Chemical Engineering 412

Introductory Nuclear Engineering

Exam 1 Review

Chapter 1 - Fundamentals

- Nuclear units
- Elementary particles/particle physics
- Isotopic nomenclature
- Atomic weight/number density
- Chart of nuclides
- Mass energy equivalency

Chapter 2 – Quantum Mechanics

- Special Relativity – time, length, mass changes
- Relativistic mass/momentum/energy relations
- Particle-wave duality
- Schrödinger's wave equation
- Heisenberg's uncertainty principle

Chapter 3 – Nuclear Models

- Nuclear energy states
- Liquid Drop Model
- Nuclear mass equation
- Shell Model
- Nuclear stability
- Binding energy/mass excess
- Modern Nucleus concepts

Chapter 4 – Nuclear Energetics

- Terminology
- Mass defect/BE
- Nuclear reactions
- Conserved quantities for various situations (not all the same!)
- ******Q-Value**** (know how to calculate for ALL reactions)**
  - Know how to deal with charge
  - Know how to deal with excited nuclei
  - Know how to deal with electrons/binding energy of electrons

Chapter 5 – Nuclear Decay

- Conservations
- Decay mechanisms – distinguishing features, Q values, energy/momentum balances
- ***Energy Diagrams***
- Alpha/Beta particle energy distribution
- Decay Constant
- Half-Life
- Activity

Chapter 5 – Nuclear Decay (cont)

- Parallel/Series Decay Routes
- Decay Chains
- Solutions to decay chain equations Secular Equilibrium
- Radionuclides in nature
- Carbon 14 dating
- Other isotopic dating methods
- Three component decays
- Isobars and most stable masses

Chapter 6 – Binary Nuclear Reactions

- Definitions
- Types of binary reactions
- Reaction Mechanisms
- Kinematics (scattering example)
- Threshold Energy
- Neutron Reactions
- Neutron Scattering/slowing
- Neutron Energy Spectrums
- Lethargy

Chapter 6 – Binary Nuclear Reactions (cont.)

- Neutron capture vs. slowing
- Fission reactions
- Emitted/recoverable fission energy
- Critical energies for fission
- Fertile vs. fissile vs. fissionable
- Fission product distribution
- Prompt vs. delayed neutrons
- Fission steps/timeline

Chapter 7 – Radiation Interactions with matter

- Linear Interaction Coefficient (micro vs. macro)
- Cross section (micro vs. macro)
- Attenuation in Material
- Derivation of material interaction
- Buildup factor
- Mass Attenuation Coefficient
- Energy dependence of cross sections
- Cross section Trends

Chapter 7 – Radiation Interactions with matter (cont.)

- Cross Section of mixture
- Total intensity/flux
- Neutron flux
- Time/space/position dependence of flux
- Fluence
- Uncollided flux transmission
- Thermal vs. fast neutrons
- Photon Interactions – types, trends, energies, cross sections
- Charged Particle interactions
- Stopping Power (collision vs. radiative)
- Range

Example 1

$N = \frac{\rho N_a}{A} e$ $\quad$ a 5% ^{238}U $\quad$ $\phi = \frac{\text{neutrons}}{cm^2 \cdot s}$

Assume a fuel rod has a diameter of 1 cm and a length of 5 m. Assuming an enrichment of 5% ^{235}U and a thermal flux of 2×10^{13} neutrons, what is the reaction rate in the fuel rod for:

a) scattering?

b) fission?

Σ_f

$$\hat{R} = \sigma_s N \phi \qquad \frac{\text{reactions}}{cm^3 \cdot s}$$

$$\sigma_s = \sigma_t - \sigma_\gamma - \sigma_f$$

$$\sigma_{s,235} = 13.7\ b$$

$$\sigma_{s,238} = 9.47\ b$$

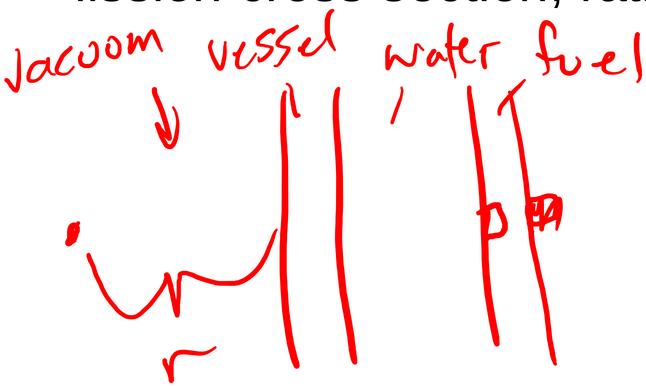
reactions

$\frac{\text{scatters}}{s}$

$$\hat{R}_s = \left[(\sigma_s N)_{238} + (\sigma_s N)_{235}\right]\phi$$

Example 2

In order to start up a fission reactor, 1 cm^3 of this rod must reach a neutron flux of 1×10^{12} neutrons/cm^2/s. Assuming that an isotropic neutron source is 1 meter away from the 4 cm thick iron reactor vessel, and that there is 8 cm of water between this rod and the vessel wall, what is the required source intensity to start this reactor? (Hint, use fission cross section, rather than the total for the ^{235}U)



$$\phi_f = \frac{S_n}{4\pi r^2}\left(e^{-\mu t}\right) \rightarrow e^{-(\Sigma_t \Delta x_w + \Sigma_t \Delta x_v)}$$

$$R = \hat{R}\cdot V_d = \Sigma_f \cdot V_d \cdot \phi_f = \frac{S_n \Delta V_d \Sigma_{f,235}}{4\pi r^2}\left[e^{-(\Sigma_t \Delta x)_w - (\Sigma_t \Delta x)_v}\right]$$

Example 3

- The Radionuclide ^{41}Ar decays by β^- emission to an excited level of ^{41}K that is 1.293 MeV above the ground state. What is the maximum kinetic energy of the emitted β^- particle?
- What makes this the maximum energy?

Solution

Q Equation

$Q_{\beta-} = \{M({}^{41}_{18}Ar) - [M({}^{41}_{19}K) + E^*/c^2]\}c^2$

[40.9645008 – 40.9618259]*931.5 – 1.293 MeV

=1.199 MeV

B) Because an antineutrino is also released, which carries away some energy – this maximum is when the antineutrino has zero energy

Example 4

- What is the probability of producing ^{91}Br in a fission reaction?
- Use fission product mass distribution chart:
- ~8.5%

Example 5

- What is the amount of thermal neutrons that are absorbed in water per cm^3 over 1 hour in a fission reactor if the thermal flux is $2.2*10^{16}$ neutrons/cm^2/s? ($\Sigma_a = 0.0197\ cm^{-1}$)

- $1.56*10^{19}$ absorptions per cm^3