β-decay

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1 Introduction and Theory

β-decay is a type of radioactive decay in which unstable nuclei reach a more energetically favourable state by attaining the optimal ratio of protons to neutrons. There are several types of β-decay; in β^--decay, a neutron in the atomic nucleus spontaneously changes into a proton and an electron. The proton will remain in the nucleus while the electron is ejected at large velocities and energies. In β^+-decay, a proton spontaneously changes into a neutron and an positron, where the positron is ejected from the nucleus again at high velocities and energies. In electron capture, no particle is emitted. Instead, a proton in the atomic nucleus captures an electron from an innermost atomic shell and transforms into a neutron.

β-decays are always accompanied by the emission of a neutrino or antineutrino. In every case of β-decay, the mother nucleus transforms into a daughter nucleus with the same mass number, but with a different atomic number. The 'β-particles' do not exist in the atomic nucleus, but are born in the instant of the decay.

In this experiment, the β-spectrum of the radioactive source ^{90}Sr is investigated. A β-spectrum consists of a graph of β-particle energy versus the number of particles of said energy reaching the detector over a given interval of time. The graph is achieved by means of an energy calibrated scintillation counter.

A scintillation counter is a piece of apparatus that employs crystals which emit light when struck by fast moving particles. The emitted light pulses are transformed into voltage pulses by a photomultiplier, where the intensity of the light produced is proportional to the energy deposited in the crystal. CASSY LAB 2 outputs a plot of channel number versus the number of particles of said energy reaching the detector over a given interval of time. This can be calibrated to output β-particle energies on the x-axis instead of channel number. This is achieved by inserting a known source into the detector such that the discrete energies of the emitted β-particles are known. The peaks in the spectrum can be analysed, and the channel number that corresponds to the peak can be found. The energy that corresponds to this channel number is known and this is used to calibrate the spectrum. In this experiment, ^{60}Co is the β-radioactive source used for calibration. The β-spectrum contains 2 peaks of known energy, and when the channel numbers corresponding to these peaks are found, the scintillation detector can be correspondingly calibrated.

In the beta decay of ^{90}Sr, the daughter nuclide ^{90}Y is produced, which is also β-radioactive. As a result, it is a superposition of the two β-spectra, each with deferent decay energies, which are measured.

This experiment also investigates the energy losses of β-particles as they travel through aluminium sheets of varying thicknesses. As the thickness of the absorber increases, the energies of the beta particles decrease linearly. By plotting absorber thickness versus the maximum energy of the beta particles, E_β, the slope can be used to identify the energy loss per unit path length in the aluminium. It should also be noted that the aluminium screening of the scintillation counter causes an additional energy loss in the β-particles such that the maximum energy that the particles reach is actually the measured maximum energy plus the energy loss in the counter screening, which has a thickness of $d_0 = 0.4$mm.

2 Experimental Method

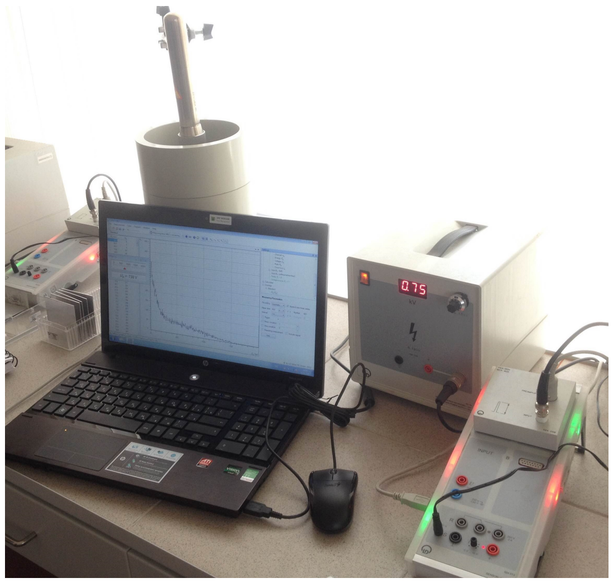

Figure 1: Experimental setup.

The experimental setup used in this experiment consisted of CASSY LAB 2 and a multichannel analyser for data analysation, a scintillation detector surrounded by a lead shield, a high voltage power supply for the scintillator, and a holder for the radioactive sources.

The CASSY LAB 2 software is calibrated using a ^{60}Co source. It is placed near the detector and the spectrum is recorded for about 100 seconds. After the spectrum is obtained and the two peaks are identified, they are fitted with Gaussian curves and the channel numbers corresponding to the mean of the peaks are noted. The two peaks of ^{60}Co are known to be 1173keV and 1332keV, so the n_a (channel number) scale is calibrated using these two points in order to display the energy in keV. Thus, the energy of the other spectra recorded in the experiment can be measured.

After the energy calibration is completed, the β-spectra of the ^{90}Sr source can be recorded for different absorber thickness. The spectrum is recorded without any aluminium absorbers, then additional spectra are obtained for a series of absorber thickness values. For each spectrum, the value E_m, the energy corresponding to the point of intersection between the spectrum and the x-axis ,is determined. Since it is difficult to determine the exact point where the spectrum intersects with the x-axis, the background radiation spectrum is obtained, and then E_m is determined to be the energy corresponding to where the spectrum falls below the background radiation. The determined values of E_m are plotted against their corresponding absorber thickness values, and the resulting graph is used to determine the aluminium absorber thickness required for the total absorption of electrons from ^{90}Sr.

3 Results and Analysis

The ^{90}Sr source was successfully used for calibration purposes, which allowed energy spectra to be obtained in the rest of the experiment.

After energy calibration, aluminium absorbers were added and the β-spectra were recorded, as well as the background radiation. The values E_m, the energy corresponding to the point where the spectra cross the

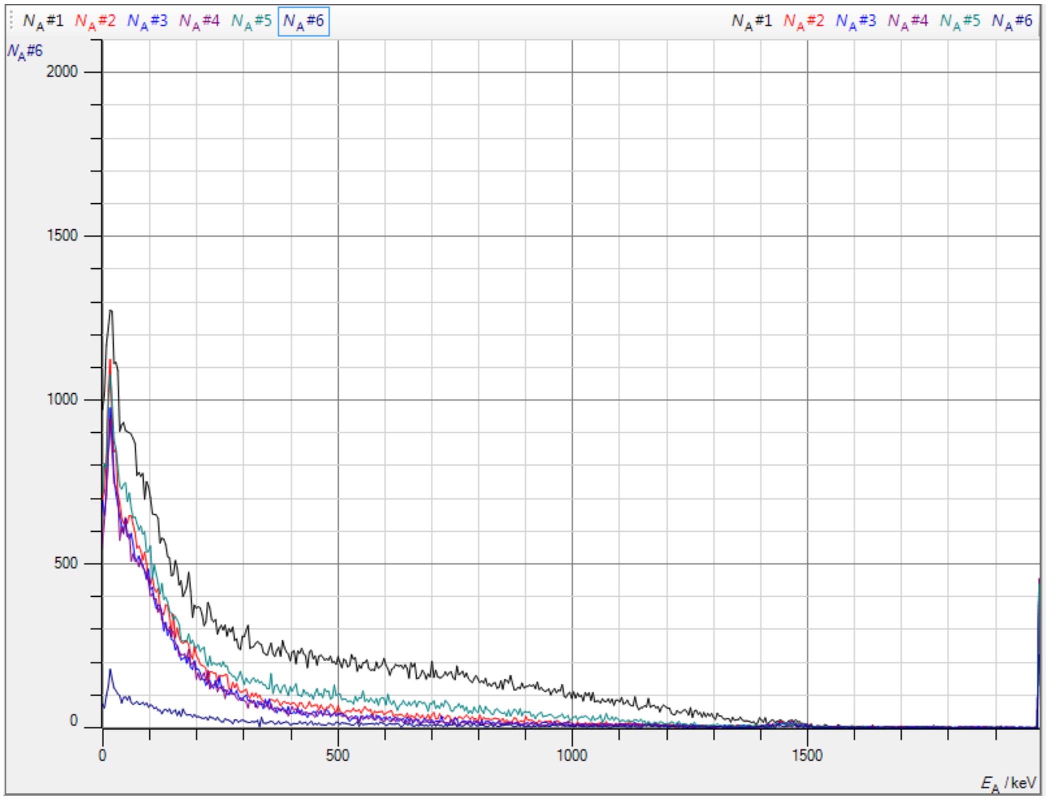

Figure 2: β-spectra for different absorber thicknesses.

background radiation, were determined. The E_m values were plotted against their corresponding thickness values, $d\,(\mathrm{mm})$. A straight line graph was obtained, with a slope of $m = -410 \pm 12$ and an intercept of $c = 1787 \pm 20$, giving an energy loss of $\frac{dE}{dx} = 410 \pm 12\mathrm{keV\,mm^{-1}}$ and a maximum energy of $E_\beta = 1787 \pm 20\mathrm{keV}$. There is a further energy loss of the β-particles due to the aluminium screening of the scintillation counter, which has a thickness of $d_0 = 0.4\mathrm{mm}$, given by

$$\Delta E = \frac{dE}{dx} d_0, \tag{1}$$

meaning there is a further energy loss of $\Delta E = 164 \pm 5\mathrm{keV}$, so the maximum energy is then $E_\beta = 1951 \pm 13\mathrm{keV}$. From the graph, the absorber thickness required for the total absorption of electrons from ^{90}Sr was determined to be $d = 4.36 \pm 0.14\mathrm{mm}$.

4 Discussion and Conclusions

The values obtained for the energy loss and the maximum energy were $\frac{dE}{dx} = 410 \pm 12\mathrm{keV\,mm^{-1}}$ and $E_\beta = 1951 \pm 13\mathrm{keV}$, respectively. The quoted values for these in the literature are $\frac{dE}{dx} = 410\mathrm{keV\,mm^{-1}}$ and $E_\beta = 2000\mathrm{keV}$; our values were close to the accepted values, but not correct within experimental errors. The estimated absorber thickness required for total absorption of electrons from ^{90}Sr was $d = 4.36 \pm 0.14\mathrm{mm}$. A large source of error was determining the values of E_m. It was very difficult to tell the exact point at which the spectra intersected with the background radiation. One possible improve would be to fit a nonlinear curve to each spectrum, and then determine the exact points of intersection.

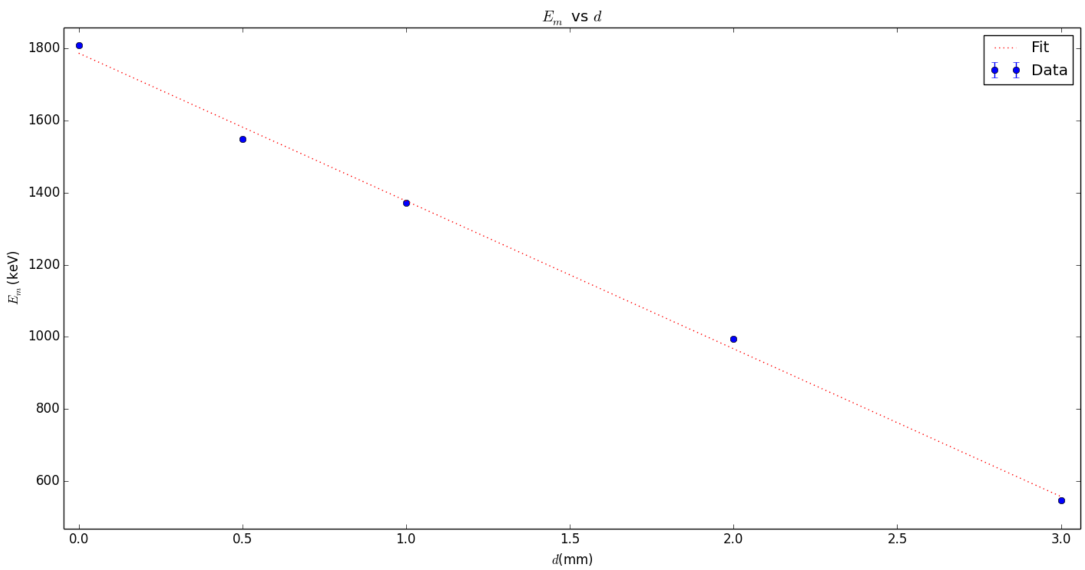

Figure 3: A graph of E_m vs d (thickness).