SEMESTER 2 EXAMINATION 2013-2014

APPLIED NUCLEAR PHYSICS

Duration: 120 MINS (2 hours)

This paper contains 11 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 translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

Copyright 2014 © University of Southampton

Section A

A1. Describe the various modes of operation of a gas counter as the applied voltage is varied between 0 and 2000 V. [3]

A2. Explain how radioactive ^{14}C is produced, stored in the ecosystem and finally incorporated into organic samples for use in radiocarbon dating. [2]

A3. Describe briefly how photons with energy between 10 and 10,000 keV can deposit energy in matter. Indicate the dominant energy range for each mechanism in your answer. [3]

A4. What is the fundamental difference between s-process and r-process nucleosynthesis mechanisms, and where might they occur? [3]

A5. Describe the processes by which a gamma-ray photon ultimately produces an electronic signal in a scintillator-photomultiplier detector. [3]

A6. Which processes allow hydrogen to be converted to helium in our Sun ? [2]

A7. Outline the main physical principles behind conventional Magnetic Resonance Imaging (MRI). [4]

Copyright 2014 © University of Southampton

Section B

B1. (a) The four-factor formula for a nuclear fission reactor is given by:

$$k_\infty = \eta \epsilon p f$$

With reference to this formula, and starting from a population of N fast neutrons, show how the processes within a fission reactor change the neutron population. Be sure to define all the terms of the four-factor formula. [8]

(b) For a finite sized reactor, the four-factor formula is given by:

$$k = \eta \epsilon p f (1 - l_f)(1 - l_t)$$

Explain the meaning of the factors l_f and l_t and their purpose. [3]

(c) Show how the response time of a fission reactor (i.e. the time for the neutron flux to change by a factor of e) depends on the neutron reproduction factor. [4]

(d) Calculate the factor by which the neutron population has increased after one second of operation with $k = 1.01$. Assume a neutron diffusion time of 1ms within the core. [2]

(e) Explain the significance of operating a fission reactor with $k < 1.0065$. [3]

TURN OVER

Copyright 2014 © University of Southampton

B2. (a) A heavy charged particle such as a proton loses energy as it passes through matter. Describe the physical processes that allow transfer of energy to the matter and show that the maximum energy which can be transferred from the charged particle to an electron in a single collision is given by:

$$\Delta E = E\frac{4m}{M}$$

where m is the electron mass, and M is the mass of the heavy charged particle. Calculate this value for a 50 MeV proton. [6]

(b) Explain the implications of the result of (a) above for absorption of energetic protons in matter. [2]

(c) Draw a graph showing how the intensity of a monoenergetic beam of protons changes with distance as it passes through a dense absorber. Label the range of the protons on your graph, and explain the meaning of the terms *energy straggling* and *range straggling* in this context. [5]

(d) Draw a second graph showing how the intensity of a monoenergetic beam of *electrons* changes with distance as it passes through a dense absorber. Label the range of the electrons on your graph, and explain why the mean range of the electrons is more poorly defined than in the case of protons. [5]

(e) Define the terms *critical energy* and *radiation length* in the context of electron absorption. [2]

Copyright 2014 © University of Southampton

B3. (a) Describe the principal components of a commercial fission power reactor. [8]

(b) Compare and contrast the Gas Cooled Reactor (GR), Pressurised Water Reactor (PWR), and the RBMK reactor designs, especially in terms of the inherent safety features of each design. [9]

(c) Explain the proposal for "safe" nuclear power based on accelerator driven fission. What are the advantages and disadvantages of this scheme? [3]

TURN OVER

Copyright 2014 © University of Southampton

B4. (a) Describe and explain the phenomenon known as the Mössbauer effect, and outline its applications. [6]

(b) Show that when a nucleus of mass m emits a gamma-ray of energy E_γ, it will recoil with energy E_r given by:

$$E_r = \frac{E_\gamma^2}{2mc^2}$$

You may assume that the recoiling nucleus is non-relativistic. [6]

(c) ^{191}Ir decays by emission of a 129 keV gamma-ray with a half-life of 0.14 ns.
Calculate the recoil energy of the nucleus. [2]

(d) Calculate the linewidth of the transition and hence demonstrate why resonant absorption of gamma-rays should not occur in this isotope. [3]

(e) Describe two ways in which resonant absorption of gamma-rays can be restored for isotopes like ^{191}Ir. [3]

END OF PAPER

Copyright 2014 © University of Southampton