STUDY GUIDE FOR PART 5 RADIOACTIVITY

Nuclear Physics

A. Nuclear Structure — Q-1; S-78

1. size of nucleus

2. structure of nucleus

3. the nucleus
   a) charge - elements (Z ≡ number of protons in nucleus)
   b) mass - isotopes (A ≡ Z + N where N ≡ number of neutrons)
   c) stability
   d) radiations (from the nucleus, not the electronic shells)
   e) mass defect and binding energy ($\Delta m = \{[Z \bullet m_H + N \bullet m_n] - m_{atom}\}$, $BE = \Delta m \bullet c^2$)

B. Radioactivity

1. rate of decay ($dN/dt \propto N$) — S-79,80
   a) exponential decay ($N = N_o e^{-\lambda t}$)
   b) decay constant (λ)
   c) half life ($T_{1/2} = \ln[2]/\lambda$)

2. activity — Q-2 to 6; S-81 to 86
   a) exponential decay ($A \equiv -dN/dt = A_o e^{-\lambda t}$)
   b) units (Bq., Curie) (see nuclear data sheet)

3. types of decay
   a) alpha (α)
   b) beta (β^-)
   c) others (β^+ = positron, γ = gamma, p, n, E.C., I.C.)
   d) reaction formulas
   e) "missing" particle: the neutrino (${}_o\nu^o$)

4. radioactive series — Q-7
   a) U^{238} (4N+2) $T_{1/2} = 4.51 \times 10^9$ years, goes to Pb^{206}
   b) U^{235} (4N+3) $T_{1/2} = 7.12 \times 10^8$ years, goes to Pb^{207}
   c) Th^{232} (4N) $T_{1/2} = 1.39 \times 10^{10}$ years, goes to Pb^{208}
   d) Np^{237} (4N+1) $T_{1/2} = 2.20 \times 10^6$ years, goes to Bi^{209}

5. man-made and other radioactive elements — Q-8; S-87

C. X-rays (Supplement)

1. x-ray photons — Q-9

2. x-ray machines — Q-10; S-88

3. mechanism of x-ray production — Q-11,12,13
   a) continuous radiation ($hf_{max} = eV$, $\lambda_{min} = c/f_{max}$)
   b) characteristic radiation (atomic: due to inner e^-, $E_{to\ ionize} = 13.6\,eV\,(Z-1)^2$)

4. nuclear x-rays (NOT due to electronic shells)

5. absorption of x-rays Q-14; S-89

STUDY QUESTIONS:

1) Why does $_{92}U^{238}$ have a higher ratio of neutrons/nucleons than $_{6}C^{12}$?

2) Describe the three major types of radiation emitted by radioactive elements.

3) What is a neutrino and in what type of process it is emitted?

4) What is K-electron capture and what type of radiation results?

5) Describe Internal Conversion (I.C.) .

6) Tell how the atomic number, neutron number, and mass number change for alpha decay, beta decay, positron emission, and K-capture.

7) Be able to follow one path along one radioactive series. You do not have to follow all branch points, but you should indicate where the atom has a choice (that is, a branch point).

8) How are man-made or artificial radioisotopes produced?

9) What are x-rays?

10) Tell how an x-ray machine produces x-rays.

11) Why is there a minimum wavelength for the x-rays produced in an x-ray tube?

12) Briefly describe the mechanism of x-ray production. Your description should include some words about continuous and characteristic radiation.

13) Tell how K-series radiation is produced. What is the difference between K_α and K_β radiation? How does L-series radiation differ from K-series?

14) What is a half-value layer?

SUPPLEMENTARY PROBLEMS (S-):

78) a) What is the binding energy of $_{8}O^{16}$ (mass = 15.994915 amu) ?
b) What is the binding energy per nucleon for $_{8}O^{16}$?

79) The half life of Th^{232} is 13.9 billion years. The age of the earth is 4.6 billion years. What percentage of a pocket of originally pure Thorium is still Thorium now?

80) The half life of C^{14} is 5730 years. a) What is the decay constant for C^{14} ? b) The ratio of C^{14} to C^{12} in the atmosphere is $1.3x10^{-12}$. What is the present activity of a 4 gram sample of carbon taken from a "modern" bone? c) A 4 gram sample of carbon taken from a bone at an archeo- logical site has an activity of 7 counts per minute. Assuming that C^{14} was formed at the same rate then as it is now, how old is the bone?

81) a) What is the mass of one Curie of Radium? b) What is the mass of one Curie of U^{238} ?

82) a) U^{238} decays by alpha decay. What is the daughter atom? b) U^{238} decays by emitting an alpha of energy 4.18 MeV and a gamma of energy 0.05 MeV. The mass of U^{238} is 238.05076 amu, and the mass of He^4 is 4.002604 amu. What is the mass of the daughter atom? (You should be able to calculate this instead of trying to look it up.)

83) U^{238} decays by alpha decay and the alpha has an energy of 4.18 MeV. a) If this energy were due to electrostatic repulsion of the alpha from the rest of the nucleus, how close would the alpha be to the rest of the nucleus assuming it has zero kinetic energy to begin with? b) What is the approximate radius of the U^{238} nucleus (use the general formula for the radius of a nucleus) ? c) Compare the answers to parts a) and b) and comment on why they are different.

84) ${}_{90}Th^{234}$ decays by beta decay. What does it decay to? Write the "equation" for this reaction.

85) The stable isotopes of iron are ${}_{26}Fe^{56}$, ${}_{26}Fe^{57}$, and ${}_{26}Fe^{58}$. a) What type of decay would ${}_{26}Fe^{61}$ most likely undergo? b) What would it become? c) What type of decay would ${}_{26}Fe^{52}$ most likely undergo? d) Write the "equation" for this reaction. e) Would Fe^{61} or Fe^{52} also be likely to decay by electron capture?

86) a) What type of decay would C^{14} most likely undergo? b) What would the "equation" for this reaction be? c) What would the energy released in this decay be? (The mass of C^{14} is 14.003233 amu.)

87) The steel compression ring for the piston of an automobile engine has a mass of 30 grams. The ring is irradiated with neutrons until it has an activity of 10 μCi due to the formation of Fe^{59} (half life of 45.1 days). Nine days later the ring is installed in an engine. After being used for 30 days, the crankcase oil has an average activity due to Fe^{59} of 12.6 disintegrations per minute per 100 cubic centimeters. What was the mass of the iron worn off this piston ring if the total volume of the crankcase oil is 6 quarts?

88) An x-ray tube uses a voltage of 10,000 volts to accelerate electrons which then strike a target. a) What is the maximum energy of the x-rays? b) What is the minimum wavelength of the x-rays? c) If the target is made of Tungsten (${}_{74}W^{170}$ or ${}_{74}W^{174}$), which has an absorption edge of 0.178 Angstroms, will the electrons or x-rays be able to knock a K-shell electron out of the Tungsten? d) If the target was made of Nickel (${}_{28}Ni^{58}$ or ${}_{28}Ni^{60}$), would it be able to knock a K-shell electron out? (Calculate K absorption edge energy from $E = (13.6 \text{ eV})(Z-1)^2$, the generalization of Bohr's formula.) e) What would the wavelength of the K_α radiation for nickel be assuming the K-electron was ejected?

89) How many half value layers of a material is necessary to reduce the intensity of a narrow monochromatic x-ray beam to a) 1/8, b) 1/10, and c) 1% of its incident value?

ANSWERS TO SUPPLEMENTARY PROBLEMS:

78) a) 127.55 MeV b) 7.97 MeV/nucleon.

79) 78% .

80) a) 1.21×10^{-4} /yr = 2.30×10^{-10} /min; b) 59.8 counts/min; c) 17,740 yrs.

81) a) one gram by definition; b) 3 metric tons (3000 kg).

82) a) $_{90}Th^{234}$; b) 234.0436 amu.

83) a) $6.2\text{x}10^{-14}$ meters; b) $7.44\text{X}10^{-15}$ meters; c) answer to a is greater than the answer to b by a factor of 8.3 which indicates quantum mechanical tunnelling has occurred.

84) $_{91}Pa^{234}$; $_{90}Th^{234} \rightarrow {}_{91}Pa^{234} + {}_{-1}\beta^0$ + antineutrino + gamma.

85) a) β; b) $_{27}Co^{61}$; c) positron (β^+); d) $_{26}Fe^{52} \rightarrow {}_{25}Mn^{52} + {}_{+1}\beta^0$ + neutrino; e) $_{26}Fe^{52}$.

86) a) β; b) $_6C^{14} \rightarrow {}_7N^{14} + {}_{-1}\beta^0$ + antinuetrino; c) 0.148 MeV.

87) 1.77 mg.

88) a) 10,000 eV = 10 KeV; b) 12.43nm; c) no; d) E_{edge} = 9914 eV so yes;
e) E = 7436 eV, λ = 0.167 nm .

89) a) 3; b) 3.32; c) 6.64 .

Nuclear Applications

A. Radiation Units and Doses

1. absorption of radiation — Q-15,16
   a) alpha
   b) beta
   c) gamma
      1) photoelectric effect
      2) compton scattering
      3) pair production
      4) total
   d) units (Roentgen)
   e) detectors
      1) cloud and bubble chambers
      2) geiger counters
      3) scintillation counters

2. radiation damage — Q-17,18,19
   a) structural
   b) biological
   c) units (rad, rem)

B. Nuclear Energy

1. cross sections (Probability: $P_f = \sigma_f/[\sigma_f+\sigma_{abs}+\sigma_{esc}]$) Q-20
2. chain reactions ($k \equiv N_{avg} P$) Q- 21
3. reactor criticality Q-22
4. moderators (slow neutrons down since $P_f(\text{slow}) > P_f(\text{fast})$) Q-23
5. power reactors Q-24 to 27
   a) fuels
   b) types
      1) boiling water reactors
      2) gas-cooled reactors
      3) breeder reactors
   c) safety
6. fusion Q-28,29; S-90,91
   a) fuels
   b) high temperature confinement problems
      1) gravitational: the sun's method
      2) magnetic
      3) inertial
   c) safety

STUDY QUESTIONS:

15) Compare the penetrating abilities of alpha particles, beta particles, and gamma rays. To what are the differences attributed?

16) What are the three mechanisms of x-ray absorption? For what energy range is each the dominant mechanism?

17) If the skin and clothing provide adequate shielding for our vital organs from beta and alpha particles, why are alpha and beta emitters considered dangerous?

18) Although not completely understood, what is the mechanism of tissue destruction by ionizing radiation?

19) Know the definitions of Roengen, rad, rem, and Curie and which are for exposure, absorption, and activity.

20) What is meant by "cross-section" in connection with nuclear reactions?

21) Tell what is meant by a chain reaction.

22) What do the words subcritical, critical, and supercritical mean in connection with nuclear fission?

23) What is a moderator, and why is it used? What are the characteristics of a good moderator?

24) How are controlled nuclear reactors controlled?

25) What is poisoning in the case of fuel elements for a fission reactor?

26) What is a breeder reactor?

27) What makes a boiling water reactor inherently stable and thus contributes to its safety?

28) What is the result of the Carbon cycle? How much energy in Joules would be released if the hydrogen in 18 grams of water went through the carbon cycle?

29) Give some advantages of fusion reactions over fission reactions as sources of power.

SUPPLEMENTARY PROBLEMS (S-):

90) a) What is the energy from fissioning one gram of ${}_{92}U^{235}$ if the average energy per fission is 200 MeV ? b) What is the energy for fusing one gram of ${}_{1}H^{1}$ into ${}_{2}He^{4}$ if the average energy per fusion is 26.7 MeV ?

91) The energy received from the sun at the top of the earth's atmosphere is 1.35 kilowatts per square meter (assuming the sunlight is normal to the collector and the collector's efficiency is 100%). a) What is the total power output of the sun (the radius of the earth's orbit around the sun is 1.49×10^{8} km) ? b) How many metric tons (1000 kg = 1 metric ton) of hydrogen are "burned" each second by the sun? (Note: the sun's mass is 2×10^{30} kg, so it has a lot of fuel. At this rate, it will take 10 billion years to burn up the fuel in the sun's core. When this happens the sun will become a red giant and fry the earth. The sun has been burning for about 4.6 billion years, so it has about 5.4 billion years left.)

ANSWERS TO SUPPLEMENTARY PROBLEMS:

90) a) 8.17×10^{10} Joules; b) 6.4×10^{11} Joules.

91) a) 3.77×10^{26} Watts; b) 5.88×10^{8} tons/sec.

Particle Physics

A. Elementary Particles
1. sub-atomic particles
2. bosons and fermions
3. strong and weak nuclear forces
4. leptons (6) - weak nuclear forces only
5. quarks (6) and baryons
    a) hadrons (3 quarks)
    b) mesons (2 quarks)
6. gluons - strong nuclear force
7. field quanta: photons, pions, others