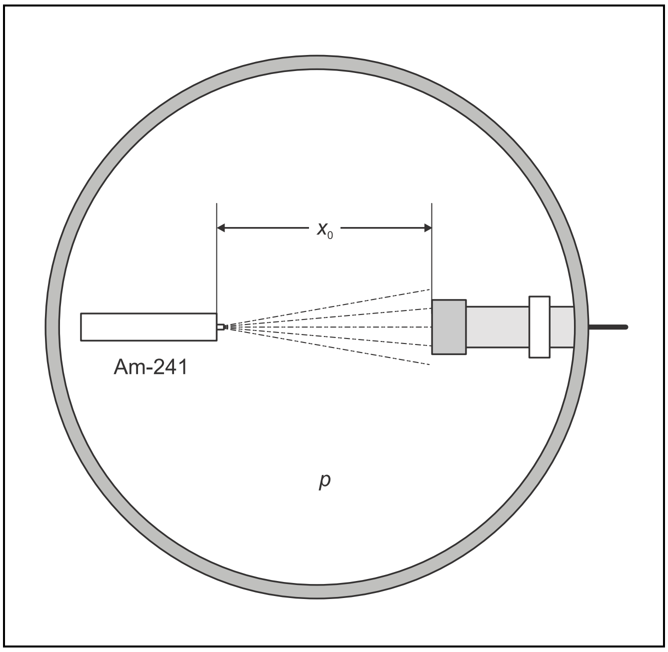
Determining the energy loss of α radiation in air

Objects of the experiments

- Recording the α spectrum of an Am–241 sample in a vacuum chamber.
- Measuring the energy loss of the α radiation as a function of the air pressure at a fixed distance between the sample and the detector.
- Calculating the energy loss of the α radiation as a function of the path length at standard pressure.
- Determining the range of the α radiation in air.



Principles

The energy loss of energy-rich α radiation in matter is mainly determined by inelastic collisions of the α particles with electrons. The direction of flight remains practically unchanged by the collisions, that is, the trajectory of an α particle is almost a straight line. In a single collision, the α particle loses only a small amount of energy, and many collisions are required to slow it down considerably. Usually, the energy loss dE of the α particle per path element dx in the moderating material is considered for a quantitative description. A fast α particle looses less energy in a collision than a slow one because it remains in the interaction region for a shorter time interval and thus can transfer less energy to the scatterer. The energy loss therefore depends on the energy.

The energy of the α particle is consumed after it has passed the path length

$$R = \int_{E_0}^{0} \frac{dx}{dE} \cdot dE \qquad \text{(I).}$$

This range is a measure for the initial energy E_0 of the α particle. Empirically, the relation between E_0 and R is given by the *Geiger* law

$$R \propto E_0^{\frac{3}{2}} \qquad \text{(II).}$$

For air

$$\frac{R}{\text{cm}} = 0{,}46 \cdot \left(\frac{E_0}{\text{MeV}}\right)^{\frac{3}{2}} \qquad \text{(III)}$$

is a good approximation. in the experiment, the energy E of the α particles from an Am–241 source is measured in a vacuum

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Apparatus

1 Am−241 preparation, 330 kBq	559 82
1 Rutherford scattering chamber	559 56
1 discriminator-preamplifier	559 93
1 MCA-CASSY	529 780
1 MS-Dos-Connector L	524 001
or from	524 007
1 multicore cable, 6-pole, 1.5 m long . . .	501 16
1 BNC cable, 1 m long	501 02
1 BNC cable, 0.25 m long	501 01
1 rotary-vane vacuum pump D 2.5 E	378 752
1 vacuum tubing, 8/18 mm dia.	307 68
1 small flange DN 16 KF with hose nozzle .	378 031
4 centring rings DN 16 KF	378 045
4 clamping rings DN 10/16 KF	378 050
1 cross DN 16 KF	378 015
1 variable leak valve DN 16 KF	378 776
1 gauge tube TR 211	378 501
1 gauge head cable, 3 m	378 502
1 vacuum meter THERMOVAC TM 21 . . .	378 500
additionally recommended:	
1 exhaust filter AF 1.8	378 764
additionally required:	
1 PC with MS-DOS 3.0 or higher version	

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 preparation by unauthorized persons.
- Before using the preparation make sure that it is intact.
- For the purpose of *shielding*, keep the preparation in its safety vessel.
- To ensure *minimum exposure time of* and *minimum activity,* take the preparation out of the safety vessel only as long as is necessary for carrying out the experiment.
- To ensure *maximum distance,* hold the preparation only at the upper end of the metal holder and keep it away from your body as far as possible.

chamber. On a fixed path length x_0 and with varying air pressure p, the α particles lose as much energy as they would lose at standard pressure p_0 on the path length

$$x = \frac{p}{p_0} \cdot x_0 \qquad \text{(IV)}$$

in air. Variation of the pressure p by means of a ventilation valve therefore provides an easy way of varying the effective path length x of the α particles in air.

Setup

The experimental setup is illustrated in Figs. 1 and 2. A Rutherford scattering chamber (559 56) is used as a vacuum chamber.

Setting up the vacuum chamber:

– Vent the vacuum chamber cautiously, and, if necessary, remove the holder with the collimating slits and the gold foil from the vacuum chamber.
– Fix the Am−241 preparation **(a)** to the preparation holder, and mount the semiconductor counter **(b)**.
– Set the swivel arm with the preparation to the position 0^0.

Connecting the rotary-vane vacuum pump:

– Mount the cross DN 16 KF with the centring ring and the clamping ring on the inlet flange of the rotary-vane vacuum pump.
– Mount the small flange with hose nozzle on the cross and the variable leak valve DN 16 KF and the gauge tube on the sides of the cross.
– Close the variable leak valve.
– Connect the vacuum gauge tube to the vacuum meter THERMOVAC.
– Connect the vacuum chamber to the small flange with hose nozzle.
– Close the tap of the vacuum chamber.

Connecting the MCA-CASSY:

– Connect the BNC output of the vacuum chamber to the input of the discriminator-preamplifier with the short BNC cable.
– Connect the analog output of the discriminator-preamplifier to the socket “external sensor” of the MCA-CASSY with the long BNC cable.
– Connect the MCA-CASSY to the MS-DOS-Connector L at the PC with the flat line and to the discriminator-preamplifier with the 6-pole multicore cable.

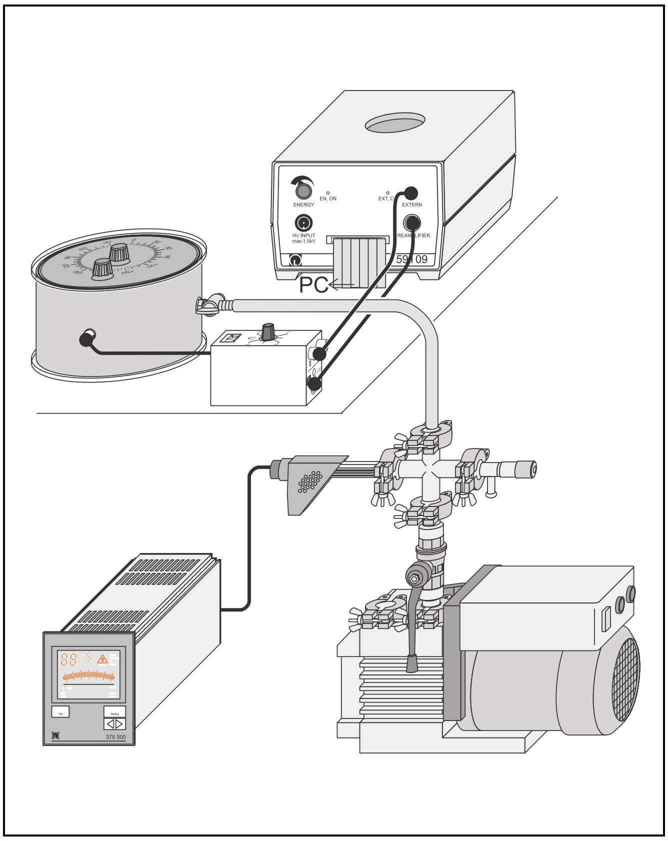

Fig. 1 Experimental setup for determining the energy loss of α radiation in air

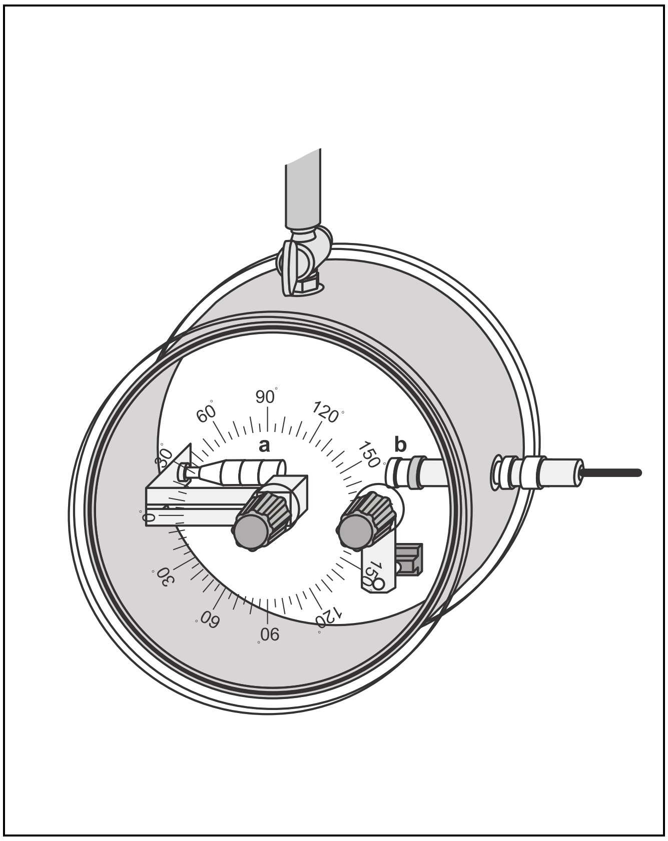

Fig. 2 Experimental setup in the vacuum chamber

Carrying out the experiment

Remark:

The semiconductor counter is light-sensitive: avoid direct illumination of the vacuum chamber so as to prevent distortion of the measuring results.

– Switch the vacuum pump on, close the vacuum chamber, press the cap, and open the tap of the vacuum chamber cautiously.
– Wait until the ultimate vacuum is reached.
– Get the program "MCA" started.
– Choose "Define settings" in the main menu:
  Resolution = 8 bit (256 channels)
  Line diagram (confirm with <CR>)
  Meas. time = 300 s
  "Attenuator on"
  "External sensor on" → "Positive edge"
– Choose "Record measurement" in the main menu:
  Choose spectrum = Spectrum 1
– Start the measurement in the measuring screen with <F1>.
– Set the attenuation with the potentiometer ENERGY of the MCA-CASSY so that the α spectrum is well distributed over 256 channels.
– Delete old measuring values with <Ctrl + C>, and start a new measurement with <F1>.

Calibration:

– When the detection time is over, change to "Graphical evaluation" in the main menu, and switch the graphics cursor on with <F9>.
– Place the cursor at the centre of the peak with <Shift + Tab> (cursor moves to the left) and <Tab> (cursor moves to the right).
– Choose the calibration mode with <>, and enter the energy 5477 keV.

Recording α spectra depending on the pressure:

– Open the variable leak valve until the pressure in the vacuum chamber is approx. 300 mbar.
– Delete old measuring values with <Ctrl + C>, and start a new measurement with <F1>.
– When the detection time is over, change to "Graphical evaluation" in the main menu, and place the cursor at the centre of the peak.
– Switch the display of the α energy on with the key <+>, and take the measuring value down.
– Increase the pressure in the vacuum chamber – at first in steps of about 100 mbar, above 800 mbar in smaller steps. In each case record the α spectrum, and determine the α energy.

Measuring example

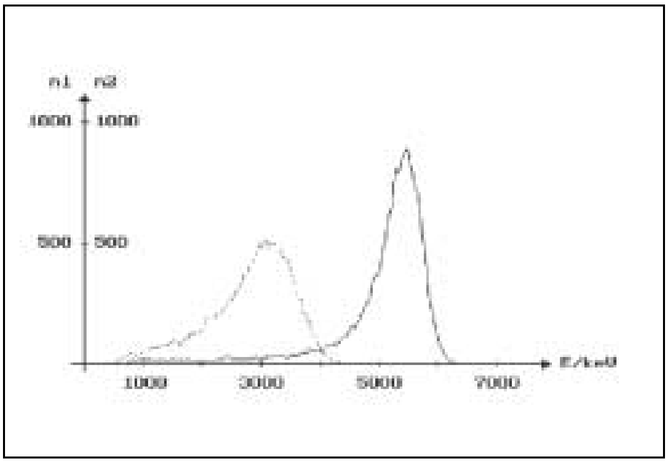

Fig. 3 α spectrum of Am–241, measured at p = 1 mbar (solid line) and p = 935 mbar (dashed line)

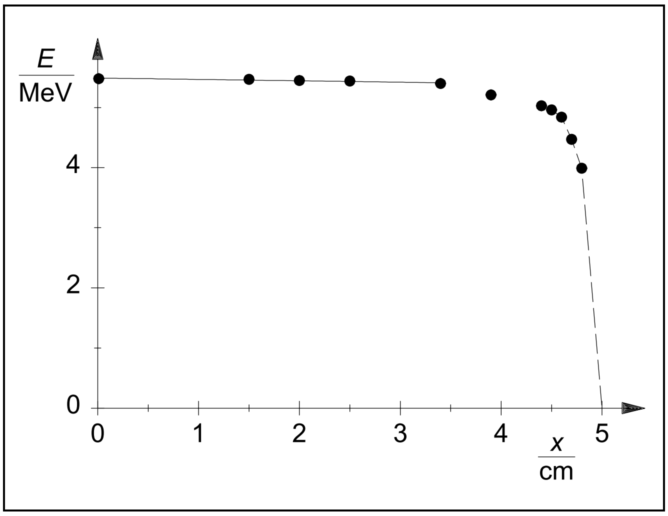

Fig. 4 α energy E as a function of the effective path length x in air at standard pressure.

Table 1: Measuring values of the α energy E as a function of the air pressure p, distance x_0 = 5.2 cm

$\frac{p}{\text{mbar}}$	$\frac{E}{\text{MeV}}$
1	5.48
290	5.47
380	5.45
480	5.44
670	5.40
760	5.21
860	5.03
880	4.96
900	4.84
920	4.47
940	3.99
970	*

* α counting rate is equal to zero

Table 2: α energy E as a function of the effective path length x in air at standard pressure

$\frac{x}{\text{cm}}$	$\frac{E}{\text{MeV}}$
0.0	5.48
1.5	5.47
2.0	5.45
2.5	5.44
3.4	5.40
3.9	5.21
4.4	5.03
4.5	4.96
4.6	4.84
4.7	4.47
4.8	3.99
5.0	*

Evaluation

In Table 2, the measuring values of Table 1 are given with the air pressure p converted into the effective path length x in air according to Eq. (IV). Fig. 4 is a plot of these values:

As long as the path length in air is below 3.5 cm, the energy loss of the α particles remains small. On average it is (see slope of the straight line drawn in Fig. 4):

$$\frac{dE}{dx} = 23\ \frac{\text{keV}}{\text{cm}}\ .$$

The range R of the α particles can be estimated by extrapolating from the last data points to E = 0:

R = 5.0 cm.

For comparison:

From Eq. (III) the range R = 5.90 cm is obtained for the α energy E = 5.477 MeV of Am–241.

The estimate R = 5.0 cm corresponds to the α energy E = 4.9 MeV. This deviation is, among other things, due to the fact that the Am–241 preparation is coated with gold foil and that the α particles leave the preparation with an energy below 5.477 MeV.

Results

α particles have a certain energy-dependent range in air. At 5 MeV this range is about 5 cm.