King Saud University
College of Applied Studies
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Department of Natural Sciences

Atom and Natural Radioactivity

General Physics II
PHYS 111

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<u>Outline</u>

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- Early Models of the Atom
  Rutherford
- Atomic Structure
- HELIUM ATOM
- The Bohr Model of the Atom
- Energy-Level Postulate
- Transitions Between Energy Levels
- The Bohr Model of the Atom:Ground and Excited States
- Line spectrum of
- some elements

Outline

- The Bohr Model of the Atom: Hydrogen Spectrum
- Radioactivity
- Radioactive Decay
- Radioactive decay processes
  1. Beta (minus) decay
  2. Beta (plus) decay
  3. Electron capture
  4. Gamma decay
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- Questions

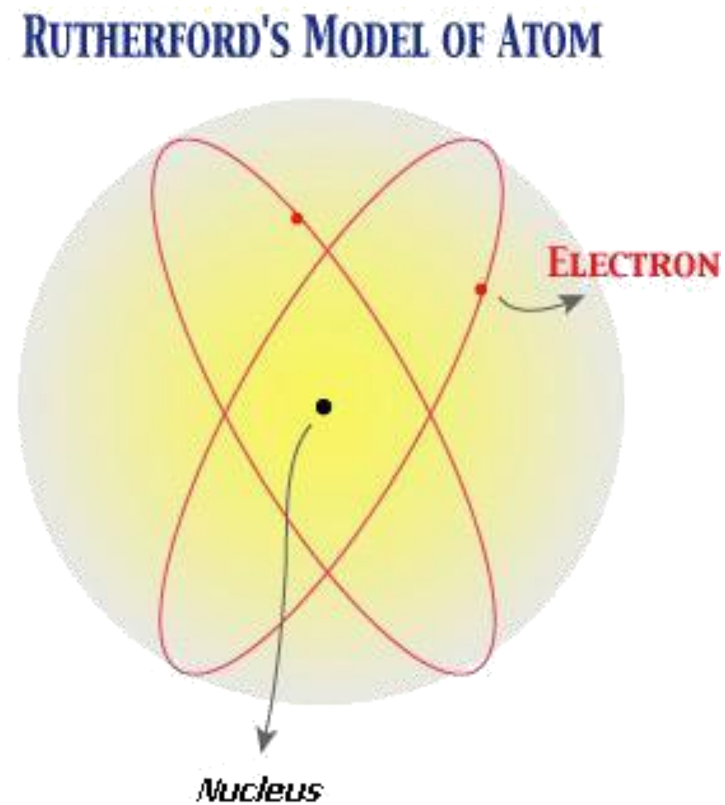
HISTORY OF THE ATOM

- **John Dalton**
  - suggested that all matter was made up of tiny spheres that were able to bounce around with perfect elasticity and called them **ATOMS**
- **Joseph Thompson**
  - found that atoms could sometimes eject a far smaller negative particle which he called an **ELECTRON**
-

Early Models of the Atom

Rutherford

- Mostly empty space
- Small, positive nucleus
- Contained protons
- Negative electrons scattered around the outside



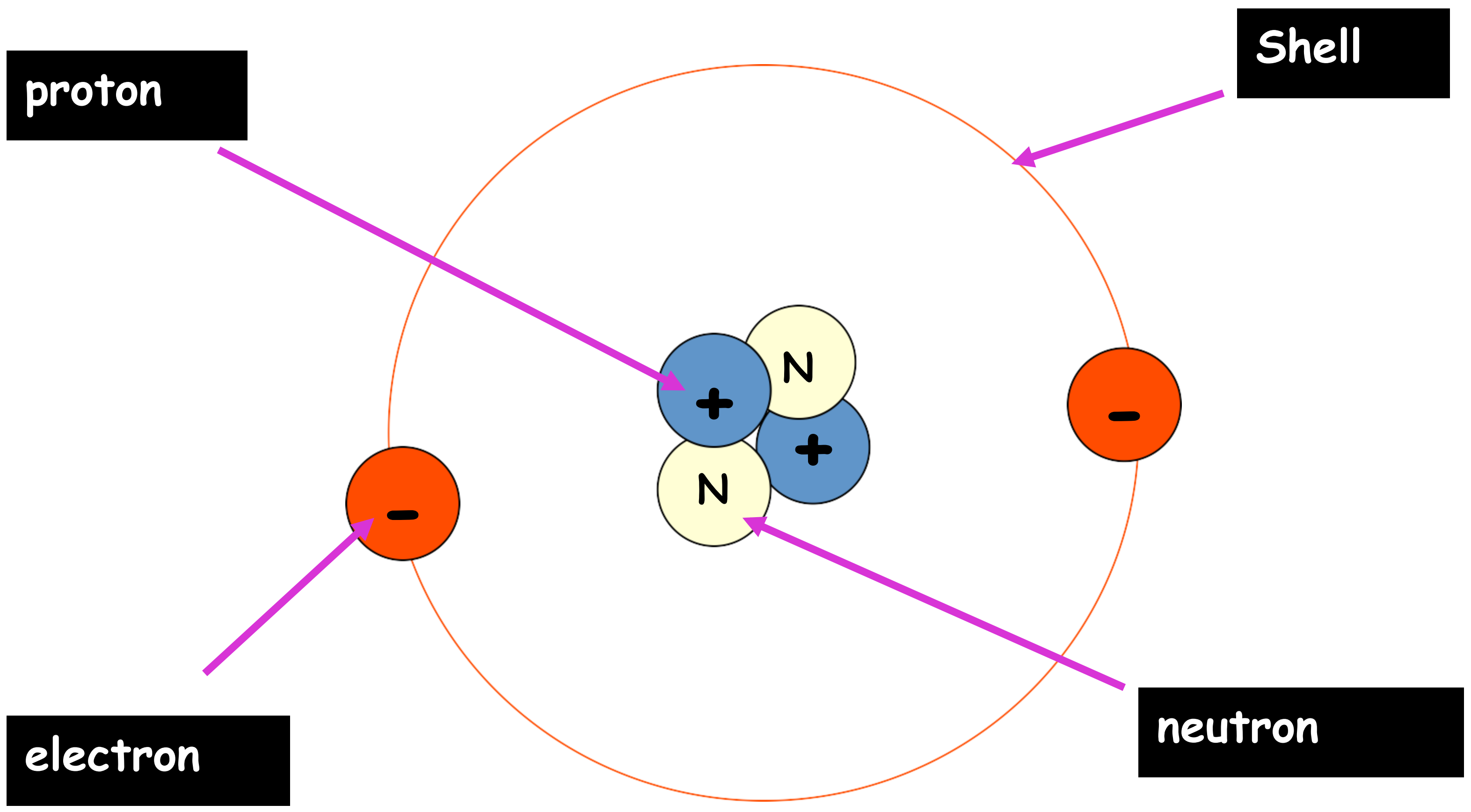
Atomic Structure

Atoms are composed of

- -**protons** – positively charged particles
- -**neutrons** – neutral particles
- -**electrons** – negatively charged particles

Protons and neutrons are located in the **nucleus**. Electrons are found in orbitals surrounding the nucleus

HELIUM ATOM



Atomic Structure

Every different atom has a characteristic number of protons in the nucleus.

atomic number = number of protons

Atoms with the same atomic number have the same chemical properties and belong to the same **element**.

ATOMIC STRUCTURE

The sum of protons and neutrons is the atom's **atomic mass**.

Isotopes – atoms of the same element that have different atomic mass numbers due to different numbers of neutrons.

ATOMIC STRUCTURE

Atomic mass

the number of protons and neutrons in an atom

Atomic number

the number of protons in an atom

$$^{4}_{2}He$$

number of electrons = number of protons

ATOMIC STRUCTURE

- ***ATOMIC NUMBER*** (Z) = number of protons in nucleus
  - ***MASS NUMBER*** (A) = number of protons + number of neutrons

    = atomic number (Z) + number of neutrons

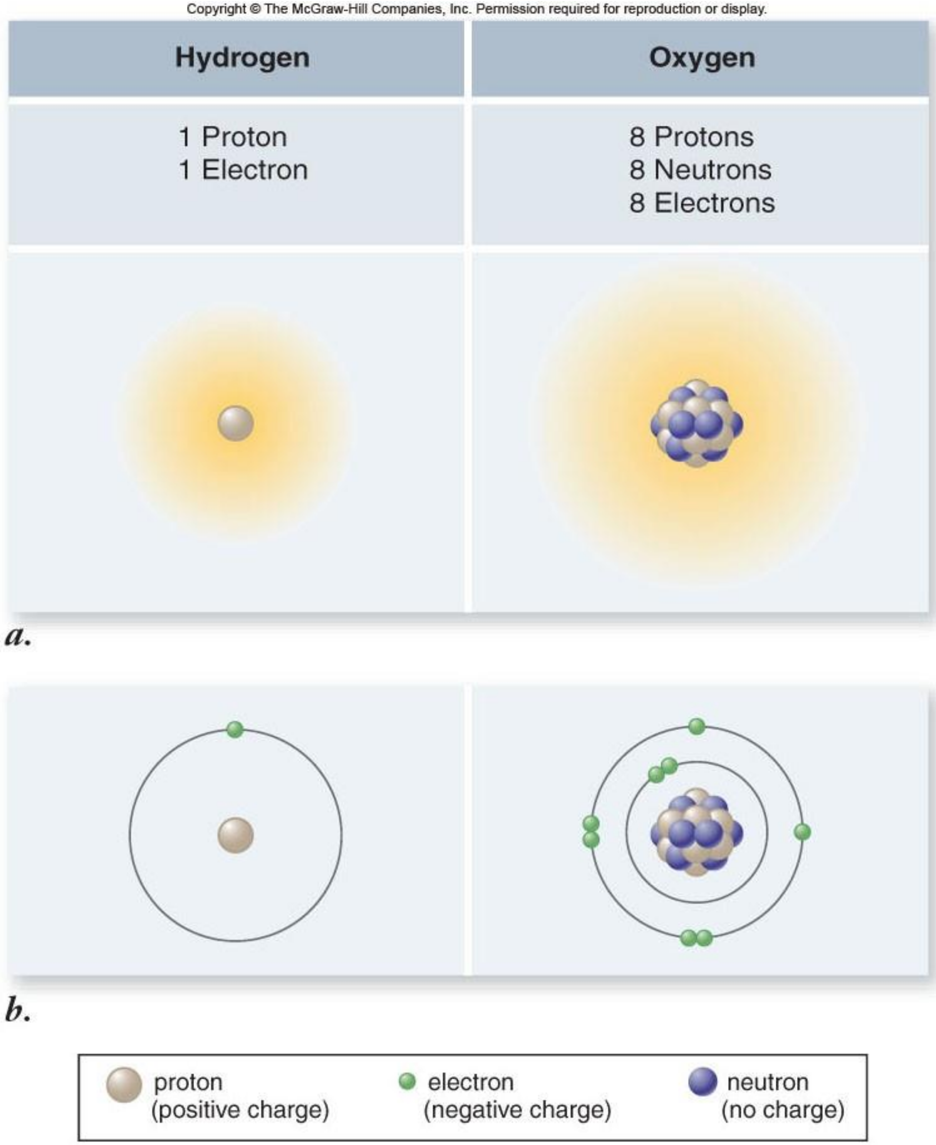
ISOTOPS are atoms of the same element (X) with different numbers of neutrons in the nucleus

Mass Number → $^{A}_{Z}X$ ← Element Symbol
Atomic Number →

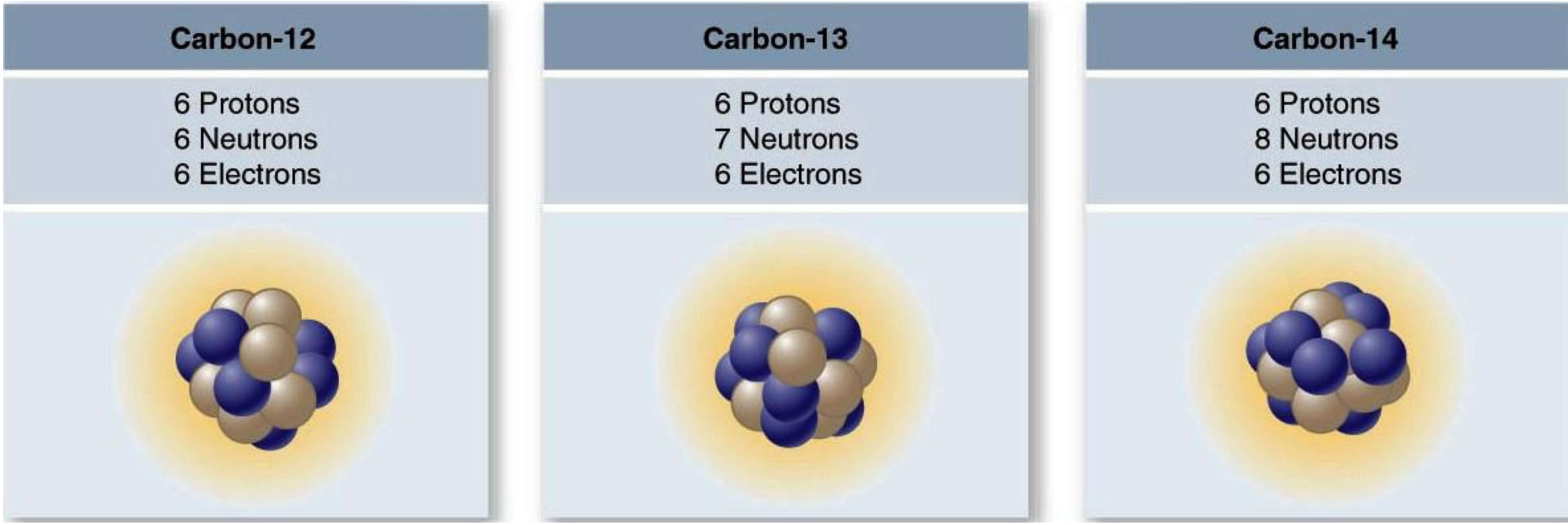
$^{1}_{1}H$ $^{2}_{1}H$ (D) $^{3}_{1}H$ (T)

$^{235}_{92}U$ $^{238}_{92}U$

Atomic Structure

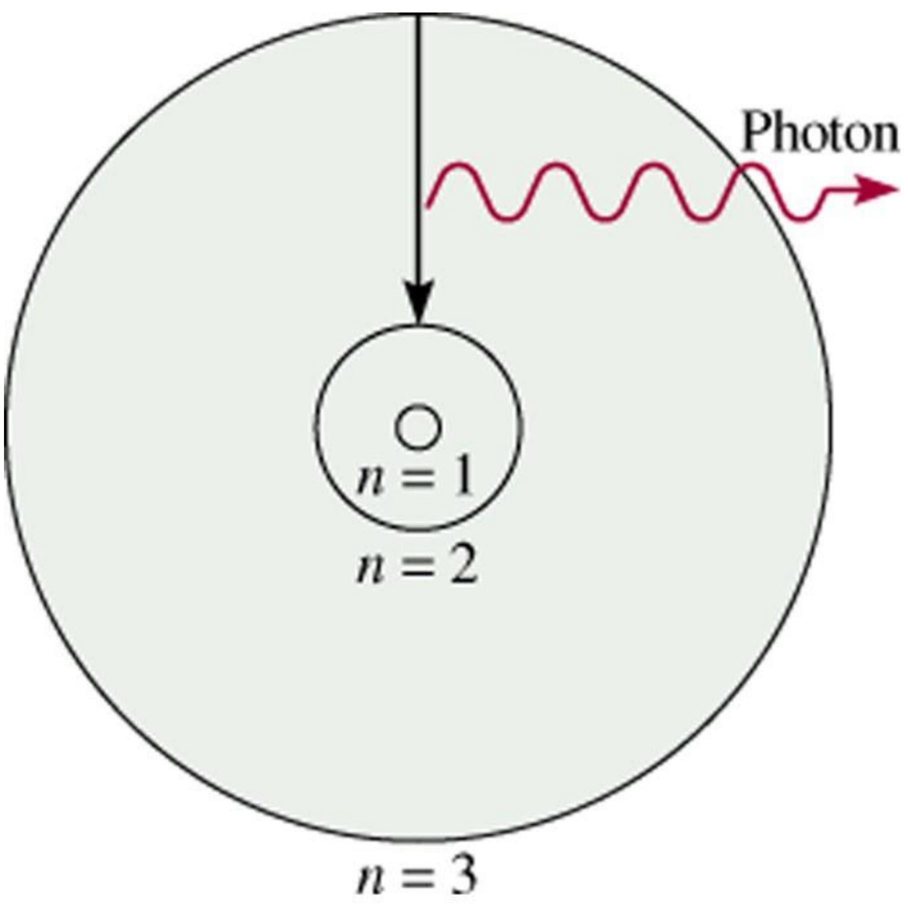


Atomic Structure



The Bohr Model of the Atom

- In 1913, Neils Bohr, set down postulates to account for
- 1. The stability of the hydrogen atom
- 2. The line spectrum of the atom



Energy-Level Postulate

•An electron can have only certain energy values, called energy levels. Energy levels are quantized.

•For an electron in a hydrogen atom, the energy is given by the following equation:

$$E = -\frac{R_H}{n^2}$$

•R_H = 2.179 x 10^{-18} J
•n = principal quantum number

Transitions Between Energy Levels

- An electron can change energy levels by absorbing energy to move to a higher energy level or by emitting energy to move to a lower energy level.
- For a hydrogen electron the energy change is given by

$$\Delta E = E_f - E_i$$

$$\Delta E = -R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

$R_H = 2.179 \times 10^{-18}$ J, Rydberg constant

Transitions Between Energy Levels

- The energy of the emitted or absorbed photon is related to $\otimes E$:

$$E_{photon} = \left| \mathbf{!} E_{\text{electron}} \right| = h\nu$$

$$h = \text{Planck's constant}$$

- We can now combine these two equations:

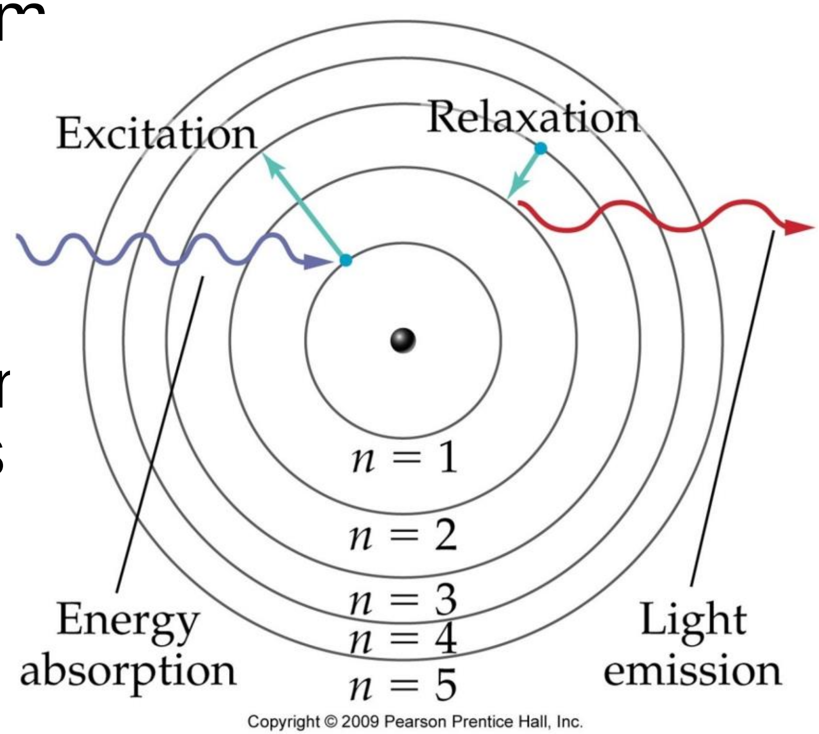
$$h\nu = \left| -R_{\text{H}} \left(\frac{1}{n_{\text{f}}^{\ 2}} - \frac{1}{n_{\text{i}}^{\ 2}} \right) \right|$$

The Bohr Model of the Atom

•Light is **absorbed** by an atom when the electron transition is from lower *n* to higher *n* ($n_f > n_i$). In this case, ⊗*E* will be positive.

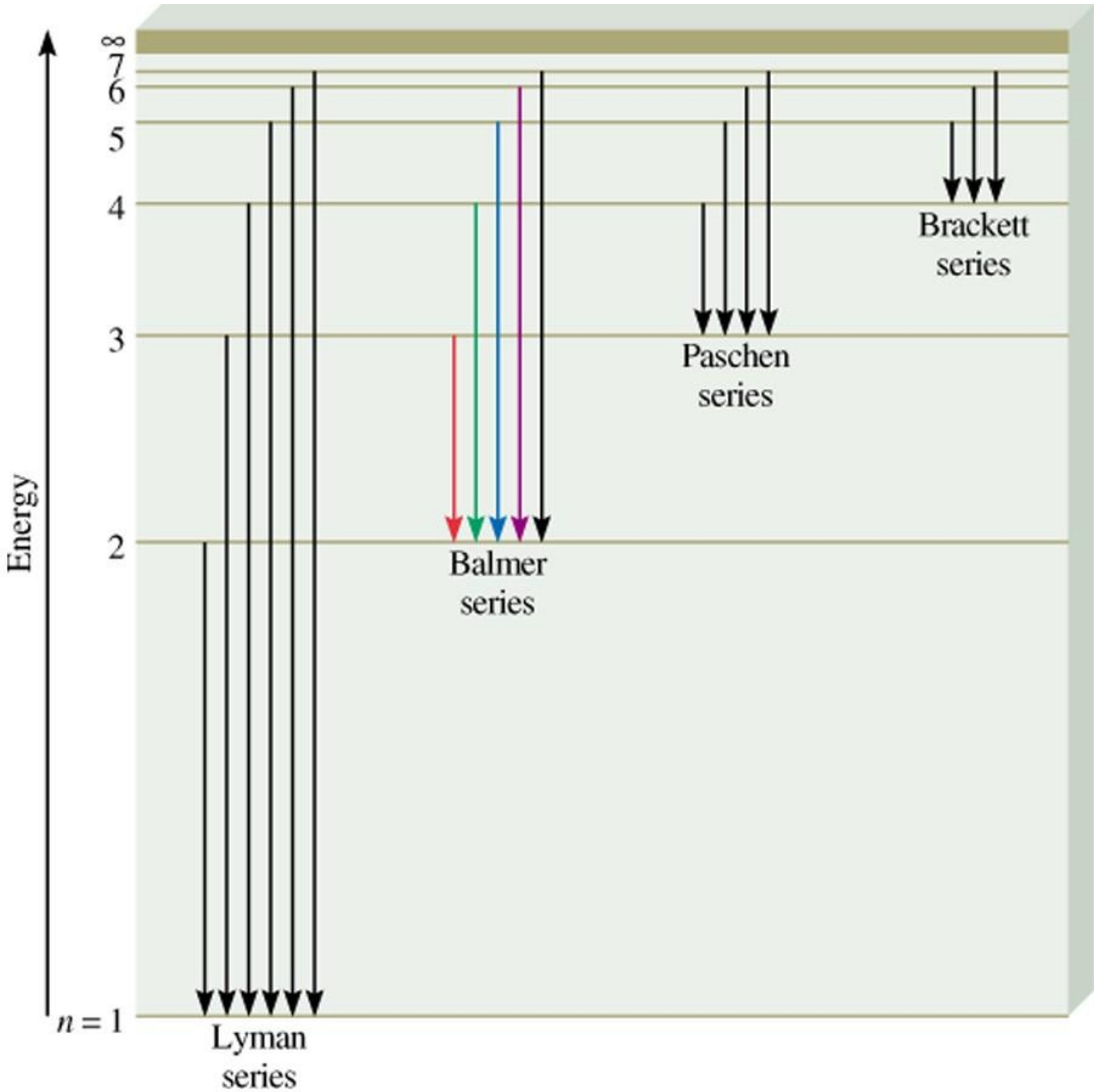
•Light is **emitted** from an atom when the electron transition is from higher *n* to lower *n* ($n_f < n_i$). In this case, ⊗*E* will be negative.

•An electron is **ejected** when $n_f = \infty$.



The Bohr Model of the Atom:Ground and Excited States

- In the Bohr model of hydrogen, the lowest amount of energy hydrogen's one electron can have corresponds to being in the ***n*** = 1 orbit. We call this its **ground state.**
- When the atom gains energy, the electron leaps to a higher energy orbit. We call this an **excited state**.
- The atom is less stable in an excited state and so it will release the extra energy to return to the ground state.



Bohr showed the energy a H atom can have E is equal to:

$$E_n = -R_H \left(\frac{1}{n^2} \right)$$

$$E_{photon} = \Delta E = E_f - E_i$$

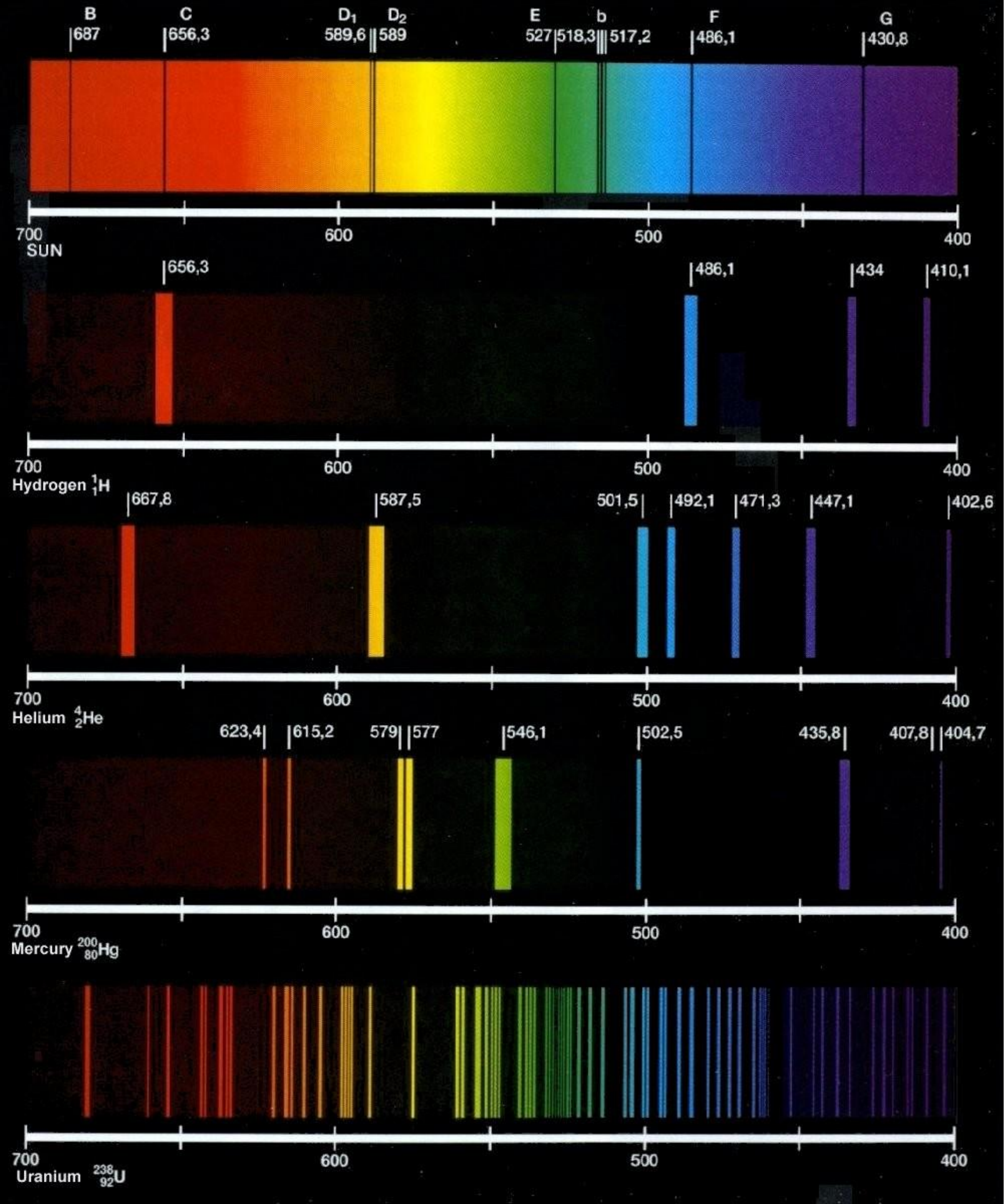
$$E_f = -R_H \left(\frac{1}{n_f^2} \right)$$

$$E_i = -R_H \left(\frac{1}{n_i^2} \right)$$

$$\Delta E = R_H \left(\frac{1}{n_i^2} - \frac{1}{n_f^2} \right)$$

R_H is the Rydberg constant

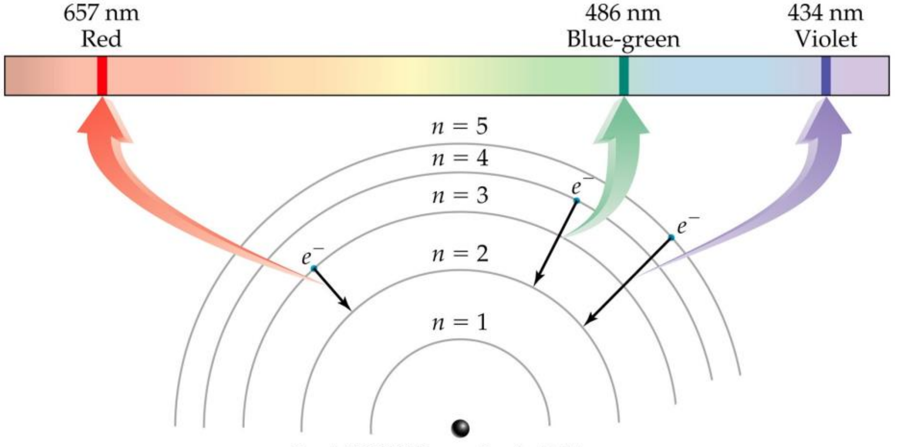
n is the principal quantum number



<u>Line spectrum of some elements</u>

The Bohr Model of the Atom: Hydrogen Spectrum

- Every hydrogen atom has identical orbits, so every hydrogen atom can undergo the same energy transitions.
- However, since the distances between the orbits in an atom are not all the same, no two leaps in an atom will have the same energy.
  - The closer the orbits are in energy, the lower the energy of the photon emitted.
  - Lower energy photon = longer wavelength.
- Therefore, we get an emission spectrum that has a lot of lines that are unique to hydrogen.



Radioactivity

- Radioactivity is a natural and spontaneous process in which an unstable atomic nucleus loses energy by emitting radiation in the form of particles or electromagnetic waves.

- After emission the remaining daughter atom can either be a lower energy form of the same element or a completely different element.

- The emitted particles or waves are called ionising radiation because they have the ability to remove electrons from the atoms of any matter they interact with.

Radioactive Decay

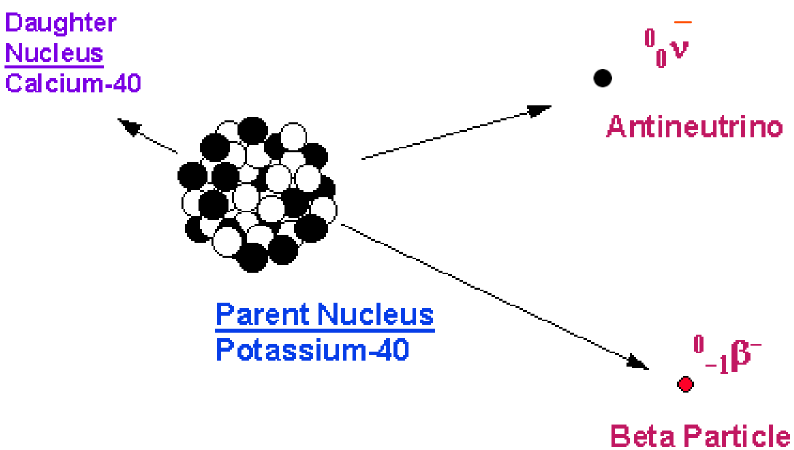
- The atoms of radioactive elements emit three distinct types of radiation called *alpha particles*, *beta particles*, and *gamma rays*.
  - alpha particles have a positive electric charge
  - beta particles are negative
  - gamma rays are electrically neutral

Radioactive decay processes

1. Beta (minus) decay, β^-
2. Beta (plus) decay , β^+
3. Electron capture, e
4. Gamma decay, γ
5. Alpha decay, α

Radioactive decay processes

1. Beta (minus) decay



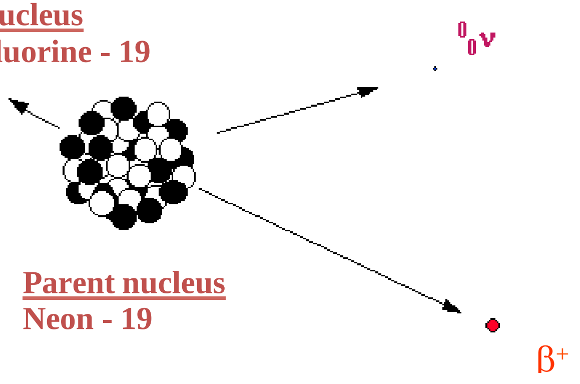
$$^{40}_{19}K \rightarrow ^{40}_{20}Ca + 1.32 MeV \ \beta^{-} \max$$

General equation for beta minus decay:

$$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + \beta^{-} + \bar{\upsilon}$$

2. Beta (plus) decay

2. Beta (plus) decay



$$ {}^{19}_{10}Ne \rightarrow {}^{19}_{9}F + 2.22 MeV \ \beta^+ + \upsilon $$

+ annihilation radiation

General equa4on for beta plus decay:

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \beta^+ + \upsilon $$

annihilation radiation = $m_e c^2$ = 0.511 MeV (x2)

3. Electron capture

3. Electron capture:

Excess of protons, stability reached by different process than β^+
Orbital electron is *captured* by the nucleus, neutrino emitted.

Commonly nucleus is left in an 'excited' state and returns to its ground state by emitting a gamma-ray photon from the *nucleus*
***In all cases* a characteristic X-ray photon is emitted by the *atom*.**

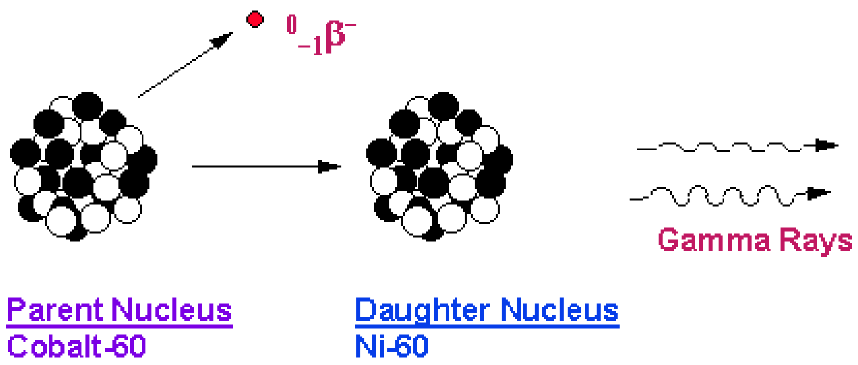
The general equation for the electron capture process is:

$$_{Z}^{A}X + e \rightarrow _{Z-1}^{A}Y + \upsilon + X - rays + \gamma - rays\ (possibly)$$

$$_{53}^{125}I + e \rightarrow _{52}^{125}Te + Tellurium \quad X - rays (0.027 Mev) + 0.035\ MeV\ \gamma - rays$$

4. Gamma decay

4. Gamma decay:



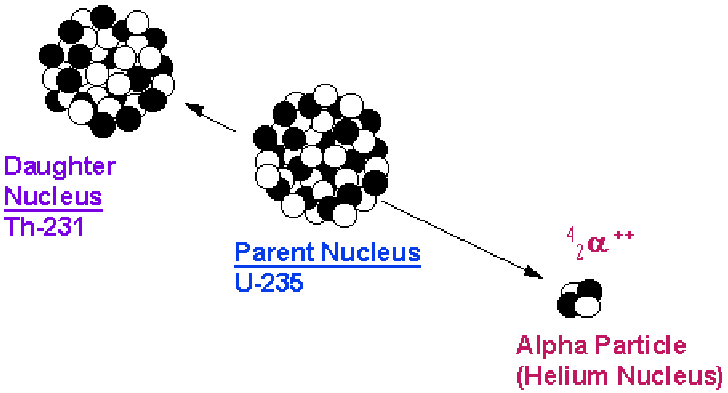
$^{60}Co_{27} \rightarrow {}^{60}Ni_{28}$ + 0.318 MeV β^{-} + 1.17 MeV γ + 1.33 MeV γ

Nucleons have quantised energy levels - emitted γ-ray photons from a particular nucleus have a unique γ-ray spectrum.

γ-ray spectrum can be used to identify unknown isotopes and calibrate instruments.

5. Alpha decay

5. Alpha decay:



Nuclides with Z > 82

α particle = $^4He_2$ (helium nucleus) and are monoenergetic

$$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$$

Decay chain:
Generally, unstable heavy elements require a series of alpha and beta decays until a lighter more stable element is reached

Type	Common equation	Example
Alpha decay	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$	${}^{238}_{92}Th \longrightarrow {}^{234}_{90}U + {}^{4}_{2}He + energy$
Beta decay	${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$	${}^{209}_{82}Pb \longrightarrow {}^{209}_{83}Bi + {}^{0}_{-1}e + energy$ ${}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e + energy$
Gamma decay	${}^{A}_{Z}X \longrightarrow {}^{A}_{Z}Y + \gamma$	${}^{210}_{84}Po \longrightarrow {}^{206}_{82}Pb + {}^{4}_{2}He + \gamma + energy$ ${}^{60}_{27}Co \longrightarrow {}^{60}_{27}Co + \gamma + energy$

Questions

- Almost the entire mass of an atom is concentrated in the___________.
  1. proton
  2. electrons
  3. nucleus
  4. neutrons
- Electron was discovered by____________.
  1. Chadwick
  2. Thomson
  3. Goldstein
  4. Bohr

Questions

- An atom has a mass number of 23 and atomic number 11. The number of protons are__________.
  1. 11
  2. 12
  3. 23
  4. 44
- The mass of the atom is determined by_________.
  1. neutrons
  2. neutron and proton
  3. electron
  4. electron and neutron

Questions

- Uranium-235, uranium-238, and uranium-239 are different
    1. elements.
    2. ions.
    3. isotopes.
    4. nucleons.