Fall 2001

Ph.D. Qualifying Examination
Interactions

1. (15 min.) A 6 MeV neutron is captured by Li-6. Derive the relevant conservation relations and then find the excitation energy of the compound nucleus. Note that the binding energy of the last neutron in Li-7 is 7.25 MeV.

2. (20 min.) An infinite slab of thickness t has a uniform surface source of monoenergetic photons on one face emitting $6S_a\eta^5/2\pi$ photons/cm^2-sec-sr into the slab, where η is the cosine of the angle between $\hat{\Omega}$ and the inward normal, and S_a is constant. The slab has a linear attenuation coefficient of μ cm^{-1} and is surrounded by vacuum. Using the Transport Equation find the angular flux density and the scalar flux density at the opposite face of the slab. Express your result for the scalar flux in terms of the Exponential Integrals. Recall:

$$\eta\frac{\partial\Psi}{\partial z}+\mu\Psi\left(z,\hat{\Omega}\right)=S\left(z,\hat{\Omega}\right),$$
$$E_n(x)\equiv\int_0^1 w^{n-2}e^{-x/w}\,dw.$$

3. (10 min.) Calculate the binding energy per nucleon for the isotope of hydrogen called tritium. Please state all your assumptions.

NOTE: The attached data table may be useful to you.

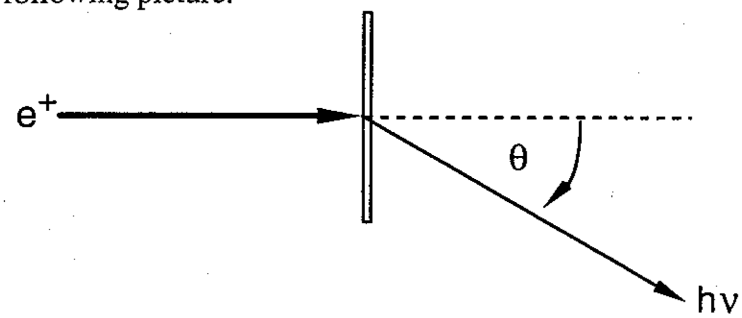
4. (10 min.) A thin tungsten foil with a mass of 0.1 grams is placed in an irradiation position in the TRIGA reactor at the Nuclear Science Center. The neutron fluence rate at this position is 2 x 10^{12} neutrons$/\text{cm}^2\cdot$s. What is the activity of ^{187}W

(a) after 24 hours of irradiation and
(b) at saturation? Please state all your assumptions.

NOTE: A portion of the Chart of Nuclides is attached.

5. (10 min.) Estimate the count rate in a 10 cm^3 hydrogen proportional counter operating at 7600 torr (10 atmospheres) when exposed to a monoenergetic 100 keV neutron field that produces a dose rate of 10 J/kg hr in water.

6. (20 min.) A positron (e^+) of velocity $v_p = 2.5 \times 10^8$ m/s collides with a thin slab of ordinary matter at rest. A 0.600 MeV photon is observed to emerge from the block at an angle θ=30° relative to the path of the incident positron as in the following picture.



Assuming that in-flight annihilation with a "stationary" electron (e^-) occurred in the block, indicate what other radiation or particle(s) were emitted and give their energies and their directions. (Explain your reasoning.)

7. (10 min.) A parallel beam of 1 GeV protons can be used for radiographic imaging of objects like rats, radiation detectors, and electronic instruments. The resulting images look very much like conventional x-rays, with dense areas of the object appearing light on a photographic film. Explain how these images are formed, that is, what physical interactions in the object and film are responsible for this "negative" image. Can 1 MeV protons be used to image changes in the thickness of a thin plastic film in the same way? The range of the 1 MeV proton is about twice the thickness of the plastic film. Explain why this will, or will not, work.

8. (15 min.) A NaI(Tl) detector inside a lead shield is exposed to Cs-137 gamma rays (662 keV) through a hole in the shield.

Describe each part of the detector-electronics system (a labeled sketch will do), and the physical processes that take place in each part of the detector-electronics system to produce a count in a particular channel on the MCA.

Sketch the expected spectrum that would be seen on the MCA, identify any features of the spectrum and name the interaction that has taken place to produce each feature.

9. (10 min.) Name two types of detectors that can be used to measure thermal neutron fluence rate in real time. Describe the advantages and disadvantages of each detector type.

Speed of light	c	2.99792458×10^{8} m/s		
Charge of electron	e	$1.60217733 \times 10^{-19}$ C		
Boltzmann constant	k	1.380658×10^{-23} J/K		
		8.617385×10^{-5} eV/K		
Faraday's constant		96485.309 C/mol		
Planck's constant	h	$6.6260755 \times 10^{-34}$ J·s		
		$4.1356692 \times 10^{-15}$ eV·s		
Gravitational constant	G	6.67259×10^{-11} $m^3/kg \cdot s^2$		
Avogadro's number	N_A	6.0221367×10^{23} mol^{-1}		
Universal gas constant	R	8.314510 J/mol·K		
Stefan–Boltzmann constant	σ	5.6705×10^{-8} $W/m^2 \cdot K^4$		
Rydberg constant	R	10973731.534 m^{-1}		
Bohr radius	a_0	$0.529177249 \times 10^{-10}$ m		
Fine structure constant	a	1/137.0359895		
Electron volt	eV	$1.60217733 \times 10^{-19}$ J		
Joule	J	6.2415×10^{-18} eV		
		10^{7} ergs		
Erg		10^{-7} J		
Unified mass unit		1.66054×10^{-27} kg	1.00000 u	931.502 MeV
Electron	e	$9.1093897 \times 10^{-31}$ kg	5.4857990×10^{-4} u	0.5109990 MeV
Proton	p	$1.6726231 \times 10^{-27}$ kg	1.00727647 u	938.27231 MeV
Neutron	n	$1.6749286 \times 10^{-27}$ kg	1.00866490 u	939.56563 MeV
Deuteron	d	$3.3435856 \times 10^{-27}$ kg	2.01355320 u	1875.62883 MeV
Tritium (^3H)	T	$5.0073595 \times 10^{-27}$ kg	3.015500688 u	2808.94492 MeV
Alpha	α	$6.6446618 \times 10^{-27}$ kg	4.001506178 u	3727.38025 MeV
Helium	He	$6.6464828 \times 10^{-27}$ kg	4.002603250 u	3728.43293 MeV

Source: *CODATA Recommended Values of the Fundamental Physical Constants*, National Institue of Science and Technology, Gaithersburg, MD, 1986. Internet address: *physics.nist.gov/PhysRefData/codata86/codata86.html*.

Z	111	112	113	114	115	116	117	118	119	120	121	122	123
81					Tl 204.3833 Thallium σ_a 3.4, 13					Tl201 3.039 d ε γ 167.4, 135.3, ... E .48	Tl202 12.23 d ε β^+ vw γ 439.6, ... E 1.36	Tl203 29.52 σ_γ 11.4, 41 σ_α <0.3 mb 202.9723286	Tl204 3.78 y β^- .763 no γ ε σ_γ 22, 90 E− .763 E+ .347
80			Hg 200.59 Mercury σ_a ~374, 8E1		Hg195 1.67 d | 9.5 h IT 122.8, e−, γ 37.1, e−, γ 261.8D, 560.3 | ε, γ 779.8, 61.4 E 1.51	Hg196 0.15 σ_γ (120+3100), (59+410) 195.9658145	Hg197 23.8 h | 2.672 d IT 165.0, e−, γ 134.0, ε, γ 279.1 | ε, γ 77.3 E .600	Hg198 9.97 σ_γ (0.017+1.9), 70 197.9667515	Hg199 42.6 m | 16.87 IT 374.1, γ 158.4 | σ_γ 2.2E3, 4E2 198.968262	Hg200 23.10 σ_γ < 60 199.9683085	Hg201 13.18 σ_γ 8, 30 200.9702851	Hg202 29.86 σ_γ 4.9, 4.5 201.9706254	Hg203 46.61 d β^- .213 γ 279.2 E .492
79			Au 196.96655 Gold σ_a 98.7, 155E1		Au194 1.58 d ε β^+ 1.49, ... γ 328.5, 293.6, ... E 2.49	Au195 30.5 s | 186.12 d IT 318.6, γ 56.8, e−, γ 261.8 | ε, γ 98.9, ... E .227	Au196 9.7 h | 6.18 d IT 174.9, γ 147.8, 188.2 | ε, γ 355.6, 332.9, β^- .259, γ 425.6 8.1 s IT 84.0 E+ 1.506 E− .686	Au197 7.8 s | 100 IT 130.2, e−, γ 279.1 | σ_γ (0+98.7), 155E1 196.966551	Au198 2.27 d | 2.6952 d IT 215.6, e−, γ 214.9, 97.2 | β^- .962, γ 411.8, σ_γ 26E3 E 1.372	Au199 3.14 d β^- .292, .25, .453 γ 158.4, 208.2, ... σ_γ 30 E .453		122	123
78	Pt 195.078 Platinum σ_a 10, 14E1	Pt190 0.01 6.5E11 y α 3.18 σ_γ 150, 70 σ_α <8 mb 189.9599297	Pt191 2.96 d ε γ 538.9, 409.5, 359.9, ... E 1.019	Pt192 0.79 σ_γ (1+9), 110 σ_α <0.2 mb 191.9610347	Pt193 4.33 d | 60 y IT 135.5, no e−, γ 12.6, e− | ε, no γ E .0566	Pt194 32.9 σ_γ (0.10+1.1), (4+?) σ_α <5 μb 193.9626630	Pt195 4.02 d | 33.8 IT 129.5, no e−, γ 98.8, 129.8 | σ_γ 29, 360, σ_α <5 μb 194.932663	Pt196 25.3 σ_γ (0.04+0.6), 5 195.9649343	Pt197 1.590 h | 18.3 h IT 346.5, γ 53.1, e−, β^- .310, γ 279.1D | β^- .642, .719, γ 77.3, 191.4 E .719	Pt198 7.2 σ_γ (0.3+3.5), ~56 197.9678754	Pt199 13.6 s | 30.8 m IT 391.9, γ 32, e− | β^- 1.69, ..., γ 543.0, 493.7 σ_γ 20 E 1.702		
77	Ir 192.217 Iridium σ_a 42E1, 28E2			Ir191 37.3 σ_γ (.14+260+660) 190.960591	Ir192 1.44 m | 73.83 d IT 57.0, e−, β^- 1.2, 1.5, γ 316.5 | β^- .67, .54, γ 317.468, ε, γ 484.6, σ_γ 14E3, 2E3 E− 1.46 E+ 1.046	Ir193 10.53 d | 62.7 IT 80.3, ω σ_γ (6+106), 14E2 192.962923	Ir194 170 d | 19.3 h β^-, γ 482.9, 328.5, ... | β^- 2.251, γ 328.5, σ_γ 1.5E3 E 2.247	118	119	120	121		

Z	107	108	109	110	111	112	113	114	115	116	117
76		Os 190.23 Osmium σ_a 15, 16E1	Os185 93.6 d ε γ 646.1, 874.8, 880.4, 717.4, ... E 1.013	Os186 1.58 2E15 y α 2.758 σ_γ 8E1, 25E1 σ_α <0.1 mb 185.953838	Os187 1.6 σ_γ 320, 700 σ_α <0.1mb 186.9557476	Os188 13.3 σ_γ 5, 160 σ_α <.03 mb 187.9558357	Os189 16.1 σ_γ (.26 mb+20), 70 σ_α <0.01 mb 188.958415	Os190 26.4 σ_γ (9+4), (22+8) σ_α <0.02 mb 189.958445	Os191 13.1 h | 15.4 d IT 74.4, (ω), e− | β^- .143, γ 129.4D, ..., σ_γ 4E2 E .314	Os192 41.0 σ_γ 2.0, 5 σ_α <0.01 mb 191.961479	Os193 30.5 h β^- 1.13, ... γ 138.9, 460.5, 73.0, ... σ_γ 40 E 1.141
75		Re 186.207 Rhenium σ_a 89, 82E1		Re185 37.40 σ_γ (.03+112), 17E2 184.952955	Re186 2E5 y | 3.718 d IT ~50, no e−, γ 59.0, 40.4 | β^- 1.071, .933, γ 137.2, ε, γ 122.5 E− 1.070 E+ .582	Re187 62.60 4.35E10 a β^- .00264 no γ σ_γ (2.8+73), 31E1 186.9557505	Re188 18.6 m | 16.94 h IT 2.4, e−, 15.9, e−, γ 63.6, 105.9 | β^- 2.118, 1.962, γ 155.0, ε, γ 122.5 E 2.120	Re189 24 h β^- 1.01 γ 216.7, 219.4, 245.1, ... E 1.01	115	116	117
74		W 183.84 Tungsten σ_a ~18.2, 35E1		W184 30.642 σ_γ (.002+1.8), 14 183.950932	W185 1.64 m | 74.8 d IT 131.6, e−, γ 65.9, e−, 173.7 | β^- .433, γ 125.4, σ_γ 3.3, 3E2 E .433	W186 28.426 σ_γ 37.8, 490 185.9543619	W187 23.9 h β^- .622, 1.312, ... γ 685.7, 479.6, ... σ_γ 60, 28E2 E 1.311	W188 69.4 d β^- .349, ... γ 290.7(ω), 227.1, 63.6, ... E .349			
73	Ta 180.9479 Tantalum σ_a 20, ~66E1	Ta181 99.988 σ_α <1μb σ_γ (.012+20), (4+~66E1) 180.947996	Ta182 15.8 m | 114.43 d IT 185.0, e−, γ 171.6, 146.8 | β^- .512, .25, γ 67.8, σ_γ 8.5E2, 9E2 E 1.814	Ta183 5.1 d β^- .62 γ 246.1, 354.0, 107.9, ... E 1.070	Ta184 8.7 h β^- 1.19, ... γ 414.0, 252.8, 920.9, ... E 2.87	112	113	114			
		108	109	110	111						