01 How to Catch a Photon

Task 1 | The Energy of a Photon

a) A resting **N-14** nuclide reacts with a **He-4** nuclide with a kinetic energy of $\mathbf{E_{kin} = 2\ MeV}$. Nuclear fusion is initiated, producing only one daughter nuclide. Note the reaction equation and determine the reaction products.

b) During the reaction, a gamma quantum (photon) with a kinetic energy is released. Calculate the kinetic energy of the photon using the conservation of energy and the rest energies of the reactants involved (see nuclide map). For the rest energy applies:

$$\mathrm{E_0 = m_A \cdot 931{,}49\ MeV/u}$$

m_A … Atomic mass in u ,
m_A is indicated in nuclide map

c) What assumptions did you have to make to calculate the photon energy in 1b? Is the calculated energy the only possible kinetic energy the photon can have?

Task 2 | Energy Levels

Figure 1 shows 4 possible energy levels of an atomic nucleus. During the transition from excited states to the ground state, photons are released whose energy is measured by a detector. The experiment is repeated several times and an energy spectrum is recorded (see Fig. 2, large on the board).

a) Some photon energies are measured conspicuously often (so-called **Peaks**). How do the energies of the peaks relate to the energy level diagram in figure 1? Explain. Formulate the relationship with the help of equations.

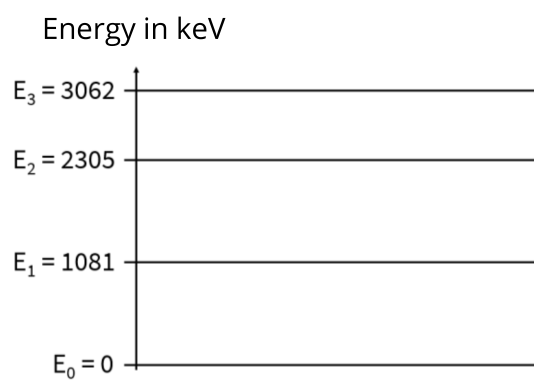

Fig.1: Term Diagram

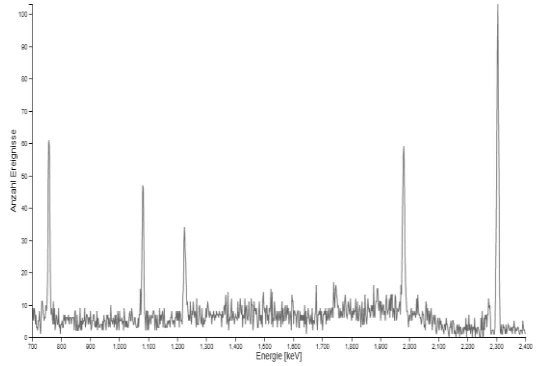

Fig.2: Related energy spectrum

b) Go back to question 1c. Do you still agree with your conjecture? Correct your guess if necessary.

Task 3 | Analyzing the Spectrum

a) Open the page on which the measurement series of the experiment are made available. Select the data set assigned to you and set a reasonable interval for the data analysis using the Term diagram. You should now see a gamma spectrum with several peaks. Now select a peak and use the zoom function to display it.

b) Determine the number of **measured events N** for the peak. Consider which **line width λ** should be used.

$\boldsymbol{\lambda} =$

$\mathbf{N}(\_\_\_\_\_\_\mathbf{keV}) =$

c) Determine the number of measured events **N** for the other energy transitions. Subtract the background according to the scheme shown. Enter your measurement results in the common measurement table.

Task 4 | Cross Section

The **cross section σ** of the reaction can now be calculated from the **count rate N** for the transitions. Use the following formula to calculate the cross section for your energy transitions. Also calculate the **total cross section σ_T** for your run (sum of the cross sections of all peaks considered).

$$\boldsymbol{\sigma} = \frac{\mathbf{N}}{\mathbf{N_P} \cdot \mathbf{p} \cdot \mathbf{d}} = \frac{\text{Count Rate}}{\text{Number Projectiles} \cdot \text{Detection Probability} \cdot \text{Target Density}}$$

Task 5 | The Thermonuclear Reaction Rate

The thermonuclear reaction rate of the reaction observed here can now be determined from the **total cross section σ_T**. It is strongly temperature dependent. If we assume that the reaction takes place inside red giants, a temperature of **1 GK** can be assumed. As an approximation, the thermonuclear reaction rate for the reaction of N-14 with He-4 is as follows:

$$\mathbf{r_{Th}}(\mathbf{T} = \mathbf{10^9 K}) = \mathbf{12889{,}6} \cdot \left(\frac{\mathbf{m_1+m_2}}{\mathbf{m_1 m_2}}\right)^{\frac{3}{2}} \cdot \boldsymbol{\sigma}_\mathbf{T} \cdot \mathbf{10^{24}} \frac{\mathbf{1}}{\mathbf{cm^2}} \qquad [\mathbf{r_{Th}}] = \frac{\mathbf{cm^3}}{\mathbf{mol \cdot s}}$$

- m_i .. Atomic Mass in u
- σ_T ... Total Cross Section

Calculate the thermonuclear reaction Rate of the $^{14}N(\alpha,\gamma)$ reaction.