# Problem Solving Class: Van Quark tot Biomaterie

**Problem Set 12: Nuclear reactions**
**Hand-in on paper Monday 2 December (before 12:00 h)**
**in Mailbox Madhu Talluri (Mailboxes W&N building)**
**Hand-in digitally, email to: m.t.talluri@vu.nl;**
**All documents in a single file [file: YourName-WC-P4]**
**All answers in English**

## 1) Proton fusion in the Sun

Consider the proton-fusion reaction:

$$4p^+ \rightarrow \alpha + 2e^+ + 2\nu + 2\gamma$$

a) Given the mass of the Sun (2 x $10^{30}$ kg) and assuming that the Sun consists entirely of hydrogen (protons), and that the Sun radiates an amount of energy of 4 x $10^{26}$ Watt, how long can the Sun go on burning on proton fusion.

b) Given the Earth-Sun distance 150 x $10^6$ km, how many neutrinos will penetrate through a human thumb (~ 5 $cm^2$) on Earth.

## 2) Fission

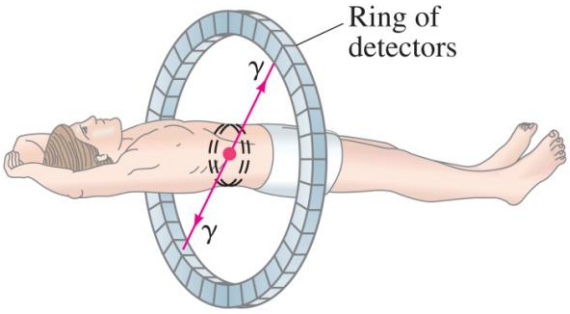
One possible fission reaction of $^{235}$U is:

$$n + {}^{235}_{92}U \rightarrow {}^{88}_{38}Sr + {}^{136}_{54}Xe + 12n$$

Assume that the incoming neutron has a negligibly small momentum/energy.
How much energy is then released in this reaction ?

## 3) Positron Emission Tomography (PET)

PET usually employs $^{18}$F isotopes. These isotopes are commonly produced (at cyclotron facilities, such as at VU) by accelerating protons and let them react with a certain isotope of oxygen: $^{18}$O. The atomic weights are M($^{18}$O)=17.999161 u and M($^{18}$F)=18.000938 u.
1 u (atomic mass unit) = 1.6605 x $10^{-27}$ kg = 931.5 MeV/$c^2$.



a) Write the nuclear reaction equation for the production process.
b) The protons must be accelerated to make this reaction go. To what energy ? You may make some assumptions, but explain.
c) Write the PET-reaction.
d) Describe how photons play a role in the “PET-process” and where do they come from ?
e) Explain why two photons are produced, and why they move in opposite directions with equal velocity.