Interactions
Fall 2007

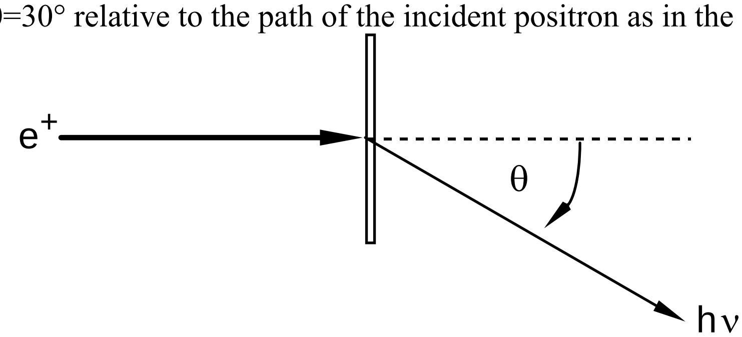
1. (20 minutes) The radionuclide ^{90}Sr (Z=38) decays by beta emission to ^{90}Y (Z=39), which then decays by beta emission to ^{90}Zr (Z=40), which is stable. The half-lives for these two radionuclides are given below:

^{90}Sr = 29.12 years

^{90}Y = 64.2 hours

a. (20%) What are the mean lifetimes of the ^{90}Sr and ^{90}Y atoms?
b. (20%) What are the specific activities of these two radionuclides (in SI units)?
c. (60%) Starting with a pure sample of ^{90}Sr at time t = 0, a researcher finds that the ^{90}Y activity is 3.4 mCi at t = 72.0 hours. What was the activity of the ^{90}Sr at t = 0?

2. (20 minutes) 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 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.

3. (15 minutes) For photons incident on a slab of material, they may undergo photoelectric absorption, pair production or Compton scattering.

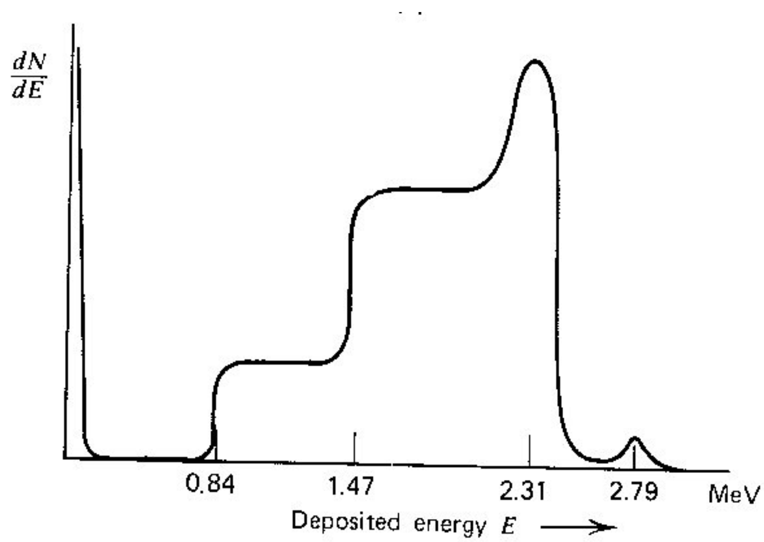
a. (60%) Briefly explain photoelectric absorption, pair production and Compton scattering, respectively.
b. (40%) For photons with energies ranging from ~0.01 to ~100 MeV, their energies can be roughly divided into three regions such as low (<1MeV), medium (1 to 10 MeV) and high energy (10 to 100 MeV) regions. Sketch the respective probabilities for photoelectric absorption, pair production and Compton scattering as functions of photon energy. The plot needs to show the regions of dominance for different mechanisms in different energy regions.

4. (10 minutes) In a particular neutron-induced fission of ^{235}U, 4 prompt neutrons are produced and one fission fragment is ^{121}Ag. What is the other fission fragment? (a periodic table is attached)

5. (10 minutes) A beam of neutrons is normally incident on a homogeneous slab 10-cm thick. The intensity of neutrons transmitted through the slab without interactions is found to be 25% of the incident intensity,

a. (50 %) What is the total cross section, Σ_t, for the slab material
b. (50 %) What is the average distance a neutron travels in this material before undergoing an interaction?

6. (15 minutes) Consider the detection of neutrons using gas filled detectors.
   a. (33 %) Identify and label the features of the pulse height spectrum shown below. This spectrum was collected using a 0.5” diameter BF_3 tube measuring thermal neutrons.



   b. (67 %) Compare the detection mechanisms for thermal neutrons using BF_3 tubes, compensated ion chambers, and fission chambers. Discuss the associated benefits and inherent problems of these detectors for the detection of thermal neutrons.

7. (10 minutes) If reprocessing is implemented in the United States, Cs-137 may be separated from spent nuclear fuel and immobilized in a stable ceramic form. Evaluate the questions listed below related to the immobilization of Cs-137 in ceramic cylinders of pure dicesium oxide (Cs_2O). Assume the ceramic "logs" have no initial porosity and are sealed in air-filled stainless steel canisters and cooled under water to remove decay heat.

<u>Questions</u>:

a. Assuming rapid chemical kinetics, develop an equation for the rate of oxygen (O_2) consumption within the storage canister?

b. If the waste storage canisters are designed such that only 5% of the initial O_2 in the air plenum will be consumed, how long will it take for the oxygen level to be depleted by 2.5% (i.e. half of the consumable O_2 is consumed)?

<u>Supporting Information</u>:

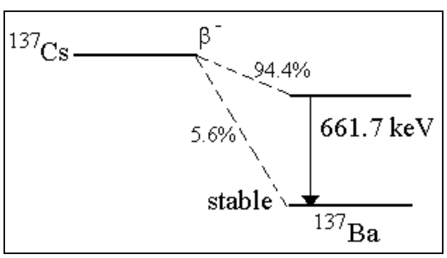
- Assume that Cs-137 makes up 25% of the elemental Cs in the initial Cs_2O.
- Over time, equilibrium suggests that the most stable form for barium oxide is BaO. Consider the following reactions as potential pathways to equilibrium:

$$^{137}Cs \xrightarrow[t_{1/2}=30.1y]{\beta^-} {}^{137}Ba + \bar{\nu}$$

$$Cs_2O \xrightarrow{2\beta^-} BaO + Ba$$

$$2Ba + O_2 \longrightarrow 2BaO$$

- The decay scheme for Cs-137 is shown below:



(the half lives of Ce-137 and Ba-137m are 30.1 y and 2.6 min.)

8. (10 minutes) Assume that a 1.0 MeV neutron is captured by ${}_3Li^6$ to form an ${}_3Li^7$ compound nucleus that then disintegrates into a triton and an alpha particle.

a. What is the total kinetic energy in MeV shared by the triton and the alpha-particle in the center-of-mass frame?
b. What is the kinetic energy (MeV) of the alpha-particle in the center-of-mass frame?

Atomic masses (amu) are: 1.008664916, 3.016049278, 4.002603254, 6.015122794. The rest mass energy of a particle with a mass of 1 amu is 931.5 MeV.

9. (10 minutes) You have been assigned to accurately measure the thermal neutron fluence rate at a test position near the NSC reactor. Preliminary measurements indicate that Φ_0 is 10^9 neutrons/cm^2-s (2200 m/s flux). You choose a 0.500 gram Au-Al alloy foil (0.200% Au, balance is Al) and irradiate for 16 hours planning to count the activity of Au-198.

a) (25%) Show that the removal of Au-198 by absorbing another neutron (burnout) is negligible.
b) (75%) Calculate the Au-198 activity at the end of irradiation.

NOTE: You may use the chart of nuclides.

PERIODINĖ CHEMINIŲ ELEMENTŲ SISTEMA

Atomo numeris — Oksidacijos laipsnis
Elementų klasifikacija (■ - metalas, □ - nemetalas, ◪ - pusmetalis)
Simbolis
Santykinė atominė masė
Pavadinimas

13 ■ Al 26,98 Aliuminis +3

	IA 1	IIA 2	IIIB 3	IVB 4	VB 5	VIB 6	VIIB 7	VIIB 8	VIIB 9	VIII 10	IB 11	IIB 12	IIIA 13	IVA 14	VA 15	VIA 16	VIIA 17	VIIIA 18
1	1 □ +1 -1 **H** 1,01 Vandenilis																	2 □ - **He** 4,00 Helis
2	3 ■ +1 **Li** 6,94 Litis	4 ■ +2 **Be** 9,01 Berilis											5 □ +3 **B** 10,81 Boras	6 □ +2 +4 **C** 12,01 Anglis	7 □ -3 +2 +3 +4 +5 **N** 14,01 Azotas	8 □ -1 -2 **O** 16,00 Deguonis	9 □ -1 **F** 19,00 Fluoras	10 □ - **Ne** 20,18 Neonas
3	11 ■ +1 **Na** 22,99 Natris	12 ■ +2 **Mg** 24,30 Magnis											13 ■ +3 **Al** 26,98 Aliuminis	14 ◪ +4 **Si** 28,09 Silicis	15 □ -3 +3 +5 **P** 30,97 Fosforas	16 □ -2 +2 +4 +6 **S** 32,07 Siera	17 □ -1 +1 +3 +5 +7 **Cl** 35,47 Chloras	18 □ - **Ar** 39,98 Argonas
4	19 ■ +1 **K** 39,10 Kalis	20 ■ +2 **Ca** 40,09 Kalcis	21 ■ +3 **Sc** 44,96 Skandis	22 ■ +3 +4 **Ti** 47,88 Titanas	23 ■ +2 +3 +4 +5 **V** 50,94 Vanadis	24 ■ +2 +3 +6 **Cr** 51,94 Cromas	25 ■ +2 +3 +4 +6 +7 **Mn** 54,94 Manganas	26 ■ +2 +3 +6 **Fe** 55,85 Geležis	27 ■ +2 +3 **Co** 58,93 Kobaltas	28 ■ +2 +3 **Ni** 58,69 Nikelis	29 ■ +1 +2 +3 **Cu** 63,55 Varis	30 ■ +2 **Zn** 65,39 Cinkas	31 ■ +3 **Ga** 69,72 Galis	32 ◪ +2 +4 **Ge** 72,61 Germanis	33 ◪ -3 +3 +5 **As** 74,92 Arsenas	34 □ -2 +4 +6 **Se** 78,96 Selenas	35 □ -1 +1 +3 +5 **Br** 79,90 Bromas	36 □ +2 **Kr** 83,80 Kriptonas
5	37 ■ +1 **Rb** 85,47 Rubidis	38 ■ +2 **Sr** 87,62 Stoncis	39 ■ +3 **Y** 89,91 Skandis	40 ■ +4 **Zr** 91,22 Cirkonis	41 ■ +3 +5 **Nb** 92,91 Niobis	42 ■ +2 +3 +4 +5 +6 **Mo** 95,94 Molibdenas	43 ■ +2 +4 +7 **Tc** (97,90) Technecis	44 ■ +2 +3 +4 +6 +8 **Ru** 101,07 Rutenis	45 ■ +2 +3 +4 +5 **Rh** 102,91 Rodis	46 ■ +2 +4 **Pd** 106,42 Paladis	47 ■ +1 +2 +3 **Ag** 107,87 Sidabras	48 ■ +2 **Cd** 112,41 Kadmis	49 ■ +1 +3 **In** 114,82 Indis	50 ■ +2 +4 **Sn** 118,71 Alavas	51 ◪ -3 +3 +5 **Sb** 121,75 Stibis	52 ◪ -2 +4 +6 **Te** 127,60 Telūras	53 □ -1 +1 +5 +7 **I** 126,90 Jodas	54 □ +2 +4 +6 +8 **Xe** 131,29 Ksenonas
6	55 ■ +1 **Cs** 132,90 Cezis	56 ■ +2 **Ba** 137,33 Baris		72 ■ +4 **Hf** 178,49 Hafnis	73 ■ +3 +4 +5 **Ta** 180,95 Tantalas	74 ■ +2 +3 +4 +5 +6 **W** 183,85 Volframas	75 ■ +2 +3 +4 +6 +7 **Re** 186,21 Renis	76 ■ +3 +4 +6 +8 **Os** 190,2 Osmis	77 ■ +2 +3 +4 +6 **Ir** 192,22 Iridis	78 ■ +2 +4 +6 **Pt** 195,08 Platina	79 ■ +1 +3 **Au** 196,97 Auksas	80 ■ +1 +2 **Hg** 200,59 Gyvsidabris	81 ■ +1 +3 **Tl** 204,38 Talis	82 ■ +2 +4 **Pb** 207,2 Švinas	83 ■ +3 +5 **Bi** 208,98 Bismutas	84 ■ +2 +4 +6 **Po** (208,98) Polonis	85 ◪ -1 +1 +3 +5 +7 **At** (209,99) Astatis	86 □ +2 **Rn** (222,02) Radonas
7	87 ■ +1 **Fr** (223,02) Francis	88 ■ +2 **Ra** (226,02) Radis		104 ■ +4 **Rf** (261,1) Rezer-fordis	105 ■ +5 **Db** (262) Dubnis	106 **Sg** (263) Syborgis	107 **Bh** (264) Boris	108 **Hs** (265) Hasis	109 **Mt** (266) Meitneris	110 **Uun** (267)								

Universalioji dujų konstanta
R= 8,31447 J mol^{-1} K^{-1}
Avogadro skaičius
N = 6,022137·10^{23} mol^{-1}
Faradėjaus skaičius
F = 96485,31 C/mol

Lantanoidai 6	57 ■ +3 **La** 138,91 Lantanas	58 ■ +3 +4 **Ce** 140,11 Ceris	59 ■ +3 +4 **Pr** 140,91 Prazeodimis	60 ■ +3 **Nd** 144,24 Neodimis	61 ■ +3 **Pm** (144,91) Prometis	62 ■ +2 +3 **Sm** 150,36 Samaris	63 ■ +2 +3 **Eu** 151,96 Europis	64 ■ +3 **Gd** 157,25 Gadolinis	65 ■ +3 +4 **Tb** 158,92 Terbis	66 ■ +3 **Dy** 162,50 Disprozis	67 ■ +3 **Ho** 164,93 Holmis	68 ■ +3 **Er** 167,26 Erbis	69 ■ +3 **Tm** 168,93 Tulis	70 ■ +2 +3 **Yb** 173,04 Iterbis	71 ■ +3 **Lu** 174,97 Liutecis
Aktinoidai 7	89 ■ +3 **Ac** (227,03) Aktinis	90 ■ +4 **Th** 232,04 Toris	91 ■ +4 +5 **Pa** (231,04) Protaktinis	92 ■ +3 +4 +5 +6 **U** 238,03 Uranas	93 ■ +3 +4 +5 +6 +7 **Np** (237,05) Neptunis	94 ■ +3 +4 +5 +6 **Pu** (244,06) Plutonis	95 ■ +3 +4 +5 +6 **Am** (243,06) Americis	96 ■ +3 +4 **Cm** (247,07) Kiuris	97 ■ +2 +3 +4 **Bk** (247,07) Berklis	98 ■ +2 +3 +4 **Cf** (251,08) Kalifornis	99 ■ +2 +3 **Es** (252,08) Einšteinis	100 ■ +2 +3 **Fm** (257,09) Fermis	101 ■ +2 +3 **Md** (258,10) Mendelevis	102 ■ +2 +3 **No** (259,1) Nobelis	103 ■ +3 **Lr** (260,1) Laurensis