UBC Physics 102

Lecture 2

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Outline

- ▷ Radioactivity
- ▷ Alpha decay
- ▷ Beta decay
- ▷ Gamma decay
- ▷ Rate of decay
- ▷ Half-life
- ▷ Activity
- ▷ Radioactive dating
- ▷ End

Radioactivity [Text: Sect. 42-3]

- **Definition:** *Radioactivity*
  - Decay of an unstable nucleus.
- **Discussion: 3 common types of decay**

Type	Particle emitted	Charge	Mass
α (alpha)	$^4\mathrm{He}$ $(2\ \mathrm{p} + 2\ \mathrm{n})$	$+2$	heavy
β (beta)	electron	-1	light
γ (gamma)	photon	none	*very* light

Alpha decay [Text: Sect. 42-4]

- **Definition:** *α decay*

$$^A_Z X \rightarrow ^{A-4}_{Z-2} X' + ^4_2\mathrm{He}$$

  - $\alpha = {}^4_2\mathrm{He}$ (helium nucleus).
  - Mass (A) and charge (Z) conserved.
- **Example: Smoke detectors**

$$^{241}_{95}\mathrm{Am} \rightarrow ^{237}_{93}\mathrm{Np} + ^4_2\mathrm{He}$$

  - Emitted α particle used to generate current between two plates.
  - Smoke interrupts current to trip alarm.

Beta decay [Text: Sect. 42-5]

- **Definition:** β *decay*

$$^A_ZX \rightarrow ^A_{Z+1}X' + e^-(+\,\text{neutrino})$$

  - $\beta = e^-$ (electron).
  - Mass (A) and charge (Z) conserved.
  - Electron comes from nucleus, not orbit.
  - Produced by decay of neutron:

$$n \rightarrow p^+ + e^-(+\,\text{neutrino})$$

Gamma decay [Text: Sect. 42-6]

- **Definition:** *Excited state*
  - Nucleus with surplus energy (often result of α or β decay).
  - Denoted by $*$, as in $^A_ZX*$.
- **Definition:** γ *decay*

$$^A_ZX* \rightarrow ^A_ZX + \gamma$$

  - Produces photon (γ particle).
  - Mass (A) and charge (Z) conserved.
- **Interactive Quiz: PRS 02a**

Rate of decay [Text: Sect. 42-8]

- **Derivation: Radioactive decay law**
  - Radioactive decay is unpredictable, quantum process.
  - Average rate of decay is proportional to amount present,

$$\frac{dN}{dt} = -\lambda N.$$

  - λ (lambda) is proportionality constant that sets rate.
  - Can integrate to find how much material remains after time t,

$$N(t) = N_0 e^{-\lambda t}.$$

Half-life [Text: Sect. 42-8]

- **Derivation: Half-life,** $T_{1/2}$
  - The time it takes for half the original amount of isotope to decay. Is solution to

$$\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}}.$$

- **Interactive Quiz: PRS 02b**
- **Definition:** *Half-life,* $T_{1/2}$

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

Activity [Text: Sect. 42-8]

- **Definition:** *Activity,* $\left|\frac{dN}{dt}\right|$
  - Rate of decay, or number of decays per second of a sample.

$$\left|\frac{dN}{dt}\right| = \lambda N.$$

- **Example:**
  - $^{31}\mathrm{Si}$ has a half-life of of $2.62\ \mathrm{hr}$. What will the activity of a $1\ \mathrm{g}$ sample be after $1\ \mathrm{week}$?

Activity, contd

- **Solution:**
  - We know $\boxed{N(t) = N_0 e^{-\lambda t}}$. Then

$$\left|\frac{dN}{dt}\right| = \lambda N_0 e^{-\lambda t}.$$

  - Need to calculate N_0, λ, and t. First, t (in hours) is $t = 1\ \mathrm{wk} = 168\ \mathrm{hr}$.
  - Now, use half-life, $\boxed{T_{1/2} = \frac{\ln 2}{\lambda}}$ to get λ,

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{2.62\ \mathrm{hr}} = 0.265\ \mathrm{hr}^{-1}.$$

Activity, contd

- **Solution: contd**
  - Finally, need to find number of particles, N_0.
  - Use atomic mass, $1\ \mathrm{particle} = 31\ \mathrm{u}$,

$$N_0 = 10^{-3}\ \mathrm{kg} \times \frac{1\ \mathrm{u}}{1.66\times10^{-27}\ \mathrm{kg}} \times \frac{1\ \mathrm{particle}}{31\ \mathrm{u}} = 1.94\times10^{22}\ \mathrm{particles}.$$

  - So activity is

$$\left|\frac{dN}{dt}\right| = \lambda N_0 e^{-\lambda t} = (0.265\ \mathrm{hr}^{-1})(1.94\times10^{22}\ \mathrm{part.})e^{-(0.265\ \mathrm{hr}^{-1})(168\ \mathrm{hr})} = 238\ \mathrm{particles/hr}. \quad \square$$

Radioactive dating [Text: Sect. 42-10]

- **Discussion: Carbon dating**
  - Unstable $^{14}\mathrm{C}$ isotope occurs naturally.
  - About $1.3\times10^{-10}\%$ of carbon in the environment is $^{14}\mathrm{C}$.
  - Absorbed during life (eating, breathing, etc.).
  - No longer absorbed after death so $^{14}\mathrm{C}$ decays.
  - Can estimate how long ago specimen died by using $\boxed{N(t) = N_0 e^{-\lambda t}}$ to determine time needed to get N down to current value,

$$t = \frac{1}{\lambda} \ln \frac{N_0}{N}.$$

  - Need to know λ, N_0, and current N.

Radioactive dating, contd

- **Discussion: Carbon dating, contd**
  - λ can be calculated from half-life, $T_{1/2} = 5730\ \mathrm{yr}$.
  - N_0 can be determined from total number of carbon atoms in sample.
  - Measure activity to get current N, from $\boxed{\left|\frac{dN}{dt}\right| = \lambda N}$.

End

- **Practice Problems:**
  - Ch. 42: Q. 7, 13, 19, 21, 25
  - Ch. 42: Pr. 35, 37, 39, 43, 45, 47, 49, 55, 63, 65
- **Interactive Quiz: Feedback**
- **Tutorial Question: tut02**