Physics 13-01 Radioactivity — *Name: ____________*

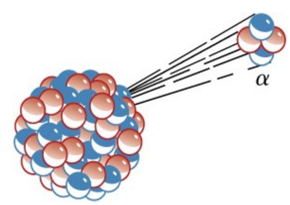
Structure of the atom

- Rutherford's Experiment
  - Shot __________ at thin __________foil
  - Expected to pass mostly straight though with __________scattering
  - Most passed straight through without scattering; Some scattered __________ – even straight back
  - Showed the nucleus was very __________and much __________space around it
  - Planetary model of the atom: Nucleus like ________, Electrons like __________, Electrical force like __________
- Nucleus
  - Contains __________and __________
- Atomic mass unit (u)
  - Neutral carbon-12 = 12 u
  - C-12 has 6 protons, 6 neutrons
  - Proton and neutrons = __________
  - 1 u = __________ MeV/c^2

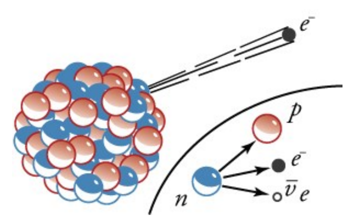
6
C
12.011

- Atomic Number (Z)
  - Number of __________ in nucleus
  - Determines the __________
- Mass Number (A)
  - Number of __________and __________
- Isotopes
  - Same element can have different number of __________
  - ${}^{A}_{Z}X$ or ${}^{A}X$
  - Then number of neutrons changes behavior of __________
- Strong nuclear force
  - Holds __________together
  - Acts at distance less than __________
- Electric forces try to __________nucleus apart
  - When electric forces are more than strong nuclear force, nuclear particles are ejected from nucleus – __________
- Nucleus wants
  - About __________number of protons and neutrons
  - Smaller radius than strong __________force

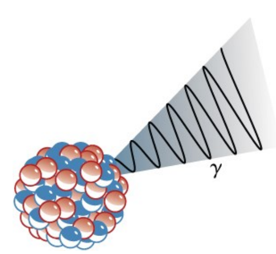
Types of Radioactivity



- Alpha Decay (α)
  - Most __________decay type
  - Happens when too many __________in nucleus
  - Nucleus ejects __________ and __________ (__________nucleus)
  - ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\text{He} \quad \rightarrow \quad {}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$
  - During α-decay, the atomic number changes and one element __________into another
    - The α-particle quickly gains two electrons and becomes a stable __________atom
    - The total number of __________stays the same
      - Law of Conservation of __________and __________
        - Any change in mass is converted to energy by _______
      - Law of Conservation of __________



- Beta decay (β)
  - Imbalance of __________and __________
  - A neutron __________into a __________and __________or vice versa
  - ${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + e^{-} + \nu \quad \rightarrow \quad {}^{14}_{6}C \rightarrow {}^{14}_{7}N + \nu + e^{-}$
    - e is __________, ν is __________
- Gamma decay (γ)
  - Occurs when nucleus drops from __________state to ground state releasing energy as a photon
  - ${}^{A}_{Z}X \rightarrow {}^{A}_{Z}X + \gamma \quad \rightarrow \quad {}^{137}_{56}Ba \rightarrow {}^{137}_{56}Ba + \gamma$



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- α-particles are massive (4 u) and have +2 charge, so they quickly interact with matter and can be stopped quickly
  - ________________________, ____________ of air, ________________________ of tissue
- β-particles are smaller (mass of e) and −1 charge, so they penetrate farther
  - ________________________ plate, _______________ of tissue
- γ-particles have no mass or charge and barely interact with matter, so they penetrate very far
  - ________________ of lead, ____________of concrete

Write the complete decay equation in ${}_{Z}^{A}X$ notation for beta decay producing ${}_{28}^{60}\text{Ni}$. Refer to the periodic table for values of Z.

Find the energy emitted in the α decay of ${}^{226}\text{Ra}$.

Practice Work

1. What leads scientists to infer that the nuclear strong force exists? (HSP C22.2)
2. What influence does the strong nuclear force have on the electrons in an atom? (HSP 22.10)
3. What is the source of the energy emitted in radioactive decay? Identify an earlier conservation law, and describe how it was modified to take such processes into account. (OpenStax C31.5)
4. Explain why an alpha particle can have a greater range in air than a beta particle in lead. (OpenStax C31.7)
5. Arrange the following according to their ability to act as radiation shields, with the best first and worst last. Explain your ordering in terms of how radiation loses its energy in matter.
   (a) A solid material with low density composed of low-mass atoms.
   (b) A gas composed of high-mass atoms.
   (c) A gas composed of low-mass atoms.
   (d) A solid with high density composed of high-mass atoms. (OpenStax C31.8)
6. Often, when people have to work around radioactive materials spills, we see them wearing white coveralls (usually a plastic material). What types of radiation (if any) do you think these suits protect the worker from, and how? (OpenStax C31.9)
7. The weak and strong nuclear forces are basic to the structure of matter. Why do we not experience them directly? (OpenStax C31.11)
8. What are isotopes? Why do different isotopes of the same element have similar chemistries? (OpenStax C31.13)

In the following eight problems, write the complete decay equation for the given nuclide in the complete ${}_{Z}^{A}X$ notation. Refer to the periodic table for values of Z.

9. β^- decay of ${}^{3}H$ (tritium), a manufactured isotope of hydrogen used in some digital watch displays and manufactured primarily for use in hydrogen bombs. (OpenStax 31.17) $\boldsymbol{{}_{1}^{3}H \rightarrow {}_{2}^{3}He + e^- + \nu}$
10. β^- decay of ${}^{40}K$, a naturally occurring rare isotope of potassium responsible for some of our exposure to background radiation. (OpenStax 31.18) $\boldsymbol{{}_{19}^{40}K \rightarrow {}_{20}^{40}Ca + e^- + \nu}$
11. α decay of ${}^{210}Po$, the isotope of polonium in the decay series of ${}^{238}U$ that was discovered by the Curies. A favorite isotope in physics labs, since it has a short half-life and decays to a stable nuclide. (OpenStax 31.23) $\boldsymbol{{}_{84}^{210}Po \rightarrow {}_{82}^{206}Pb + {}_{2}^{4}He}$
12. α decay of ${}^{226}Ra$, another isotope in the decay series of ${}^{238}U$, first recognized as a new element by the Curies. Poses special problems because its daughter is a radioactive noble gas. (OpenStax 31.24) $\boldsymbol{{}_{88}^{226}Ra \rightarrow {}_{86}^{222}Rn + {}_{2}^{4}He}$

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In the following four problems, identify the parent nuclide and write the complete decay equation in the $^{A}_{Z}X$ notation. Refer to the periodic table for values of Z.

13. β^- decay producing ^{137}Ba. The parent nuclide is a major waste product of reactors and has chemistry similar to potassium and sodium, resulting in its concentration in your cells if ingested. (OpenStax 31.25) $\boldsymbol{^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + e^- + \nu}$
14. β^- decay producing ^{90}Y. The parent nuclide is a major waste product of reactors and has chemistry similar to calcium, so that it is concentrated in bones if ingested (^{90}Y is also radioactive.) (OpenStax 31.26) $\boldsymbol{^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + e^- + \nu}$
15. α decay producing ^{228}Ra. The parent nuclide is nearly 100% of the natural element and is found in gas lantern mantles and in metal alloys used in jets (^{228}Ra is also radioactive). (OpenStax 31.27) $\boldsymbol{^{232}_{90}Th \rightarrow {}^{228}_{88}Ra + {}^{4}_{2}He}$
16. α decay producing ^{208}Pb. The parent nuclide is in the decay series produced by ^{232}Th, the only naturally occurring isotope of thorium. (OpenStax 31.28) $\boldsymbol{^{212}_{84}Po \rightarrow {}^{208}_{82}Pb + {}^{4}_{2}He}$
17. (a) Write the complete α decay equation for ^{226}Ra. (b) Find the energy released in the decay. ($^{226}_{88}Ra = 226.025402\ u$, $^{222}_{86}Rn = 222.0175763\ u$, $^{4}_{2}He = 4.002602\ u$(OpenStax 31.35) **4.87 MeV**
18. (a) Write the complete α decay equation for ^{249}Cf. (b) Find the energy released in the decay. ($^{249}_{98}Cf = 249.074844\ u$, $^{245}_{96}Cm = 245.058830\ u$, $^{4}_{2}He = 4.002602\ u$)(OpenStax 31.36) **12.5 MeV**
19. (a) Write the complete β^- decay equation for the neutron. (b) Find the energy released in the decay. ($^{1}_{0}n = 1.008664915\ u$, $^{1}_{1}H = 1.007276466\ u$, $e^- = 0.000548579\ u$, $\nu \approx 0\ u$) (OpenStax 31.37) **0.7823 MeV**
20. (a) Write the complete β^- decay equation for ^{90}Sr, a major waste product of nuclear reactors. (b) Find the energy released in the decay. ($^{90}_{38}Sr = 89.9077279\ u$, $^{90}_{39}Y = 89.9071519\ u$, e^- =included in the mass of Y, $\nu \approx 0\ u$) (OpenStax 31.38) **0.537 MeV**