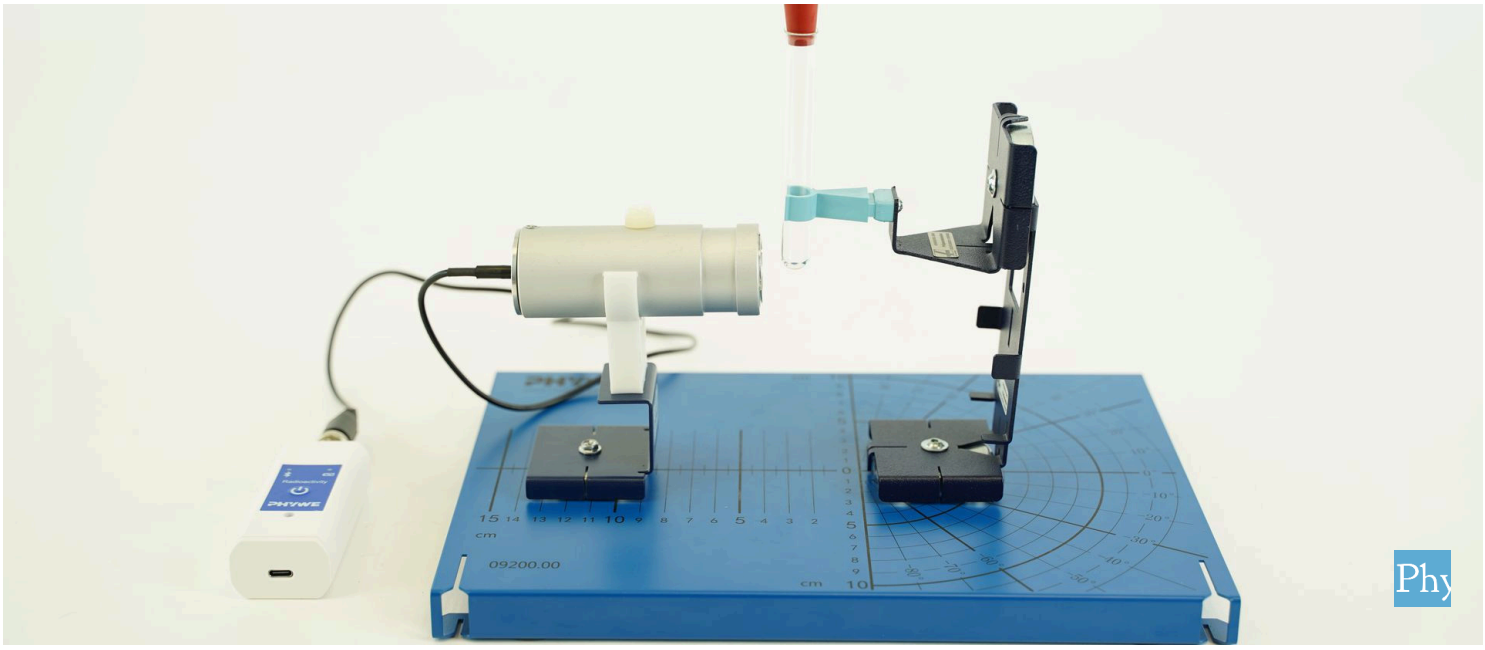
Half-life and radioactive equilibrium with Cobra4



Physics | Modern Physics | Radioactivity

Difficulty level	Group size	Preparation time	Execution time
-	-	-	-

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General information

Application

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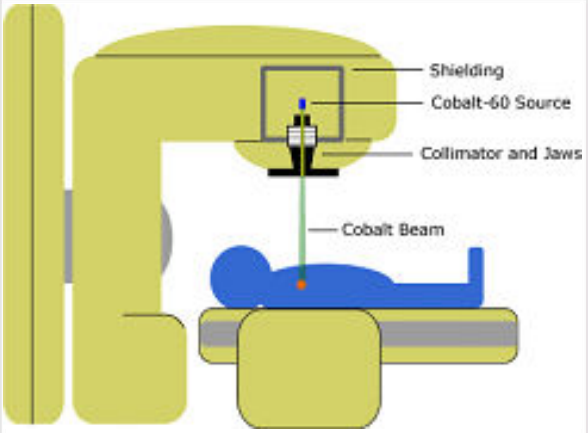

Cancer treatment with Cobalt-60

Half-life is the time it takes for one-half of the atoms of a radioactive material to disintegrate. Certain radioactive materials are used in:

- Cancer treatment: Cobalt-60, Radium-226
- Biochemical tracer : Hydrogen-3
- Smoke detector: Americium-241

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Other information (1/2)

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Prior knowledge

Radioactive decay is the spontaneous breakdown of an unstable atomic nucleus resulting in the release of energy and matter from the nucleus. Three of the most common types of decay are alpha decay, beta decay, and gamma decay, all of which involve emitting one or more particles or photons.

Scientific principle

The half-life of a ^{137m}Ba daughter substance eluted (washed) out of a ^{137}Cs isotope generator is measured directly and is also determined from the increase in activity after elution.

Other information (2/2)

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Learning objective

Understanding the properties behind the rate of radioactive decay in dependence upon reaction time.

Tasks

1. Measure the activity of a freshly eluted solution of ^{137m}Ba m as a function of time.
2. Measure the activity of the isotope generator as a function of time immediately after elution.

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Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

Radioactive substances can be hazardous to your health! Always reduce the time spent handling radioactive substances to a minimum. The source should only be removed from the storage container for the duration of the experiment

Always wash your hands after contact with them!

Theory (1/4)

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The isotope generator contains 400 kBq of ^{137}Cs , which serves as the parent substance; its half-life is 30.25 years. ^{137}Cs decays into the barium isotope ^{137}Ba with the emission of β-radiation.

This transition occurs, in part, directly (approximately 5%) to the stable ground state of ^{137}Ba and, in part (approximately 95%) via the meta stable state of ^{137m}Ba .

^{137m}Ba decays with a half-life of only 2.6 min under emission of γ-radiation ($E_\gamma = 662\,keV$) in the stable ground state of ^{137}Ba .

In the elution process, the ^{137m}Ba is washed out of the isotope generator.

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Theory (2/4)

The counting rate decreases to half of its original value after a time period can be determined by

$$\dot{N} = \dot{N}_0 \, e^{-\lambda t}$$

and

$$\frac{1}{2}\,\dot{N} = \dot{N}_0 \, e^{-\lambda \tau} \quad .$$

Thus,

$$\lambda = \frac{\ln 2}{\tau} \quad .$$

$\dot{N}$: Actual rate of decay

$\dot{N}_0$: Counting rate at time

λ : Decay constant

t : Time

τ : Half-life

Theory (3/4)

By taking the logarithm of

$$\dot{N} = \dot{N}_0 \, e^{-\lambda t}$$

the following is obtained

$$\ln \dot{N} = -\lambda t \, \ln \, \dot{N}_0$$

Comparing the coefficients with the regression line $y = mtb$ shows that the slope of the regression line m corresponds to the negative decay constant:

$$m = -y$$

The decay constant λ is characteristic for the gradual decline in radioactivity: It is thus linked to the specific time period in which the substance quantity decays to half of its initial radioactivity (half-life τ).

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Theory (4/4)

Formation of daughter substance subsequent to disturbance of the equilibrium by elution

Calculation of the half-life. At time *t* an activity is measured that can be calculated according to the following formula:

$$\dot{N}(t) = \dot{\overline{N}} + \dot{N}_0(1 - e^{-\lambda t}) \quad .$$

$\dot{N}(t)$: Actual counting rate

$\dot{\overline{N}}$: Activity of the β-radiating ^{137}Cs (through the opining in the source) and the residual activity of the ^{137m}Ba, which results from incomplete elution.

$\dot{N}_0$: Equilibrium activity of the daughter substance, ^{137m}Ba

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Equipment

Position	Material	Item No.	Quantity
1	Cobra SMARTsense- Radioactivity (Bluetooth + USB)	12937-01	1
2	Isotope generator Cs-137, 370 kBq	09047-60	1
3	Base plate for radioactivity	09200-00	1
4	Holder for SMARTsense counter tube on holding magnet	09207-00	1
5	Plate holder on fixing magnet	09203-00	1
6	Source holder on fixing magnet	09202-00	1
7	Test tubes 100x12 mm,FIOLAX,100pc	36307-10	1
8	Rubber stopper,d=14.5/10.5mm, w/o	39253-00	1
9	measureLAB, multi-user license	14580-61	1

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Setup and procedure

Setup (1/3)

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The Cobra SMARTsense Photogate and measureAPP are required to perform the experiment. The app can be downloaded for free from the App Store - QR codes see below. Check whether Bluetooth is activated on your device (tablet, smartphone).

measureAPP for Android operating systems

measureAPP for iOS operating systems

measureAPP for Tablets / PCs with Windows 10

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Setup (2/3)

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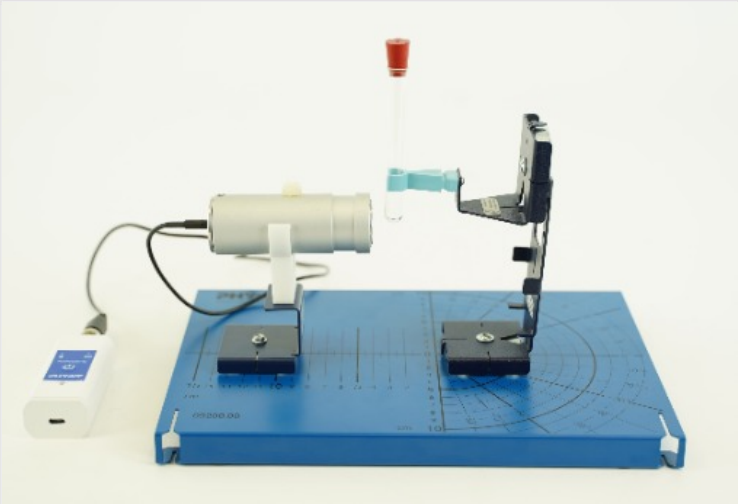

Experimental set-up

Experimental set-up for measuring the decay of the daughter substance is shown in the figure.

Setup (3/3)

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Experimental set-up

Experimental set-up for measuring the formation of the daughter substance is shown in the figure.

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Procedure (1/2)

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Measure the background radiation without the radiation source.Then, send the measurement to measure and divide the number of counts by 50, so that you get the number of counts per 10 s.

Perform elution of the generator in accordance with its operating instructions. The eluted liquid in the test tube (sealed with stopper!) is supported by the source holder clamp and positioned directly in front of the counting tube window.

Click on in the button to start the measurement. Stop the measurement after approx. 15 minutes and send the data to measure.

After the measurement series has been completed, the display is automatically scaled; the individual data points and the calculated half-life have also been entered.

Procedure (2/2)

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Measurement of the formation of daughter substance subsequent to disturbance of the equilibrium by elution.

Perform elution of the generator in accordance with its operating instructions. The eluted liquid in the test tube (sealed with stopper!) is set aside and poured down the drain after it has stood for half an hour. The cylindrical generator sample is fixed in the source holder and moved to a position directly in front of the counting tube with its plane side facing the counter. Don’t touch the window of the counter tube with the generator sample!

Click on in the button to start the measurement. Stop the measurement after approx. 15 minutes and send the data to measure.

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Evaluation (1/6)

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In the elution process, the ^{137m}Ba is washed out of the isotope generator. Figure shows the counting rate that decreases exponentially over time.

Calculation of the half-life of Ba-137m's decay

Evaluation (2/6)

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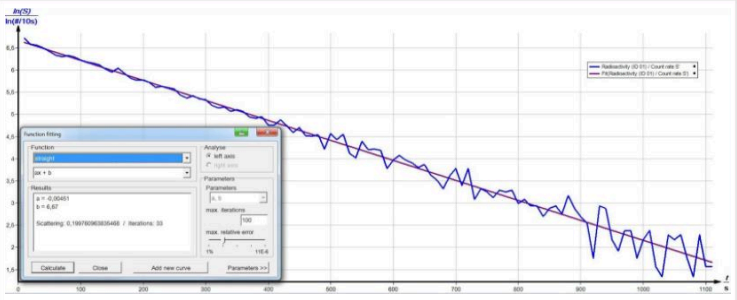

Logarithmic plot of the counting rate of Ba-137m's decay

Figure shows the semilogarithmic plot with its calculated regression line.

From the regression line's slope m, the halflife of the eluted source is determined to be $\tau = 153.69\ s$

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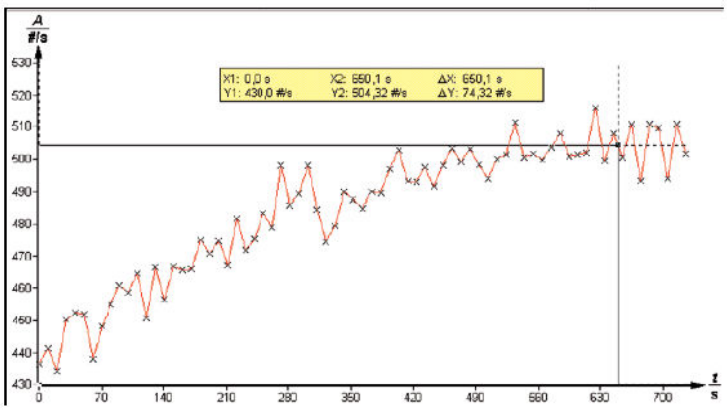
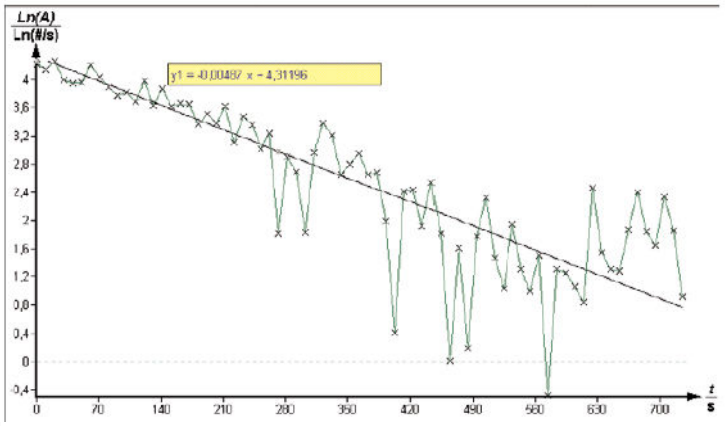
Evaluation (3/6)



Plot of the counting rate of Ba-137m being formed

By subtracting the equilibrium activity after approximately 650 s, which is comprised of $\dot{N}$ and $\dot{N}_0$, from the respective actual counting rate, in this case 504.28.

Evaluation (4/6)



Logarithmic plot of the counting rate of Ba-137m being formed

By calculating the natural logarithm of the previous variable's value, this diagram is obtained.

The half-life for this measurement, $\tau = 142.33\ s$, follows from the slope of the drawn regression line.

$$\tau = -\frac{ln\,2}{m} = -\frac{ln\,2}{-0.00487} = 142.33\ s$$

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Evaluation (5/6)

Fill in the blanks:

Half -time of a nuclear decay process is the interval of _____ required for _____ of the unstable _____ of a radioactive sample to decay. The radioactive substances changes spontaneously into other nuclear species by emitting particles and _____ .

atomic nuclei
energy
one-half
time

Check

Evaluation (6/6)

For a given number of atoms, a radioactive sample with shorter half-lives

- [ ] decays more rapidly
- [ ] undergoes a greater number of radioactive decays at a given time
- [ ] decays more rapidly

Check

Fill in the missing words

The amount of radioactive decay is dependent on _____.

Check

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Slide	Score/Total
Slide 21: Question 1	0/4
Slide 22: Multiple tasks	0/3

Total Score 0/7

Show solutions Retry

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