Georgia Institute of Technology

The George W. Woodruff School of Mechanical Engineering
Nuclear & Radiological Engineering/Medical Physics Program

Ph.D. Qualifier Exam

Spring Semester 2011

_______________ Your ID Code

Radiation Physics (Day 1)

Instructions

1. Use a separate page for each answer sheet (no front to back answers).
2. The question number should be shown on each answer sheet.
3. ANSWER 4 OF 6 QUESTIONS ONLY.
4. Staple your question sheet to your answer sheets and turn in.

NRE/MP Radiation Physics

Answer any 4 of the following 6 questions.

Q1. a. Consider a decay chain $A \xrightarrow{\lambda_{AB}} B \xrightarrow{\lambda_B} C(stable)$, at t=0, $N_A(0) = N_0$ $N_B(0) = N_C(0) = 0$. Derive an expression for $N_C(t)$.

b. Now assume that nucleus A can decay into C from a different channel at the same time besides the one shown in a): $A \xrightarrow{\lambda_{AD}} D \xrightarrow{\lambda_D} C(stable)$. Derive an expression for $N_C(t)$.

Q2. At t=0, there are exactly N_0 hypothetical radioactive nuclei. At t = T, N_T nuclei are left. The decay constant is calculated in terms of N_0, N_T and T.

a. Assuming that N_0 and T are known exactly, estimate the standard deviation of the calculated decay constant.

b. After repeating the experiment many times under the same conditions, the standard deviation of the calculated decay constant is measured as σ_λ. Comparing the measured value with the estimated value obtained in a), you find the difference is significant. After checking the experiment procedures, it is believed that the measured time T using the timer contains random errors with a standard deviation of σ_T. Estimate σ_T in terms of σ_λ, N_0, N_T and T.

(Hint: If two variables X and Y are independent, the variance of their product is given by: Var(XY) = mean(X)^{2}Var(Y)+mean(Y)^{2}Var(X)+Var(X)Var(Y).)

Q3. In the following scenarios of elastic scattering between mono-energetic neutrons and various types of nuclei: (a) *1-keV* neutrons interacting with ^1H nuclei, (b) *1-keV* neutrons interacting with ^{12}C nuclei, (c) *10-MeV* neutrons interacting with ^{12}C nuclei, and (d) *10-MeV* neutrons interacting with ^{238}U nuclei.

a. Which scenario produces a scattered neutron that is most isotropic in the center-of-mass system? Apply partial-wave analysis for each scenario to justify your answer. Some constants needed to carry out calculations can be found in Attachment A.

b. Which scenario produces a scattered neutron that is most isotropic in the laboratory system? Why?

CONSTANTS

Speed of light	c	2.99792458×10^{8} m/s
Charge of electron	e	1.602189×10^{-19} C
Boltzmann constant	k	1.38066×10^{-23} J/K
		8.6174×10^{-5} eV/K
Planck's constant	h	6.62618×10^{-34} J · s
		4.13570×10^{-15} eV · s
	$\hbar = h/2\pi$	1.054589×10^{-34} J · s
		6.58217×10^{-16} eV · s
Gravitational constant	G	6.6726×10^{-11} N · m²/kg²
Avogadro's number	N_A	6.022045×10^{23} mole⁻¹
Universal gas constant	R	8.3144 J/mole · K
Stefan-Boltzmann constant	σ	5.6703×10^{-8} W/m² · K⁴
Rydberg constant	R_∞	1.0973732×10^{7} m⁻¹
Hydrogen ionization energy		13.60580 eV
Bohr radius	a_0	5.291771×10^{-11} m
Bohr magneton	μ_B	9.27408×10^{-24} J/T
		5.78838×10^{-5} eV/T
Nuclear magneton	μ_N	5.05084×10^{-27} J/T
		3.15245×10^{-8} eV/T
Fine structure constant	α	1/137.0360
	hc	1239.853 MeV · fm
	$\hbar c$	197.329 MeV · fm
	$e^2/4\pi\epsilon_0$	1.439976 MeV · fm

PARTICLE REST MASSES

	u	MeV/c^2
Electron	5.485803×10^{-4}	0.511003
Proton	1.00727647	938.280
Neutron	1.00866501	939.573
Deuteron	2.01355321	1875.628
Alpha	4.00150618	3727.409
$\pi^{\pm}$	0.1498300	139.5669
π^{0}	0.1448999	134.9745
μ	0.1134292	105.6595

CONVERSION FACTORS

1 eV = 1.602189×10^{-19} J

1 b = 10^{-28} m²

1 u = 931.502 MeV/c^2
= 1.660566×10^{-27} kg

1 Ci = 3.7×10^{10} decays/s

Q4. In the reaction $\alpha + {}^{9}Be \rightarrow {}^{12}C + n$, find the maximum and minimum neutron energies when the incident a energy is *5.0 MeV*. The rest mass for neutron is *1.008665 u*, where *1 u = 931.5 MeV*. The atomic masses for α, ${}^{9}Be$, and ${}^{12}C$ are *4.002603 u, 9.012182 u,* and *12.00000 u*, respectively.

Q5. a. Describe what you understand by wave particle duality

b How will you determine if an entity with kinetic energy T and rest mass m_0 shows wave like or particle like characteristics?

c. What speed (m/s) and kinetic energy would a neutron have if its relativistic mass were 20% greater than its rest mass?

Q6. a. Quantitatively compare the stopping power of a medium with regards to proton radiation and alpha particle radiation if the two particles have the same velocity.

b. What is the ratio of their range in the medium?

c. Repeat (a) when the proton and the alpha particle and the proton have the same kinetic energy.