

Ph.D. Qualifying Examination  
Interactions

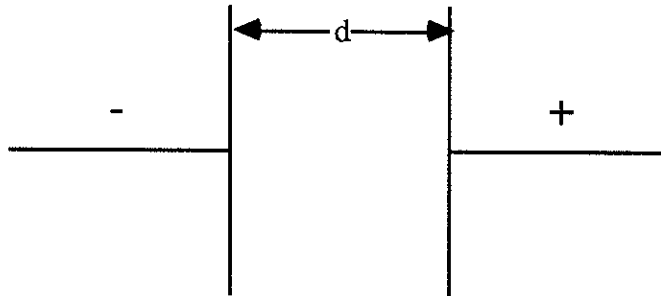
1. (15 min.) A recent proposal has been submitted on a new method to rid the country of transuranic (TRU) radioactive waste. The TRU material is loaded into glass blocks such that 25% of the final weight of the block is TRU and the average atomic weight of the TRU is 240.5. These blocks are then loaded as a blanket around a high flux reactor. If the average flux at these locations is  $1.0E12$  neutrons/cm<sup>2</sup> - sec, and the average cross-section for TRU destruction is 12 barns, how long must the blocks be irradiated to destroy 90% of the TRU atoms?
2. (15 min.) A radioactive plume is sufficiently thin that it can be modeled as a disk source 100 m in diameter and 40 m above the ground. If this plume contains  $100 \mu\text{Ci}/\text{m}^2$  of <sup>41</sup>Ar (which emits a single 1.293 MeV gamma, 99% yield), what is the dose rate at ground level, centered under the plume? Neglect shielding by intervening air. The following factors may be useful.

mass attenuation coefficient for tissue at 1.293 MeV is  $0.065 \text{ cm}^2/\text{g}$   
mass energy absorption coefficient at 1.293 MeV is  $0.026 \text{ cm}^2/\text{g}$   
rad =  $10^{-5}$  joules/g

3. (15 min.) A foil of indium is 1 cm in diameter and has an areal density of  $1 \text{ mg}/\text{cm}^2$ . It is exposed to a thermal neutron flux for 20 minutes. Three hours after removal from the flux it has a decay rate of 30,000 dpm. In-116m has a half life of 54.2 min and an activation cross section of 130 barns at room temperature. Indium contains 96% In-116m and the density of In is  $7.28 \text{ g}/\text{cm}^3$ .

Calculate the neutron flux that irradiated the foil.

4. (15 min.) Consider the "mobility" or "drift velocity" in a radiation counter. For simplicity consider a parallel plate ion chamber.



Assume the following information:

Voltage = 1000 volts  
 Gas Pressure = 0.5 atm  
 $d = 2$  cm

Electron mobility constant:  $\mu_e = 10^{-1} \frac{\text{m}^2 \cdot \text{atm}}{\text{V} \cdot \text{sec}}$

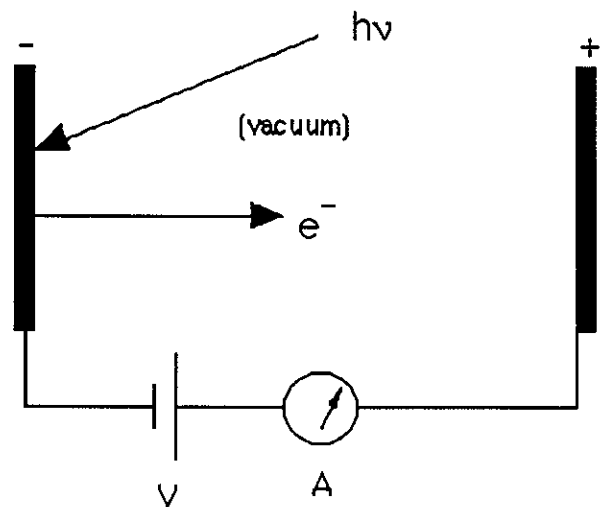
Ion mobility constant:  $\mu_i = 10^{-4} \frac{\text{m}^2 \cdot \text{atm}}{\text{V} \cdot \text{sec}}$

- Calculate the electron drift velocity
  - Calculate the ion drift velocity
  - Explain some of the factors that would affect the drift velocity in an ion chamber.
5. (15 min.) A uniform, infinite slab of thickness  $t$  is in vacuum. The left face has uniform and monoenergetic sources emitting  $S_a(\Omega) = S_a \eta / \pi$  photons/cm<sup>2</sup>-sec-sr into the slab;  $\eta$  is the cosine of the angle between  $\Omega$  and the inward normal. The slab has a linear attenuation coefficient  $= \mu \text{ cm}^{-1}$ . Using the Transport Equation, find the uncollided angular flux as a function of  $z$  in the slab.  $z$  is perpendicular to the slab faces, and  $z = 0$  corresponds to the left face.

Note:  $\eta \frac{\partial \Psi}{\partial z} + \mu \Psi(z, \eta) = S(z, \eta).$

6. (15 min.)

A certain metal has a photoelectric work function  $W_0 = 5 \text{ eV}$  and is the cathode for a capacitor that is used to measure photoionization current. ( $h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$ )



- If the metal is illuminated by 0.1 watts of 500 nm radiation, what current is measured in the circuit.
- If the metal is illuminated by 0.1 watts of 50 nm radiation, what current is measured in the circuit.

7. (15 min.) A radioactive sample was counted with a radiation detector and gave 500 counts in 1 min. The sample was removed and a 1 minute background count gave 480 counts.

- (80%) What is the net count rate and its standard error (one standard deviation)?
- (10%) With 95% confidence, can you say that the sample is radioactive?
- (10%) With what percent confidence can you say that the sample is radioactive?

**Useful Information:**

Error Propagation Equation

Variance of a function  $f = f(x_1, x_2, \dots, x_M)$ :

$$\sigma_f^2 = \left(\frac{\partial f}{\partial x_1}\right)^2 \sigma_1^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 \sigma_2^2 + \dots + \left(\frac{\partial f}{\partial x_M}\right)^2 \sigma_M^2$$

Standard Normal Distribution

The attached table gives areas under the standard normal distribution from 0 to  $z$ , where  $z$  is the number of standard deviations above the mean, which for this distribution is zero. Values across the top of the table give the second decimal digit of  $z$ . For example, the area from  $\bar{x}$  to  $\bar{x} + 2.04 \sigma$  is read from the table as 0.4793 or 47.93% of the total area under the curve.

8. (15 min.) You are requested to prepare a standard sample of technicium-99 to determine the counting efficiency of a gas flow proportional counter. You choose to prepare the standard sample by electrodeposition onto a polished, 2 in. diameter disk of tungsten.

Other relevant facts and conditions are:

Tc-99<sup>m</sup> solution is certified by NIST

Tc-99 half-life = 213,000 years

Tc-99 decays almost entirely by beta particle emission (assume no photons)

Tc-99 maximum beta particle energy = 0.293 MeV

Proportional counter chamber diameter = 2 inches (hemispherical)

Source disk is positioned very near (e.g. 1 mm) to proportional counter window

Window of the proportional counter is made of very thin Mylar (100  $\mu\text{g}/\text{cm}^2$ )

Tc-99 deposited as a thin, homogeneous layer on the tungsten disk surface;  
e.g. ~1 mg total Tc mass

- a. (70%) Describe the factors affecting the observed counting efficiency for the conditions described above. List and briefly discuss each factor and its relative importance to the observed counting efficiency.
- b. (30%) What would you predict the counting efficiency to be under these conditions?

7. (20 min.) At the Nuclear Science Center (NSC), the neutron lifetimes in water are approximately 6.0 microseconds slowing down time and 0.2 milliseconds thermal lifetime.

For  $U - 235$  the delayed neutron constants are:

Group	$\beta_i$	$\tau_i$	$\beta_i\tau_i$
0 (prompt)	99.359	$\approx 0.001$	0.0994
1	0.021	80.40	1.688
2	0.140	32.79	4.591
3	0.126	9.01	1.135
4	0.253	3.32	0.840
5	0.074	0.88	0.065
6	0.027	0.33	0.009
Total	100		8.428 (Groups 1 through 6)

- a) If a control rod is pulled so that an asymptotic period of 2 minutes is obtained, what worth in dollars was inserted into the core? Assume that for the NSC  $\beta_{eff}$  is 10 % greater than  $\beta$ .
- b) Explain physically, why is  $\beta_{eff}$  greater than  $\beta$  in an operating reactor ?

5. (20 minutes) Water flows through a 10-ft-long heated tube with a one inch inner diameter. The tube is uniformly heated with a heat flux on the inner surface of 100,000 BTU/hr-ft<sup>2</sup>. The inlet velocity is 10 ft/s, and the water is saturated liquid. The system pressure is 100 psia.

- A. (30%) Find the outlet quality.
- B. (30%) Find the outlet void fraction, assuming that the slip ratio is 2.5.
- C. (40%) Estimate the pressure losses for the tube using the homogeneous flow model.

Properties at 100 psia:

$\rho_g$	= 0.226 lb <sub>m</sub> /ft <sup>3</sup>	$\rho_f$	= 56.37 lb <sub>m</sub> /ft <sup>3</sup>
$\mu_g$	= 0.0363 lb <sub>m</sub> /hr-ft	$\mu_f$	= 0.411 lb <sub>m</sub> /hr-ft
$h_{fg}$	= 888.6 BTU / lb <sub>m</sub>	$h_f$	= 298.5 BTU / lb <sub>m</sub>