ORTEC®

AN34 Experiment 17

Neutron Activation Analysis (Slow Neutrons)

Equipment Needed from ORTEC

- 113 Scintillation Preamplifier
- 266 Photomultiplier Tube Base
- 4006 or 4001A/4002D Bin and Power Supply
- 556 High Voltage Power Supply
- 575A Amplifier
- 905-3 2-in. x 2-in. or 905-4 3-in. x 3-in. NaI(Tl) Detector and PM Tube
- Easy-MCA 2k System including a USB cable, a suitable PC and MAESTRO-32 software (other ORTEC MCAs may be substituted)
- Coaxial Cables and Adapters:
  - One C-24-1/2 RG-62A/U 93-Ω coaxial cable with BNC plugs on both ends, 15-cm (1/2-ft) length.
  - One C-24-12 RG-62A/U 93-Ω coaxial cable with BNC plugs on both ends, 3.7-m (12-ft) length.
  - Two C-24-4 RG-62A/U 93-Ω coaxial cables with BNC plugs on both ends, 1.2-m (4-ft) length.
  - One C-36-12 RG-59B/U 75-Ω cable, with SHV female plugs on both ends, 3.7-m (12-ft) length.

Equipment Required from Other Manufacturers

- Oscilloscope (bandwidth ≥100 MHz).
- 1- to 3-Ci Am-Be neutron source (locked into Neutron Howitzer).
- Neutron Howitzer and Activation Chamber. (see Appendix)
- 313 Activation Sample Set. (see Appendix)
- 317 Activation Sample Set. (see Appendix)
- Cd-17 Cadmium Foil Shield.
- V-17 Vanadium Saturation Factor Kit: 10 ea. identical vanadium samples; similar to the 313 Activation Sample Set.
- RE-17 Special Sample Set. (see Appendix)
- ~1 µCi activity ^{137}Cs source and ^{60}Co source for energy calibration; from Source Kit SK-1G (sealed solid-disk gamma-ray sources).
- Small flat-blade screwdriver for tuning screwdriver-adjustable controls, or an equivalent potentiometer adjustment tool.

Purpose

This experiment will demonstrate the principles of element identification using the technique of slow neutron activation.

Introduction

Neutron activation analysis is a very powerful analytical technique for identifying many elements present in samples of unknown composition. Basically, the technique is quite simple. A sample is irradiated by slow neutrons and becomes radioactive. By measuring the β^+, β^-, and γ emissions, and the half-life of the radioactive sample, the elemental constituents of the sample and their relative concentrations can be determined.

Industrial activation analysis is usually done with slow neutrons from a reactor, where the neutron flux can be as high as 5×10^{13} neutrons/cm^2/s, or with an accelerator with fast neutron fluxes of 10^{10} neutrons /cm^2/s. When activation analysis is compared with other analytical methods, such as gravimetric, colorimetric, spectrographic, or mass spectroscopy, its sensitivity is usually shown to be better by a factor of 10 than that of other methods. Activation analysis is used extensively in such fields as geology, medicine, agriculture, electronics, metallurgy, criminology, and the petroleum industry.

The Neutron Source

This experiment is described using 1 Ci of Am-Be for the neutron source, with the source located in the center of a paraffin howitzer. The samples are irradiated at a point ~4 cm from the source by the neutrons whose energies have been moderated by the paraffin between that point and the source. Any of the commonly found isotopic neutron sources can be used for this experiment.

Neutron Activation Equations

Assume that the sample has been activated in the howitzer. At the instant when the activation has been terminated, ($t_c = 0$), the activity of the sample is given by the following expression:

$$A_0 = \frac{\sigma m \eta \phi \alpha S}{w_A} \qquad (1)$$

Where

A_0 = the number of disintegrations per second of the element in the sample at $t_c = 0$ (when irradiation stops and counting begins),

σ = the cross section for the reaction in cm^2,

m = the mass of the target element in grams,

η = Avogadro's number, 6.023×10^{23} molecules/mole

ϕ = the neutron flux, expressed in neutrons/cm^2/s,

α = fraction of the target isotope in the sample (e.g., with an ordinary copper sample producing the ^{63}Cu (n, γ) ^{64}Cu reaction, $\alpha = 0.69$ since 69% of all natural copper is ^{63}Cu),

$S = 1 - e^{-\lambda t}$ is the saturation factor, where $\lambda = 0.693/T_{1/2}$ and $T_{1/2}$ is the half-life for the reaction products, while t is the time spent under neutron irradiation.

w_A = the gram atomic weight of the element.

(Note: In the above definitions, t and $T_{1/2}$ must be in the same time units.)

Let us examine Eq. (1) in terms of our knowledge about a reaction. For example, if we were activating an aluminum sample, the following reaction would take place:

$$^{27}\text{Al}(n,\gamma)^{28}\text{Al}, \qquad T_{1/2} = 2.3 \text{ min.} \qquad (2)$$

The cross section from ref. 13 is 0.21×10^{-24} cm^2. For our example then, we can determine everything in Eq. (1), except A_0 and ϕ. A_0 can be measured with a scintillation counter (the technique that is outlined), and ϕ will be determined in Experiment 17.1.

Table 17.1 is a list of common thermal neutron cross sections that is taken from ref. 11.

Table 17.1 Common Thermal Neutron Cross Sections.		
	Reaction	σ (barns)
1.	$^{27}Al(n,\gamma)^{28}Al$	0.210 ±0.020
2.	$^{51}V(n,\gamma)^{52}V$	5.00 ±0.010
3.	$^{63}Cu(n,\gamma)^{64}Cu$	4.51 ±0.23
4.	$^{23}Na(n,\gamma)^{24}Na$	0.536 ±0.010
5.	$^{55}Mn(n,\gamma)^{56}Mn$	13.3 ±0.2

After irradiation the sample is transferred immediately to the NaI(Tl) detector, and a spectrum is accumulated for a counting time, t_c, long enough to get reasonable statistics for the counts in the photopeak. The time is usually at least one half-life. The true number of disintegrations, N_d, that occurred during t_c can be determined from the following:

$$N_d = \frac{\Sigma_p - \Sigma_B}{G\varepsilon_P f} \qquad (3)$$

Where

Σ_p = the sum of the counts under the photopeak,

Σ_B = the background for the same counting period under the photopeak,

G = $A/2\pi s^2$, where A = the area of detector in cm^2, and s = the distance from the source to detector in cm.

ε_p = the intrinsic peak efficiency for the gamma-ray energy and the detector size used (Fig. 3.6, Experiment 3.6 , or ref. 10 in Experiment 3), and

f = the decay fraction of the unknown activity, which is the fraction of the total disintegrations in which the measured gamma is emitted (refs. 7 and 10 and Table 3.2 in Experiment 3.6).

From the decay equation, N_0 can be calculated:

$$N_d = N_0(1-e^{-\lambda t_c}) \qquad (4)$$

Where N_0 is the number of radioactive nuclei (of the isotope being detected) that existed in the sample at time, $t_c = 0$, and t_c is the time during which the gamma rays from the sample were counted.

Subsequently, the activity at time $t_c = 0$ can be calculated from

$$A_0 = \lambda N_0 \qquad (5)$$

Therefore we have reduced unknown parameters in Eq. (1) to one, i.e., ϕ, which is the number of neutrons/cm^2/s for our howitzer. The secondary purpose of this experiment is to find ϕ for the howitzer, using the $^{27}Al(n,\gamma)^{28}Al$ reaction. We will also use that value of ϕ to determine the cross section for the $^{51}V(n,\gamma)^{52}V$ reaction.

EXPERIMENT 17.1

Neutron Flux Determination

Procedure

1. Set up the electronics as shown in Fig. 17.1. The details for cable connections and instrument settings are:
   a. Ensure the NIM bin power and the HV Power Supply are turned off.
   b. Connect the ANODE output of the 266 PMT Base to the INPUT of the 113 Scintillation Preamplifier using the 15-cm C-24-1/2 RG-62A/U 93-Ω cable. Set the INPUT CAPacitance switch on the 113 to zero.
   c. Connect the 113 Preamplifier power cable to the PREAMP POWER connector on the rear panel of the 575A Amplifier. Check that the time constant switches accessible through the side panel of the 575A Amplifier are all set to 0.5 μs.
   d. Insert the 575A Amplifier and the 556 HV Power Supply in the NIM bin.
   e. Connect the 113 Preamplifier OUTPUT to the 575A Amplifier INPUT using the 3.7-m C-24-12 RG-62A/U 93-Ω cable. Set the amplifier input polarity to NEGative.
   f. Using the 3.7-m C-36-12 RG-59B/U 75-Ω cable with two SHV female plugs, connect the OUTPUT of the 556 HV Power Supply to the POS HV input of the 266 PMT Base. Check that the POLARITY switch on the rear panel of the 556 is set to POSitive. Set the front-panel voltage controls on the 556 to their minimum values.
   g. Connect the Bipolar output of the 575A Amplifier to the analog INPUT of the Easy-MCA using the 1.2-m C-24-4 RG-62A/U 93-Ω cable.
   h. Turn on power to the NIM bin and the computer that supports the Easy MCA.

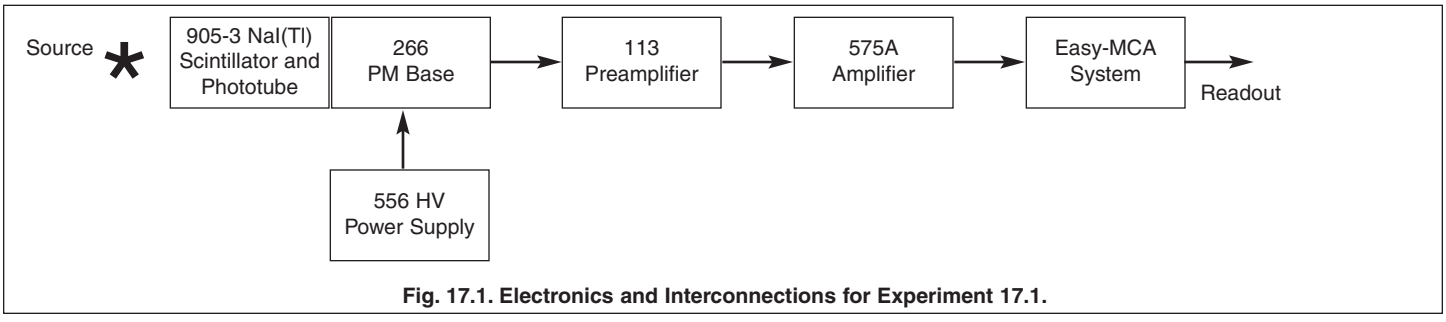

Fig. 17.1. Electronics and Interconnections for Experiment 17.1.

2. Position a ^{60}Co radioactive source from the source kit in front of the NaI(Tl) detector.
3. Adjust the controls on the instruments as follows:
   a. Set the 556 high voltage to the value that is recommended for the scintillation detector. Turn on the 556 HV POWER.
   b. Set the amplifier gain for a bipolar output amplitude of approximately +6 V, as observed on the 1-MΩ input of the oscilloscope. Check that the FOCUS control on the related 266 PMT base has been adjusted to maximize the above pulse height. Reconnect the 575A BIpolar OUTput to the analog INPUT of the Easy-MCA.
4. Connect the UNipolar OUTput of the 575A Amplifier to the 1-MΩ input of the oscilloscope. Set the horizontal scale of the oscilloscope to 50 µs/cm and the vertical scale to 100 mV/cm. With a small, flat-blade screwdriver, adjust the PZ ADJ on the 575A Amplifier to make the pulses on the UNIpolar OUTput return to baseline as quickly as possible without undershooting the baseline between pulses. For further guidance on the Pole-Zero Cancellation adjustment, consult the instruction manual for the amplifier, or the introduction to the amplifier product family on the ORTEC web site at www.ortec-online.com.
5. Via the Acquire menu and the ADC tab in the MAESTRO-32 software that operates the Easy-MCA, select the Gate Off option, and adjust the Upper Level discriminator to its maximum value. Adjust the Lower Level discriminator as low as possible without causing excessive counting rate on the noise. It may be useful to temporarily turn off the 556 High Voltage for the Lower Level discriminator adjustment. Under the Preset tab, clear all data fields, and do the same for the MDA Preset option (if supported). Clearing those fields will default to manual control for starting and stopping spectrum acquisition. Select the analog-to-digital conversion range to be 1024 channels for a 0 to +10-V input. Familiarize yourself with the software controls for setting up, acquiring and erasing spectra.
6. Adjust the amplifier gain to calibrate the system for full scale on the MCA of ~2 MeV. Use the ^{137}Cs and ^{60}Co gamma sources from the source kit for the calibration. Draw the calibration line (as in Experiment 3 or use the MCA energy calibration feature).
7. Place the aluminum sample in the howitzer and activate it for 5 minutes. Transfer it immediately to the scintillation counting position and count it for a clock time [t_c in the discussion preceding Eq.(3)] of 2 minutes.

EXERCISE

a. Identify the 1.78-MeV gamma-ray peak in the spectrum and record the sum of the counts in a Region of Interest set across the entire photopeak. Write down the elapsed counting time, and the percent dead time displayed by the MCA.

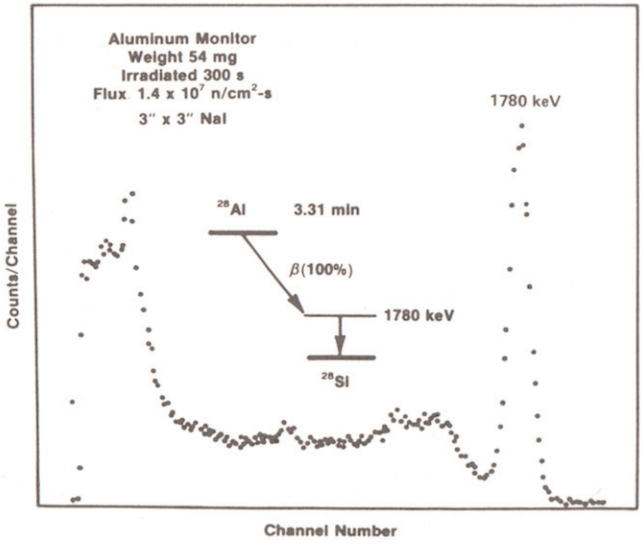

Fig 17.2 Thermal Neutron Activation Spectrum of ^{28}Al.

8. Remove the sample and count the background in the same Region of Interest for the identical 2-minute counting time. Record the percent dead time. From your data determine N_d of Eq (3).

EXERCISES

b. Substitute the value for N_d into Eq (4). Solve for N_0 and A_0 in Eqs. (4) and (5).

c. Solve Eq. (1) for ϕ using the accepted cross section for the ^{27}Al(n,γ)^{28}Al reaction (0.21 x 10^{-24} cm^2).

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9. Since the half-life for the reaction is 2.24 min, the sample activity will die out within approximately 20 minutes. After approximately this period of time, repeat the experiment and determine a second value for ϕ. If the work has been done carefully, the numbers should agree to within 5% of each other. Determine the average value of ϕ to be used in Experiment 17.2.
10. QUESTIONS: What effect does the dead time recorded above have on your calculated value of ϕ? What is the error in the averaged value of ϕ resulting from the standard deviations estimated from the number of recorded counts?

EXPERIMENT 17.2

Measurement of the Thermal Neutron Cross Section for the $^{51}V(n,\gamma)^{52}V$ Reaction

Procedure

1.Use the same electronics setup as for Experiment 17.1

2. Activate the vanadium sample for 5 min. Transfer it to the scintillation counting station and count for t_c = 2 min.

3. Measure the counts in a region of interest set to span the 1.434 MeV gamma-ray peak from the ^{52}V decay.

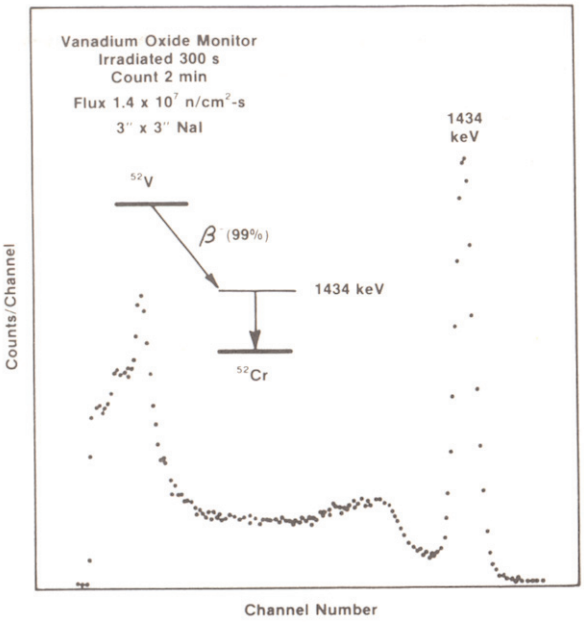

Figure 17.3 Thermal Neutron Activation Spectrum of ^{52}V.

EXERCISE

Use the average value of ϕ from Experiment 17.1 and the procedure discussed above to solve for σ, the cross section for the $^{51}V(n,\gamma)^{52}V$ reaction. The accepted value is 4.9 x 10^{-24} cm^2. Do your results agree with this value? How does the uncertainty from counting statistics affect the agreement?

EXPERIMENT 17.3

Determination of the Half-Life for the $^{27}Al(n,\gamma)^{28}Al$ Reaction

Procedure

1. Use the same electronics setup as for Experiment 17.1.

2. Set the MCA Region of Interest, (ROI), so that it brackets the 1780-keV peak from the decay of ^{28}Al. See Fig. 17.2 for a typical spectrum from aluminum.

3. Activate the aluminum sample (used in Experiment 17.1) for 5 min.

4. Transfer the sample and take a 15-s counts every 45 s, for a total experiment time of at least 6 minutes.

5. Record the counts in the ROI, the counting time and the percent dead time for each 15-s spectrum.

EXERCISE

a. Plot the counts from the ROIs versus elapsed laboratory clock time on semilog paper or in an Excel graph, and determine $T_{1/2}$.

b. QUESTIONS: Was the percent dead time high enough to cause a significant distortion of the decay curve? What was the contribution to the uncertainty in $T_{1/2}$ caused by counting statistics?

NOTE: Many other slow neutron reactions can be studied with the isotopic neutron source and the electronics of Experiment 17. Any of these can be undertaken if the appropriate target materials are available. For example, Figure 17.4 shows the fall-off in intensity of the ^{51}Ti activity ($T_{1/2}$ = 5.8 min.) displayed as four pulse-height spectra. The reaction was $^{50}Ti(n,\gamma)^{51}Ti$. If we were doing this experiment, the ROI would be set to bracket the 320-keV photopeak.

Reference 11 outlines many of the interesting neutron activation experiments. Table 17.2 (taken from ref. 11) is a rather complete listing of reactions that seem to work well for experiments by students. Some of the resulting decay schemes are more complex than those we have studied in Experiments 17.1, 17.2, and 17.3. For example, Fig 17.5 shows the decay of ^{187}W. Some of the pertinent gamma-ray energies are listed in Table 17.2

Table 17.2 Recommended slow Neutron Reactions.

Element	Target Nuclide	Target Material	Product Nuclide	$T_{1/2}$	E_γ(MeV)
Aluminum	^{27}Al	Al, Al_2O_3	^{28}Al	2.24 m	1.78
Sodium	^{23}Na	Na_2CO_3	^{24}Na	15.0 h	2.75, 1.37
Vanadium	^{51}V	NH_4VO_3 or metal	^{52}V	3.77 m	1.43
Manganese	^{55}Mn	MnO_2	^{56}Mn	2.58 h	0.845, 1.81, 2
Cobalt	^{59}Co	CoO or foil	^{60m}Co	10.5 m	0.059
Copper	^{63}Cu	CuO or foil	^{64}Cu	12.9 h	0.511 $\gamma\pm$
Gallium	^{71}Ga	Ga_2O_3	^{72}Ga	14.3 h	0.63, 0.83
Germanium	^{74}Ge	Ge (metal)	^{75}Ge	82 m	0.26, 0.20
Arsenic	^{75}As	As_2O_3	^{76}As	26.5 h	0.56, 0.66, 1
Bromine	^{79}Br	NH_4Br	^{80}Br	18 m	0.62, 0.51 $\gamma\pm$
Indium	^{115}In	In (metal foil)	^{116m}In	54 m	0.40, 1.09, 1.27, 2.08
Tellurium	^{130}Te	Te	^{131}Te	25 m	0.15, 0.45
Iodine	^{127}I	NH_4I	^{128}I	25 m	0.46
Lanthanum	^{139}La	La_2O_3	^{140}La	40.2 h	0.48, 1.59
Tungsten	^{186}W	WO_3	^{187}W	24 h	0.480, 0.686, 0.134
Gold	^{197}Au	Au-Dowex-1 (gold foil)	^{198}Au	64.8 h	0.411

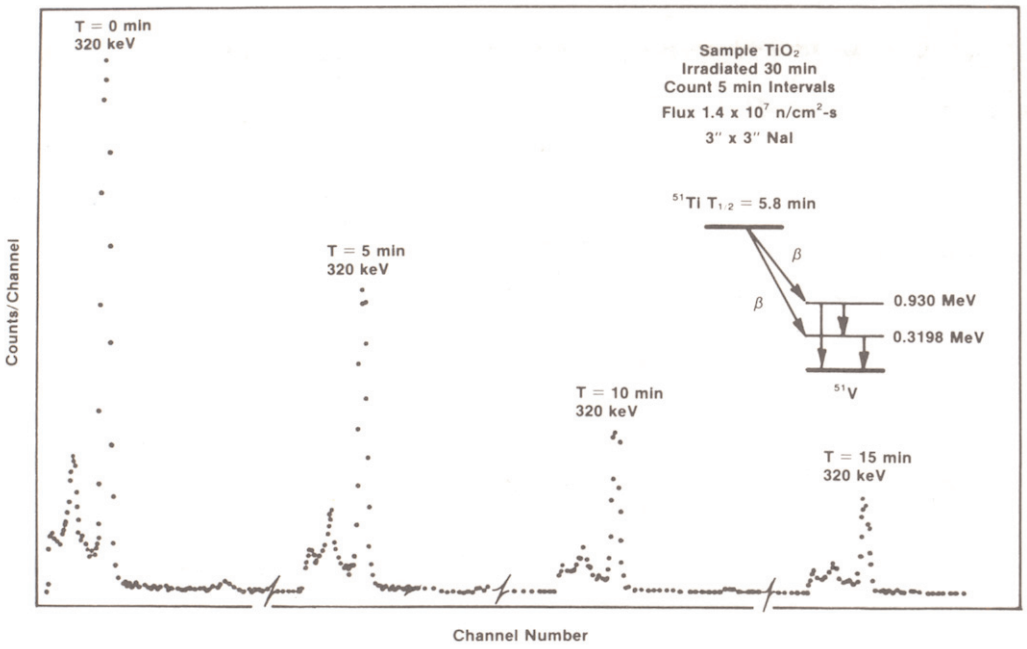

Figure 17.4 Series of Four Pulse-Height Spectra for ^{51}Ti Showing the Fall-Off in Activity over Time.

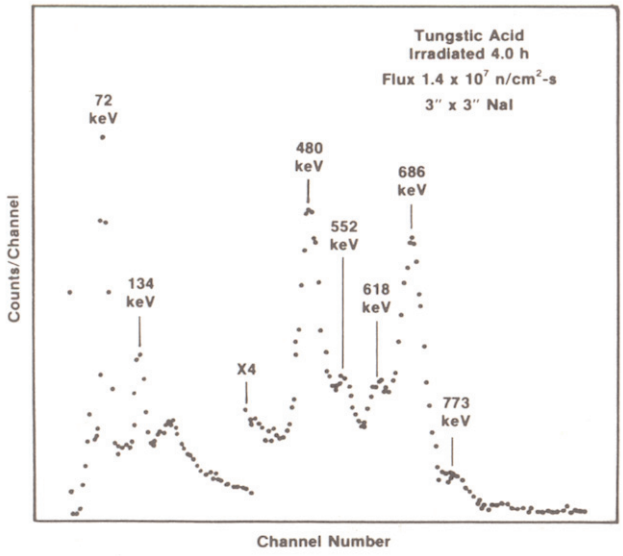

Figure 17.5 Gamma-ray Spectrum for Tungsten Resulting from Neutron Activation.

EXPERIMENT 17.4

The Saturation Factor in Neutron Activation Analysis

From the definitions at the beginning of Experiment 17, the saturation factor is given by:

$$S = 1 - e^{-\lambda t} \quad \text{with} \quad \lambda = \frac{0.693}{T_{1/2}} \qquad (6)$$

From this expression it can be seen that the activity after a neutron irradiation time, t, is given by:

$$A_t = A_S(1 - e^{-\lambda t}) \qquad (7)$$

Where A_S is the activity at saturation. As t becomes very large compared to $T_{1/2}$, the activity, A_t, approaches the saturation activity, A_S, which is the maximum possible activity. Eq. (7) reveals that the activity will reach 90% of the saturation activity if irradiated for 3.3 half-lives, and 95% of the maximum possible activity if irradiated for 4.3 half-lives. Consequently, there is no point in irradiating the sample much longer than 3 to 4 half-lives.

In this experiment we will verify Eq. (7) for the decay of ^{52}V (Fig. 17.3). Each of the vanadium samples in the Model V-17 Kit contains 2 g of NH_4VO_3. In the experiment, we will irradiate these identical samples for different times, t, and plot the corresponding ^{52}V activity as a function of irradiation time.

Procedure

1. Use the electronics shown in Fig. 17.1 as set up in Experiment 17.1.
2. Set the ROI of the MCA so that it brackets the 1434-keV gamma-ray line (Fig.17.3). This can be done by irradiating one

of the samples for 5 min and counting it directly against the face of the NaI(Tl) detector.

3. Irradiate samples for 2, 4, 6, 10, 15, and 25 min. Note: To save time, all of the ports of the neutron howitzer may be used, if the flux density, ϕ, has been determined to be the same in all ports. Otherwise use the same port for each sample.
4. After irradiation, immediately transfer each sample to the counting station and count for exactly 100 s. The distance between the sample and the detector must be identical for each sample. For each acquired spectrum, record the counts in the ROI set on the 1.434-MeV photopeak, the percent dead time, the counting time and the irradiation time.

EXERCISE

a. Since the $T_{1/2}$ of the vanadium activity is 3.77 min, an irradiation time of 25 min (6.6 half-lives) should yield an activity within 1% of A_S in Eq. (7). Therefore, we can call the counts under the ROI for the 25-minute irradiation A_S. For any other irradiation time, define the counts under the ROI to be A_t.

b. On two-cycle semi-log graph paper, or on an Excel graph, make a plot of the experimental data A_t/A_S versus irradiation time. Plot the theoretical function, $1–e^{-\lambda t}$, on the same graph.

c. QUESTIONS: How well does the experimental data fit the theoretical curve? Did excessive dead time distort any segment of the data? What uncertainty do you estimate in the reproducibility of the distance from the sample to detector? How does that uncertainty influence the solid angle subtended by the detector, and what is the consequential uncertainty in the measured activity? What do you estimate for the uncertainty in the activity resulting from the activation process?

EXPERIMENT 17.5

The Study of a Complex Sample with Two Half-Lives Present

Ordinary silver has two pronounced isotopes, ^{107}Ag (51.35%) and ^{109}Ag (48.65%). If we activate a piece of silver, the following reactions take place, leading to radioisotopes of differing half-lives: ^{107}Ag(n,γ)^{108}Ag ($T_{1/2}$ = 2.3 min) and ^{109}Ag(n,γ)^{110}Ag ($T_{1/2}$ = 24 s). The purpose of this experiment is to determine these half lives by graphically extracting the components of the compound decay curve. ^{108}Ag has a 0.44-MeV gamma ray, while ^{110}Ag has 0.66-MeV and 0.94-MeV gamma rays.

Procedure

1. Set up the electronics according to Experiment 17.1.
2. Obtain two silver samples from the Activation Sample Set No. 317.
3. Activate the first sample for 5 min., and immediately place it against the face of the NaI (Tl) detector. Set the ROI of the analyzer so that it includes all of the gamma-ray peaks from both isotopes (0.44 MeV, 0.66 MeV and 0.94 MeV) in one Region of Interest. Under these conditions we are counting both half lives. The sole function of this first irradiated sample is to facilitate setting the ROI.
4. We are now ready to take data for the complex decay curve. Irradiate the second silver sample for a time of 10 min. Transfer the sample to the counting station and take 10-s counts every 20 s for 8 min. It is necessary that you record each ROI reading and erase quickly in preparation for the next reading. For each spectrum acquisition, record the counts in the ROI, the percent dead time and the laboratory clock time for the start of the acquisition. Because of the rapid repetition sequence, it may be useful to divide up the three tasks among team members: 1) operating the MCA and reading the data, 2) reading the laboratory clock time, and 3) logging the numbers.

EXERCISE

a. Plot the resulting data on a semilog scale (counts) versus a linear scale (laboratory clock time). The straight line that represents the long-lived (2.3 min.) component can easily be drawn on the curve by constructing a line through all points taken after 3.5 minutes. Determine the half life of the long-lived component.

b. Extrapolate the straight line for the 2.3-minute activity back to zero time. Now subtract the straight line counts from this activity from all points from t = 0 to t = 3.5 min. Plot the resulting short-lived activity and determine the half life of the short-lived activity.

c. QUESTION: Was the percent dead time at the beginning of the series of acquisitions large enough to distort the shape of the 24-s decay curve?

EXPERIMENT 17.6

Thermal Neutron Shielding

In Experiment No. 3, we showed that the attenuation of gamma rays through a lead absorber is given by the following expression:

$$I = I_0 e^{-\mu x} \qquad (8)$$

Where μ is the linear absorption coefficient, and x is the thickness of the lead absorber. I_0 is the counting rate of the gamma-rays when the absorber is omitted, and I is the counting rate of the gamma-rays with the absorber placed between the source and the detector.

A similar expression can be written for the attenuation of neutrons through a pure-element absorbing foil.

$$I = I_0 e^{-N_v \sigma x} \qquad (9)$$

Where

N_V = the number of atoms/cm^3 in the absorber,

σ = the thermal neutron cross section (in cm^2),

x = the absorber thickness (in cm),

I_0 = the neutron counting rate when the absorber is omitted, and

I = the neutron counting rate when the absorber is inserted between the source and detector.

The number of atoms/cm^3 can be calculated from

$$N_V = \frac{\rho\eta}{w_A} \qquad (10)$$

Where

ρ = the density of the foil in gm/cm^3,

η = Avogadro's number (6.023 x 10^{23} atoms per mole), and

w_A = the gram atomic weight of the element in the foil in gm/mole.

In this experiment, we will measure the reduction of the thermal neutron flux, ϕ, by placing a thin sheet of cadmium around the sample to be irradiated.

Procedure

1. Setup the electronics as outlined in Experiment 17.1 and Fig. 17.1.
2. Take two identical aluminum samples from the Activation Sample Set No. 317. Wrap one of the samples with a cadmium foil from the Cadmium Foil Set No. CD-17. The samples are now ready to irradiate.
3. Place the unshielded aluminum sample in the howitzer and irradiate for 8 min. By using the $^{27}Al(n,\gamma)^{28}Al$ cross section, (0.219 barns), and the techniques in Experiment 17.1 determine the flux, ϕ, in the howitzer. Define this flux to be $\phi 1$.
4. Repeat step 3 exactly for the aluminum sample that is wrapped with the cadmium foil. Determine the new value of flux and label it $\phi 2$.

EXERCISE

From Eq. (8) it can be seen that

$$\frac{\phi_2}{\phi_1} \; e^{-N_V \sigma x} \qquad (11)$$

The density of cadmium is 8.65 g/cm^2 , and it atomic weight is 112.4. This gives NV = 4.64 x 10^{22} atoms/cm^3.

From your lab instructor or the foil kit, find the thickness, x, of the cadmium foil. From Eq. (11), the thermal absorption cross section for cadmium can be determined.

QUESTIONS: How does your value for the thermal absorption cross section compare to the accepted value of 2500 barns? What value did you measure for the effective shielding parameter for cadmium [ϕ_2/ϕ_1 in Eq. (11)].

EXPERIMENT 17.7

The Measurement of Thermal Neutron Activation Cross Sections of Elements with High Sensitivity Ratios

The "Neutron Activation Sensitivities" table, included in the Appendix, lists relative sensitivities of selected elements to thermal neutron activation. In this experiment we will use the value of flux, ϕ, for the howitzer as determined by Experiment 17.1. From this value of ϕ we will calculate the cross section, σ, for several selected elements from the Special Sample Set RE-17.

Procedure

1. Setup the electronics as specified for Experiment 17.1.
2. Place the indium sample in the howitzer and irradiate for two half-lives ($T_{1/2}$ = 54.2 min). Transfer it to the NaI(Tl) counting station and count for 600 s.

EXERCISE

Sum under the 1270-keV peak, and determine σ from Eqs. (1) through (5).

QUESTION: How does your value compare with the accepted value of 210 barns (Table 17.3)?

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3. Repeat for several of the other samples from the Special Sample Kit RE-17. In each case, the sample should be irradiated for at least two half-lives. The counting time should be adjusted so that reasonable statistics are obtained under the peak of interest. Table 17.3 shows some recommended parameters for the samples in the RE-17 Kit.

Table 17.3 Recommended Activation Parameters for the Elements in Sample Kit RE-17.

Element	Reaction	σ_{barns}	$T_{1/2}$	Measured γ (keV)	Activation Time	Counting Times(s)
Indium	$^{115}In(n,\gamma)^{116}In$	210	54.2 min	1270	108 min	600
Copper	$^{65}Cu(n,\gamma)^{66}Cu$	2.10	5.1 min	1040	10 min	200
Germanium	$^{74}Ge(n,\gamma)^{75}Ge$	0.60	82 min	266	82 min	600
Tungsten	$^{184}W(n,\gamma)^{185}W$	2.0	1.7 min	171	6 min	100
Titanium	$^{50}Ti(n,\gamma)^{51}Ti$	0.140	5.8 min	322	12 min	200
Manganese	$^{55}Mn(n,\gamma)^{56}Mn$	13.3	2.58 h	845	4 h	1000

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NOTE OF CREDIT: Some parts of this experiment were taken from ref. 11 by G. I. Gleason. Reference 11 contains 18 excellent experiments that can be implemented in Activation Analysis.

Appendix: Apparatus Description

308 Neutron Howitzer

Figure 17.6 shows a picture of the 308 Neutron Howitzer originally manufactured by Metrix Products for experiment 17. The following description from Metrix Products may facilitate the custom fabrication of this activation chamber.

The chamber dimensions form a cube, 3-ft (0.91 m) wide on each face. The four 1-inch (2.54-cm) activation ports are symmetrically located on the four sides of the cube. The neutron source is loaded from the top. Neutron sources up to 1.25-inches (3.18-cm) in diameter and up to 10 Ci were accommodated. Adaptors were used to insert smaller source diameters. The neutron source could be locked in place for safety. The neutrons are slowed to thermal energies by the paraffin surrounding the source and ports. The chamber is constructed to provide fluxes at each port that are equal within ±5%. Samples to be activated are loaded into 1-inch (2.54-cm) diameter x 1-inch (2.54-cm) long polyethylene cylinders. These cylinders are placed into the loading tubes, which are, in turn,

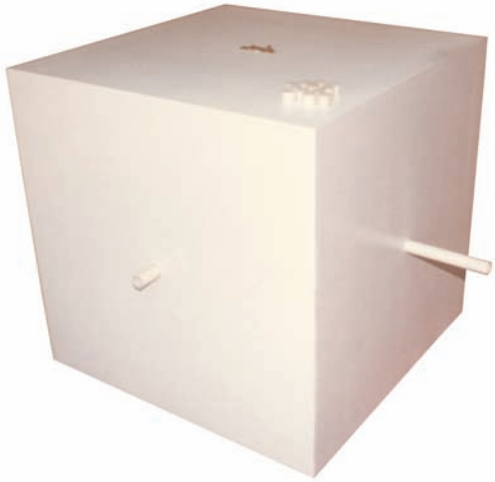

Fig. 17.6 The Neutron Howitzer Originally Manufactured by Metrix Products.

inserted into the ports for activation. The outer skin of the chamber employs 3/4-inch (2-cm) thick plywood to confine the paraffin contents.

- Moderator: Paraffin and Polyethylene.
- Polyethylene slide-out chambers for all ports.
- Thin polyethylene containers for samples.
- Polyethylene 1-inch (2.54-cm) spacers for each port.
- Sample position reproducibility: ±0.2 mm.
- Minimum source to sample distance: 2 cm ±0.05 cm.

313 Activation Sample Set

Neutron Activation Sample Set: Contained 3-gm samples of high-purity metals: V, Al, Ge, Mn and Cu. The samples were each enclosed in a contaminant-free polystyrene cylindrical container 2.54-cm diameter x 2.54-cm long. The materials were chosen to avoid interfering gamma-ray lines from any contaminants.

317 Activation Sample Set

Neutron Activation Sample Set: Contained: Ag, Ti, W, Na, and Co. Otherwise similar to the 313 Activation Sample Set.

RE-17 Special Sample Set

Contained elements with high activation cross sections: samples of In, La, Br, and I; size similar to 313 Activation Sample Set.

ORTEC®

AN34 Experiment 17

Neutron Activation Analysis (Slow Neutrons)

Neutron Activation Sensitivities

Atomic Number	Element	Product Nuclide	Half-Life	Measured γ (keV)	Relative Sensitivity*
9	Fluorine	^{20}F	11.6 s	1634	60.
11	Sodium	^{24}Na	15.0 h	2754	1.5
12	Magnesium	^{27}Mg	9.46 m	844	35.
13	Aluminum	^{28}Al	2.32 m	1779	1.0
17	Chlorine	^{38}Cl	37.3 m	2168	8.
19	Potassium	^{42}K	12.4 h	1525	28.
20	Calcium	^{49}Ca	8.8 m	3084	260.
21	Scandium	^{46m}Sc	18.7 s	143	0.03
22	Titanium	^{51}Ti	5.79 m	320	18.
23	Vanadium	^{52}V	3.75 m	1434	0.07
24	Chromium	^{51}Cr	27.8 d	320	85.
25	Manganese	^{56}Mn	2.58 h	847	0.015
27	Cobalt	^{60m}Co	10.5 m	59	0.23
28	Nickel	^{65}Ni	2.53 h	1482	130.
29	Copper	^{66}Cu	5.10 m	1039	6.
30	Zinc	^{69m}Zn	14.1 h	439	23.
31	Gallium	^{72}Ga	14.1 h	834	0.32
32	Germanium	^{75m}Ge	48.0 s	140	5.2
33	Arsenic	^{76}As	26.4 h	559	0.32
34	Selenium	^{77m}Se	17.4 s	162	0.27
35	Bromine	^{80}Br	16.8 m	616	0.8
37	Rubidium	^{86m}Rb	1.02 m	556	5.
38	Strontium	^{87m}Sr	2.83 h	389	3.
39	Yttrium	^{89m}Y	16.1 s	909	23.
42	Molybdenum	^{101}Tc	14.2 m	307	8.
44	Ruthenium	^{105}Ru	4.4 h	724	12.
45	Rhodium	^{104m}Rh	4.3 m	51	0.03
46	Palladium	^{109m}Pd	4.7 m	189	5.5
47	Silver	^{110m}Ag	24.0 s	658	0.35
48	Cadmium	^{111m}Cd	49.0 m	245	18.

Atomic Number	Element	Product Nuclide	Half-Life	Measured γ (keV)	Relative Sensitivity*
49	Indium	^{116m}In	53.7 m	1293	0.006
50	Tin	^{125m}Sn	9.5 m	331	15.
51	Antimony	^{122}Sb	64.3 h	564	0.7
52	Tellurium	^{131}Te	24.8 m	150	5.7
53	Iodine	^{128}I	25.0 m	443	0.3
55	Cesium	^{134m}Cs	2.9 h	127	0.4
56	Barium	^{139}Ba	83.0 m	166	3.2
57	Lanthanum	^{140}La	40.2 h	1597	0.8
58	Cerium	^{143}Ce	33.7 h	293	14.
59	Praseodymium	^{142}Pr	19.2 h	1576	5.
60	Neodymium	^{149}Nd	104.0 m	211	5.
62	Samarium	^{153}Sm	46.8 h	103	0.07
63	Europium	^{152m}Eu	9.3 h	963	0.008
64	Gadolinium	^{161}Gd	3.6 m	360	–
65	Terbium	^{160}Tb	72.0 d	299	4.
66	Dysprosium	^{165}Dy	2.32 h	95	0.01
67	Holmium	^{166}Ho	26.8 h	81	0.2
68	Erbium	^{171}Er	7.52 h	308	0.36
69	Thulium	^{170}Tm	129.0 d	84	90.
70	Ytterbium	^{175}Yb	101.0 h	396	1.5
71	Lutetium	^{176m}Lu	3.7 h	88	0.2
72	Hafnium	^{179m}Hf	18.6 s	214	0.05
73	Tantalum	^{182}Ta	115.0 d	1121	35.
74	Tungsten	^{187}W	24.0 h	686	0.4
75	Rhenium	^{188}Re	16.7 h	155	0.07
76	Osmium	^{193}Os	31.5 h	139	35.
77	Iridium	^{192}Ir	74.2 d	317	0.3
78	Platinum	^{199}Pt	31.0 m	543	25.
79	Gold	^{198}Au	64.7 h	412	0.027
80	Mercury	^{197}Hg	65.0 h	78	1.2

*The numbers in this column indicate the number of units (weight) of an element that provide a count rate equal to the count rate furnished from irradiation of one unit weight of aluminum.

Specifications subject to change
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