2nd Mid-Term Exam

Answer 4 out of 5 questions

1. Explain the main features of the interaction of alpha- and beta- particles, and gamma-rays with matter (energy loss, path, range, straggling…)

2. a) In a PIXE experiment, a 0.2 mg/cm^2 film containing 5 parts per million by weight of an element of mass number 100 is bombarded with a 200 nA beam of protons for 10 minutes. The cross section for exciting the L shell of the element is 800 barns and the probability of the excited atom emitting an L X-ray is 50%. Calculate the number of counts recorded if the overall detection efficiency is 0.5%.

   b) Calculate the mass of ^{210}Po required to generate 10W of electric power using a thermoelectric converter that operates with an efficiency of 15%. ^{210}Po has a half-life of 138 days and decays by alpha emission with an alpha decay Q-value of 5.4 MeV.

3. a) Draw a diagram showing the behavior of the stopping power or energy loss as a function of energy for a heavy charged particle (e.g. Hydrogen, Carbon, Lead, etc). The plot should go from very low to very high energy.

   b) Explain the main features of the plot.

   c) A beam of Ar (Z=18) ions at an energy of 2 MeV/u is used to irradiate the following target materials: calcium (Z=20), carbon (Z=6), uranium (Z=92) and tin (Z=50). Write the list of target materials in order of increasing stopping power.

4. Explain very briefly (a couple of sentences):
   a) What is meant by a compound-nucleus reaction? Give an example.
   b) In calculating the reaction rate, i.e. the number of atoms/s expected in a typical nuclear structure experiment, what three important parameters are required?
   c) There are 4 fundamental nuclear structure observables which may be obtained via laser spectroscopy. What are they?
   d) A thermal neutron can induce fission in ^{235}U. Why is the same mechanism not possible for ^{238}U?
   e) Why is there a threshold energy in pair production and what is this energy?
   f) Why is it not possible to identify light elements such as hydrogen in a Rutherford backscattering experiment?

5. a) List as many ingredients you believe necessary for successful (and safe) operation of a nuclear reactor. How is the energy extracted?

The graphite core of a fission reactor contains 1 atom of 1.5% enriched uranium fuel to every 500 atoms of carbon. In steady-state operation the reactor produces 3.5 MW of power for every tonne of fuel. The core is an intimate mixture of fuel and moderator.

b). Calculate the neutron flux φ in the core.
c). Calculate the thermal neutron utilization factor f.

You may need the following data:
Recoverable energy per fission = 200 MeV
Cross section for thermal neutron-induced fission of ^{235}U σ_f = 579b
Cross section for thermal neutron absorption in the fuel $\sigma_a(F)$ = 12.9 b
Cross section for thermal neutron absorption in graphite $\sigma_a(M)$ = 0.0045 b

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 · m^2/kg^2
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/m^2 · K^4
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} m^2

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

1 Ci = 3.7×10^{10} decays/s