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**Bragg's additivity law of stopping power for 5 MeV  $\alpha$  particles in O<sub>2</sub>, N<sub>2</sub>, CO<sub>2</sub>, CO, NH<sub>3</sub> and hydrocarbon gases**  
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# National Research Council of Canada

Division of Applied Physics

BRAGG'S ADDITIVITY LAW OF STOPPING POWER FOR 5 MeV  $\alpha$  PARTICLES  
IN  $O_2$ ,  $N_2$ ,  $CO_2$ ,  $CO$ ,  $NH_3$  AND HYDROCARBON GASES

BY

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It is well known that a considerable fraction of stopping electrons are  
lost to the valence shells. This fact will be accounted for  
at low energy when principally the outer electrons are  
effective in the stopping process.

by

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# Bragg's Additivity Law of Stopping Power for 5 MeV $\alpha$ 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  $\alpha$  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  $\alpha$  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  $\alpha$ -particles from an  $Am^{241}$  source lose their energy, and of a semiconductor detector at a fixed distance, which measures the residual  $\alpha$  energy. The gas pressure in the cell is adjusted so that the energy loss by  $\alpha$  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  $\alpha$  particles

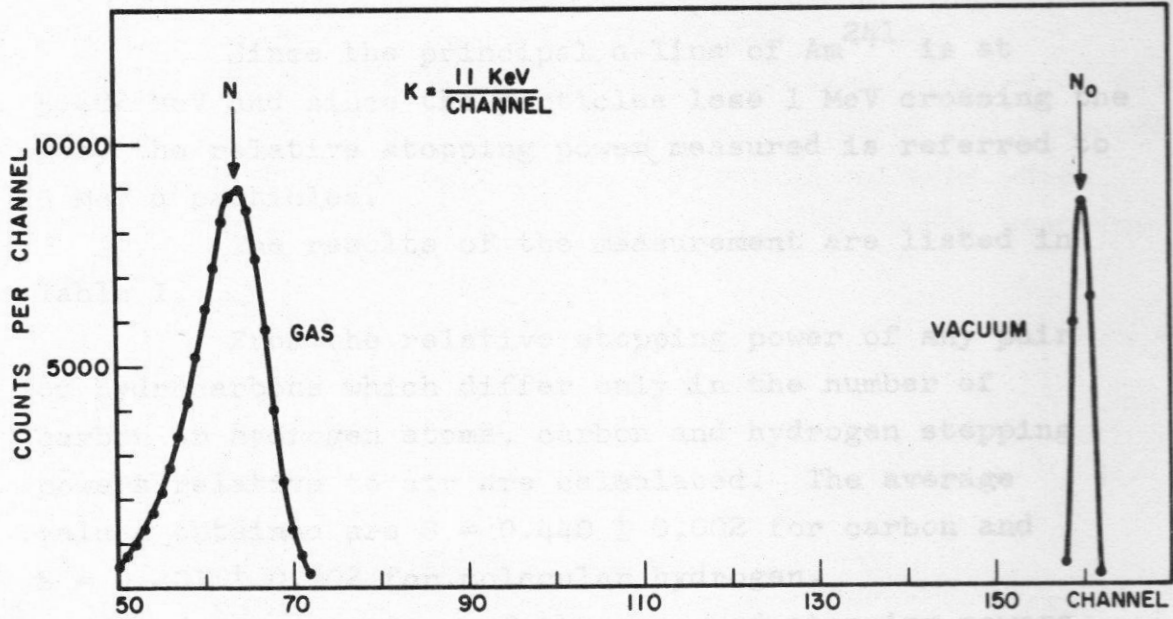


Fig. 1 Pulse height spectra from Am-241  $\alpha$ -source in vacuum; energy loss approximately 1 MeV.

in vacuum and after passing through a gas. The mean energy of  $\alpha$  particles is represented by the peak channel because the pulse height closely approximates a Gaussian shape as expected from theory. Let  $N$  and  $N_0$  be the numbers of the peak channel in gas and in vacuum, then  $K(N_0 - N) = K N$  represents the energy lost by  $\alpha$  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

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

Since the principal  $\alpha$ -line of  $\text{Am}^{241}$  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  $\alpha$  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  $\text{O}_2$ ,  $\text{N}_2$ ,  $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{NH}_3$ ,  $S = 0.440 \pm 0.002$  has been found for carbon and  $S = 0.202 \pm 0.002$  for  $\text{H}_2$  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  $\alpha$  particles at 5 MeV.

The last two columns of Table I show the relative stopping powers for 5 MeV  $\alpha$  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	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	3.306	
Pentane	$C_5H_{12}$						
	$O_2$	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 <sup>(a)</sup>	0.440	0.433	0.424
C <sup>(b)</sup>	0.440		0.434
H <sub>2</sub> <sup>(a)</sup>	0.201		
H <sub>2</sub> <sup>(b)</sup>	0.202		
H <sub>2</sub> <sup>(c)</sup>		0.209	0.206

a) derived from hydrocarbon

b) derived from O<sub>2</sub>, N<sub>2</sub>, CO<sub>2</sub>, CO, NH<sub>3</sub>

c) measured directly

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