Chem 481 Lecture Material
3/27/09

Radiation Detection and Measurement

Gamma-ray Spectrum Analysis

When a gamma ray interacts with a detector it transfers all (photoelectric absorption or pair production) or part (Compton scattering) of its energy to the medium. Theoretically, when photoelectric absorption occurs, the same number of charge carriers are produced and collected and the same size output pulse is generated. This would result in counts being added to a single channel of the MCA memory (see figure below). Compton scattering events in the detector would give rise to a continuous range of energy deposition (up to a maximum for a scattering angle of 180°) and a continuous range of channels receiving approximately equal numbers of counts (see figure below).

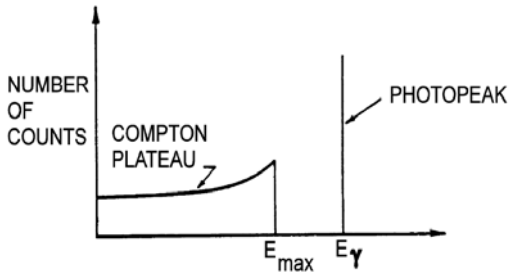
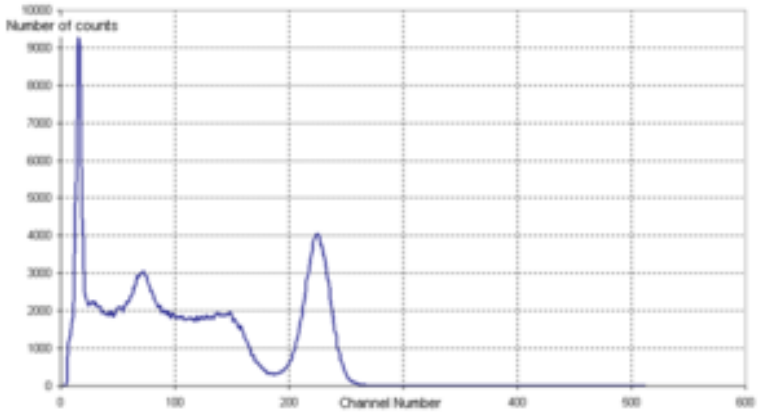


Figure 2. - Idealization of gamma-ray spectrum

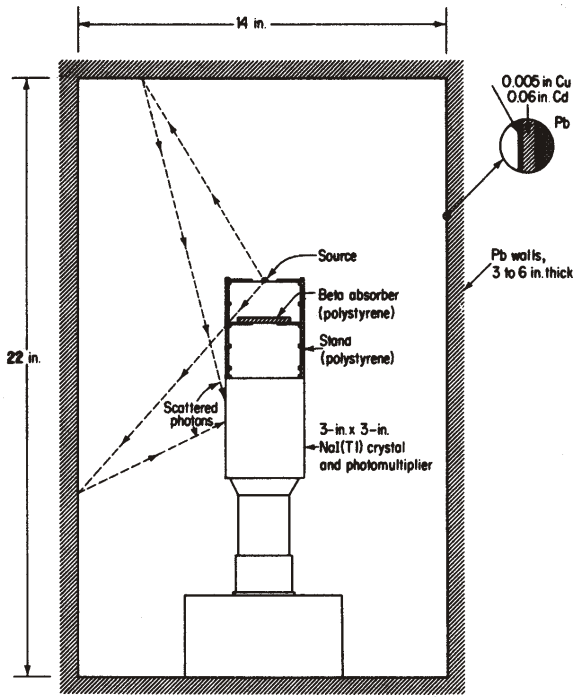
Experimentally, however, the spectrum of a sample emitting a single gamma-ray energy appears as in the figure below for ^{137}Cs counted with a NaI(Tl) detector.



The photopeak is broadened because of statistical fluctuations in the production and collection of the charge carriers. The Compton edge (E_{max}) is rounded because of multiple Compton scattering events. The peak around 200-225 keV is called a backscatter peak and results from gamma rays undergoing large-angle Compton scattering in the material surrounding the detector before entering the detector. The

very low energy peak is associated with x-rays emitted following internal conversion by the radionuclide or x-rays produced by gamma ray interactions in the material surrounding the detector (for example, the principal Pb x-rays range in energy from 72.8 - 87.3 keV).

The backscatter peak can be minimized by placing shielding further from the detector. The x-rays from the shielding can be lessen by using a 'graded' shielding. The shielding shown in the figure below is primarily lead lined with a sheet of cadmium metal which is further lined with a sheet of copper. X-rays produced in the lead will be absorbed efficiently by the Cd which can produce Cd x-rays that are absorbed efficiently by the copper. X-rays produced in copper (8 - 8.9 keV) are so low in energy that they do not interfere with gamma-ray photopeaks.



It is also common practice to cover the gamma detector with a thick plastic cap to absorb any beta radiation emitted by the sample. The low-Z plastic also minimizes the production of bremsstrahlung radiation.

There are also other 'artifact' peaks found in many gamma ray spectra. A peak may appear at 511 keV. This could be an authentic gamma ray emitted with this particular energy, however, it is more likely coming from the positron-electron annihilation reaction. The sample may contain a radionuclide that decays by β^+ emission, or it may emit high energy gamma rays that undergo pair production in the material surrounding the detector with subsequent positron annihilation.

Pair production can also occur in the detector and result in what are known as 'escape peaks'. In the figure below, notice that γ_3 produces a positron-electron pair in the smaller detector volume. The electron energy is absorbed by the detector while the positron annihilates producing two 511-keV gamma rays that escape the smaller detector volume. Thus γ_3 will have deposited an amount of energy equal to the original gamma ray energy (E_γ) minus the energy of the escaping annihilation photons (1022 keV). This will result in a 'double escape' peak in the gamma ray spectrum at an energy equal to E_γ - 1022 keV. If only one of the annihilation gamma rays escapes from the detector a 'single escape' peak at E_γ - 511 keV will appear. Remember that escape peaks are only possible if E_γ > 1022 keV and are usually only prominent for HPGe spectra and gamma energies much larger than this minimum. Depending upon the size of the detector, the escape peak(s) may be larger than the photopeak for the original gamma ray.

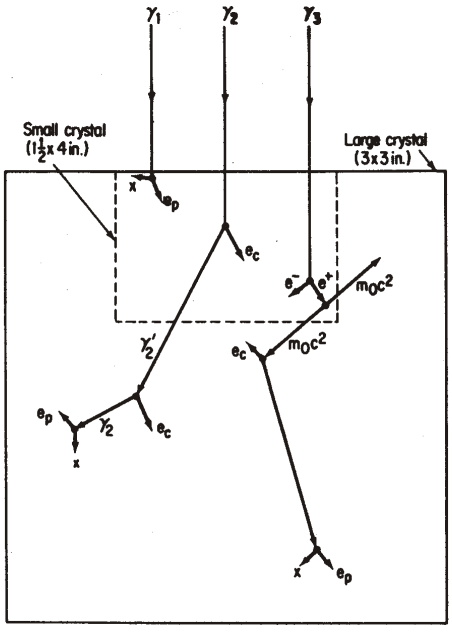


Fig. 7-2. Schematic representation of γ-ray interactions within NaI(Tl) crystals of two sizes. From O'Kelley (8).

If two gamma rays interact with the detector at the same time then a 'sum' peak appears at an energy equal to the sum of the two gamma ray energies. This event becomes more likely the closer the sample is to the detector and the higher the sample activity. It is much more likely for two gamma that are emitted in a cascade to sum together than two gamma emitted from different decaying nuclei. Thus, when a sample of ^{60}Co is counted, one observes photopeaks at 1173.2 keV and 1332.5 keV and a sum peak at 2506 keV.

Interpretation of Gamma-ray Spectra

When assigning a radionuclide to a particular peak in the gamma-ray spectrum of a sample following neutron irradiation, one must take into account other factors in addition to the peak energy. These include: (1) other gamma-ray energies emitted by this radionuclide, (2) the intensity of gamma ray emissions from the radionuclide, (3) the half life of the radionuclide and (4) other radionuclides formed from the suspected target element. Examples of how to use these factors are illustrated below.

Case 1: peak observed at 1173 keV

From the tabulated list of gamma energies (Appendix B in Lab Manual), this should correspond to ^{60}Co in the sample. To confirm this, look up ^{60}Co in the table of radionclides in Appendix C to see if other gamma rays are emitted. Note that ^{60}Co also emits a gamma ray at 1332 keV (also with high intensity). Thus, if ^{60}Co is present in the sample you should observe both peaks in the spectrum. If there is no peak at 1332 keV, ^{60}Co is not the source of the peak at 1173 keV. A possible source is ^{82}Br. Note that ^{82}Br emits gamma rays at 554 keV, 619 keV, 698 keV, 777 keV, 827 keV, 1044 keV, 1317 keV and 1474 keV. If this pattern of peaks is observed then ^{82}Br is present in the sample. Note that a sum peak resulting from 554 keV + 619 keV would occur at 1173 keV, so if ^{82}Br is present, this could explain the 1173 keV peak.

Case 2: peak observed at 320 keV

This is challenging because both ^{51}Cr and ^{51}Ti emit this gamma energy (see Appendix B) as they decay to the same ^{51}V daughter nuclide. It is made more difficult by the fact that this is the only emission expected from ^{51}Cr and the only gamma ray emitted with high intensity from ^{51}Ti. Thus, if the low-intensity emission at 929 keV from ^{51}Ti is not observed, the only way to assign this peak is to consider the vast difference in half life between ^{51}Cr (27 d) and ^{51}Ti (5.8 min). One could wait 30 minutes and recount the sample. If this peak is still present at about the same intensity, then it can't be from ^{51}Ti. Further confirmation of the presence of ^{51}Cr could be obtained by recounting the sample after a much longer decay time (~20 days) to see if the peak intensity is decreasing at the expected rate.

Case 3: peaks observed at 1368 keV, 1732 keV, 2243 keV and 2754 keV

The peaks at 1368 keV and 2754 keV suggest the presence of ^{24}Na (see Appendix B). Note that ^{77}Ge is ruled out for the 1368 peak unless much more intense peaks at 211 keV, 216 keV and 264 keV are observed. There are no listings in Appendix B close (within 1-2 keV) to 1732 keV and 2243 keV. These peaks, however, correspond to the double (2754 - 1022) and single (2754 - 511) escape peaks for the 2754-keV gamma ray.

Case 4: peak observed at 275 keV

There 4 radionuclides listed in Appendix B that emit a gamma ray with an energy within 1 kev of 275 keV (^{147}Nd, ^{151}Pm, ^{81}Se and ^{133m}Ba). ^{147}Nd, ^{151}Pm and ^{81}Se all have other gamma rays emitted with high intensity that could be used to confirm or exclude the presence of each of these radionuclides, however, ^{133m}Ba does not have other emissions. Note that ^{133m}Ba decays to ^{133}Ba by isomeric transition (see Chart of the Nuclides). Thus, if ^{133m}Ba is present, it will form ^{133}Ba and you will observe the high intensity emissions (especially at 80.8 keV and 356 keV) from the decay of ^{133}Ba. Also note that one does not expect to see ^{151}Pm in a sample. There are no stable isotopes of Pm and ^{151}Pm is not likely to be formed by neutron irradiation.