State Examinations Commission – Physics Higher Level, 2004.

## Question 10

Beta decay is associated with the weak nuclear force.
List two other fundamental forces of nature and give one property of each force. (12)
In beta decay, a neutron decays into a proton with the emission of an electron. Write a nuclear equation for this decay. Calculate the energy released during the decay of a neutron. (21)
Momentum and energy do not appear to be conserved in beta decay. Explain how the existence of the neutrino, which was first named by Enrico Fermi, resolved this. (8)
During the late 1930s, Fermi continued to work on the nucleus.
His work led to the creation of the first nuclear fission reactor in Chicago during 1942. The reactor consisted of a 'pile' of graphite moderator, uranium fuel with cadmium control rods.
i) What is nuclear fission?
(ii) What is the function of the moderator in the reactor?
(iii) How did the cadmium rods control the rate of fission? (15)
(mass of neutron = $1.6749 \times 10^{-27}$ kg; mass of proton = $1.6726 \times 10^{-27}$ kg;
mass of electron = $9.1094 \times 10^{-31}$ kg; speed of light = $2.9979 \times 10^{8}$ m $s^{-1}$)

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List two other fundamental forces of nature and give one property of each force. (12)
Gravity – weak force that acts over all distances on all matter. Always attractive.
Electromagnetic – stronger force that acts over all distances on charged particles. Attractive or repulsive.

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$$n_0^1 \rightarrow H_1^1 + \beta_{-1}^0$$

Mass defect = $(1.6749 \times 10^{-27} - 1.6726 \times 10^{-27} - 9.1094 \times 10^{-31}) = 1.3891 \times 10^{-30}$ kg.

$E = mc^2$
$= 1.3891 \times 10^{-30} \times (2.9979 \times 10^{8})^2$
$= 1.248 \times 10^{-13}$ J.

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During beta decay, an atom's nucleus sheds excess energy by converting a neutron into a proton and an electron and, as scientists now know, an antineutrino. Scientists noticed that when atoms of a particular isotope underwent beta decay, they always lost the same amount of energy, but the electrons were ejected with a range of energies. It appeared as if energy was being destroyed in the reaction, violating a concept known as the conservation of energy. They also noticed that the ejected electron and the recoiling nucleus didn't always move apart on a straight line, but sometimes did so at an angle. This violated another concept known as the conservation of momentum. Believing that the two conservation laws were valid, Pauli stated than an undetected particle must be produced during beta decay, one that would carry away the missing energy and momentum. Fermi termed this particle a neutrino.

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i) What is nuclear fission?

The splitting up of a large nucleus into two similar sized smaller ones with the release of energy.

ii) What is the function of the moderator in the reactor?

Used to slow down the fast neutrons produced by fission to thermal energies so that they may cause further fission.

iii) How did the cadmium rods control the rate of fission? (15)

Cadmium is a neutron-absorbing material and the rods are inserted or withdrawn from the core to control the rate of reaction, or to halt it.

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