactive equilibrium between Cs–137 and the daughter nuclide Ba–137m is already restored after 20 minutes so that another elution can be made after that time.

The lifetime of the Cs/Ba–137 m isotope generator is limited by contaminants which get into the generator with the eluting solvent and clog the filters, which are very fine-pored. If the original high-purity eluting solvent is used, the generator can be eluted 500–1000 times.

Measuring example and evaluation

Fig. 5 shows the decay curve of Ba–137 m. Further evaluation and determination of the half-life $t_{1/2}$:

– Click the diagram with the right mouse button, select the menu item “Fit Function → Exponential function e^x”, and mark the beginning and the end of the range to be fitted with the mouse.
– Activate the horizontal line with the key combination Alt+W and place it at a well-defined value of the counting rate (e. g. 80 1/s) with the mouse.
– Place further horizontal lines at the half, quarter and eighth of the selected value.
– Activate vertical lines with the key combination Alt+S and place them with the mouse at the intercepts of the fitted curve with the horizontal lines.
– Activate the difference measurement with the key combination Alt+D, and determine the half-life $t_{1/2}$ as the difference between two neighbouring vertical lines.

From Fig. 5 $t_{1/2}$ = 145.2 s = 2.42 min is obtained.

Value quoted in the literature:

$t_{1/2}$ = 153.08 s = 2.5514 min

Results:

The number $N(t)$ of nuclei of a radioactive substance that have not yet decayed at the time t and the activity of this substance $A(t)$ decrease exponentially as functions of time. This decrease is characterized by the half-life $t_{1/2}$, after which the number or activity has dropped to half its initial value.

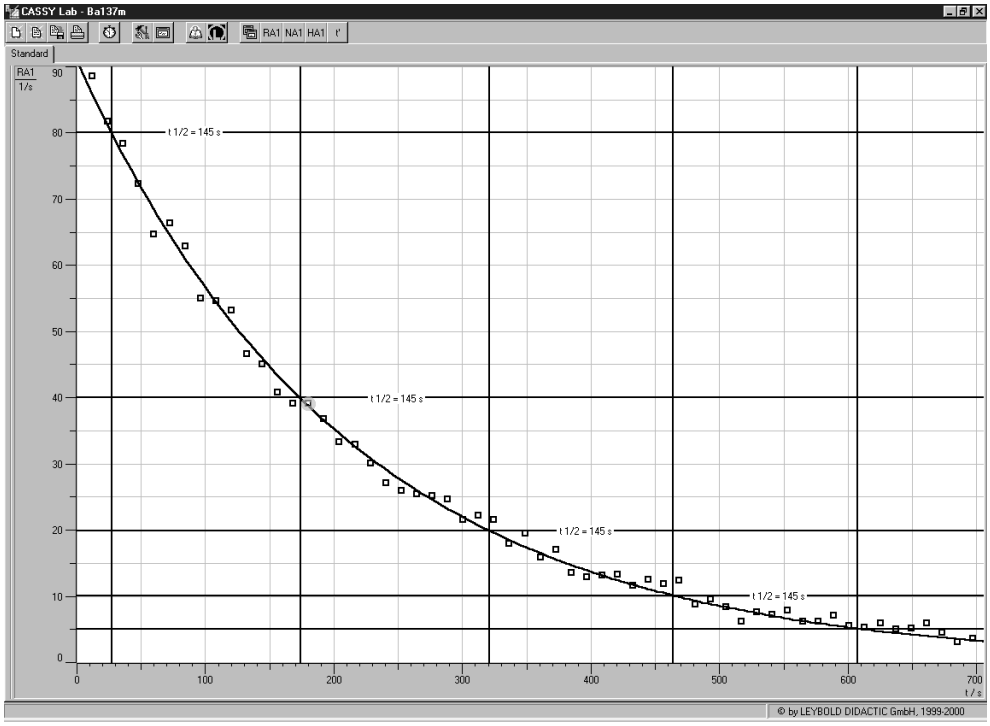


Fig. 5 Decay curve of Ba–137 m, recorded and evaluated with CASSY