PA1140: Waves and Quanta

Unit 4: Atoms and Nuclei

Tipler 6th ed, Chapters 36 (36-1 to 36-2) & 40

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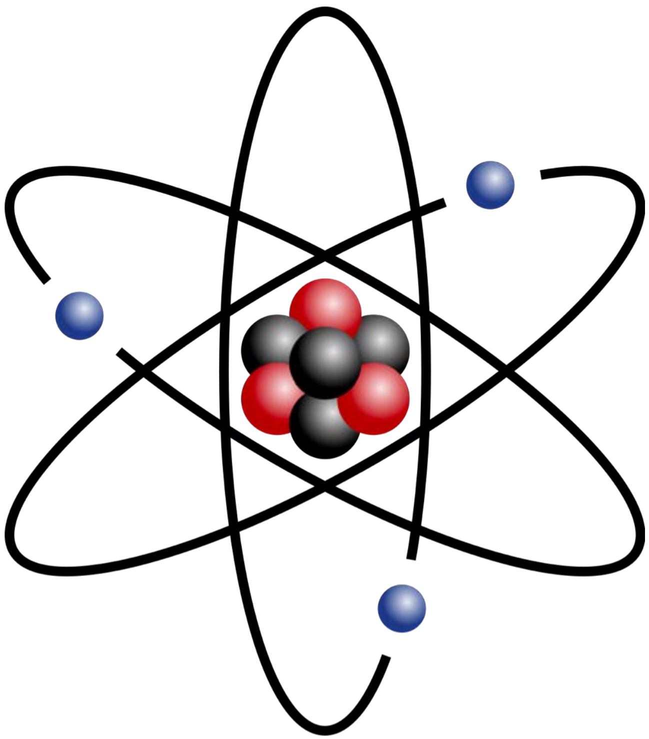

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Lecture 3 Recap

Radioactivity

Decay Rate or Activity of a Sample after n half-lives:

$$\boxed{R_n = \left(\frac{1}{2}\right)^n R_0}$$

Lifetime or e-folding time:

$$\boxed{\tau = \frac{1}{\lambda}}$$

Half-life:

$$\boxed{t_{1/2} = 0.693\tau}$$

Radioactive Decay

Beta Decay:

Conversion of proton to neutron (β plus) or neutron to proton (β minus)
Used to determine age of organic material (**radiocarbon dating**)

Gamma Decay:

Excited state nucleus decays to ground state

Alpha Decay:

Decay of heavier nuclei leading to formation of ^{4}He and A of daughter nucleus reduced by 4 relative to parent nucleus

Nuclear Reactions

Energy released or absorbed during a nuclear reaction:

$$\boxed{Q = -\Delta m c^2}$$

$\boldsymbol{Q > 0}$: exothermic

$\boldsymbol{Q < 0}$: endothermic

Fission:

Heavy nucleus reacts with neutron and breaks apart into two medium-mass nuclei

Fusion:

Two light nuclei fuse together to form a nucleus of greater mass

Practice Problem 1

The wavelength of the emission lines produced by the hydrogen atom are given by the formula

$$\frac{1}{\lambda} = 1.096776 \times 10^{-2} \left(\frac{1}{n_2^2} - \frac{1}{n_1^2} \right) \mathrm{nm}^{-1}$$

a) What are the wavelengths of the first two lines in the Balmer series that involve transitions to level $n = 2$?

b) Calculate the energy in eV required to raise an electron from the ground state to level 2.

c) Electrons of energy 12.2 eV are fired at hydrogen atoms in a gas discharge tube and excite hydrogen atoms from their ground state to some excited state. Determine the wavelengths (in nm) of the radiation that can be emitted by the hydrogen gas atoms. Sketch an energy level diagram and label the transitions that result in the emitted photons by the hydrogen gas.

Practice Problem 1

The wavelength of the emission lines produced by the hydrogen atom are given by the formula

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a) What are the wavelengths of the first two lines in the Balmer series that involve transitions to level $n = 2$? Answer: 656.5 nm, 486.3 nm

b) Calculate the energy in eV required to raise an electron from the ground state to level 2. Answer: -10.2 eV (10.2 eV required)

c) Electrons of energy 12.2 eV are fired at hydrogen atoms in a gas discharge tube and excite hydrogen atoms from their ground state to some excited state. Determine the wavelengths (in nm) of the radiation that can be emitted by the hydrogen gas atoms. Sketch an energy level diagram and label the transitions that result in the emitted photons by the hydrogen gas. Answer: 102.6 nm, 656.1 nm, 121.6 nm.

Practice Problem 2

Substitute the missing atomic number, mass numbers, and/or symbols in the following nuclear reactions and radioactive decays:

$$\boxed{{}^{59}_{27}\mathrm{Co} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{61}_{29}\mathrm{Cu} + ?}$$

$$? + {}^{63}_{29}\mathrm{Cu} \rightarrow {}^{64}_{30}\mathrm{Zn} + \mathrm{n}$$

$$\mathrm{p} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{2}_{1}\mathrm{H} + ?$$

$$? + {}^{235}_{92}\mathrm{U} \rightarrow {}^{93}_{37}\mathrm{Rb} + {}^{141}_{55}\mathrm{Cs} + 2\mathrm{n}$$

$$\boxed{\mathrm{n} + {}^{238}_{92}\mathrm{U} \rightarrow {}^{239}_{93}\mathrm{Np} + \mathrm{e}^{-} + ?}$$

$${}^{239}_{93}\mathrm{Np} \rightarrow {}^{239}_{94}\mathrm{Pu} + ? + \overline{\nu}$$

$$\boxed{{}^{15}_{8}\mathrm{O} \rightarrow {}^{15}_{7}\mathrm{N} + ? + \nu}$$

$$\boxed{{}^{175}_{78}\mathrm{Pt} \rightarrow {}^{171}_{76}\mathrm{Os} + ?}$$

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$$^{15}_{8}\mathrm{O} \rightarrow {}^{15}_{7}\mathrm{N} + \beta^{+} + \nu$$

$$^{175}_{78}\mathrm{Pt} \rightarrow {}^{171}_{76}\mathrm{Os} + {}^{4}_{2}\mathrm{He}$$

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Practice Problem 3

A building on a military base has accidentally been contaminated by 5.0 kg of radioactive ${}^{90}_{38}\mathrm{Sr}$ (Strontium-90), which has an atomic mass of 89.9077 u and a half-life of 29.1 years. Strontium-90 is particularly dangerous because it substitutes for calcium in bones. Assuming that the safe decay rate is defined at 10.0 decays/min, for how long will the building be unsafe?

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Answer: 1662 years