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PHYS-E0460 Introduction to Reactor Physics, 1st mid-term exam
30 October 2018

You are allowed to use a non-programmed calculator and the document "Mathematical Tools for Reactor Physics".

1. Give a concise explanation of the following terms:
   a) decay constant λ
   b) breeding
   c) fissile isotope
   d) fast fission factor ϵ
   e) thermal disadvantage factor ζ
   f) reflector savings.

2. The β^--active isotope ^{14}C ($T_{1/2} = 5730$ a) is produced in the atmosphere by cosmic radiation so that its concentration in air is roughly constant. A corresponding fraction of it is metabolically absorbed into the tissues of living organisms. After death, the ^{14}C content of the tissues begins to diminish by beta decay. The phenomenon is used in determining the age of ancient samples of organic matter: this is called radiocarbon dating.

   a) Limitations of measurement accuracy make radiocarbon dating difficult, when only about 0.4% of the living organism's ^{14}C concentration remains in the sample. What is the maximum age of samples that can be dated by the ^{14}C method?

   b) A 5 g sample of carbon is extracted from the mummy of an Egyptian pharaoh who died 3500 years ago. What is the beta activity of the sample? The molar mass of natural carbon is 12.011 g/mol and the atomic fraction of ^{14}C in air is $1.8 \cdot 10^{-12}$. Avogadro's constant is $6.022 \cdot 10^{23}$.

3. a) Derive the formula for the flux of an isotropic point source in a diffusive medium, starting from the 1-group diffusion equation $\nabla^2\phi - (1/L^2)\phi = 0$ $(r > 0)$. b) Four identical isotropic point sources S are located at the corners of a square with edge length a in an infinite medium (diffusion coefficient D, diffusion length L). Derive expressions for the neutron flux and the neutron current at the middle point of one side of the square.

4. Using 2-group diffusion theory, derive the criticality condition

$$\frac{k_\infty}{(1 + B^2 L_T^2)(1 + B^2 \tau_T)} = 1$$

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for a bare thermal reactor assuming that the thermal and fast flux fulfill the equation $\nabla^2\phi + B^2\phi = 0$. The diffusion length of thermal neutrons has been denoted by L_T and the Fermi age of fast neutrons by τ_T. Explain the physical meaning of the terms of the criticality condition (including the four factors of k_∞).

5. Describe the three types of radiation from radioactive nuclei. What kinds of nuclei are typical emitters of each type, what is emitted from them, and how are the nuclei altered in the process?