PHYS3710 Short experimental projects I
Department of Physics
The Chinese University of Hong Kong, Hong Kong

Topic: Nuclear detectors & spectroscopy

designed by

H.K. Wong, June 23, 2006, revised on August 29, 2007 &Nov. 28, 2011

Topics you should know first:

Learn basic principle of various nuclear detectors (Ref. 1(a) and Ref. 2)
and vacuum pumps & gauges (Ref. 1(b)).

Objectives:

1. Operate various nuclear detectors
   (GM tube, NaI(Tl) scintillation counter, semiconductor detector, cloud chamber etc.)
   Get familiar with nuclear electronics: nuclear instrument module (NIM), multichannel analyzer (MCA), preamplifier, amplifier, high voltage (HV) power supply, pulser, …)
2. Learn α spectroscopy.
3. Learn β spectroscopy.
4. Learn γ spectroscopy.
5. Learn radioactivity in nature.

Precaution:

Radioactive sources and expensive equipment are used. Please following instructions.
Always use tweezers to handle sources and keep sources in Pb shield.

Check-list for the project:

(I) Geiger counter (for β particles):

1. Check setup configuration & electronics. Make sure you understand the operation of all components.
2. Put a ^{137}Cs source (emitting both β & γ rays**)** onto the sample holder.
3. Measure count rate as a function of applied voltage (< 1200 V)
4. For the rest of the experiment, set the applied voltage at near the lower end of the plateau.
5. ***Counting statistics & counting error***:
   Keep the source far away from the detector so that the count rate is about 1 cps (counts per sec). Count for one minute and repeat for about 100 times. Plot the frequency distribution. Take a bin size = 2 cpm for the histogram. You should get a Poisson distribution with a standard deviation $\sigma = \sqrt{N}$ where *N* is the count rate at the peak of the distribution.

(II) Scintillation counter (for γ rays):

1. Check setup configuration & electronics. Make sure you understand the operation of all components (HV, preamp, amp, MCA, etc.).
2. Connect the pulser output to the "test" input of preamp. MCA should display a narrow peak. Get the channel number of the peak (*N*). Repeat with other heights (*H*) of pulser output. Plot *N* as a function of *H* to check linearity of the system & whether the MCA has proper zero setting.
3. **γ spectroscopy:**
   Mount a ^{137}Cs source close to the scintillator. Set applied voltage at 900 V.
   Get the energy spectrum of ^{137}Cs. Adjust amplifier gain to get a clear spectrum.
   Identify all features as specified in the nuclear detector notes. Use the full energy peak and the escape peak to calibrate the MCA.
4. **Radioactivity in Nature:**
   Study ^{40}K in natural material. Use KI or KCl powder or banana as sample and take a spectrum. Calculate the activity per gm and compare it with data in handbook. Use ^{60}Co as a standard.
   (For detail, see Ref. 1(c), Am. J. Phys. **36**, 920 (1968), Am. J. Phys. **67**, 440 (1999) &
   http://www.physics.isu.edu/radinf/natural.htm.)

(III) Semiconductor detector (for *α & β particles*):

Exp. 1: Range of α particles:

1. Use the cylindrical stainless-steel vacuum chamber that is equipped with a large Si detector. Pay attention: **Different semiconductor detectors may require different bias voltages.**
2. Check setup configuration & electronics. Make sure you understand the operation of all components (MCA, pumps etc.).
3. Mount a ^{241}Am source on the holder and keep it far away from the detector.
4. The vacuum chamber has a Baratron (a pressure gauge) to measure pressure (full range = 1000 Torr & 10 V). It should read 7.60 V (corresponding to 760 Torr) at atmospheric pressure.
5. Pump down the system to about 10^{-1} Torr with a mechanical pump & then 10^{-2} Torr with a sorption pump. Baratron should read ~ 0 mV. Otherwise adjust ZERO on the Baratron.
6. Measure α spectrum at a function of pressure. Note: the count rate drops abruptly at a critical pressure. (See Ref. 3 for details.)
7. Determine the equivalent range of α particle in 1 atmospheric pressure air.

Exp. 2: α spectroscopy

1. Use the cylindrical stainless-steel vacuum chamber that is equipped with a small Si detector. This detector has better energy resolution.
   Note: (a) Different detector has different biased voltage for the operation.
   (b) This detector must be operated in vacuum. Do not turn on biased voltage unless the chamber is in vacuum.
   Check setup configuration & electronics. Make sure you understand the operation of all components.
2. Again use the ^{241}Am source.
3. Pump down the vacuum chamber with a mechanical pump to ~ 10^{-1} Torr and then use a sorption pump to get down to ~ 10^{-2} Torr.
4. Turn on biased voltage and then collect the energy spectrum. You may need to adjust amplifier gain to get a clear spectrum. Use a CRO to check amplifier output.
5. **Turn off biased voltage** before you vent the vacuum chamber to atmospheric pressure.
6. Repeat experiment with another α source.
7. **Turn off biased voltage** before you vent the vacuum chamber to atmospheric pressure.
8. Based on the known α particle energies, the channel number can be converted to α energy.
9. Plot energy spectra.

Exp. 3: β spectroscopy

1. Use the rectangular vacuum chamber that is equipped with a small Si detector. (This setup is for the special relativity project.)
   Check setup configuration & electronics. Make sure you understand the operation of all components.
2. Mount a ^{137}Cs source directly facing the detector.
3. Pump down the vacuum chamber with a mechanical pump to ~ 10^{-1} Torr and then use a sorption pump to get down to ~ 10^{-2} Torr.
4. Turn on biased voltage and then collect the energy spectrum. You may need to adjust amplifier gain to get a clear spectrum.
5. **Turn off biased voltage** before you vent the vacuum chamber to atmospheric pressure.
6. The spectrum has two features: one continuous β spectrum and two peaks due to internal conversion (IC) electrons. You can use the IC peaks to calibrate the MCA. Check the end-point energy of the continuous β spectrum.
7. Plot energy spectrum.

(IV) Cloud chamber (optional)

References

1. (a) Notes on nuclear detectors;[#] (b) Notes on vacuum pumps[#] & (c) Notes on K40.[#]
2. W.R. Leo, *Techniques for nuclear and particle physics experiments : a how-to approach* (QC793.46 .L46 1994)
3. A.C. Melissinos, *Experiments in modern physics* (QC33.M52 2003)

[#] available on SEPI CoursePage.