The University Of Sheffield.

DEPARTMENT OF PHYSICS & ASTRONOMY

Autumn Semester 2006-2007

NUCLEAR PHYSICS **2 Hours**

Answer question ONE (COMPULSORY) and TWO other questions.

A formula sheet and table of physical constants is attached to this paper.

All questions are marked out of ten. The breakdown on the right-hand side of the paper is meant as a guide to the marks that can be obtained from each part.

COMPULSORY

1 Write a brief explanation, with sketches and diagrams where appropriate, of each of the following ten terms, and their significance in nuclear physics.

(i) Binding energy; [1]

(ii) Compound nucleus; [1]

(iii) Thermal reactor; [1]

(iv) Deuteron magnetic moment; [1]

(v) Exchange force; [1]

(vi) Electric quadrupole moment; [1]

(vii) Isospin; [1]

(viii) Liquid drop model; [1]

(ix) Positron Emission Tomography; [1]

(x) the Sievert. [1]

2 (a) Explain, with reference to the appropriate decay chain, the origin of radon gas. What are typical levels of radon in the environment and why is radon particularly harmful to humans? **[4]**

(b) Consider the alpha particle decay ${}^{230}_{90}\mathrm{Th} \rightarrow {}^{226}_{88}\mathrm{Ra} + \alpha$ and use the following expression to calculate the values of the binding energy B for the two heavy nuclei involved in this process:

$$B = a_{\mathrm{v}}A - a_{\mathrm{s}}A^{2/3} - \frac{a_{\mathrm{c}}Z(Z-1)}{A^{1/3}} - \frac{a_{\mathrm{a}}(N-Z)^2}{A} - a_{\mathrm{p}}A^{-3/4}$$

where values for the constants a_{v}, a_{s}, a_{c}, a_{a} and a_{p} are respectively 15.5, 16.8, 0.72, 23.0 and −34.5 MeV.

Given that the total binding energy of the alpha particle is 28.3 MeV, find the energy Q released in the decay. **[4]**

(c) This energy appears as the kinetic energy of the products of the decay. If the original thorium nucleus was at rest, use conservation of momentum and conversation of energy to find the kinetic energy of the daughter nucleus ${}^{226}\mathrm{Ra}$. **[2]**

3 (a) Explain the term *magic numbers* in relation to the shell model of the nucleus and, with the aid of sketches, explain two pieces of experimental evidence that support this model. **[3]**

(b) Making use of the shell model, sketch the ground state configuration of protons and neutrons for ${}^{12}_{6}\mathrm{C}$ and the next three isotopes of increasing A. Give the spin and parity assignment for the ground state of ${}^{13}_{6}\mathrm{C}$ and compare this with the equivalent assignments for the ground state of ${}^{15}_{6}\mathrm{C}$. **[4]**

(c) The isotope ${}^{14}_{6}C$, with half-life 5730 years, is used in carbon dating. Estimate, by making use of the expression for specific activity

$$A\exp\left[-\frac{\ln 2}{t_{1/2}}t\right],$$

the age of a sample of wood found to have specific activity 2.1 Bq where a control sample of 0 years old has activity 5.3 Bq. **[3]**

4 (a) With the aid of sketches describe the observed form of typical beta decay spectra and state two important differences between alpha decay and beta decay. Describe the Fermi-Curie plot and its importance in relation to neutrino mass. **[4]**

(b) Write down the equations for the energy release Q for the three processes of electron emission, positron emission and electron capture, carefully defining the symbols that you use. What is the rest mass of the positron? **[3]**

(c) The nuclide ${}^{21}_{11}\mathrm{Na}$ (atomic mass $M_{\mathrm{Na}} = 19.558$ GeV/c^2) decays at rest by positron emission to ${}^{21}_{10}\mathrm{Ne}$ (atomic mass $M_{\mathrm{Ne}} = 19.553$ GeV/c^2). What is the total kinetic energy Q of the positron and neon nuclide when the associated neutrino has zero energy?

The emerging positron is relativistic with velocity v_e whereas the nuclide, with velocity v_{Ne}, is massive and so nonrelativistic. Given this information write conservation equations for the momentum and energy, making appropriate use of the Lorentz factor

$$\gamma_e = (1 - v_e^2 / c^2)^{-1/2} \ .$$

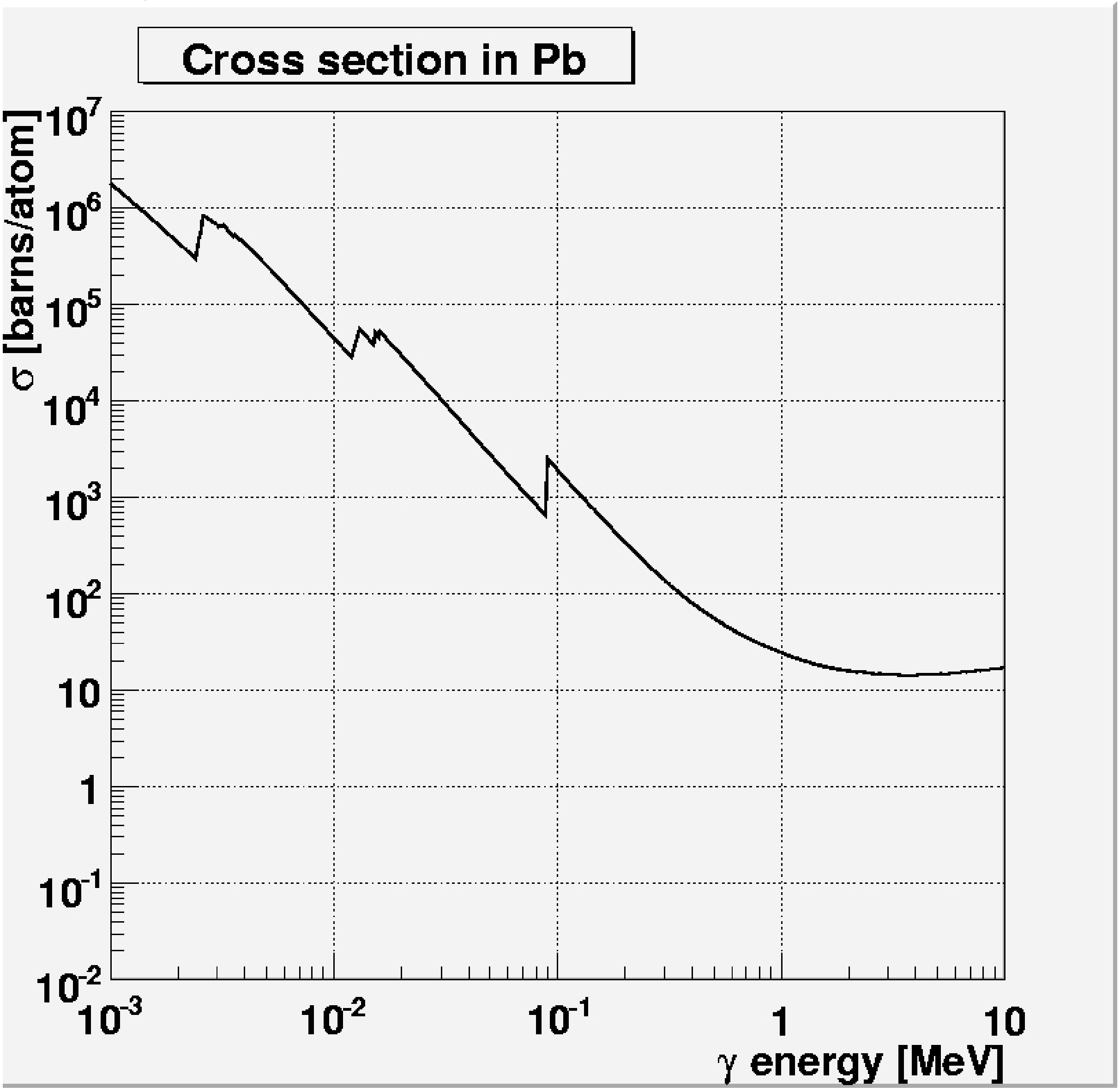
It can be shown by solving these equations that $\gamma_e = 7.85$. Using this information show that the kinetic energy of the positron is 3.5 MeV. **[3]**

5 (a) Describe, with sketches and reference to the figure below showing the attenuation coefficient for gamma rays in lead, the three most important interaction processes for gamma-rays in matter. Contrast this with a description of the three principal processes important for neutron interactions in matter. **[4]**

(b) Lead is sometimes used as a shielding material to protect workers from intense radiation sources involving gammas and neutrons, for instance DD or DT neutron beams. Using the figure below estimate the thickness of lead (density 11.3 kg m^{-3}) required to absorb 99.9% of gamma rays of energy 1 MeV. **[3]**

(c) Consider a beam of 1 MeV neutrons of intensity 10^5 s^{-1} directed at normal incidence to a shield of lead (average A = 207) of thickness 0.1 kg/m^2. Find the total number of Pb atoms per m^2 and hence calculate the attenuation of the neutron beam by the shield given that $\sigma_T(1\ \text{MeV}) = 3.0 \times 10^{-24}\ \text{m}^2$.

Comment on the relative merits of lead as a shield for neutrons and gammas. **[3]**



END OF EXAMINATION PAPER