THE RANGES OF ALPHA PARTICLES IN H₂, He, CH₄ AND CO₂
AT ENERGIES FROM 0.5 TO 5.3 MeV

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Energy losses of alpha particles in H₂, He, CH₄ and CO₂ have been measured in the energy region from 0.5 to 5.3 MeV. Alpha-particle ranges are given in the form of polynomials in the energy.

1. Introduction

In this laboratory, counter telescopes consisting of gas-filled proportional counters and surface-barrier silicon detectors are used to investigate (n, α)-reactions. The counter pulse heights are analysed to identify alpha particles and to obtain their energies. For that purpose the ranges of alpha particles in the counting gas must be known rather well.

Comprehensive tables of heavy-particle energy-loss data have been published by Barkas and Berger and, more recently, by Northcliffe and Schilling. The tables of Barkas and Berger contain proton data only down to 1 MeV. From those alpha-particle ranges may be calculated down to 4 MeV. Stopping-power and range data down to alpha-particle energies as low as 50 keV have been presented by Northcliffe and Schilling. Their data, however, are not consistent with those of Barkas and Berger in the energy region between 4 and 15 MeV. Furthermore, when we tried to use the data of Northcliffe and Schilling for our alpha-particle identifying method, we did not succeed. For these reasons we have measured energy losses of alpha particles in H₂, He, CH₄ and CO₂ in the energy region between 0.5 and 5.3 MeV.

2. Experimental procedure

The experimental arrangement is simple. A similar set-up has been used first by Rotondi and Geiger.

Alpha particles with an initial energy of (5.298 ± 0.002) MeV are emitted by a ²¹⁰Po source. They pass through the gas to be studied. Their residual energies are measured by means of a semiconductor detector spectrometer.

The distance from source to detector was determined by carefully machined spacers. Spacers for distances of (74.47 ± 0.28) mm, (124.47 ± 0.22) mm, 194.37 ± 0.54) mm and (325.0 ± 0.5) mm were available. The 3 mm source diameter and a 7 mm aperture, placed near the detector, defined the alpha-particle beam.

This apparatus had been mounted into a vacuum-tight chamber. It could be evacuated down to 10⁻⁵ mm Hg and filled with H₂, He, CH₄ or CO₂ up to a pressure of 600 mm Hg. A mercury manometer was used to measure the gas pressure. To determine the gas density, the chamber temperature was measured, too.

The semiconductor detector spectrometer consisted of a 300 Ω cm surface-barrier silicon detector with an active area 8 mm in diameter, a 30 V bias supply, a spectroscopy amplifier ORTEC 451 and a 1024-channel pulse-height analyser ORTEC 6220-01. The overall linearity of the electronic system was tested by means of a precision pulse generator ORTEC 204.

To calibrate the spectrometer, the chamber was evacuated. The energy per channel was determined from the position of the centroid of the 5.30 MeV peak in the pulse-height spectrum. The width of this peak was 30 keV (fwhm). This was mainly due to the overall energy resolution of the spectrometer.

About 40 residual-energy spectra have been taken for each gas, each containing about 5000 alpha-particle events.

3. Evaluation and results

The mean residual alpha-particle energies were calculated from the centroid positions of the alpha-particle peaks in the pulse-height spectra. They were corrected for the energy losses within the gold dead layer on the silicon detector which was 40 μg/cm² thick. To that end the energy-loss data of Northcliffe and Schilling have been used. These corrections were not critical, because they amounted only to 14 keV at 1 MeV and to 9 keV at 5 MeV. The energy losses within the ²¹⁰Po source were negligible.

The finite source and aperture diameters caused
some spread of the alpha-particle path lengths. The path-length distributions and the mean path lengths were computed by a Monte Carlo program.

From the pressure and the temperature of the gas and from the mean path length the traversed mass per unit area was calculated for each spectrum.

The corrected experimental data were fitted by least-squares polynomials \( X(E) \), representing the traversed gas mass per unit area as a function of the residual energy \( E \) within the interval from 0.5 MeV to 5.3 MeV. The statistical errors of the residual energies obtained from the pulse-height spectra and the statistical errors of the traversed masses per unit area were taken into account.

For an estimation of the goodness of the fit, chi-square tests were done. The degrees of the fitting polynomials were increased until the probability of statistically significant deviations of the experimental data from the polynomials was less than 5%. Polynomials of degree 3 resp. 4 proved to be sufficient.

### Table 1

The coefficients of the range polynomials, valid between 0.5 MeV and 5.3 MeV.

<table>
<thead>
<tr>
<th></th>
<th>( a_0 ) (mg cm(^{-2}))</th>
<th>( a_1 ) (mg cm(^{-2}) MeV(^{-1}))</th>
<th>( a_2 ) (mg cm(^{-2}) MeV(^{-2}))</th>
<th>( a_3 ) (mg cm(^{-2}) MeV(^{-3}))</th>
<th>( a_4 ) (mg cm(^{-2}) MeV(^{-4}))</th>
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<tr>
<td>( H_2 )</td>
<td>(-1.688 \times 10^{-1})</td>
<td>(-5.083 \times 10^{-2})</td>
<td>(-3.057 \times 10^{-1})</td>
<td>(4.848 \times 10^{-3})</td>
<td>(0)</td>
</tr>
<tr>
<td>( \text{He} )</td>
<td>(5.487 \times 10^{-2})</td>
<td>(2.502 \times 10^{-1})</td>
<td>(2.176 \times 10^{-1})</td>
<td>(4.516 \times 10^{-1})</td>
<td>(0)</td>
</tr>
<tr>
<td>( \text{CH}_4 )</td>
<td>(4.135 \times 10^{-2})</td>
<td>(6.796 \times 10^{-2})</td>
<td>(3.120 \times 10^{-2})</td>
<td>(7.192 \times 10^{-3})</td>
<td>(0)</td>
</tr>
<tr>
<td>( \text{CO}_2 )</td>
<td>(-5.212 \times 10^{-4})</td>
<td>(1.620 \times 10^{-3})</td>
<td>(1.030 \times 10^{-2})</td>
<td>(-9.195 \times 10^{-4})</td>
<td>(-2.400 \times 10^{-3})</td>
</tr>
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**Fig. 1.** The range of alpha particles in hydrogen.

**Fig. 2.** The range of alpha particles in helium.
There are two ways to obtain the ranges $R(E)$ from the polynomials $X(E)$:

a) Extrapolating the measured data to zero residual energy results in "extrapolated" ranges

$$R_{ex}(E) = X(0) - X(E).$$

b) Adopting ranges $R(E_0)$ published by other authors at a single energy $E_0$ within the interval covered by our measurements results in "adjusted" ranges

$$R_{adj}(E) = R(E_0) + X(E_0) - X(E).$$

The difference between $R_{adj}(E)$ and $R_{ex}(E)$ is equal to $R_{adj}(0)$. This is a constant. In our application, such an additive constant is unimportant.

We have adopted the ranges at 5.30 MeV given by Northcliffe and Schilling to obtain adjusted range polynomials

$$R_{adj}(E) = \sum_{i=0}^{4} a_i E^i.$$  

The coefficients are given in table 1. Extrapolated ranges are obtained by cancelling the zero-order coefficients.

From the statistical errors of the measured residual energies and gas thicknesses the errors of the range polynomials were computed for some energies using the formalism described by Mathews and Walker$^9$). They are listed in table 2.
For comparison, range curves were computed from the stopping-power data of Barkas and Berger also. For that purpose the stopping powers must be extrapolated to energies below 4 MeV. The resulting ranges have also been adjusted to the ranges of Northcliffe and Schilling at 5.3 MeV.

The range curves are shown in figs. 1–4. Our polynomials agree rather well with the range curves obtained from the stopping-power data of Barkas and Berger. One should bear in mind, however, that below 4 MeV the latter are questionable because of the extrapolation. There is a considerable difference between our polynomials and the range curves of Northcliffe and Schilling.

Another fitting polynomial, representing the range of alpha particles in CH₄, was based on our CH₄ measurements at energies below 5.25 MeV and on data of Barkas and Berger above that energy. It has been used effectively to identify alpha particles at energies from 2.5 MeV to 14 MeV, thus supporting the data of Barkas and Berger at energies above 5 MeV.

References
3) M. Brendle and G. Steidle, to be published.
6) M. Brendle, Nucl. Instr. and Meth. 128 (1975) 69.