General Physics II **Exam 5 - Chs. 30, 31 - Nuclear Physics** **Dec. 17, 2013**

Name Rec. Instr. Rec. Time

For full credit, make your work clear. Show formulas used, essential steps, and results with correct units and significant figures. Points shown in parenthesis. For TF and MC, choose the *best* answer.

1. (3) Which of the following particles are considered "nucleons"? Check all that apply.

a. electrons. b. positrons. c. protons. d. neutrons. e. muons. f. α-particles.

2. (3) Nuclear isotopes are

a. nuclei with the same number of protons but different numbers of neutrons.
b. nuclei with the same number of nucleons but different numbers of neutrons.
c. nuclei with the same number of neutrons but different numbers of protons.

3. (3) For a spontaneous nuclear decay to take place (like alpha, beta or gamma decays),

a. the combined masses of the products must be greater than the mass of the parent nucleus.
b. the combined masses of the products must be less than the mass of the parent nucleus.
c. the combined masses of the products must be exactly equal to the mass of the parent nucleus.

4. (3) Which quantities are conserved in spontaneous radioactive decays?

a. electric charge. b. linear momentum c. nucleon number d. particle number e. mass.

5. (3) Carbon-14 forms naturally in Earth's atmosphere due to a nuclear transmutation of which element X, according to the reaction, n+X $\rightarrow$ $^{14}_{6}$C + p ?

a. oxygen (O) b. nitrogen (N) c. boron (B) d. silicon (Si)

6. (3) When a fission reaction takes place, which takes away most of the released energy (as KE)?

a. the parent nucleus. b. the daughter nuclei. c. the neutrons. d. the electrons.

7. (12) Phosphorous-32 ($^{32}_{15}$P) is a radioactive isotope with an atomic mass of 31.973907 u. Calculate its binding energy per nucleon. Make use of this: Hydrogen (i.e., proton+electron) $^{1}_{1}$H atomic mass is 1.007825 u, and neutron mass is 1.008665 u.

8. (4) Phosphorous-32 ($^{32}_{15}$P) decays by β^- emission. Write the equation for the radioactive decay, and give the name of the element and mass number for the daughter nucleus.

9. (4) Uranium-232 ($^{232}_{92}$U) can decay by α-emission. Write the equation for the radioactive decay, and give the name of the element and mass number for the daughter nucleus.

---

10. (3) In the decay of a nucleus $^{A}_{Z}$X by β^+ emission, the daughter nucleus will have atomic number

a. $Z-2$ b. $Z-1$ c. Z d. $Z+1$ e. $Z+2$.

---

11. (3) In the decay of a nucleus $^{A}_{Z}$X by γ-emission, the daughter nucleus will have atomic number

a. $Z-2$ b. $Z-1$ c. Z d. $Z+1$ e. $Z+2$.

---

12. (3) When atoms emit alpha, beta, or gamma particles, where do they really come from?

a. the electron cloud. b. the nucleus. c. the space between the nucleus and electron cloud.

---

13. (12) Plutonium-239 ($^{239}_{94}$Pu, 239.052157 u) can decay by α-emission into uranium-235 ($^{235}_{92}$U, 235.043923 u). Calculate the reaction energy Q, in MeV.

---

14. (12) Radon-222 decays by α-decay with a half-life of 3.824 days. Initially (at time $t = 0$) a sample has 5.000×10^6 radon-222 nuclei.

a) (6) How many radon-222 nuclei will be left 14.00 days later?

b) (6) How long after $t = 0$ will the number of nuclei fall to 5.000×10^3? Give the answer in days.

15. (18) Americium-241 ($^{241}_{95}$Am) is radioactive and decays mainly by α-emission with a half-life of 432.2 years. A typical smoke detector uses an Am-241 source with an activity of 37.0 kBq, where 1 Bq = 1 decay/second.

a) (6) How large is the decay constant, λ, in units of s^{-1}?

b) (6) How many Am-241 atoms would have an activity of 37 kBq? (1 Bq = 1 decay/s).

c) (6) What mass of Am-241 is being used in a typical smoke detector?

---

16. (12) A proton bombards a carbon-14 nucleus (14.003242 u) to produce nitrogen-14 (14.003074 u) in the reaction, $\mathrm{p} + {}^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + \mathrm{n}$.

a) (6) Find the Q of the reaction. Explain whether the reaction requires a minimum KE of the incident proton.

b) (6) If the proton's kinetic energy is 4.00 Mev, what will be the combined kinetic energy of the outgoing nitrogen-14 and neutron?

17. (15) For each of the following reactions, find the missing quantity X:

a) (3) $\mathrm{n} + {}^{14}_{7}\mathrm{N} \rightarrow {}^{14}_{6}\mathrm{C} + X,$ $X =$

b) (3) ${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + X,$ $X =$

c) (3) ${}^{238}_{92}\mathrm{U} \rightarrow X + {}^{4}_{2}\mathrm{He},$ $X =$

d) (3) ${}^{60}_{27}\mathrm{Co} \rightarrow X + \beta^{-} + \bar{\nu},$ $X =$

e) (3) $\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{132}_{54}\mathrm{Xe} + {}^{88}_{38}\mathrm{Sr} + X,$ $X =$

18. (3) Which reaction in question 17 is an example of a fusion reaction?

a. a b. b c. c d. d e. e

19. (3) Which reaction in question 17 is an example of a fission reaction?

a. a b. b c. c d. d e. e

20. (3) Which reaction in question 17 is an example of beta-decay?

a. a b. b c. c d. d e. e

21. (3) Which reaction in question 17 is an example of alpha decay?

a. a b. b c. c d. d e. e

---

22. (18) A reaction in which deuterium undergoes fusion is ${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + \mathrm{n}$, with energy $Q = 3.27$ MeV. Based on this reaction, engineers want to make a nuclear reactor with a power output of 250 kW.

a) (6) How many of the given reactions must take place per second in the reactor?

b) (6) If the reactor operates continuously for one year, what mass (in grams) of deuterium fuel will be needed?

c) (6) During one year of continuous operation, what mass (in grams) gets transformed into energy?

Prefixes

a=10^{-18}, f=10^{-15}, p=10^{-12}, n=10^{-9}, $\mu = 10^{-6}$, m=10^{-3}, c=10^{-2}, k=10^{3}, M=10^{6}, G=10^{9}, T=10^{12}, P=10^{15}

Physical Constants

$k = 1/4\pi\epsilon_0 = 8.988$ GN·m^2/C^2 (Coulomb's Law)
$e = 1.602 \times 10^{-19}$ C (proton charge)
$c = 3.00 \times 10^{8}$ m/s (speed of light)
$m_e = 9.1094 \times 10^{-31}$ kg = (electron mass)
$m_n = 1.67493 \times 10^{-27}$ kg = (neutron mass)
$h = 6.6262 \times 10^{-34}$ J·s (Plank's constant)

$\epsilon_0 = 1/4\pi k = 8.854$ pF/m (permittivity of space)
$\mu_0 = 4\pi \times 10^{-7}$ T·m/A (permeability of space)
$c = 2.99792458 \times 10^{8}$ m/s (exact value in vacuum)
$m_p = 1.67262 \times 10^{-27}$ kg = (proton mass)
$hc = 1240$ eV·nm (photon energy = hc/λ)
$\hbar = 1.05459 \times 10^{-34}$ J·s (Plank's constant/2π)

Units

$N_A = 6.02 \times 10^{23}$/mole (Avogadro's #)
1.0 eV = 1.602×10^{-19} J (electron-volt)
1 F = 1 farad = 1 C/V = 1 C^2/J
1 A = 1 ampere = 1 C/s = 1 coulomb/second
1 T = 1 tesla = 1 N/A·m = 1 newton/ampere·meter
1 Bq = 1 becquerel = 1 decay/s

1 u = 1 g/N_A = 1.6605×10^{-27} kg = 931.5 MeV/c^2
1 V = 1 volt = 1 J/C = 1 joule/coulomb
1 H = 1 henry = 1 V·s/A = 1 J/A^2
1 Ω = 1 ohm = 1 V/A = 1 J·s/C^2
1 G = 1 gauss = 10^{-4} T = 10^{-4} tesla
1 Ci = 1 curie = 3.70×10^{10} decays/s = 37.0 GBq

Some Masses (for neutral atoms)

electron = ${}^{0}_{-1}$e = 0.00054858 u = 0.51100 MeV/c^2
neutron = ${}^{1}_{0}$n = n = 1.008665 u = 939.57 MeV/c^2
deuterium = ${}^{2}_{1}$H = d = 2.014102 u
helium-3 = ${}^{3}_{2}$He = 3.016029 u

proton = ${}^{1}_{1}$p = p =1.007276 u = 938.27 MeV/c^2
hydrogen = ${}^{1}_{1}$H = 1.007825 u = 938.78 MeV/c^2
tritium = ${}^{3}_{1}$H = t = 3.016049 u
helium-4 = ${}^{4}_{2}$He = α = 4.002603 u

Chapter 30 Equations

Nuclides:

$A = N + Z$, (mass, neutron, proton numbers)
$r = (1.2 \text{ fm})\ A^{1/3}$ (nuclear radius)
ΔE =[(mass of parts) - (mass of nuclide)]c^2 (binding energy)
$Q = [M_{\text{parent}} - M_{\text{products}}]c^2$ (disintegration energy)

Half-life and decay constant

$N = N_0 e^{-\lambda t}$ (decay of parent nuclei)
$\left|\frac{\Delta N}{\Delta t}\right| = N\lambda$ (radio-activity)
$t = \frac{-1}{\lambda}\ln(N/N_0)$ (time when N nuclei remain)
$M = Nm$ = mass = (# of nuclei)×(nuclear mass)
$\lambda T_{\frac{1}{2}} = \ln 2$ (decay constant, half-life)
$\tau = \frac{1}{\lambda}$ (mean life time)
$\#({}^{14}_{6}C)/\#({}^{12}_{6}C) = 1.2 \times 10^{-12}$ (live carbon ratio)
1 year = 3.156×10^{7} seconds

Chapter 31 Equations

Reactions:

$Q = [M_{\text{reactants}} - M_{\text{products}}]c^2$ (reaction energy)
$Q > 0$ (Q = mass converted to energy)
$Q < 0$ ($|Q|$ = threshold energy)

Energy, power and mass in nuclear reactors:

$E = mc^2$ (Einstein's mass-energy equivalence)
$P = E/t$ (power)
$E = NQ$ [energy= (# of reactions)×(reaction energy)]
1 u $\cdot\ c^2$ = 931.5 MeV
$M = Nm$ [mass used= (# of reactions)×(reaction mass)]
$E_{\text{out}} = eE_{\text{in}}$ [output energy = (efficiency)×(input energy)]