National Examination May 2003
98-Phys-B1, Radiation Physics
Three (3) Hours Duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. This is an **open book exam**.
   Any non-communicating calculator is permitted.
3. All questions must be attempted.
4. Total Worth of Exam: 100 points.
5. Duration: Three (3) Hours.

1. (15 points)
Max Planck introduced in 1900 a constant, h, to describe the distribution of radiation emitted by a blackbody. This constant later became a fundamental constant of quantum mechanics. Use this Planck's constant to:
   (a) Determine the energy of a typical gamma-ray photon in MeV (State the radiation frequency you used).
   (b) Calculate the linear momentum of a typical infrared photon in kg m/s (State the radiation frequency you used).
   (c) Prove that a microwave photon cannot be confined within an atom (State the radiation frequency you used). Hint: use the uncertainty principle.
   (d) Using values for photon energy, explain why infrared radiation and microwave radiation are non-ionizing, while gamma-radiation is an ionizing radiation.

2. (19 points)
In monitoring the decay of a freshly produced radioactive substance, the following results were recorded:

Time, hr (t)	Counts per minute (N)	$\frac{dN}{dt}$	$\hat{N} = \ln\left(1 - \frac{N}{N_\infty}\right)$	$\frac{d\hat{N}}{dt}$
0	1,000		−0.442	
4	1,150	37.50	−0.529	−0.0218
8	1,300	37.50	−0.624	−0.0239
16	1,500	25.00	−0.767	−0.0179
32	1,900	25.00	−1.135	−0.0230
48	2,200	18.75	−1.540	−0.0253
80	2,500	9.38	−2.234	−0.0217
120	2,800	7.50		

   (a) Determine the value of N_∞ used in the calculation of the results reported in the table.
   (b) State what N_∞ is supposed to represent and why.
   (c) Based on the reported results, determine whether the parent nuclide has a long or a short half-life, and justify your answer.
   (d) Estimate the statistical uncertainty in reported count, N, and count rate, $\frac{dN}{dt}$, at time $t = 4$ hours.
   (e) Estimate the half-life of the daughter substance that is building up.

3. (6 points)
A radiation worker has received a total annual biological dose of 4.4 mSv from dual exposure to gamma-rays and thermal neutrons. The gamma field in this place of work is typically five (5) times stronger than the thermal-neutron field. Estimate the exposure (absorbed dose) in mGy the worker received from each of the gamma-ray and thermal-neutron fields.

4. (15 points)
   The following equation represents a typical thermal-neutron fission:

$$^{1}n + ^{235}U \longrightarrow ^{236}U^{*} \longrightarrow ^{92}Kr + ^{142}X + 2\, ^{1}_{0}n + \gamma$$

   (a) Identify the isotope X (name it).

   (b) At what neutron energy is this reaction most likely? Justify your answer.

   (c) Assuming that the total kinetic energy of the fission products is 167 MeV, determine the energy of each of the two fission fragments.

   (d) Fission products continue to release energy even after the fission process is terminated. Why?

   (e) The fission fragments are neutron-rich compared to stable nuclides. What are the implications of this fact?

5. (15 points)
   Using the following information:

   14 MeV neutrons: microscopic cross section for steel = 2.574 b.

   1.25 MeV gamma-rays: mass attenuation coefficient for steel = 5.350×10^{-2} cm^2/g.

   (a) Determine the half-value layer (thickness to reduce intensity by half) for the 14 MeV neutrons

   (b) Determine the half-value layer for the 1.25 MeV gamma rays.

   (c) Based on the above results design a steel shield to reduce the radiation intensity to at least 12.5% of its initial value for each of the two radiation types.

6. (10 points)
   A 1 MeV photon undergoes three consecutive collisions in water so that it is scattered by 45°, 30° and 60°, respectively, with all angles being measured with respect to the direction after each collision.

   (a) Calculate the final photon energy.

   (b) Determine the angle of scattering that would result in one collision the same amount of energy loss produced together by the above three consecutive collisions.

7. (5 points)
   During a hypothetical nuclear accident, plant operators are faced with the dilemma of releasing some radioactive gases to the environment to alleviate the pressure buildup in the reactor vessel and avoid fuel damage, or maintaining the gases within the containment building to prevent exposing the public to any amount of radiation.

   (a) What is the guiding safety principle in deciding on the proper action?

   (b) What is in your view the appropriate action to take in the above described situation. Support your answer by some cost-benefit analysis?

8. (15 points)
A neutron detector has a volume of 50 cm^3 filled at a pressure of 10 kPa and temperature of 20°C with 96% enriched $^{10}BF_3$.

(a) Calculate the number of atoms in the detector that are most sensitive to thermal-neutrons.

(b) What is the thermal-neutron flux corresponding to 1000 counts per minute (cpm)?

(c) Calculate the sensitivity of this detector to thermal neutrons in cpm/nv.

<u>Hint</u>: the flux is equal to $\frac{1.128 \times \text{count rate}}{\text{number of interacting atoms} \times \text{interaction microscopic cross section}}$