Energy Loss of Charged Particles (Alphas)

EQUIPMENT NEEDED FROM EG&G ORTEC

Source Kit SK-1A
Surface Barrier Detector R-017-050-100
142A Preamplifier
Bin and Power Supply
575A Amplifier
807 Vacuum Chamber
428 Detector Bias Supply
480 Pulser
ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
ORC-5 Cable Set
Mechanical Vacuum Pump
Oscilloscope
AuFI-x (gold foil) and NiFI-x (nickel foil) (see Appendix)
Copper Absorber Kit MCU-5
Nickel Foils MNI-5

Purpose

In this experiment the principal concern will be the specific ionization and rate of energy loss, dE/dx, of an alpha particle as it passes through matter. The two experiments relate to alpha particles passing through copper foil and through a gas.

Theory

As stated previously, alphas from natural sources typically have energies in the range of 3 to 8 MeV. The alpha is a relatively massive nuclear particle compared with the electron (~8000 times the mass of the electron). When an alpha particle goes through matter it loses energy primarily by ionization and excitation. Since the alpha particle is much larger than the electrons with which it is interacting, it travels through matter in a straight line. The energy required to strip one electron from a gas typically lies between 25 and 40 eV. For air, the accepted average ionization potential is 32.5 eV. The number of ion pairs that are theoretically possible can therefore be calculated easily.

Specific ionization is defined as the number of ion pairs produced per unit of path length. Specific ionization is energy dependent. The reason for this energy dependence is that it affects the rate of travel through the material that is being ionized; lower energy alpha particles spend more time per unit of path length than do the higher energy particles. Figure 5.1 is the familiar Bragg curve for alpha particles.

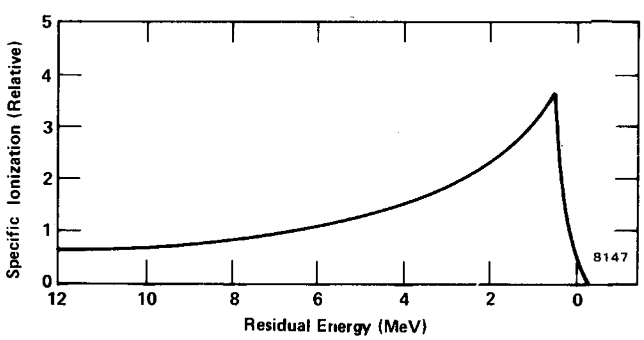

Fig. 5.1. Bragg Curve for Alpha Particles.

The dE/dx for alphas, the stopping power in ergs/cm, is given by the following expression (ref. 10).

$$\frac{dE}{dx} = \frac{2\pi Z_i^2 e^4 NZ}{m_0 c^2 \beta^2} \ln \left(\frac{2m_0 c^2 \beta^2 Q_{max} - 2\beta^2}{I^2(1-\beta^2)} \right) \quad (1)$$

where

Z_i = the atomic number of the incident particle,
e = electronic charge (esu),
m_0 = rest mass of electron (g),
c = velocity of light (cm/s),
β = ratio of incident alpha velocity divided by velocity of light,
NZ = number of electrons per unit volume of absorber (electrons/cm^3),
Q_{max} = maximum energy transfer from an electron to the alpha (ergs),
I = mean ionization potential of the target (ergs),
E = energy of the incident particle (ergs).

A careful evaluation of Eq. (1) for 5-MeV alpha particles will show that the dE/dx is approximately constant for thin absorbers in which the alpha particle will lose only 1 MeV or so

The range of an alpha particle can be found by rearranging and integrating Eq. (1) from E_0 to zero, where E_0 is the initial energy of the alpha. Figure 5.2 is an example of a graph of energy vs range. Note that the range is expressed in mg/cm^2 in Fig. 5.2.

In Fig. 5.2 E_0 is the initial energy of the alpha particle before it passes through the foil, R_0 is the range in copper of an alpha of energy E_0, E_f is the energy that still accompanies the alpha after it has passed through the foil, R_f is the range of an alpha with an E_f, and ΔX is the foil thickness in mg/cm^2.

The theoretical energy loss that should be expected for a given foil thickness can be determined by the method shown in Fig. 5.2. In the laboratory the alpha energy from the source, E_0, and the foil thickness, ΔX (mg/cm^2), will be

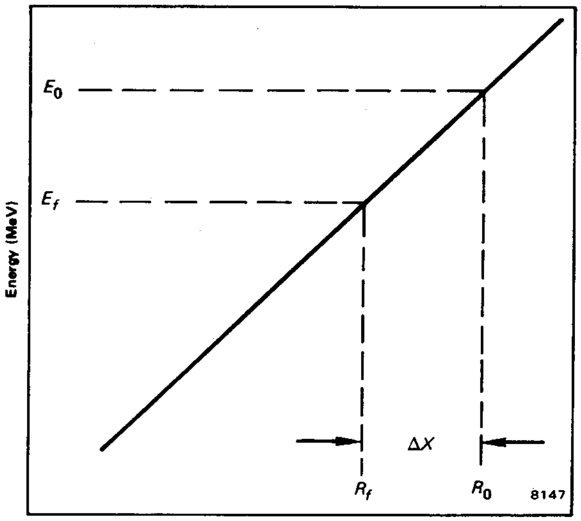

Fig. 5.2. Energy vs Range (Illustrative) for Charged Particles.

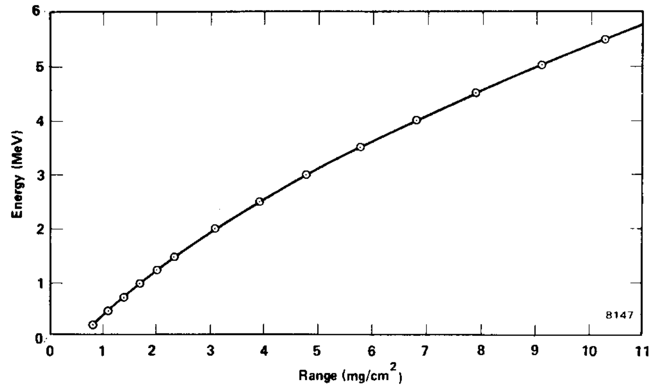

Fig. 5.3. Energy vs Range for Alpha Particles in Copper.

provided. It is then a simple matter to determine R_f, because $R_f = R_0 - \Delta X$. From R_f, energy E_f can be determined quickly.

Table 5.1 tabulates some range-energy information for copper, nickel, gold, and helium. Figure 5.3 shows a plot of these data for copper.

The foils that are best suited to dE/dx measurements are copper, nickel, and gold. Seven copper foils are included in Absorber Kit MCU-5.

Table 5.1. Range-Energy Values for Alpha Particles in Various Absorbers*

E_0 (MeV)	Ranges (mg/cm²)			
	Copper	Nickel	Gold	Helium
0.25	0.79	0.74	1.31	0.181
0.50	1.09	1.02	1.90	0.245
0.75	1.38	1.29	2.50	0.316
1.00	1.69	1.58	3.12	0.399
1.25	2.01	1.88	3.79	0.490
1.50	2.36	2.21	4.47	0.601
2.00	3.11	2.91	5.97	0.850
2.50	3.93	3.68	7.59	1.14
3.00	4.82	4.50	9.34	1.48
3.50	5.80	5.44	11.0	1.86
4.00	6.81	6.39	13.1	2.29
4.50	7.9	7.40	15.2	2.76
5.00	9.1	8.51	17.4	3.27
5.50	10.3	9.66	19.7	3.82
6.00	11.6	10.87	22.1	4.41
7.00	14.3	13.46	27.1	5.70

*Data taken from ref. 10.

EXPERIMENT 5.1

dE/dx for Alpha Particles in Copper Foil

Prerequisite: Experiment 4.1.

Procedure

1. Connect the equipment as shown in Fig. 5.4. Calibrate the system with the ^{210}Po source from the SK-1A source kit so that the 5.31-MeV alpha particles from the ^{210}Po are being stored in the top quarter of the analyzer. Plot the calibration curve and determine the resolution of the pulser and of the alpha source as in Experiment 4.1.

Module Settings:

575A Amplifier: negative input, unipolar output.
480 Pulser: positive pulse polarity, attenuated output.
428 Detector Bias Supply: negative output; raise bias slowly to value recommended for the detector.*

2. Erase the data from the MCA. Turn off the pulse generator and store the ^{210}Po spectrum long enough to obtain a sum under the alpha peak of ~4000 counts.

3. Reduce the bias voltage to zero. Open the vacuum system and place the thinnest copper foil between the source and the detector. Do not change the source-detector geometry during the rest of this experiment; both the distance and the angle of incidence must remain constant.

4. Pump the vacuum back down, increase the bias voltage gradually, and accumulate the spectrum for the same time that was used in step **2**. Determine the peak position and the sum.

5. Repeat steps **3** and **4** for all the foil thicknesses in the Absorber Kit. Figure 5.5 shows some typical data that were obtained for alpha particles on copper foil.

EXERCISES

a. From the calibration curve and the MCA data, measure the energy loss, ΔE, for each foil thickness. Note that the

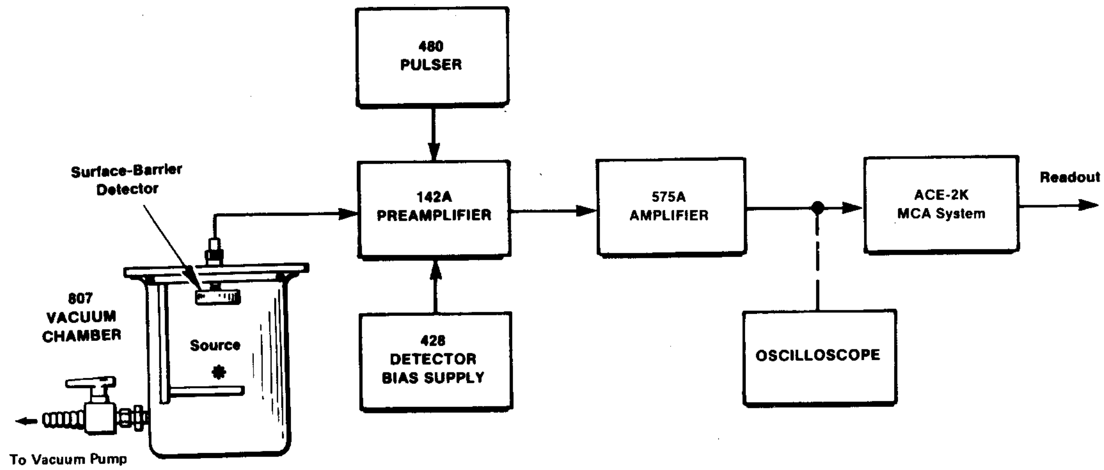

Fig. 5.4. Electronics for *dE/dx* Measurement.

resolution gets worse as the foil thickness and the ΔE values increase. Determine the resolution for each peak.

b. On linear graph paper plot the range vs energy for copper (Table 5.1). From the graph and the foil thicknesses find E_f by the method outlined in "Theory." Use the ΔE values and construct a table similar to that furnished for Fig. 5.5 (Table 5.2) for your data and fill it in.

c (optional). Repeat Experiment 5.1 with the nickel foils in Absorber Kit MNI-5.

Table 5.2. Energy Loss Data for Fig. 5.5.

Curve	Foil Thickness (mg/cm²)	Alpha Particle Energy* (MeV)	Alpha Particle Resolution (keV)	ΔE (MeV) Measured	ΔE (MeV) Calculated
A	0.00	5.47	30	0.00	0.00
B	1.23	4.95	64	0.53	0.54
C	2.06	4.55	106	0.93	0.91
D	2.50	4.36	112	1.12	1.10
E	3.74	3.69	160	1.79	1.71
F	4.22	3.44	170	2.03	1.98
G	5.00	3.03	202	2.45	2.40
H	6.24	2.33	223	3.15	3.09

*After passing through copper foil.

absorber. The pressure can be monitored by a gauge in the vacuum/supply line. The general procedure consists of placing the source ~2 cm from the detector, or closer if necessary to get good statistics within a reasonable time, pumping the full vacuum, closing off the vacuum pump, and then leaking the gas (air or helium, for example) into the chamber for the desired pressure. The number of mg/cm² of the gas can be determined by STP conditions.

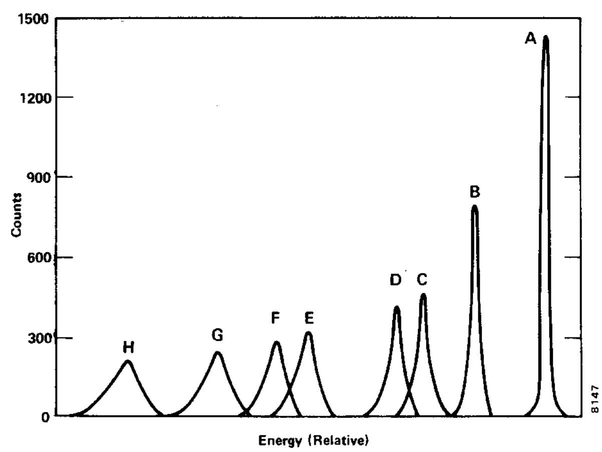

Fig. 5.5. Measured Energy Loss of Alpha Particles in Copper Foil.

EXPERIMENT 5.2

dE/dx of Alpha Particles in Gas

(optional if helium is available)

There are many advantages in using gas as an absorbing medium, because the gas pressure can be varied to any value that is desired in order to regulate the thickness of the

Procedure

1. Repeat all the steps of Experiment 5.1 using helium as the absorbing medium rather than copper foils. Take enough measurements so that your measured ΔE has at least six values between no absorber and ΔE = 4 MeV.

2. Repeat step **1** for air. Range-vs-energy values for air can be found in ref. 4. Compare your results with those shown in Table 5.3 and Fig. 5.6.

Table 5.3. Energy Loss Data for Fig. 5.6.

Curve	Air Thickness (mg/cm^2)	Alpha Particle Energy* (MeV)	Alpha Particle Resolution (keV)	ΔE (MeV) Measured	ΔE (MeV) Calculated
A	0.00	5.47	137	0.00	0.00
B	0.95	4.77	149	0.73	0.73
C	1.89	3.96	168	1.54	1.52
D	2.84	3.03	195	2.47	2.46
E	3.78	1.95	230	3.55	3.60

*After passing through air.

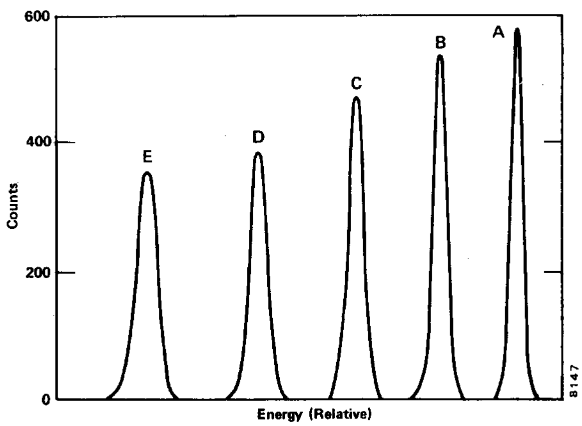

Fig. 5.6. *dE/dx* for Alpha Particles in Air.

References

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