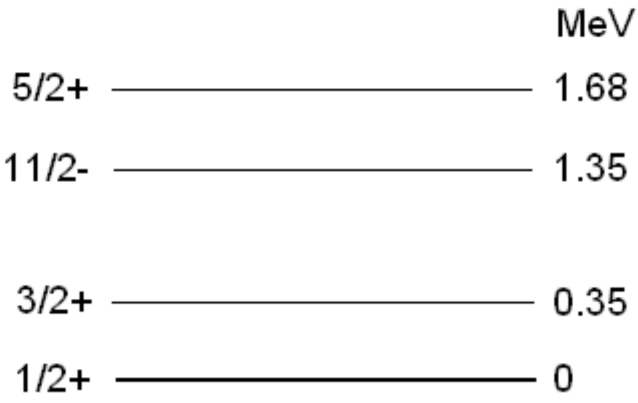
NUCLEAR PHYSICS 1 FYSN300

Second Mid-term exam Dec. 14, 2012

Answer 4 out of 5 questions

1. The low-lying spectrum of ^{207}Tl is shown below. Show the main γ-ray transitions for the three excited states, indicating the most probable types and multipolarities in each case. Estimate the half-lives of the states using Weisskopf single-particle estimates (attached). Do you expect isomeric states? Ignore transitions with spin change larger than 5.



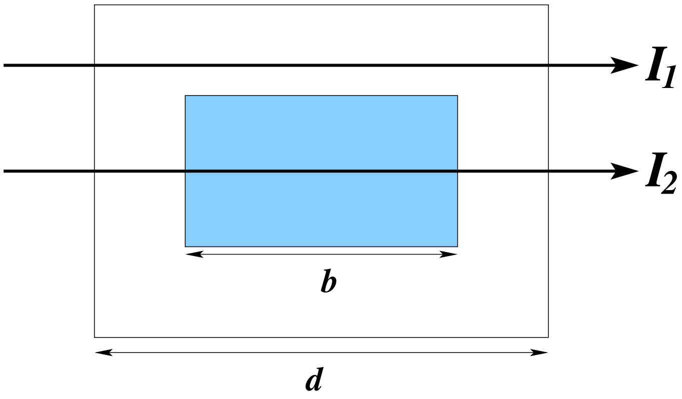
2. **a)** Describe briefly the interactions between energetic photons (gamma and X-ray quanta) and matter. **b)** Gamma quanta with energies of 70 keV and 100 keV are absorbed via the photoelectric effect in a lead shield. What is the essential difference between the absorption of these quanta? The binding energies of K-electrons and L-electrons in lead are 88 keV and approximately 13-16 keV, respectively. **c)** Explain what is meant by the Compton edge and what is meant by escape peaks?

3. In a recent experiment, the Nuclear Spectroscopy group at JYFL produced the nucleus ^{256}Rf using the reaction ^{50}Ti + ^{208}Pb. The charge of the beam particles was +11e and the intensity of the beam measured in terms of electric current was 320.0 nA. The surface mass density of the target was 450 micrograms/cm^2. The total detection efficiency of the RITU separator and focal plane detectors was 35% (the ratio between the number of detected nuclei and those produced in the target). The duration of the experiment was 450 hours. **a)** If a total of 2300 nuclei were observed during the experiment, calculate the reaction cross section in barns. **b)** What is the total number of beam ions incident on the target foil during the experiment? **c)** If the kinetic energy of the beam particles is 250 MeV, what power would be dissipated in a Faraday cup used to stop the beam and measure the beam current? ($e=1.60\text{x}10^{-19}$ C; $N_A=6.02\text{x}10^{23}$ mol^{-1})

4. The table below gives the mass attenuation coefficients μ_m in units of cm^2 g^{-1} for photons in human tissue and bone. **a)** Using the data from the table calculate the percentage transmission of photons with energies of 60 keV and 511 keV through a person represented by 20cm of tissue.

Material	Density (g cm^{-3})	60 keV photons	511 keV photons
Tissue	1.0	0.20	0.097
Bone	1.8	0.32	0.090

b) The figure below is a schematic representation of a piece of bone surrounded by tissue, which is irradiated by 60 keV photons. If the ratio of transmitted photon intensities, I_1 (through tissue) to I_2 (through tissue plus bone) is 2, calculate the thickness of bone, b, using the information in the table given above.



5. **a).** Briefly describe the common ingredients of a nuclear reactor.

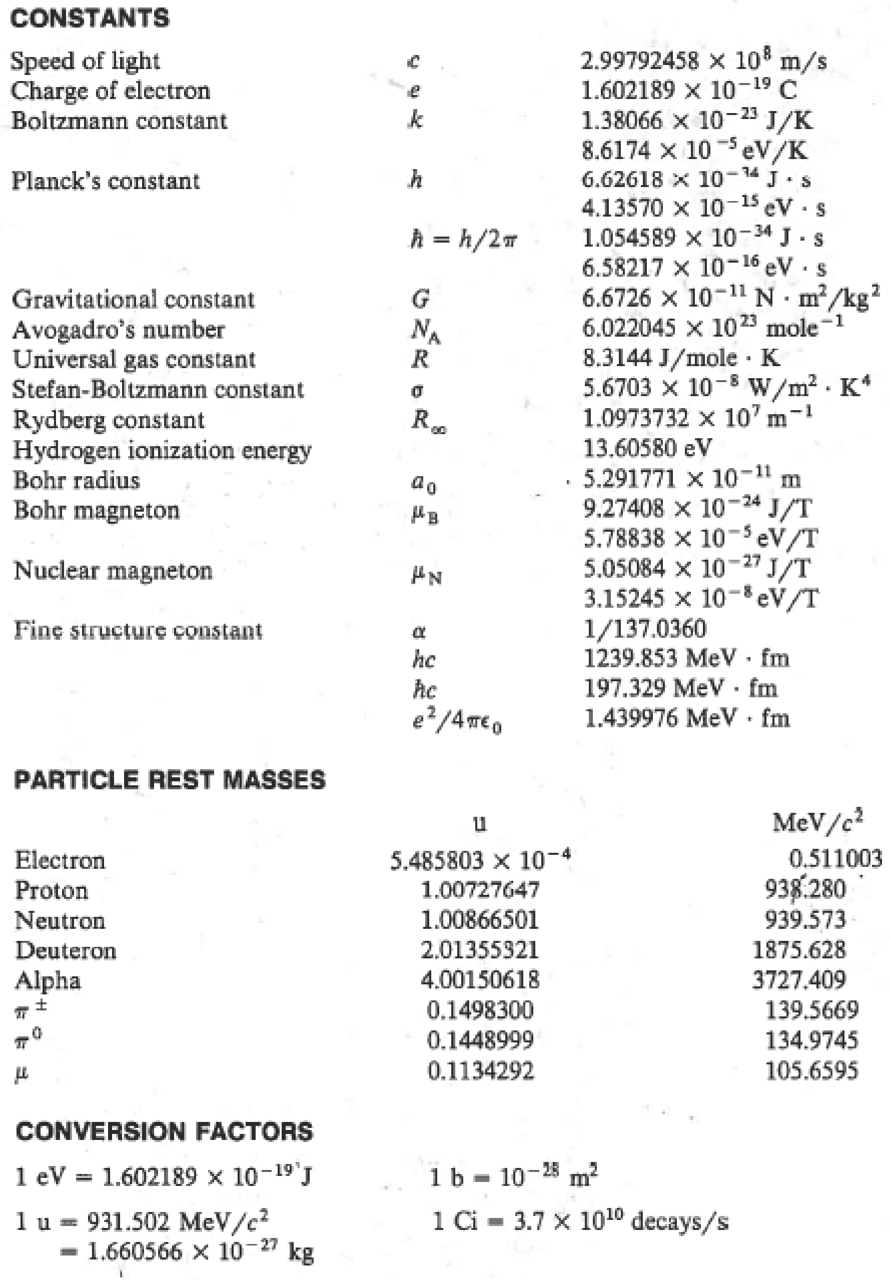
The fuel load of a pressurized water reactor is 150 tonnes of uranium with ^{235}U having an enrichment of 3%. The nominal power is 1 GW.

b). What is the consumption of ^{235}U (kg/yr)?
c). Assume that the rest of the fuel consists of ^{238}U. The fission cross sections for thermal neutrons are 0 b (^{238}U) and 577 b (^{235}U). The neutron capture cross sections are 2.72 b (^{238}U) and 101 b (^{235}U), respectively. What is the overall ratio N_{fiss}/N_{capt} of fission reactions and neutron capture reactions?

Note that approximately 200 MeV of energy is released in the fission from a uranium atom. Other standard constants are found in the attached table.

Table: Single-particle transition rate estimates (Weisskopf estimates) for electromagnetic transitions. E is the transition energy in units of MeV. The transition rate λ is given in units of s^{-1}. A is the mass number.

Electric transitions	Magnetic transitions
$\lambda(E1) = 1.0 \cdot 10^{14} \cdot A^{2/3} \cdot E^{3}$	$\lambda(M1) = 3.1 \cdot 10^{13} \cdot E^{3}$
$\lambda(E2) = 7.3 \cdot 10^{7} \cdot A^{4/3} \cdot E^{5}$	$\lambda(M2) = 2.2 \cdot 10^{7} \cdot A^{2/3} \cdot E^{5}$
$\lambda(E3) = 34 \cdot A^{2} \cdot E^{7}$	$\lambda(M3) = 10 \cdot A^{4/3} \cdot E^{7}$
$\lambda(E4) = 1.1 \cdot 10^{-5} \cdot A^{8/3} \cdot E^{9}$	$\lambda(M4) = 3.3 \cdot 10^{-6} \cdot A^{2} \cdot E^{9}$
$\lambda(E5) = 2.4 \cdot 10^{-12} \cdot A^{10/3} \cdot E^{11}$	$\lambda(M5) = 7.4 \cdot 10^{-13} \cdot A^{8/3} \cdot E^{11}$



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

$1 \text{ eV} = 1.602189 \times 10^{-19}$ J

$1 \text{ b} = 10^{-28}$ m²

$1 \text{ u} = 931.502$ MeV/c^2
$= 1.660566 \times 10^{-27}$ kg

$1 \text{ Ci} = 3.7 \times 10^{10}$ decays/s