Gen. Phys. II **Exam 6 - Chs. 31,32 - Nuclear Physics** **May. 11, 2021**

Rec. Time **Name**

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.

OpenStax Ch. 31 - Nuclear Properties & Radioactivity

1. (5) Potassium-40 is found in the human body as a naturally occurring unstable isotope. Match the spontaneous decay of ${}^{40}_{19}\mathrm{K}$ with the correct daughter isotope X, from the choices ${}^{32}\mathrm{S}$, ${}^{36}\mathrm{Cl}$, ${}^{38}\mathrm{P}$, ${}^{40}\mathrm{K}$, or ${}^{40}\mathrm{Ca}$.

   a) ${}^{40}\mathrm{K} \to \mathrm{X} + \beta^- +$ neutrino
   b) ${}^{40}\mathrm{K} \to \mathrm{X} + \alpha$
   c) ${}^{40}\mathrm{K} \to \mathrm{X} + \gamma$

2. (2) Nuclei can decay spontaneously by a number of different processes. What is the daughter isotope X in the α-decay, ${}^{239}_{94}\mathrm{Pu} \to \mathrm{X} + \alpha$?

   a. ${}^{239}\mathrm{U}$ (uranium) b. ${}^{235}\mathrm{U}$ (uranium) c. ${}^{235}\mathrm{Np}$ (neptunium) ${}^{235}\mathrm{Cm}$ (curium).

3. (3) Consider this spontaneous decay: ${}^{3}_{1}\mathrm{H} \to {}^{3}_{2}\mathrm{He} + \beta^- +$ a neutrino. The masses are m(${}^{3}_{1}\mathrm{H}$) = 3.016049u, m(${}^{3}_{2}\mathrm{He}$)=3.016029u. Is the reaction allowed, or prohibited by charge, nucleon number, or mass/energy conservation?

   a. The reaction is allowed.
   b. The reaction is prohibited because it does not conserve charge.
   c. The reaction is prohibited because it does not conserve nucleon number.
   d. The reaction is prohibited because it violates mass/energy conservation.

4. (6) The half-life of ${}^{222}\mathrm{Rn}$ is 3.8 days, that of ${}^{90}\mathrm{Sr}$ is 29 years and ${}^{40}\mathrm{K}$ has a half-life of 1.3×10^9 years. For 1.00 ng samples of each, rank them according to their activity. Hint: You don't need to calculate R for each. Just find how R depends on $T_{1/2}$ and the atomic masses, for samples with the same mass.

   lowest activity ____________ middle activity ____________ highest activity ____________

5. (5) ${}^{24}\mathrm{Na}$ decays by β^- emission and has a half-life of 14.95 hours. If you start with a 50.0 ng sample being used for medical research, what mass of ${}^{24}\mathrm{Na}$ is left 27.5 hours later, in ng?

6. (6) A particular radioactive sample has 1.88×10^{15} nuclei (or atoms) and is producing 9.89 decays/second or becquerels of activity. What is the half-life of the decay process, in mega-years or millions of years? It may help to know that 1 year $\approx 3.156 \times 10^7$ s.

7. (5) Potassium-40 with atomic mass = 39.963 999 u can decay by beta-minus emission into calcium-40, whose mass is 39.962 591 u. Calculate the energy released in the decay, in MeV. Use a precision smaller than 0.01 MeV.

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8. (8) This is the problem for which you must upload your work.

About 0.15% of the mass in whole milk is potassium. Out of that, 0.0117% of the naturally occurring potassium is radioactive ^{40}K, which decays with a half-life of 1.277×10^9 years. Estimate the activity in 402 grams of milk, due to ^{40}K, in becquerels (decays/second). Hint: Try to find the number of ^{40}K nuclei in the sample, as well as the decay constant. It may help to use 1 year $\approx 3.156 \times 10^7$ s.

1. (3) Nuclear radiation comes in many forms. Which of the listed types of radiation from nuclei tends to be the most deeply penetrating (has the largest range)?

a. beta particles b. slow neutrons. c. alpha particles. d. gamma rays.

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2. (6) You have heard about ionizing radiation being the type that causes damage to living tissue. Which of the following would be ionizing radiation? Check all that apply.

a. white light from a flashlight. b. infrared light from a TV remote control. c. 1 MeV α-particles
d. 25 keV electrons in a CRT e. 880 MHz radio waves from a satellite phone.

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3. (3) For radiation particles with the same energy, that get absorbed by living tissue, which type produces the most biologically devastating damage?

a. beta particles b. slow neutrons. c. alpha particles. d. gamma rays.

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4. (3) You learned that effective dose (or dose equivalent) depends the type of radiation via its RBE. The relative biological effectiveness (RBE) accounts for radiation damage in living tissue in what sense?

a. Lighter particles cause more localized damage that is harder to repair.
b. Heavier particles cause more localized damage that is harder to repair.
c. Electrically charged particles cause the most significant damage.
d. The faster the particle, the worse is the damage it does.

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5. (6) Consider this nuclear reaction where a neutron crashes into a uranium nucleus,

$$\mathrm{n} + {}^{235}\mathrm{U} \rightarrow {}^{135}\mathrm{Cs} + {}^{A}_{Z}\mathrm{X} + 13\mathrm{n}$$

The mass number of the unknown nuclide X is A = ____________.
The atomic number of the unknown nuclide X is Z = ____________.
The symbol for the unknown nuclide X is ____________.

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6. (5) Exothermic nuclear fission reactions can be used to generate power for our modern society. Which of the following isotopes (with mass numbers shown) could be used as fuel for a fission reactor? Check all that apply.

a. iron-56 b. plutonium-239 c. helium-3 d. hydrogen-1 e. uranium-235

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7. (6) Fissioning of uranium-235 (neutral atom mass = 235.043923u) releases on average about 200 MeV of energy for each fission event, although the exact value will depend on the particular fission fragments. Besides that, uranium-235 makes up only 0.720% of natural uranium. A reactor is to be designed that produces 54 MW (megawatts) of thermal power. How many kilograms of natural uranium is needed (from which the U-235 will be extracted) to supply the reactor for 1.00 year?

8. (8) This is the question for which you must show your work in the file upload.
Radon-222 decays by emission of 5.58 MeV α-particles, whose RBE=20. Radon concentration in the air depends on the local geology and the ventilation of the building. Suppose the radon activity is 15.9 pCi/L (picocuries per liter of air). For an adult whose average total lung volume is 5.3 L and total lung mass is 1.30 kg, calculate the annual effective radiation dose due to radon, in mSv (millisieverts), assuming all of the alphas are absorbed in the mass of the lungs.

Ch. 31 = ___________/40 Ch. 32 = ___________/40

Prefixes

z=10^{-21},	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},	E=10^{18},	Z=10^{21}
zepto,	atto,	femto,	pico,	nano,	micro,	milli,	centi,	kilo,	mega,	giga,	tera,	peta,	exa,	zeta

Physical Constants

$k = 1/4\pi\epsilon_0 = 8.988$ GNm^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)
$h = 6.62607 \times 10^{-34}$ J·s (Planck's constant)
$\sigma = 5.67 \times 10^{-8}$ W/(m^2·K^4) (Stefan-Boltzmann const.)

$\epsilon_0 = 1/4\pi k = 8.854$ 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)
$hc = 1239.84$ eV·nm (photon energy = hc/λ)
$\hbar = 1.05457 \times 10^{-34}$ J·s (Planck's constant/2π)
hc =1239.84 eV·nm (photon energy constant)

Units

$N_A = 6.02214 \times 10^{23}$/mole (Avogadro's #)
1.0 eV = 1.602×10^{-19} J (electron-volt)
1 F = 1 C/V = 1 farad = 1 C^2/J
1 A = 1 C/s = 1 ampere = 1 coulomb/second
1 T = 1 N/A·m = 1 tesla = 1 newton/ampere·meter
1 Bq = 1 becquerel = 1 decay/s

1 u = 1 g/N_A = 1.66054×10^{-27} kg = 931.5 MeV/c^2
1 V = 1 J/C = 1 volt = 1 joule/coulomb
1 H = 1 V·s/A = 1 henry = 1 J/A^2
1 Ω = 1 V/A = 1 ohm = 1 J·s/C^2
1 G = 10^{-4} T = 1 gauss = 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

OpenStax Chapter 31 Equations - Radioactivity & Nuclear Physics

Nuclides:

$A = N + Z$, (mass, neutron, proton numbers) $r = (1.2 \text{ fm})\ A^{1/3}$ (nuclear radius)

$\Delta E =$[(mass of parts) - (mass of nuclide)]c^2 $\leftarrow$ (binding energy)

$Q = [M_{\text{parent}} - M_{\text{products}}]c^2$ $\leftarrow$ (disintegration energy)

1 u = 1 gram / 6.02214×10^{23} (atomic mass unit) 1 u $\cdot\, c^2 = 931.5$ MeV (energy unit)

Half-life $T_{1/2}$ and decay constant λ

$N = N_0 e^{-\lambda t}$ (decay of parent nuclei) $N = N_0 \left(\frac{1}{2}\right)^{t/T_{1/2}}$ (decay by half-lives)

$t = \frac{-1}{\lambda} \ln(N/N_0)$ (time when N nuclei remain) $R = \left|\frac{\Delta N}{\Delta t}\right| = N\lambda$ (radio-activity)

$\lambda T_{\frac{1}{2}} = \ln 2$ (decay constant, half-life) $M = Nm$ = mass = (# of nuclei)$\times$(nuclear mass)

$\#({}^{14}_{6}C)/\#({}^{12}_{6}C) = 1.3 \times 10^{-12}$ (live carbon ratio) 1 year = 3.156×10^7 seconds

OpenStax Chapter 32 Equations - Applications of Nuclear Physics

Radiation doses:

absorbed dose = energy absorbed / mass affected $\leftarrow$ SI unit = 1 gray = 1 Gy = 1 J/kg = 100 rad.

effective dose = absorbed dose $\times$ RBE $\leftarrow$ SI unit = 1 sievert = 1 Sv = 1 J/kg = 100 rem.

RBE = relative biological effectiveness RBE = QF = quality factor (units = Sv/Gy).

radiation:	γ-rays	slow β's	fast β's	slow neutrons	fast neutrons	protons	α's	heavy ions
RBE =	1	1.7	1	2–5	10	10	10–20	10–20

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)$\times$(reaction energy)] 1 u $\cdot\, c^2 = 931.5$ MeV

$M = Nm$ [mass used= (# of reactions)$\times$(reaction mass)]

$E_{\text{out}} = eE_{\text{in}}$ [output energy = (efficiency)$\times$(input energy)]

Periodic Table of the Elements§

Symbol	Cl 17	Atomic Number
Atomic Mass§	35.4527	
	$3p^5$	Electron Configuration (outer shells only)

Group I	Group II	Transition Elements										Group III	Group IV	Group V	Group VI	Group VII	Group VIII
H 1 1.00794 $1s^1$																	He 2 4.002602 $1s^2$
Li 3 6.941 $2s^1$	Be 4 9.012182 $2s^2$											B 5 10.811 $2p^1$	C 6 12.0107 $2p^2$	N 7 14.00674 $2p^3$	O 8 15.9994 $2p^4$	F 9 18.9984032 $2p^5$	Ne 10 20.1797 $2p^6$
Na 11 22.989770 $3s^1$	Mg 12 24.3050 $3s^2$											Al 13 26.981538 $3p^1$	Si 14 28.0855 $3p^2$	P 15 30.973761 $3p^3$	S 16 32.066 $3p^4$	Cl 17 35.4527 $3p^5$	Ar 18 39.948 $3p^6$
K 19 39.0983 $4s^1$	Ca 20 40.078 $4s^2$	Sc 21 44.955910 $3d^1 4s^2$	Ti 22 47.867 $3d^2 4s^2$	V 23 50.9415 $3d^3 4s^2$	Cr 24 51.9961 $3d^5 4s^1$	Mn 25 54.938049 $3d^5 4s^2$	Fe 26 55.845 $3d^6 4s^2$	Co 27 58.933200 $3d^7 4s^2$	Ni 28 58.6934 $3d^8 4s^2$	Cu 29 63.546 $3d^{10} 4s^1$	Zn 30 65.39 $3d^{10} 4s^2$	Ga 31 69.723 $4p^1$	Ge 32 72.61 $4p^2$	As 33 74.92160 $4p^3$	Se 34 78.96 $4p^4$	Br 35 79.904 $4p^5$	Kr 36 83.80 $4p^6$
Rb 37 85.4678 $5s^1$	Sr 38 87.62 $5s^2$	Y 39 88.90585 $4d^1 5s^2$	Zr 40 91.224 $4d^2 5s^2$	Nb 41 92.90638 $4d^4 5s^1$	Mo 42 95.94 $4d^5 5s^1$	Tc 43 (98) $4d^5 5s^2$	Ru 44 101.07 $4d^7 5s^1$	Rh 45 102.90550 $4d^8 5s^1$	Pd 46 106.42 $4d^{10} 5s^0$	Ag 47 107.8682 $4d^{10} 5s^1$	Cd 48 112.411 $4d^{10} 5s^2$	In 49 114.818 $5p^1$	Sn 50 118.710 $5p^2$	Sb 51 121.760 $5p^3$	Te 52 127.60 $5p^4$	I 53 126.90447 $5p^5$	Xe 54 131.29 $5p^6$
Cs 55 132.90545 $6s^1$	Ba 56 137.327 $6s^2$	57–71†	Hf 72 178.49 $5d^2 6s^2$	Ta 73 180.9479 $5d^3 6s^2$	W 74 183.84 $5d^4 6s^2$	Re 75 186.207 $5d^5 6s^2$	Os 76 190.23 $5d^6 6s^2$	Ir 77 192.217 $5d^7 6s^2$	Pt 78 195.078 $5d^9 6s^1$	Au 79 196.96655 $5d^{10} 6s^1$	Hg 80 200.59 $5d^{10} 6s^2$	Tl 81 204.3833 $6p^1$	Pb 82 207.2 $6p^2$	Bi 83 208.98038 $6p^3$	Po 84 (209) $6p^4$	At 85 (210) $6p^5$	Rn 86 (222) $6p^6$
Fr 87 (223) $7s^1$	Ra 88 (226) $7s^2$	89–103‡	Rf 104 (261) $6d^2 7s^2$	Db 105 (262) $6d^3 7s^2$	Sg 106 (266) $6d^4 7s^2$	Bh 107 (264) $6d^5 7s^2$	Hs 108 (269) $6d^6 7s^2$	Mt 109 (268) $6d^7 7s^2$	Ds 110 (271) $6d^9 7s^1$	111 (272) $6d^{10} 7s^1$	112 (277) $6d^{10} 7s^2$						

†Lanthanide Series	La 57 138.9055 $5d^1 6s^2$	Ce 58 140.115 $4f^1 5d^1 6s^2$	Pr 59 140.90765 $4f^3 5d^0 6s^2$	Nd 60 144.24 $4f^4 5d^0 6s^2$	Pm 61 (145) $4f^5 5d^0 6s^2$	Sm 62 150.36 $4f^6 5d^0 6s^2$	Eu 63 151.964 $4f^7 5d^0 6s^2$	Gd 64 157.25 $4f^7 5d^1 6s^2$	Tb 65 158.92534 $4f^9 5d^0 6s^2$	Dy 66 162.50 $4f^{10} 5d^0 6s^2$	Ho 67 164.93032 $4f^{11} 5d^0 6s^2$	Er 68 167.26 $4f^{12} 5d^0 6s^2$	Tm 69 168.93421 $4f^{13} 5d^0 6s^2$	Yb 70 173.04 $4f^{14} 5d^0 6s^2$	Lu 71 174.967 $4f^{14} 5d^1 6s^2$
‡Actinide Series	Ac 89 (227.02775) $6d^1 7s^2$	Th 90 232.0381 $6d^2 7s^2$	Pa 91 (231) $5f^2 6d^1 7s^2$	U 92 238.0289 $5f^3 6d^1 7s^2$	Np 93 (237) $5f^4 6d^1 7s^2$	Pu 94 (244) $5f^6 6d^0 7s^2$	Am 95 (243) $5f^7 6d^0 7s^2$	Cm 96 (247) $5f^7 6d^1 7s^2$	Bk 97 (247) $5f^9 6d^0 7s^2$	Cf 98 (251) $5f^{10} 6d^0 7s^2$	Es 99 (252) $5f^{11} 6d^0 7s^2$	Fm 100 (257) $5f^{12} 6d^0 7s^2$	Md 101 (258) $5f^{13} 6d^0 7s^2$	No 102 (259) $5f^{14} 6d^0 7s^2$	Lr 103 (262) $5f^{14} 6d^1 7s^2$

§ Atomic mass values averaged over isotopes in the percentages they occur on Earth's surface. For unstable elements, mass of the longest-lived known isotope is given in parentheses. 2003 revisions. (See also Appendix B.)