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University of Ottawa

Department of Mechanical and Engineering

GNG 4128 Introduction to Nuclear Engineering **Instructor: Nabel Sadek**
Mid-Term exam **Time allowed: 90 minutes**
Date: March 6 / 2018 **Calculators (non-programmable) allowed**

NOTE: Closed-Book Exam. Every student is allowed to use a one page, size A4, double sided, hand written formula sheet. The formula sheet has to be submitted with the answer booklet. Students should write their name on the formula sheet.

1. The table below gives the thermal neutron cross-sections of U-235 and U-238 for elastic scattering, radiative capture, and fission, (Cross-sections given in barns).

	σ_s	σ_c	σ_f
U-235	17.6	98.3	580
U-238	10.0	2.71	0.0

   (a) If a thermal neutron interacts with a nucleus of U-235, what is the probability that fission occurs? **3 points**
   (b) What is the probability that a thermal neutron moving through an infinite medium of natural uranium will eventually produce a fission (atomic abundance of U-235 in natural uranium = 0.7%). Given that the gram density of natural uranium is 19 g/cm3 and $M_{U\text{-}235}$ =235 g/mole and $M_{U\text{-}238}$= 238 g/mole **3 points**

2. A person in North America uses approximately 10^{11} Joules of energy per year. Assume that this amount of energy comes only from the fission of U-235 by thermal neutrons. Given that each fission produces 200 Mev of energy and the atomic weight of U-235 is 235 g/mole, evaluate (a) the mass of U-235 fissioned, (b) the mass of U-235 consumed using the values of cross sections given in Q.1. **6 points**
3. The isotope thorium-232($^{232}_{90}Th$) decays successively to form($^{228}_{88}Ra$), ($^{228}_{89}Ac$), ($^{228}_{90}Th$), ($^{224}_{88}Ra$), and finally becoming radon-220 ($^{220}_{86}Rn$).What particles are emitted in each of these five steps. **3 points**
4. The radioisotope sodium-24 ($^{24}_{11}Na$), half-life 15 h, is used to measure the flow rate of salt water. By irradiation of stable $^{23}_{11}Na$ with neutrons, suppose that we produce 5 micrograms of the isotope. How much do we have at the end of 24 h? **5 points**
5. List the factors (parameters) affecting the binding energy in a nucleus! **2 points**
6. Name and define the SI units of radioactivity! **1 point**
7. Define nuclear cross-section. Specify the factors affecting its value. **2 points**
8. Name the following neutron reactions a) C-13 (n, γ)? b) O-17 (n, p)? c) O-17 (n, α) ? d) N-14 (n, p)? **2 points**
9. What do we mean by resonance regions of nuclear cross sections? Why do they happen? **3 points**

Solution of Mid-Term

1. (a) Given that the neutron has already interacted with U-235, then

$$p(\text{fission}) = \frac{580}{17.6 + 98.3 + 580} = 0.833$$

3 points

(b) In this case the effect of U-238 has to be considered.

The number density $N = \frac{w \rho N_a}{M}$

$$N_{U\text{-}235} = \frac{0.007 * 19 * 6.023 \times 10^{23}}{235} = 3.4 \times 10^{20}\ \text{atm/cm}^3$$

$$N_{U\text{-}238} = \frac{0.993 * 19 * 6.023 \times 10^{23}}{238} = 4.7 \times 10^{22}\ \text{atm/cm}^3$$

1 point

$$\Sigma_{U\text{-}235} = N_{U\text{-}235} * \sigma_{U\text{-}235}$$

$$= 3.4 \times 10^{20} \left[(580 + 98.3 + 17.6) * 10^{-24} \right] = 0.2366\ \text{cm}^{-1}$$

0.5 points

$$\Sigma_{U\text{-}235\,f} = 3.4 \times 10^{20} * 580 * 10^{-24} = 0.1972\ \text{cm}^{-1}$$

0.5 points

$$\Sigma_{U\text{-}238} = 4.7 \times 10^{22} \left[(10.0 + 2.71) * 10^{-24} \right] = 0.5974\ \text{cm}^{-1}$$

0.5 points

$$\text{Probability of fission} = \frac{0.1972}{0.2366 + 0.5974} = 0.236$$

0.5 points

Ques #2

(a) Number of fissions $= \dfrac{10^{11}}{200 * 1.602 * 10^{-13}}$

$$= \frac{10^{24}}{200 * 1.602} = 3.12 \times 10^{21} \text{ fissions}$$ 1.5 pts

mass of U-235 fissioned $= \dfrac{3.12 * 10^{21} * 235}{6.023 * 10^{23}}$

$= 1.217$ grams of U-235 fissioned 1.5 pts

(b)

For each U-235 atom fissioned there will be

$$\frac{\sigma_f + \sigma_c}{\sigma_f} = \frac{\sigma_a}{\sigma_f} \text{ atoms consumed}$$

$$\frac{\sigma_a}{\sigma_f} = \frac{580 + 98.3}{580} = 1.169$$ 1.5 pts

$\therefore$ mass of U-235 consumed $= 1.217 * 1.169$

$= 1.42$ grams #

1.5 pts

problem 3

$$^{232}_{90}Th \xrightarrow{\alpha} {}^{228}_{88}Ra \xrightarrow{\beta^-} {}^{228}_{89}Ac \xrightarrow{\beta^-} {}^{228}_{90}Th \;---$$

$$\xrightarrow{\alpha} {}^{224}_{88}Ra \xrightarrow{\alpha} {}^{220}_{86}Rn$$

∴ The particles are successively $\alpha, \beta^-, \beta^-, \alpha, \alpha$

3 points

problem # 4

$$N = N_0 \exp\left[-\frac{0.693\, t}{T_{1/2}}\right]$$

$$\frac{N}{N_0} = \exp\left[-\frac{0.693 * 24}{15}\right] = 0.33$$

3 points

∴ The remaining Na-24 $= 5 * 0.33$

$= 0.167$ micrograms

2 points

problem 5

Factors affecting the binding energy are

1- Volume effect
2- Surface effects
3- Coulomb effects
4- Pairing effects
5- Pauli exclusion effect

2 points

problem # 6

SI unit of activity is Bequerel (Bq) 0.5

It is defined as the activity of radioactive material in which one nucleus decays per second. 0.5

key respons

problem # 7

A typical answer would the following

Nuclear cross-section is a measure of the liklihood (Probability) of a particular nuclear reaction and it has the units of area (L^2).
It is not probability in mathematical sense

1 point

Factors affecting nuclear Cross-Section :-

1- The energy of incident neutron
2- The target nucleus.

1 point

problem # 8

(a) radiative capture 0.5

(b) charged particle reaction 0.5
or (transmutation)

(c) Charged particle reaction 0.5
(Transmutation)

(d) charged particle reaction 0.5
or (Transmutation)

problem # 9

Resonance is a sharp spike in the nuclear cross-sections for a particular nuclear reaction. It occurs when the incident neutron happens to have the right amount of energy such that the Compound nucleus formed of a nuclear reaction match one of the quantized (discrete) energy levels of that nucleus.

3 points