SEMESTER 2 EXAMINATION 2014-2015

APPLIED NUCLEAR PHYSICS

Duration: 120 MINS (2 hours)

This paper contains 10 questions.

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 word to word® translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

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]

Section B

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

(b) 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]

(c) Show that, for the simple case of a direct head-on elastic collision of a neutron with a nucleus of atomic mass A, the ratio of the neutron's energy after the collision, E, to that before the collision, E_0, is given by:

$$\frac{E}{E_0} = \left(\frac{A-1}{A+1}\right)^2$$ [5]

(d) The number, n, of collisions needed to reduce the energy of a neutron from E_0 to E is given approximately by

$$n = \frac{1}{\zeta} ln \frac{E_0}{E}$$

where

$$\zeta = 1 + \frac{(A+1)^2}{2A} ln \frac{A-1}{A+1}.$$

If E=1 MeV, calculate ζ and n for collisions, with both deuterium and carbon, to bring neutrons down to the energy which is most effective for inducing fission in ^{235}U. [3]

(e) Discuss the various contributions to the total neutron scattering cross section, including how the cross section varies with atomic number and with energy. [2]

TURN OVER

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

(b) 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]

(c) 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]

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

B3. **(a)** 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]

(b) What factors define the lifetime of the prompt neutrons emitted during fission? [1]

By making reasonable estimates of typical reactor parameters, estimate by what factor the neutron flux might rise in one second in a prompt supercritical reactor. [3]

Describe why practical reactor response times can be made as long as a few hundred seconds. [2]

(c) 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]

TURN OVER

B4. **(a)** What percentage of the background radiation dose to which we are subject comes from natural sources? [1]

Upon which factors does the natural background depend? [3]

(b) For which purposes is radiation used in medicine? [1]

Draw, and describe the operation of, the components of a gamma-camera. [5]

Explain how the gamma-camera is used to diagnose the presence of damaged tissue. [1]

(c) Compare the use of photons (X-rays or Gamma-rays) with that of particles for radiotherapy in nuclear medicine. Consider different possible particle types separately. [4]

(d) Discuss the physical principles behind Magnetic Resonance Imaging (MRI) and compare the use of MRI with X-ray Computed Tomography. [5]

END OF PAPER