EXPERIMENT 21

Alpha-Induced Innershell Ionization Studies with an ^{241}Am Source

EQUIPMENT NEEDED FROM EG&G ORTEC

Source Kits SK-1A and SK-1X
1 mCi ^{241}Am excitation source
Bin and Power Supply
Surface Barrier Detector A-016-100-100
Si(Li) Detector SLP-06175
142B Preamplifier
572 Amplifier
428 Bias Supply
Oscilloscope
480 Pulser
459 5-kV Detector Bias Supply
ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
Vacuum Pump
Model MAX-21 Chamber for innershell ionization studies with aluminum excitation foils and alpha absorber foils
807 Vacuum Chamber
ORC-21 Cable Set

Purpose

Alpha particles from an ^{241}Am source will be used to excite the characteristic x rays from an aluminum sample. Many of the techniques used in this experiment are the same as those used for Experiment 12, X-Ray Fluorescence. The major difference is that in Experiment 12, we used photons to excite the characteristic x rays whereas in this experiment alphas from an ^{241}Am source will be used. The experimental results of this experiment will be compared to theoretical calculations of Coulomb ionization for interaction of this type. We will also have to use the experimental techniques developed in Experiments 4, 5, and 8 to obtain the measurements in this experiment.

Introduction

The cross section for a reaction of a given type is defined to be the relative probability that an interaction will occur. In this experiment, alpha particles are allowed to bombard a thin foil of aluminum. As we saw in Experiment 5 (dE/dx measurements), the most probable event to occur when an alpha particle enters a foil is for it to lose energy by making Coulomb interactions with weakly-bound electrons. It is also possible for the alpha particle to interact with the more tightly bound K, L, or M electrons. If, for example, the Coulomb interaction occurs with the K shell electron, it can impart enough energy to completely remove this K shell electron. From the table of "X-Ray Critical Absorption and Emission Energies" in the Appendix of this manual, the binding energy of the K shell x ray in aluminum is only 1.559 keV. When this K shell electron is removed, the vacancy is immediately filled by an electron falling down from a higher orbit or an Auger transition. Auger electrons are given off when the energy difference between the two levels involved is used to eject electrons in outer-lying shells. The ratio of x rays emitted to vacancies produced is called the fluorescence yield. The probability of producing an x ray by alpha particle bombardment is quite high when it is compared to the probability of a nuclear interaction.

In this manual, one of the largest nuclear cross sections that we have dealt with is the slow neutron cross section, (5 barns), for $^{51}V(n,\gamma)^{52}V$ in Experiment 17. This is to be contrasted with Fig. 21.1 which shows that the ionization cross section for 5-MeV alphas on a manganese target is ~400 barns.

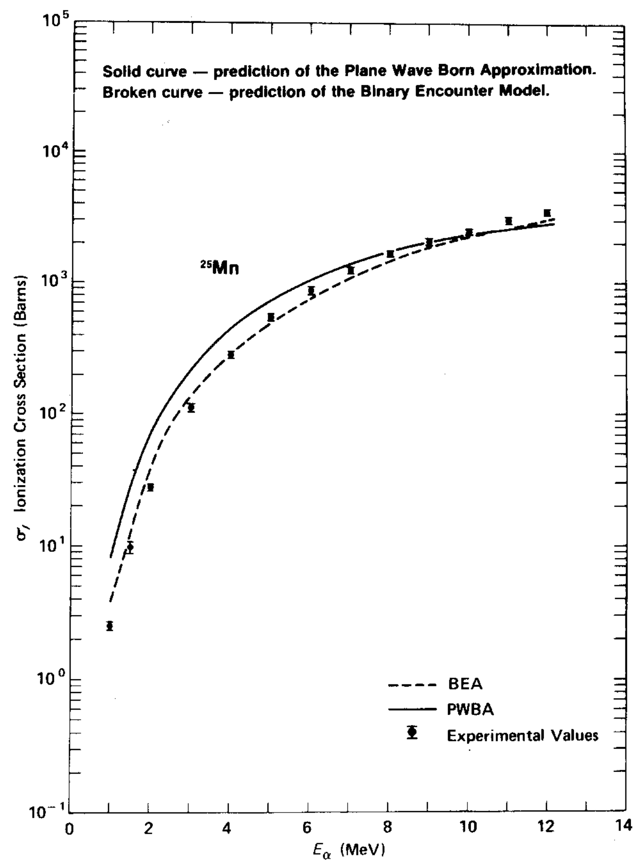

Fig. 21.1. K Shell Ionization Cross Section for Manganese by Alpha Impact.

EXPERIMENT 21.1

Innershell Ionization Induced by Alpha Particles

In this experiment it is necessary to measure the ionization cross section as a function of the alpha energy (Fig. 21.1).

The energy of the incident alpha particles from the source will be changed by inserting thin Mylar absorbers between the source and the target. These absorbers are supplied with the target chamber. Each foil has a thickness of 2.29 x 10^{-4}g/cm^2 ± 5%. Our first problem is to find the energy of the alphas from the source. Figure 4.8 in Experiment 4 shows the spectrum of alphas from a thin ^{241}Am source. The maximum energy is 5.48 MeV. The spectrum will look quite different for the 1 mCi source used in this experiment. The 5.48-MeV alphas will be attenuated before they get out of this thick source. This attenuation is produced by dE/dx in the source material itself and the material that is used to seal the source. Therefore the alpha group will appear at ~4.5 MeV. In this experiment the exact energy of the alphas will be determined from the source and also their energy after they have been attenuated with Mylar foils.

Procedure

1. Set up the 807 vacuum can with the electronics used in Experiment 4 (Fig. 4.7). Place the ^{241}Am source from source kit SK-1A ~40 mm from the detector. Pump down, apply the bias, and adjust the gain of the 572 Amplifier so that the 5.48-MeV alpha is being stored in the upper quadrant of the MCA (approximately channel 800). Turn on the pulse generator and calibrate the pulser so that 548/1000 on the pulse-height dial corresponds to the same channel where the 5.48-MeV alpha peak was being stored. With the aid of the 480 Pulser, make a calibration curve for the MCA.

2. Turn off the bias, let the system up to air, and remove the weak ^{241}Am source from the chamber. Put the "hot" 1-mCi source in the 807 chamber and measure its spectrum. Reproduce the geometry that will ultimately be used in the innershell ionization studies (Fig. 21.2). The plane passing through the source should be 40 mm from the parallel plane passing through the face of the detector. The source is off-axis by 18 mm. Under these conditions the source will be 44 mm from the center of the detector and the geometry of Fig. 21.2 has been reproduced. Evacuate the system and turn on the bias. Accumulate a spectrum in the MCA and determine the energy of the peak. Record this value; it will be our first excitation energy (no absorber) when we do the ionization experiment. We would also like to find the number of alphas/s that bombard the detector under these geometrical conditions. Note, the detector has been chosen, (100 mm^2), so that it is the same size as the aluminum target that will be used in the ionization experiment. From the MCA determine the number of alphas/s that are counted. Remember this is a "hot" source, so analyzer dead time corrections must be made. Record the number of alphas/s in Table 21.1.

3. Lower the bias to zero, let the system up to air, and place the first Mylar foil over the source. Pump down, turn on the bias, and determine the number of alphas/s and the energy of the peak. Repeat for all seven absorbers and record all data in Table 21.1. A plot of these peaks would look similar to Fig. 5.5 in Experiment 5.

EXPERIMENT 21.2

Efficiency of the Si(Li) Detector

In Experiment 8.2 the efficiency of a Si(Li) detector was measured. The student should read all of Experiment 8 before proceeding with this experiment. The sources that will be used for this calibration are the x-ray sources from source kit SK-1X, that is, ^{57}Co, ^{54}Mn, and ^{65}Zn.

Procedure

1. The chamber shown in Fig. 21.2 will be used for this experiment. Set up the electronics as shown in Fig. 21.2. Do not put the 1-mCi ^{241}Am source in the chamber. Place the ^{57}Co source from the source kit directly on top of the aluminum target in Fig. 21.2. Evacuate and adjust the gain of the 572 Amplifier so that the 5.9-keV peak is being stored at around channel 500. Figure 8.4 shows the spectrum. Determine the channel position of both peaks and the total num-

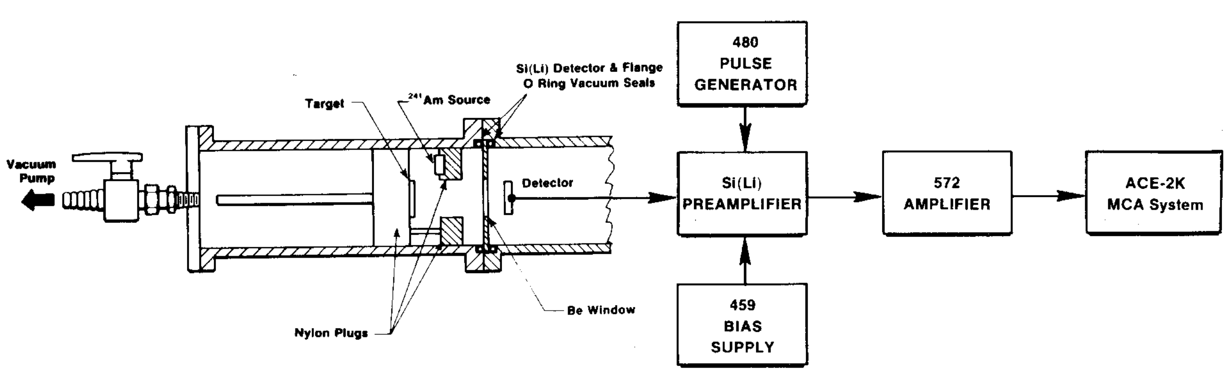

Fig. 21.2. Chamber for Innershell Ionization Studies with Electronics.

Table 21.1. Innershell Ionization Measurement Data.

Mylar Absorbers	E_α Measured	N_i Alphas/s (on the target)	Σ X Rays/s	σ_x Experimental	σ_x Theory
No Absorber					
1					
2					
3					
4					
5					
6					
7					

ber of x rays/s. Repeat for the ^{54}Mn and ^{65}Zn sources in the source kit.

2. Make an energy calibration curve. From the known number of x rays for each source (Table 21.2) and Experiment 8.2, plot the efficiency, E, for the three K_α lines for these isotopes. Please note that the intensity ratios, X/γ, shown in Table 21.2 include K_α and K_β in the summation.

Table 21.2. Energy and X-Ray Intensity Ratios of ^{54}Mn, ^{57}Co, and ^{65}Zn.

Nuclide	Energy of X-Rays and Low-Energy Gamma (keV)	Energy of High-Energy Gamma (keV)	Intensity Ratio X/γ
^{54}Mn	5.414 (K_α)	834.8	0.2514 (±0.5%) $K_\alpha + K_\beta$
	5.946 (K_β)		
^{57}Co	6.40 (K_α)	122.1	0.5727 (±2.0%)
	7.06 (K_β)		0.7861 (±2.9%)
	14.41 (γ)		0.112 (±1.8%)
^{65}Zn	8.04 (K_α)	1115.5	0.6596 (±0.8%)
	8.9 (K_β)		0.0911 (±2.0%)

3. The aluminum K_α line has an energy of 1.487 keV. The lowest point on the efficiency data above is 5.414 keV from the ^{54}Mn source. The efficiency of the detector can be calculated for the aluminum K_α line and normalized to the above experimental data to give the complete efficiency curve. This method has been described extensively in the literature (refs. 9 and 10). Figure 8.2 (Experiment 8) shows the window cutoff effect which completely dominates the efficiency at these low energies. For the detector used in this experiment the window attenuation can be calculated from the following:

$$I = I_0 \exp^{(-\Sigma \mu_i x_i)}, \qquad (1)$$

where the μ_i are the linear absorption coefficients for the various window parameters and the x_i are the quoted thicknesses of these parameters from the detector specification sheets. For the detector used in this experiment these parameters consist of: the Be entrance window, the gold contact (2.2 μm), and the silicon dead layer (0.5 μm). There is also a Mylar entrance window (2.54 μm) on the chamber. The linear absorption coefficients of all of these materials are given in ref. 11.

Figure 21.3 shows an efficiency curve for a Si(Li) detector with a thick (10 mil) piece of Mylar between the target and the entrance window of the detector. The dashed portion of the curve is the part that was calculated with the attenuation equations. In our case the normalization would be to the ^{54}Mn K_α line at 5.414 keV.

For a typical 0.5×10^{-3} in. Be window detector, the efficiency, E, for the aluminum K_α was calculated to be 1.72×10^{-4}. The value that you calculate for your detector may be slightly different depending on the Be entrance window thickness, etc.

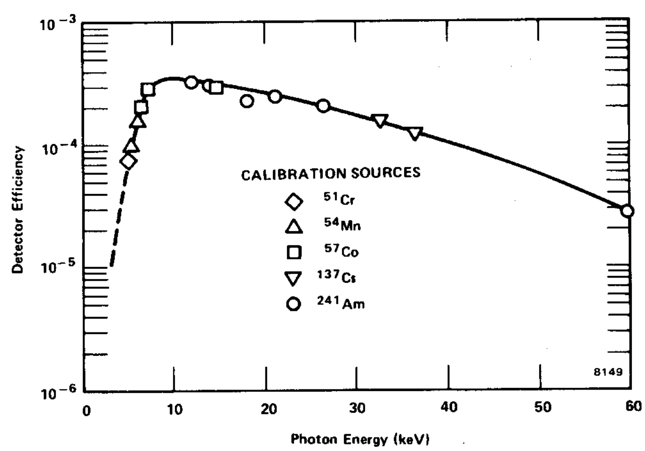

Fig. 21.3. Typical Si(Li) Detector Efficiency Curve (using 10-mil Mylar absorber).

EXPERIMENT 21.3

The Innershell Ionization Measurements

Procedure

1. Remove the x-ray calibration sources and place the 1-mCi ^{241}Am source in the chamber (no Mylar absorber). Pump back down and accumulate a spectrum for a time period long enough to record 2000 counts in the 1.48-keV aluminum $K\alpha$. Figure 21.4 shows a typical pulse height spectrum of an alpha excited aluminum $K\alpha$ x ray. Record the number of x rays/s in Table 21.1.

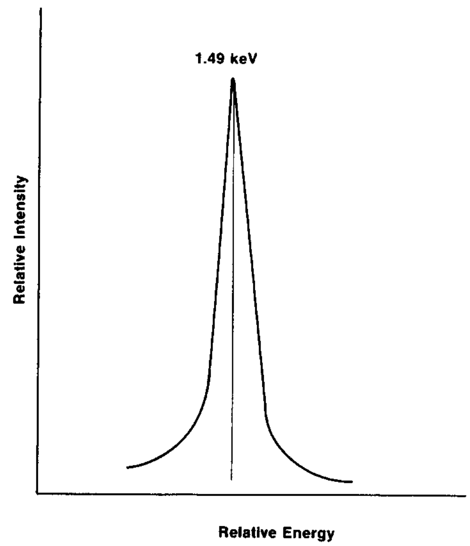

Fig. 21.4. Characteristic K X-Ray Spectrum for Alpha Particles on Aluminum.

2. Open the vacuum system and place the first Mylar foil over the ^{241}Am source and accumulate a spectrum. Repeat for all the foils in the foil kit. Record the data in Table 21.1.

3. At this time the experimental cross section can be calculated. The experimental x-ray production cross section is given by:

$$\sigma_x = \frac{\Sigma_x}{N_0 N_I \epsilon} \qquad (2)$$

where Σ_x is the number of aluminum x rays/s minus the background, N_0 is the number of target nuclei/cm^2, N_I is the number of alphas/s that bombard the target, and ϵ is the Si(Li) detector efficiency. We have previously measured everything except N_0. The aluminum target foil is 2.6×10^{-4} g/cm^2 which gives $N_0 = 5.9 \times 10^{18}$ atoms/cm^2. You can now calculate σ_x for all of the incident alpha energies that were used for the experiment. Record these values as σ_x (Experimental) in Table 21.1.

4. Table 21.3 shows the theoretical values for the x-ray production cross section for alphas on aluminum.

Table 21.3. σ_x (Theory) Plane Wave Born Approximation, (PBWA), Calculations.
[Cross sections are x-ray production, W_k, (Fluorescence Yield) = 0.039 for aluminum. (These calculations are easily done from the formulas outlined in refs. 5, 12, 13, and 14.)]

E_α (MeV)	σ_x (theory) (barns)
5.0	3.18×10^3
4.5	2.98×10^3
4.0	2.71×10^3
3.5	2.37×10^3
3.0	2.00×10^3
2.5	1.59×10^3
2.0	1.21×10^3
1.5	0.72×10^3
1.0	0.33×10^3

These theoretical cross sections are presented in the literature (refs. 5, 12, 13, and 14) in such a manner that a student can do the simple calculations and thus determine the values shown in Table 21.3. From Table 21.3 plot σ_x vs E_α (theory) and plot the measured σ_x vs E_α (experimental) from Table 21.1. The final plot, Fig. 21.5, compares the theoretical (PWBA) curve and the experimental points.

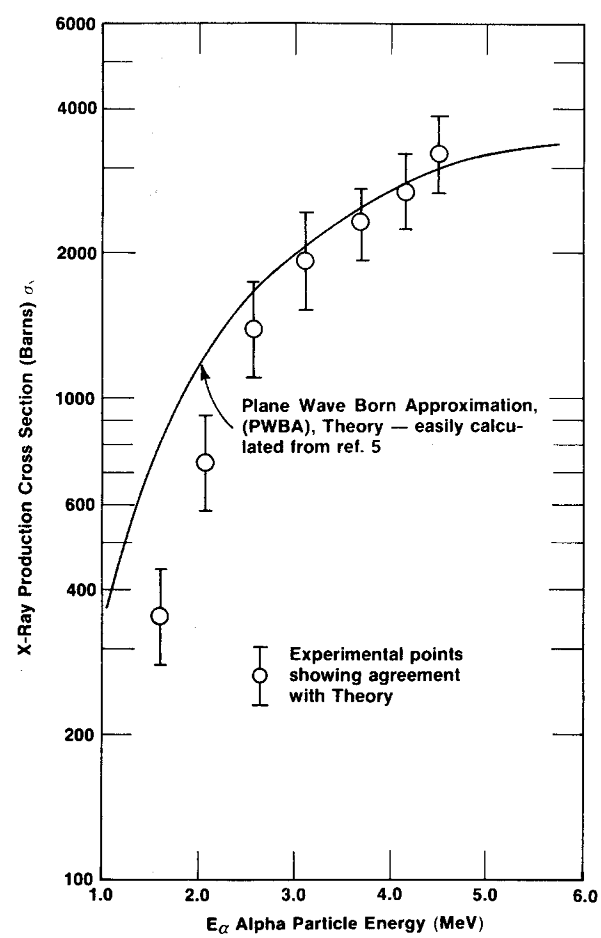

Fig. 21.5. Aluminum X-Ray Production Cross Section vs Alpha Particle Energy.

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