ORTEC®

AN34 Experiment 5

Energy Loss of Charged Particles (Alphas)

Equipment Needed from ORTEC

- Charged Particle Detector BU-014-050-100
- 142A Preamplifier
- 4001A/4002D NIM Bin and Power Supply
- 575A Spectroscopy Amplifier
- 807 Vacuum Chamber
- 428 Detector Bias Supply
- 480 Pulser
- C-36-12 Cable
- C-24-12 Cables (4 ea.)
- C-24-1 Cable
- C-29 BNC Tee Connector
- TRUMP-2K-32 Plug-In MCA Card with MAESTRO-32
- ALPHA-PPS-115 Portable Vacuum Pump Station

Other Equipment Needed (not available from ORTEC)

- PC with Windows 98/2000/XP
- Unsealed Alpha Sources (Disk Type) 0.01–0.1 µCi, ^{241}Am, ^{210}Po, ^{244}Cm (substitute alternate sources with similar energies)
- Cu foil set containing 10 copper absorbers in the range from 1.25 mg/cm^2 to 7.05 mg/cm^2
- Ni foil set containing 10 nickel absorbers in the range from 1.5 mg/cm^2 to 8.25 mg/cm^2
- Gold Foil, 1.31 to 27.1 mg/cm^2
- Nickel Foil, 0.74 to 13.46 mg/cm^2
- Oscilloscope

Purpose

In this experiment the principle 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 electron with which it is interacting, it travels through matter in a straight line. The energy required to strip an electron from a gas typically lies between 25 and 40 eV. For air, the accepted average ionization potential is 32.5 eV. Therefore, the number of ion pairs that are theoretically possible can be easily calculated.

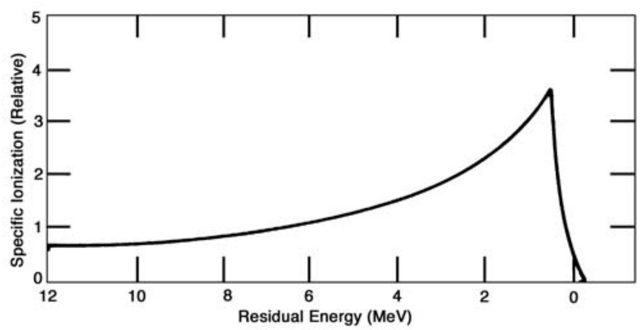

Fig. 5.1. Bragg Curve for Alpha Particles.

Specific ionization is defined as the number of ion pairs produced per unit path length. Specific ionization is energy dependent in that the energy of a particle affects its rate of travel through the material being ionized; lower energy alpha particles spend more time per unit of path length than do higher energy particles. Fig. 5.1 is the familiar 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 shows 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. Fig. 5.2 is an example of a graph of energy vs. range. Note in Fig. 5.2 that the range is expressed in mg/cm^2.

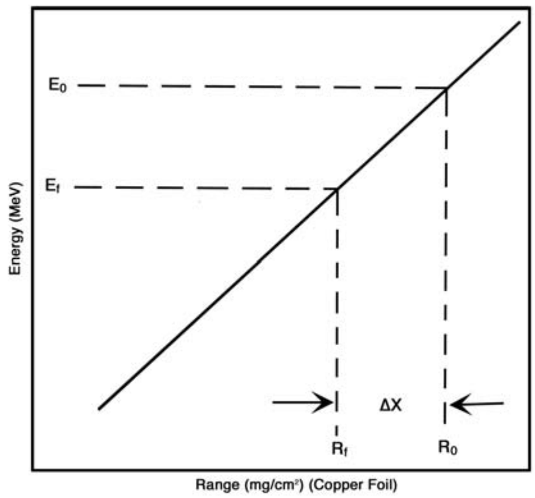

Fig. 5.2. Energy vs. Range (illustrative) for Charged Particles.

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 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. Range-Energy Values for Alpha Particles in Various Absorbers (data taken from ref. 10)

E_0 (MeV)	Ranges (mg/cm^2)			
	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	11.00	1.86
4.00	6.81	6.39	13.10	2.29
4.50	7.90	7.40	15.20	2.76
5.00	9.10	8.51	17.40	3.27
5.50	10.30	9.66	19.70	3.82
6.00	11.60	10.87	22.10	4.41
7.00	14.30	13.46	27.10	5.70

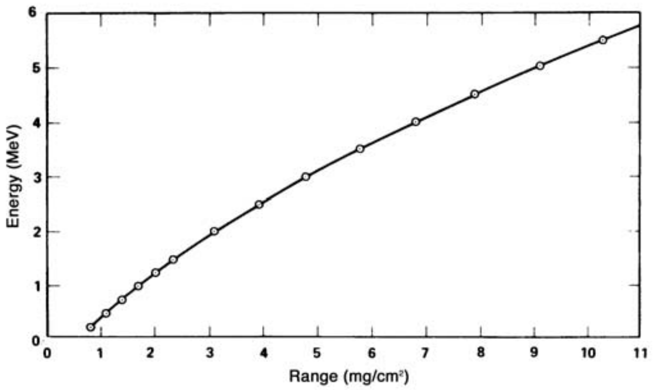

Fig. 5.3. Energy vs. Range for Alpha Particles in Copper.

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

The foils best suited to dE/dx measurements are copper, nickel, and gold.

EXPERIMENT 5.1

dE/dx for Alpha Particles in Copper Foils

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 alpha source kit so that the 5.31 MeV alpha particles from the ^{210}Po source are being stored in the top quarter of the MCA. Plot the calibration curve and determine the resolution of the pulser and of the alpha source as in Experiment 4.1.

Instrument Settings

575A Amplifier: Positive input; unipolar output.

480 Pulser: Negative pulse polarity; attenuated output.

428 Detector Bias Supply: Positive bias output; raise bias voltage slowly to value recommended for the detector.

2. Clear the MCA. Turn off the pulse generator and accumulate the ^{210}Po spectrum long enough to obtain ~4000 counts under the alpha peak.

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

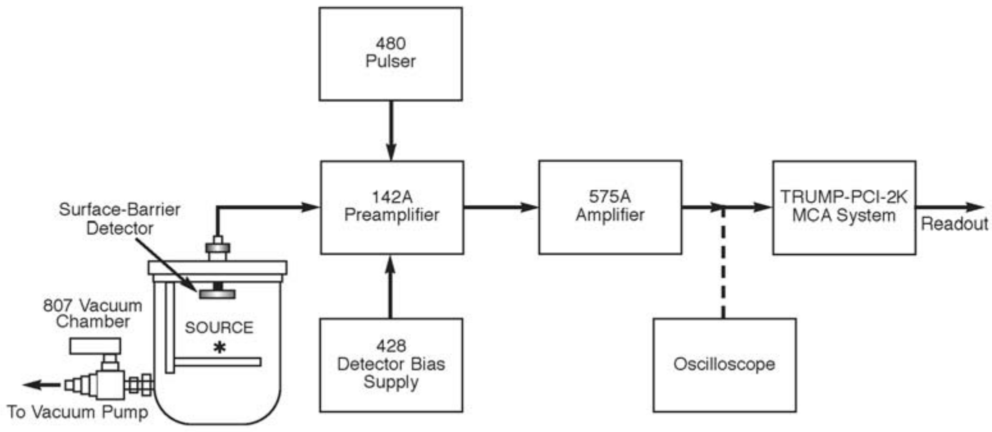

Fig. 5.4. Electronics for dE/dx Measurements.

4. Evacuate the vacuum chamber, gradually apply the bias voltage, and accumulate a 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. Fig. 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 of the foil thicknesses. Note that the 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.

Table 5.2. Energy Loss Data for Fig. 5.5

Curve	Foil Thickness (mg/cm^2)	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.

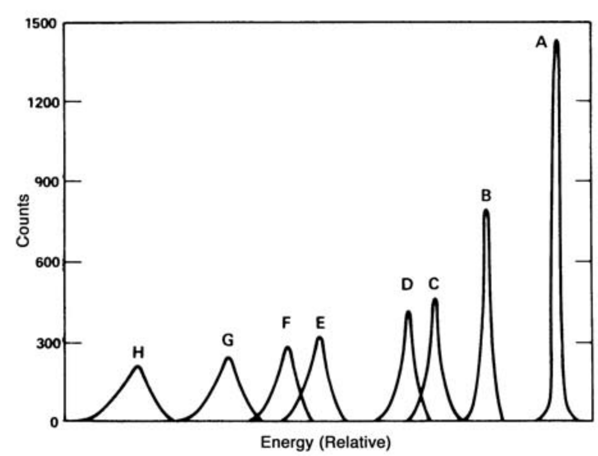

Fig. 5.5. Measured Energy Loss of Alpha Particles in Copper Foil.

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 desired value in order to regulate the thickness of the 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 acquisition 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/cm^2 of the gas can be determined by STP (standard temperature and pressure) conditions.

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	Foil 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.

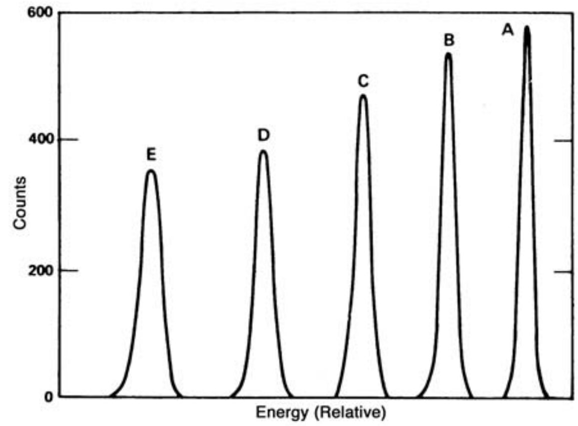

Fig. 5.6. dE/dx for Alpha Particles in Air.

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