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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40002730
APXNR (National Research Council Canada. Division of Applied Physics); no. APXNR-1846, 1966-05-31

National Research Council of Canada

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APXNR - 1846 NRC - 9076 31 MAY 1966

ARCV

31 May 1966 Report No. APXNR-1846
NRC-9076

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Bragg's Additivity Law of Stopping Power for 5 MeV α Particles in O_2, N_2, CO_2, CO, NH_3 and Hydrocarbon Gases

Introduction

The purpose of this work has been to verify Bragg's additivity law of stopping power for α particles of 5 MeV.

Slight deviations from Bragg's rule can occur when a considerable fraction of stopping electrons are in the valence shells. This fact will be accentuated at low energy when principally the outer electrons are effective in the stopping process.

For these reasons the Bragg additivity law for α particles of 5 MeV has been investigated in hydrocarbon gases.

Measurements and Results

The experimental apparatus, reported in a previous work (1) (2), consists of a gas absorption cell in which α-particles from an Am^{241} source lose their energy, and of a semiconductor detector at a fixed distance, which measures the residual α energy. The gas pressure in the cell is adjusted so that the energy loss by α particle in the cell is approximately 1 MeV.

For all gases the cell is flushed several times with gas, before measuring. Pressure is measured with a mercury manometer. The purity of gas as given by supplier is listed in Table I. The wall temperature of the cell is maintained at 22.5°C to within 0.2°C. Fig. 1 gives the pulse height distribution of α particles

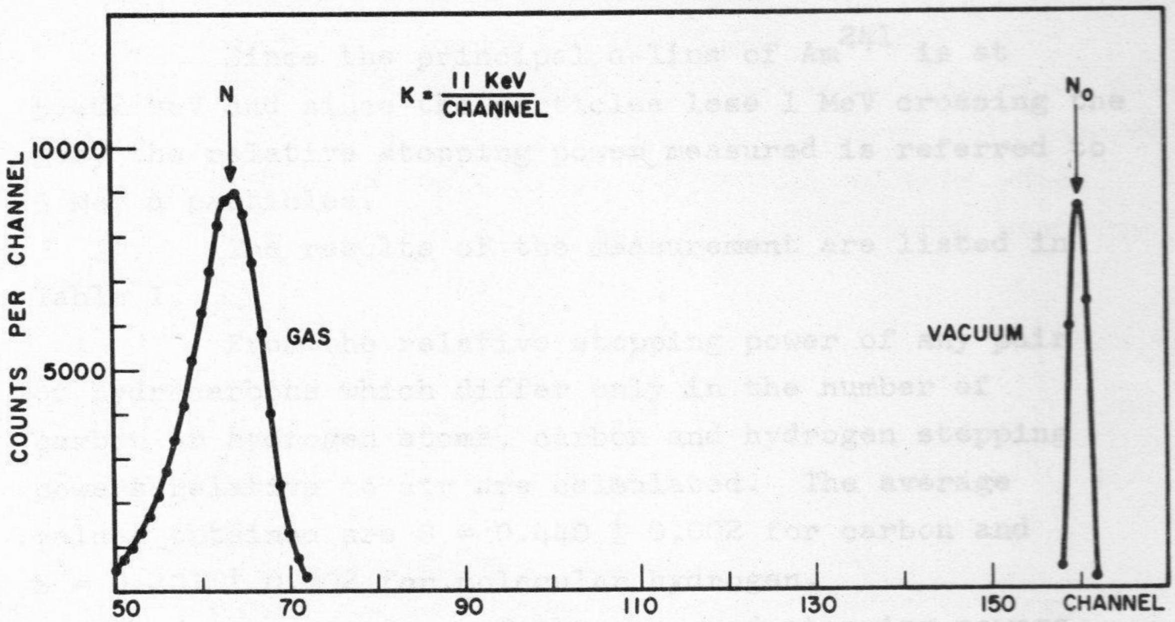

Fig. 1 Pulse height spectra from Am-241 α-source in vacuum and in gas; energy loss approximately 1 MeV.

in vacuum and after passing through a gas. The mean energy of α particles is represented by the peak channel because the pulse height closely approximates a Gaussian shape as expected from theory. Let N and N_o be the numbers of the peak channel in gas and in vacuum, then $K(N_o - N) = K\,N$ represents the energy lost by α particles in the gas where the gas pressure P is adjusted such that K N represents about 1 MeV.

The stopping power of gas relative to air is given by the relation

$$S = \frac{N_{gas}}{N_{air}} \frac{P_{air}}{P_{gas}}$$

Since the principal α-line of Am^{241} is at 5.482 MeV and since the particles lose 1 MeV crossing the gas, the relative stopping power measured is referred to 5 MeV α particles.

The results of the measurement are listed in Table I.

From the relative stopping power of any pair of hydrocarbons which differ only in the number of carbon or hydrogen atoms, carbon and hydrogen stopping powers relative to air are calculated. The average values obtained are $S = 0.440 \pm 0.002$ for carbon and $S = 0.201 \pm 0.002$ for molecular hydrogen.

A comparison of the measured stopping powers with the values obtained by summing the stopping powers of their respective constituents is also shown in Table I, and the difference between the directly measured stopping power and that obtained by addition is reported. The values are in good agreement; the maximum deviation is 0.3% and of the same order as the experimental errors.

From the measured relative stopping power of O_2, N_2, CO_2, CO, NH_3, $S = 0.440 \pm 0.002$ has been found for carbon and $S = 0.202 \pm 0.002$ for H_2 in very good agreement with those obtained from the hydrocarbon series.

Conclusion

These results show that within the limit of experimental errors (less than $\pm 1\%$) the Bragg additivity law of stopping powers is valid for α particles at 5 MeV.

The last two columns of Table I show the relative stopping powers for 5 MeV α particles as given by Riezler (3) and Schepers and the values derived from the data of Palmer (4). Palmer's values are slightly higher than the present ones but her directly measured value for H_2 ($S = 0.209 \pm 0.006$) agrees with the present ones, as well as her derived value for C ($S = 0.433 \pm 0.009$). Similar agreement is obtained with Riezler et al. Table II summarizes again the values obtained for hydrogen and carbon and no significant difference appears which would indicate an effect of chemical bond in the stopping process.

Table I Relative stopping power at 5 MeV

Gas		Purity %	measured	calculated	difference	Palmer(4)	Riezler et al.(3)
Air			1			1	1
Ethylene	C_2H_4	99.5	1.282 (±0.4%)	1.282	0	1.311 (±2%)	
Ethane	C_2H_6	99.0	1.487	1.483	+0.004	1.491	1.461 (±1.5%)
Propylene	C_3H_6	99.0	1.920	1.923	-0.003	1.989	
Cyclopropane	$(CH_2)_3$	99.5	1.922	1.923	-0.001	1.989	
Propane	C_3H_8	99.99	2.118	2.124	-0.006	2.150	2.089
1,3-butadiene	C_4H_6	99.69	2.369	2.363	+0.006		
1-butyne	C_4H_6					2.392	
1-butene	C_4H_8	99.52	2.566	2.564	+0.002	2.634	
Butane	C_4H_{10}	99.99	2.769	2.765	+0.004	2.715	2.763
3-methylbutene-1	C_5H_{10}	99.92	3.200	3.205	-0.005		
Cyclopentane	C_5H_{10}					3.064	
Neopentane	C_5H_{12}	99.87	3.400	3.406	-0.006		
Pentane	C_5H_{12}					3.306	
	O_2	99.6	1.073				
	N_2	99.7	0.980				
	CO_2	99.8	1.511	1.513	-0.002		
	CO	99.5	0.978	0.976	+0.002		
	NH_3	99.99	0.795	0.796	-0.001		
	H_2					0.209	0.206

Table II Relative Stopping Power for Hydrogen and Carbon

Element	Present Work	Palmer (4)	Riezler et al.(3)
$C^{(a)}$	0.440	0.433	0.424
$C^{(b)}$	0.440		0.434
$H_2^{(a)}$	0.201		
$H_2^{(b)}$	0.202		
$H_2^{(c)}$		0.209	0.206

a) derived from hydrocarbon

b) derived from O_2, N_2, CO_2, CO, NH_3

c) measured directly

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