UNIVERSITY OF SOUTHAMPTON PHYS3009W1

SEMESTER 2 EXAMINATION 2012-2013

APPLIED NUCLEAR PHYSICS

Duration: 120 MINS (2 hours)

This paper contains 9 questions.

Answers to Section A and Section B must be in separate answer books

Answer **all** questions in **Section A** and **only two** questions in **Section B**.

Section A carries 1/3 of the total marks for the exam paper and you should aim to spend about 40 mins on it.

Section B carries 2/3 of the total marks for the exam paper and you should aim to spend about 80 mins on it.

An outline marking scheme is shown in brackets to the right of each question.

A Sheet of Physical Constants is provided with this examination paper.

Only university approved calculators may be used.

A foreign language translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

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Section A

A1. Draw a labelled diagram showing the pulse-height spectrum you would obtain from a germanium gamma-ray spectrometer illuminated by a 5 MeV gamma-ray source. Mark the energy of any lines or other features in the spectrum, and very briefly describe their origin. [4]

A2. What is the fundamental difference between **r-process** and **s-process** nucleosynthesis, and under what conditions might these processes occur? [3]

A3. What is an isochron? Write down the two essential features that must be possessed by isochronic samples used in geological dating. [3]

A4. What are the relative advantages and disadvantages of radiochemical and Cherenkov detectors for studying solar neutrinos? [3]

A5. With the help of a labelled graph, describe how the energy lost per unit distance by a heavy charged particle moving through matter varies with the particle velocity. Use your answer to explain the term *minimum ionising particle*. [4]

A6. What are the two main reactions used in fusion research reactors? State the advantages and disadvantages of each one. [3]

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Section B

B1. Outline the qualitative naming conventions used to describe the energy of neutrons. [4]

Describe the interactions of neutrons with matter, being sure to discuss the energy dependence of each interaction, and the neutron energy range over which it is most applicable. [6]

Show that for a neutron of mass m, scattering elastically from a nucleus of mass M, the ratio of the scattered to original neutron energies is given by:

$$\frac{E}{E_0} = \frac{M^2 + m^2 + 2Mm\cos\theta}{(M+m)^2}$$

where θ is the scatter angle in the centre-of mass frame. [6]

Hence show that in units of nucleon masses, the energy of the scattered neutron E' is restricted to the range:

$$\left(\frac{A-1}{A+1}\right)^2 < \frac{E}{E_0} < 1$$

where E_0 is the neutron energy before it scatters and A is the mass of the scattering nucleus. [2]

Sketch the energy distributions of a population of initially monoenergetic neutrons after they have undergone 1, 2, 3 and 10 elastic scatters in a non-hydrogenous material. What is the shape of the final neutron energy distribution after a very large number of scatters? [2]

TURN OVER

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B2. Describe how radioactive ^{14}C is produced, distributed within the ecosystem and incorporated into organic samples. [4]

A simplistic approach to radiocarbon dating might assume that the abundance of ^{14}C in natural carbon is the same at all times and places. Discuss the problems with this assumption, and the methods used to deal with any changes to the ^{14}C abundance. [6]

The half-life of ^{14}C is 5730 years, and young natural carbon contains ^{14}C at a concentration of 1 part in 10^{12}. How many decays will occur per gram of young natural carbon per minute. [2]

A sample of 50mg of carbon of unknown age produces 0.09 counts/minute - use this information to estimate its age. [4]

Discuss various ways in which the decay rate of small samples of carbon can be measured. [4]

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B3. In a fission reactor, the neutron reproduction factor can be described by the four-factor formula, normally written as $k_\infty = \eta\epsilon p f$.

Starting with a population of N thermal neutrons in the fuel of a fission reactor core, describe the neutron reproduction cycle, defining all the terms of the four-factor formula. Quantify all neutron loss and gain processes that can occur in an infinite-sized reactor. [8]

Write down and explain an expression that shows how the four-factor formula can be extended to describe k, the neutron reproduction factor for a finite-sized reactor. [2]

Explain why the value of k = 1.0065 is so important in reactor operations. Estimate the reactor response time for the conditions $k < 1.0065$ and $k > 1.0065$. [6]

Sketch a graph showing how the value of k changes through the start-up, operation and shutdown of a reactor. [2]

What practical means are used to control the value of k during reactor operation? [2]

END OF PAPER

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