CARST : MARST Course : Nuclear Physics Module : 2006

Exam : Detection of radiation, Nuclear reaction mechanisms, Accelerators

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Instructions: Answer all questions.
Time: 2 hour = 120 minutes
Total Marks: 100 marks (100 marks = 100%)

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1. Consider the equation

$$-\frac{dE}{dx} \propto \frac{\rho m z^2}{E}.$$

   (a) Discuss the meaning of each symbol on the righthand side of the formula above as well as the meaning of the term $-\frac{dE}{dx}$. (5)

   (b) Use this equation, estimate how much more penetrating a positron would be compared to an alpha particle of the same energy. (8)

   (c) Explain why this equation applies only to charged particles. (3)

   (d) Explain how this equation can be used to estimate the range of an energetic charged particle in matter. (4)

Total for Question 1 [20]

2. (a) Name the three main interactions of a photon with matter and describe briefly the characteristics of each of them. (9)

   (b) Draw a typical spectrum as it would appear in a HPGe detector for a radioactive source producing only 1.533 MeV gamma ray photons, and show clearly evidence for all three interactions you have just mentioned. (9)

   (c) The immediate environment of a reactor contains a large flux of γ-rays with energies in the vicinity of 5-10 MeV. What thickness of lead is required to reduce the photon intensity by a factor of 10^{12} ?
   (Density of lead is 13.344 g/cm^3 and the total mass attentuation coefficient is 0.08 cm^2/g @ 10 MeV). (7)

Total for Question 2 [25]

3. (a) Consider Rutherfords experiment in the case where an alpha particle of energy 4.8 MeV rebounds back on its original trajectory from a gold foil. Use arguments based on the conservation of energy to show that the mass of the atom must be concentrated in a dense positively charged nucleus whose diameter is smaller than 100 fm, whereas the diameter of the atom is about an angstrom. (6)

   (b) Assuming that nuclei are spheres, determine the average density of nuclei (in nucleons/fm^3 and kg/m^3). (6)

   (c) Give the famous Einstein relation which specifies the equivalence between matter and energy. (2)

   (d) Explain in some detail the relevance of this relation to understanding the energetics of nuclear reactions. (6)

   (e) Calculate the binding energy of the helium nucleus.
   ($m(^4\mathrm{He}) = 4.002602$ u, $m(^1\mathrm{H}) = 1.007825$ u, $m_n = 1.008665$ u). (6)

   (f) i. Identify the defining features of a nuclear reaction that proceeds via the formation of a compound nucleus. [6]

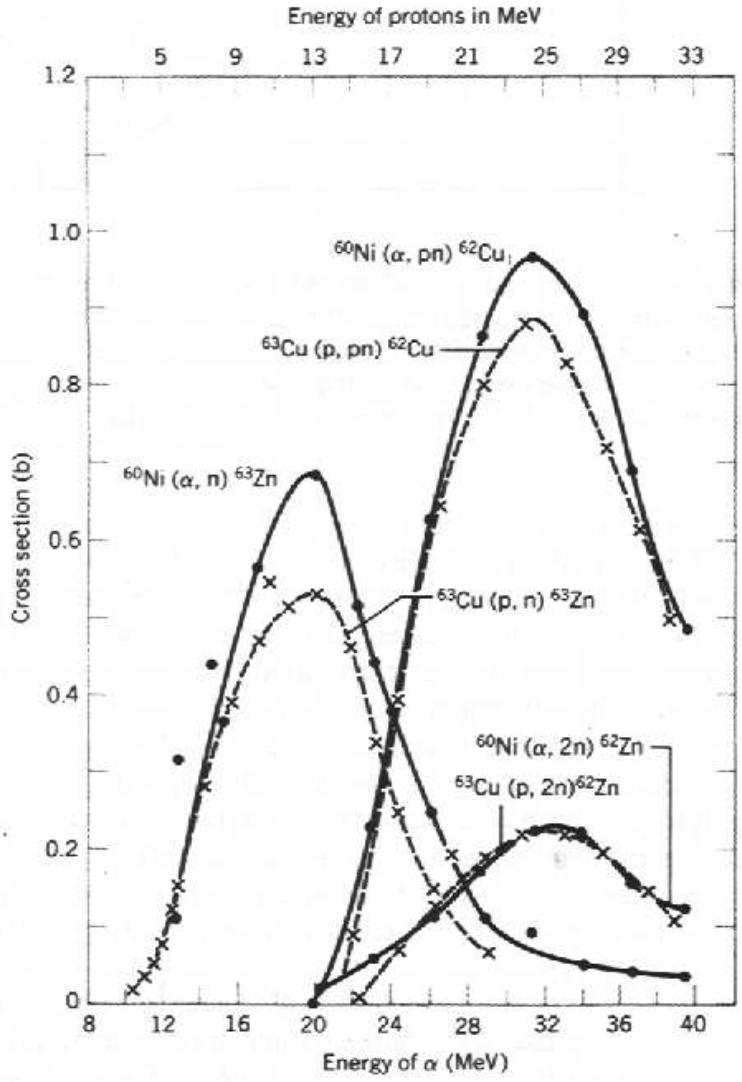
   ii. Explain how the figure below identifies the set of reactions as all proceeding through the compound nucleus mechanism. [6]

   iii. Identify the compound nucleus in question. [2]

Total for Question 3 [40]

4. Discuss the operation of a linac accelerator, including a labelled sketch of the acceleration systems, and also including a derivation of drift length resonance condition for non-relativistic particles. Total for Question 4 [15]

Total Marks **[100]**


Energy of protons in MeV
5
9
13
17
21
25
29
33
1.2
1.0
0.8
0.6
0.4
0.2
0
Cross section (b)
^{60}Ni (α, pn) ^{62}Cu
^{63}Cu (p, pn) ^{62}Cu
^{60}Ni (α, n) ^{63}Zn
^{63}Cu (p, n) ^{63}Zn
^{60}Ni (α, 2n) ^{62}Zn
^{63}Cu (p, 2n)^{62}Zn
8
12
16
20
24
28
32
36
40
Energy of α (MeV)