A2-2011 Q2

When a beam of protons from a particle accelerator hits a target, particles are produced which have a very short lifetime. For a particle to be formed, one side of the particle must "be in touch with" the far side of the particle, so that a signal from one side of the particle must reach the other side before the particle decays.

The diameter of the particle can be taken as the range of the Strong Nuclear Force which is about 1×10^{-15} m. If the signal propagates at the speed of light, what would be the shortest lifetime of such a particle?

(4 marks)

A2-2012 Q1

When a satellite is launched to a distant planet, a radioisotope thermoelectric generator (RTG) is used to provide electrical power for the satellite. This consists of a decaying radioactive source producing heat which can then be converted to electrical power. NASA is allowed to launch with a maximum 25 kg mass of plutonium dioxide (PuO_2) on a single satellite, but it never uses the maximum.

a) Pu-238 itself alpha decays and NASA quotes the *specific activity* of the radioactive PuO_2 as 17 Cu/g, where 1 curie (Cu) is 3.7×10^{10} decays per second. Calculate the number of alphas released per second from 1 g of PuO_2.

b) If the plutonium emits 5.5 MeV alphas, how many watts of power per gram are released by the radioactive source? This quantity is known as the *power density*.

c) At launch, 4.5 kW of heat power are required from the source. What mass of radioactive PuO_2 is required?

d) If the conversion efficiency from thermal to electrical energy is 7%, what electrical power will this supply initially?

e) Why are solar panels not used for satellites travelling to distant planets?

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

(6 marks)

A2-2009 Q5

In order to probe the structure of a nucleus, whose radius is about 10^{-15} m, a beam of electrons from a particle accelerator is fired at a solid target containing a high density of nuclei. If the wavelength of the electrons is similar to the size of the nucleus, then a diffraction effect will occur and the size of the nucleus can be determined.

(a) Calculate the momentum of the electron beam which is needed to make the wavelength equal to the nuclear diameter.

(2 marks)

(b) Calculate the energy of the electron beam, both in joules and in electron volts. Assume that the electrons are moving at almost the speed of light, and use $E = mc^2$ with the momentum, $p = mc$, where m is the mass of the electron.

(2 marks)

(c) If the beam current is 10^{-8} A, calculate the number of the electrons hitting the target each second.

(2 marks)

(d) A copper target of thickness 0.1 cm intercepts the electron beam in part (b). The beam has a cross sectional area of 9 mm^2 when it hits the copper target. What is the volume of copper through which the beam passes? Show that the number of target nuclei lying in the beam is approximately 8×10^{20}.

(3 marks)

(e) If the cross sectional area of the nuclei are very small and they do not lie behind each other, then calculate the ratio of the total area of the nuclei lying in the beam path to the cross sectional area of the beam.

(2 marks)

(f) The ratio in part (e) can be taken as the probability that an electron will collide with a target nucleus. From your answer in part (c) calculate the number of interactions in the target per second.

(2 marks)

[13]

$e = 1.6 \times 10^{-19}$ C
mass of electron = 9.1×10^{-31} kg
Density of copper is 8900 kg m^{-3}
Relative atomic mass of copper is 63.5
Avogadro's number, $N_A = 6.02 \times 10^{23}$ atoms/mol