E5 Kern- und Teilchenphysik
WiSe 17/18 – Exercise 4

Discussion: 05.12.2017 bis 11.12.2017

Students studying "Lehramt Gymnasium" please solve the exercises 1, 2a, 3 and 4. All other students please solve exercises 1, 2 and 3

1. Energy Loss of Cosmic Muons in Iron

Consider a cosmic muon of the energy $E = 3\,\text{GeV}$, which flies through a 5 cm thick iron plate ($Z = 26$, $A = 55.85$, $\varrho = 7.874\ \text{g/cm}^3$). Calculate the energy loss of the muon in the iron. Why can the energy loss assumed to be a constant instead of integrating over the distance traveled by the Muon?

Note: Ignore the density effect correction and assume an ionization potential of $I \approx Z \cdot 10\,\text{eV}$.

2. Solar Neutrinos

In the attendance exercise we considered the energy generation of the sun by thermonuclear fusion. In the so-called pp chain, four protons are fused in several intermediate steps to form a ^{4}He nuclei. The overall reaction is as follows:

$$4p \;\rightarrow\; {}^4\text{He}^{++} + 2e^+ + 2\nu_e + Q \tag{1}$$

with the total energy released Q.

(a) What is the life expectancy for the Sun assuming that all the protons present in the Sun are converted to He in the pp chain? For this purpose, use the neutrino flux calculated in the attendance exercise on the earth (i.e., in 1 AE $= 1.5 \times 10^{11}$ m distance from the sun) of $\Phi_{pp} = 6.89 \times 10^{14}\,\frac{1}{\text{m}^2\text{s}}$.

In a side branch of the pp chain the trapping of an electron in ^{7}Be in the reaction

$$e^- + {}^7\text{Be} \;\rightarrow\; {}^7\text{Li} + \nu_e \tag{2}$$

produces mono-energetic neutrinos with an energy of $E_{\text{Be}} = 862\,\text{keV}$ which can be detected in underground detectors via neutrino-electron scattering. In the so-called *Borexino* experiment, e.g. a high-purity liquid scintillator (pseudocumene, C_9H_{12}) of 100 t mass acts as the electron target in which the rebound electrons produce a light signal.

(b) **Optional for Lehramtsstudierende:**
Explain qualitatively why the neutrino emitted in reaction (2) is mono-energetic. You can neglect a possible excitation of the ^{7}Li nucleus since it is generated in the ground state in 89.48% of decays.

(c) **Optional for Lehramtsstudierende:** Calculate the number of $\nu_e - e^-$ scattering events in the detector per day. Assume an interaction cross section of $\sigma_{\nu_e - e^-} = 7.93 \times 10^{-21}$ b and a neutrino flux on earth of $\Phi_{Be} = 3.3 \times 10^{13}\,\text{m}^{-2}\text{s}^{-1}$.
Note: The rate of neutrino-electron scattering is analogous to the reaction rate for scattering on a stationary target. See Attendance Exercise 1-1c.

3. Trace Element Analysis (State examination assignment)

Pesticides used in viticulture may contain arsenic. In order to determine how much of this is in the wine, a wine sample of 2.00 g is irradiated for 16.0 minutes in a reactor with a neutron flux density $\Phi = 1.0 \times 10^{15}\,\mathrm{s^{-1}cm^{-2}}$. During this irradiation natural ^{75}As is converted into a radioactive As isotope with $t_{1/2} = 26.5\,\mathrm{h}$ (activation). The cross-section for this process is $\sigma = 5.4 \times 10^{-24}\,\mathrm{cm^2}$.

(a) Specify the reaction equation for neutron capture. What decay process is to be expected for the radioactive As isotope? Specify the decay equation.

(b) Calculate the production rate of the radioactive As isotope when the sample consists of 10^{-5} parts by weight of arsenic.

Note: The production rate is analogous to the reaction rate for scattering on a stationary target. See Attendance Exercise 1-1c.

(c) How large is the number N_{akt} of As atoms which are activated during the entire irradiation process? Discuss the extent to which N_{akt} exactly corresponds to the number N_0 of the radioactive As atoms present at the end of the irradiation.

4. Thermal Neutrons and Uranium Fission (State examination assignment, optional for students on Bachelor physics or Bachelor plus)

(a) Explain the role of the neutron in the fission of an Uranium nucleus ^{235}. Explain why the cross section increases with decreasing neutron energy.

(b) In a nuclear reactor, H_2O is often used as the moderator to cool the neutrons to a thermal energy of $E_{n,\mathrm{therm}} \sim 0.025\,\mathrm{eV}$. Consider a neutron ($m_n = 939.6\,\mathrm{MeV/c^2}$) with a kinetic energy $E_{\mathrm{kin},n} = 1.74\,\mathrm{MeV}$ and determine the kinetic energy

i. after central impact with a stationary H nuclei ($m_p = 938.3\,\mathrm{MeV/c^2}$), and

ii. after central impact with a stationary O nuclei ($m_O = 14900\,\mathrm{MeV/c^2}$).

(c) Taking into account non-central collisions of the neutron with stationary H nuclei we obtain an average of $E_{n,\mathrm{after}} = 0.368 \cdot E_{n,\mathrm{before}}$ for each collision. Calculate the amount N of such collisions which are necessary to cool a neutron with $E_n = 1.74\,\mathrm{MeV}$ to thermal energy.