High Resolution α/β Spectrometry with Silicon Detectors

1) Scope

In this experiment we will study the α and β^- spectra emitted by different samples by means of high resolution Silicon detectors. The interaction of this high ionizing radiation with matter will be studied by analyzing its transmission / attenuation in Aluminum. It will be seen that, although the measured α particles have higher energies than the measured β^- particles, the α particle radiation is stronger attenuated in matter than the β^- radiation due to the higher stopping cross section. A Fermi-Kurie plot will be used to study the β^- spectra measured with different samples to obtain the maximum β^- emission energy.

The students will get familiar with the operation of Silicon detectors in vacuum chambers as well as with advanced data analysis techniques studying the interaction of ionizing radiation with matter.

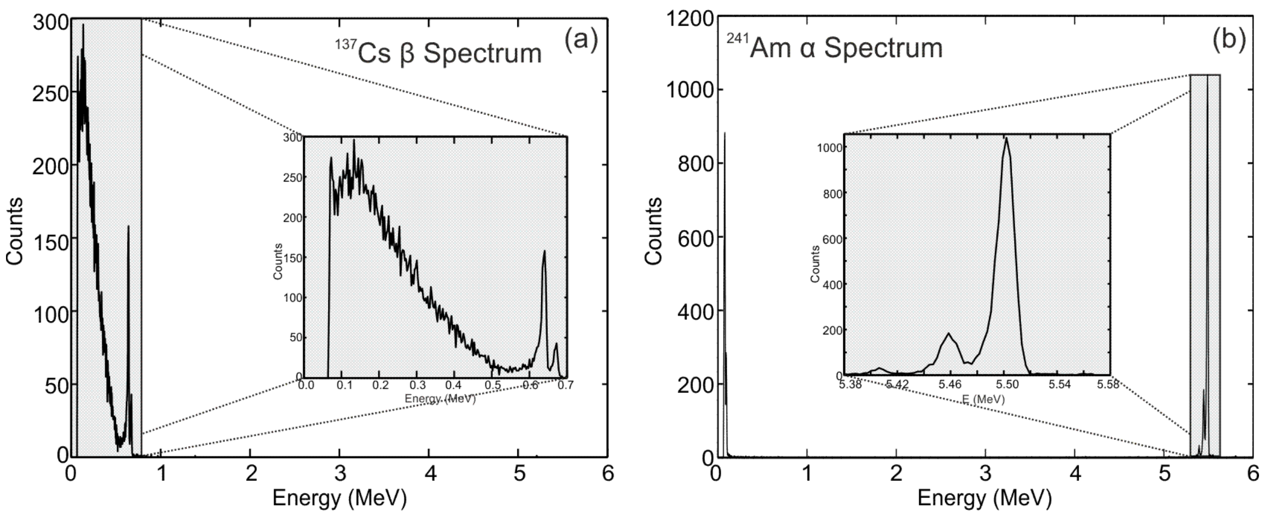

Fig. 1. (a) ^{137}Cs β^- spectrum. (b) ^{241}Am α spectrum.

2) Material

1. Vacuum chamber (measurement vacuum = 10^{-2} mb).
2. High resolution Si detectors with preamplifier (operation voltage = 140V).
3. High voltage bias supply.
4. Multi-Channel Analyzer (MCA).
5. PC with MCA software for spectra data acquisition.
6. Set of radioactive sources. ^{214}Am, ^{137}Cs, ^{90}Sr, ^{36}Cl, ^{14}C and ^{201}Tl.
7. Set of Al targets with different thicknesses.

3) Experimental Procedure

The instructor will provide information in regard to the proper bias voltage and other data for the Si detector as well as important aspects to operate the Si detector in the vacuum chamber. The student should understand the setup, making a plot of the entire system. The MCA should have an elevated number of channels in order to take advantage of the inherent resolution capabilities of the detector. For this experiment the MCA will be set at 4096 channels.

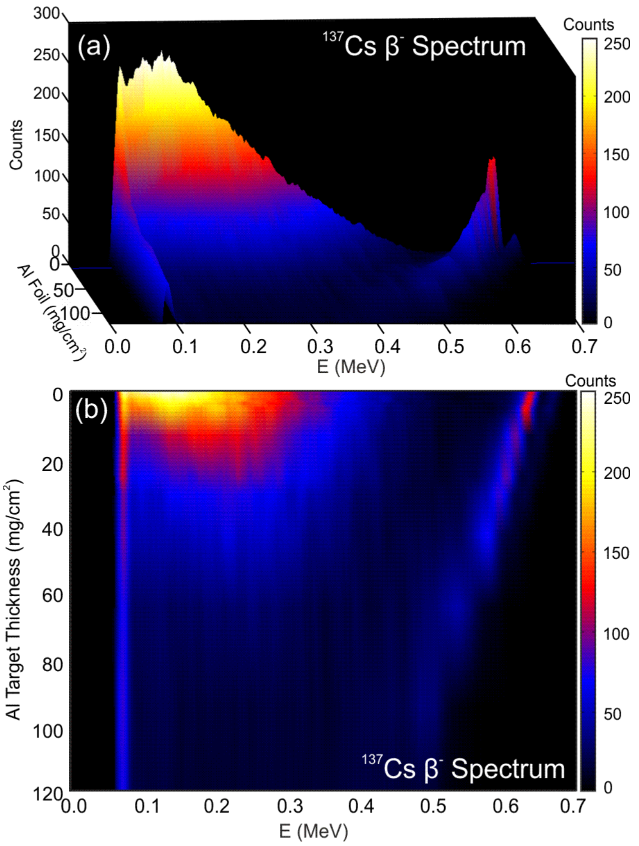

Fig. 2. Attenuation of 137 Cs β- spectrum in Aluminium of different thicknesses. (a) 3D plot and (b) projection on a plane.

1) Calibration in energy*: Measure the spectra for the ^{137}Cs and ^{241}Am samples. Identify the channels and energies of the different maxima in both spectra using the corresponding decay diagrams. Construct an energy calibration curve for the entire spectra. Reproduce figure 1 of this document.

2) Measure the spectra for all other samples, i.e. ^{90}Sr, ^{36}Cl, ^{14}C and ^{201}Tl and discuss the differences.

3) Measure the ^{137}Cs β$^-$ transmission in Al using different target thicknesses. Measure the ^{137}Cs β$^-$ spectrum using different Al foils with mass surface densities ranging from 2.7 mg/cm^2 to 216.2 mg/cm^2.

4) Reproduce figure 2 of this document. It is highly recommended to use Matlab or a similar advanced data analysis software.

5) Measure the ^{241}Am α transmission in Al using different target thicknesses. Measure the ^{241}Am α spectrum using different Al foils with mass surface densities ranging from 2.7 mg/cm^2 to 9.4 mg/cm^2. Plot the ^{137}Cs β$^-$ and ^{241}Am α spectra measured for these different Al thicknesses in the same figure and discuss the result.

**Note that using the same calibration curve for both, α and β detection, may induce an error of up to 2.2% in the spectra as they do not necessarily produce exactly the same number of electron-hole pairs in Si.*

Each student will elaborate a report which will include a short theoretical background, the explanation of the different spectra and the required calculations (with errors).

Additional questions

1. Determine the maximum β^- emission energy for each sample through Fermi-Kurie plots.

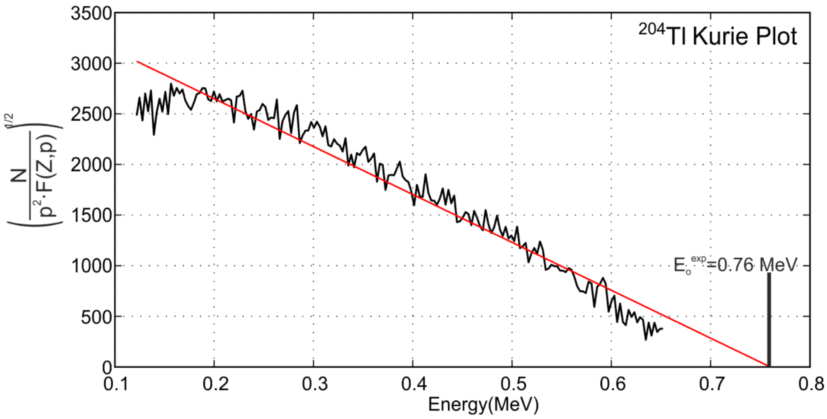

Fig. 3. ^{204}Tl Fermi-Kurie plot together with its linear fit and experimentally obtained E_o^{max}.

For "allowed decays" inside the nucleus, the electron energy spectrum can be "linearized" if one accounts for the Coulomb distortion via the Fermi function F(Z,p). Calculate the Fermi function for all samples, use a linear regression to fit the spectrum near the maximum energy to obtain the experimental maximum β^- emission energy for each sample as in figure 3 of this document. To calculate the Fermi factor use the following expressions:

$$F^{\pm}(Z',p) \cong \frac{x}{1-e^{-x}}, \quad x = \mp \frac{2\pi\,\alpha\,Z'}{\beta}, \quad \beta = \frac{\mathrm{v}}{c}, \quad \alpha = \frac{e^2}{4\pi\varepsilon_o \hbar c} = \frac{1}{137}$$

2. Calculate the mass attenuation coefficient for ^{137}Cs β^- emission in Al through an exponential fit of the tail of the experimental data with $I = I_0\, e^{-\mu_m x_m}$ for different energies. Compare the mean measured mass attenuation coefficient with the theoretical value as in figure 4 of this document.

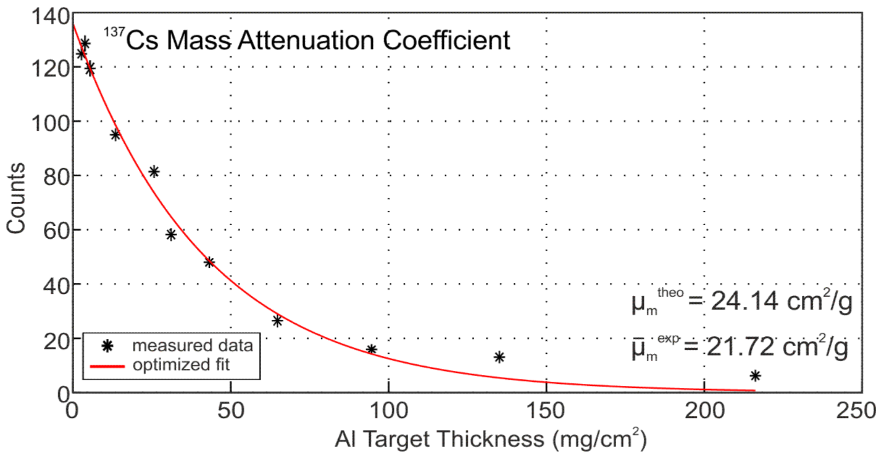

Fig. 4. Attenuation of ^{137}Cs β^- emission in Aluminium.

References

G.F. Knoll, Radiation Detection and Measurement, (John Wiley & Sons, Inc.). Fourth Edition (2010)