K5

Beta-spectroscopy and Fermi theory of beta decay

Laboratory session preparation task

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Before the laboratory session:

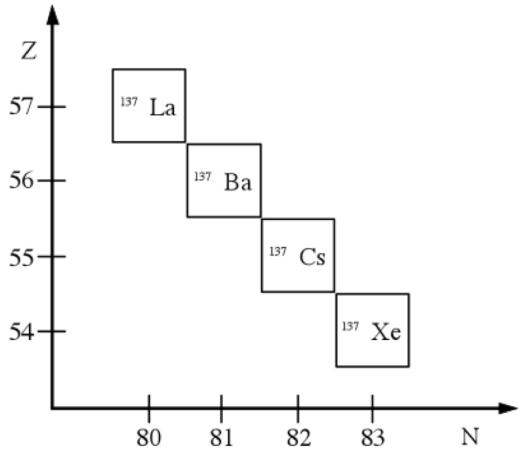
- Solve the homework problems of Sec. 1.
- Perform the excercise calibration task in Sec. 2.

You will need to show the successfull calibration exercise to the lab supervisor, in order to be admitted to the lab.

1 Homework problems

Refer to the course textbook for solving these problems before the lab session.

1. The radioactive isotope ^{137}Cs beta decays with a half life of 30 years. Use the tabulated atomic-mass data below to figure out the type of beta decay and the daugther nucleus.



$M\left(^{137}\mathrm{La}\right) = 136.906350$ u
$M\left(^{137}\mathrm{Ba}\right) = 136.905815$ u
$M\left(^{137}\mathrm{Cs}\right) = 136.907074$ u
$M\left(^{137}\mathrm{Xe}\right) = 136.911742$ u
1 u (atomic mass unit) corresponds to 931.504 MeV/c^2.

Figure 1: Part of the $A = 137$ isobar.

Decay mode for ^{137}Cs:

$$^{137}\mathrm{Cs} \qquad \rightarrow$$

Also, compute the ground-state Q-value of the decay.

$$Q_\beta\left(^{137}\mathrm{Cs}\right) = \qquad [\mathrm{MeV}].$$

2. Make a table with selection rules for different classes of beta decay

Class	ΔI	$\Delta\pi$
Allowed ($S_\beta = 0, 1$)		
First forbidden, Fermi ($S_\beta = 0$)		
First forbidden, Gamow-Teller ($S_\beta = 1$)		
Second forbidden, Fermi ($S_\beta = 0$)		
Second forbidden, Gamow-Teller ($S_\beta = 1$)		

Hint: The selection rules originate in the conservation of angular momentum and parity in the decay process. The total angular momentum carried away by the β-particles comes from their intrinsic spins and the orbital angular momentum.

Both the electron and the neutrino are fermions with spin $s_e = s_\nu = 1/2$. This gives the total spin $\vec{S}_\beta = \vec{s}_e + \vec{s}_\nu$ that can take values $S_\beta = 0, 1$ depending on if the spins are anti-parallell or parallell. A decay with the former spin coupling is known as a Fermi transition while the latter is a Gamow-Teller transition.

The quantum number characterizing the orbital angular momentum of the β-particles can take any positive, integer value $L_\beta = 0, 1, 2, \ldots$. However, the momentum and length scales involved in the decay would classically allow only $L_\beta = 0$. These transitions are therefore known as allowed transitions, whereas the others are forbidden[a]. The orbital angular momentum also determines the parity of the wave function describing the motion of the β-particles. This parity is given by $\pi_\beta = (-1)^{L_\beta}$.

The conservations of angular momentum and parity for a $\beta^\pm$-transition between two nuclear states (in different isotopes) with spin-parity $I_i^{\pi_i}$ and $I_f^{\pi_f}$ are

$$\vec{I}_i = \vec{I}_f + \vec{J}_\beta, \text{ where } \vec{J}_\beta = \vec{S}_\beta + \vec{L}_\beta, \text{ and}$$
$$\pi_i = \pi_\beta \cdot \pi_f.$$

For a certain angular-momentum difference between the nuclear states that are involved, $\Delta I = |I_i - I_f|$, and parity change, $\Delta\pi = \pi_i \cdot \pi_f$, the conservation laws will in principle just decide whether L_β is even or odd, and provide a minimum value. In practice, however, the "most allowed" class of decays (lowest L_β) will dominate to such a degree that the other possibilities can be disregarded.

3. Use a nuclear shell model diagram and make spin-parity assignments for the ground states of ^{137}Cs and its beta decay daughter nucleus.

   Refer to the course textbook for details.

[a]The term forbidden is somewhat of a misnomer as they are not really forbidden in quantum-mechanical systems; only much less probable.

2 Calibration exercise

During the laboratory session you will study the beta-decay energy spectrum of ^{137}Cs. For the data analysis you will need to perform an energy calibration. The following exercise is aimed to provide some experience and understanding for this task.

In addition to this calibration exercise you should also read the full lab PM.

Download of data and calibration codes

To perform this excercise you will need to download:

- Data and peak information
- Matlab script (fitpeak.m)

This can be downloaded from the following URL:

`http://fy.chalmers.se/subatom/sublab/k5example.php`

Energy calibration

In the laboratory you will study the beta-decay of the long-lived ^{137}Cs isotope. You will measure the energy spectrum of the emitted β-particles and you will employ theoretical knowledge to interpret the measured energy spectrum and determine the decay scheme.

During the laboratory session a calibration of channel number versus electron energy will be performed utilizing the decay of ^{207}Bi. The decay of ^{207}Bi is a multistep process that involves the emission of conversion electrons (see the chapter on gamma decay in the text book). These conversion electrons are emitted with discrete energies and will therefore show up as peaks in the energy spectrum.

For this excercise we will insted use the fictious student isotope $^{mm+dd}$St, where mm and dd are your month and date of birth. In the decay spectrum of the fictious $^{mm+dd}$St isotope there are four different peaks in the energy spectrum, see Fig 2. By performing peak fits, and thus determining the channel numbers of the conversion electron peaks in the spectrum, it is possible to perform the energy calibration by finding a linear relation between channel numbers and energies (see Appendix A).

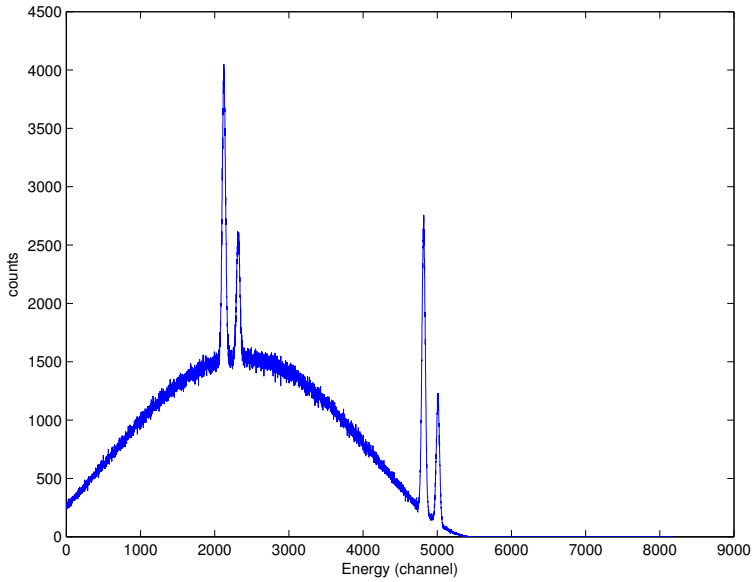


Figure 2: Uncalibrated data.

The data that you download will contain information concerning the energies of three of these peaks. Your tasks are to:

1. Use the Matlab script fitpeak.m described in the Appendix and perform peak fits for these three peaks. The end result of such a sequence of fits is shown in Fig. 3.

2. Armed with the peak channel numbers from these fits you're in a position to perform a linear calibration of energy versus channel number. You should create an energy-calibrated electron spectrum such as the one presented in Fig 4. Bring a printout to the laboratory session to show the lab supervisor.

3. This spectrum also allows you to determine the energy of the fourth conversion-electron peak and to estimate the Q-value for the observed beta-decay branch (i.e. the end point of the continuous electron energy spectrum). A visual inspection of the end-point energy is enough for this estimate.

Although you will have individual sets of data we encourage that you work together on solving these tasks. We will also be happy to answer any questions that you might have.

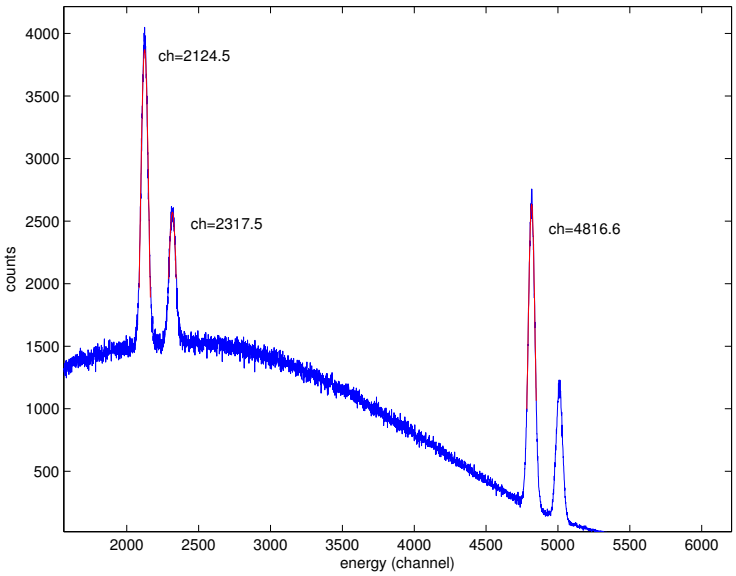


Figure 3: Peak fits.

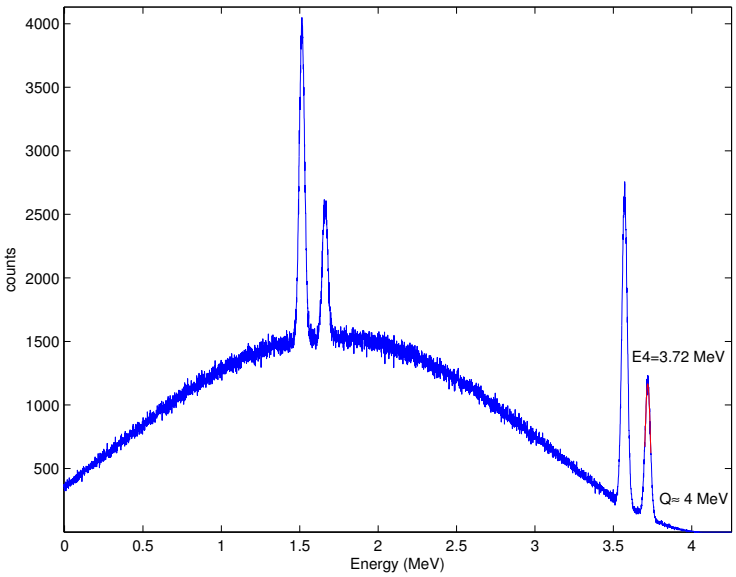


Figure 4: Energy-calibrated data.

A Data acquisition and data analysis

A.1 Data analysis – MATLAB operations

The experimental data will be analysed using MATLAB.

Calibration

- Fitting peaks (using parabola-fit of log-values). Select range approximately at half-maximum;

```
>> rangemin = 1850;
>> rangemax = 1950;
>> [peak1,fit1,fitrange]=fitpeak(rangemin,rangemax,data(:,1),data(:,2))
>> peak1
peak1 =
   1.8919e+03
```

  `peak` is the x-value of the peak (fitted to the data), `fit` is a vector with the y-values of the fit and `fitrange` is a vector with the x-values of the fit.

- Find and fit three peaks and make the linear calibration by fitting the parameters of the energy scale (keV):

```
>> polyfit([peak1 peak2 peak3],[e1 e2 e3],1)
ans =
    0.2586   -5.4891
```

  where `e1`, `e2`, `e3` are the known peak energies.

- Create a vector with raw channels (`ch`), and then an energy calibrated vector (`e`):

```
>> ch=data(:,1);
>> e=ans(1)*ch+ans(2);
```

- Finally, you can plot the energy-calibrated data:

```
>> figure;semilogy(e,data(:,2))
```

- To retrieve values at certain locations you can use the fit function, `fitpeak`.