# Nuclear Chemistry

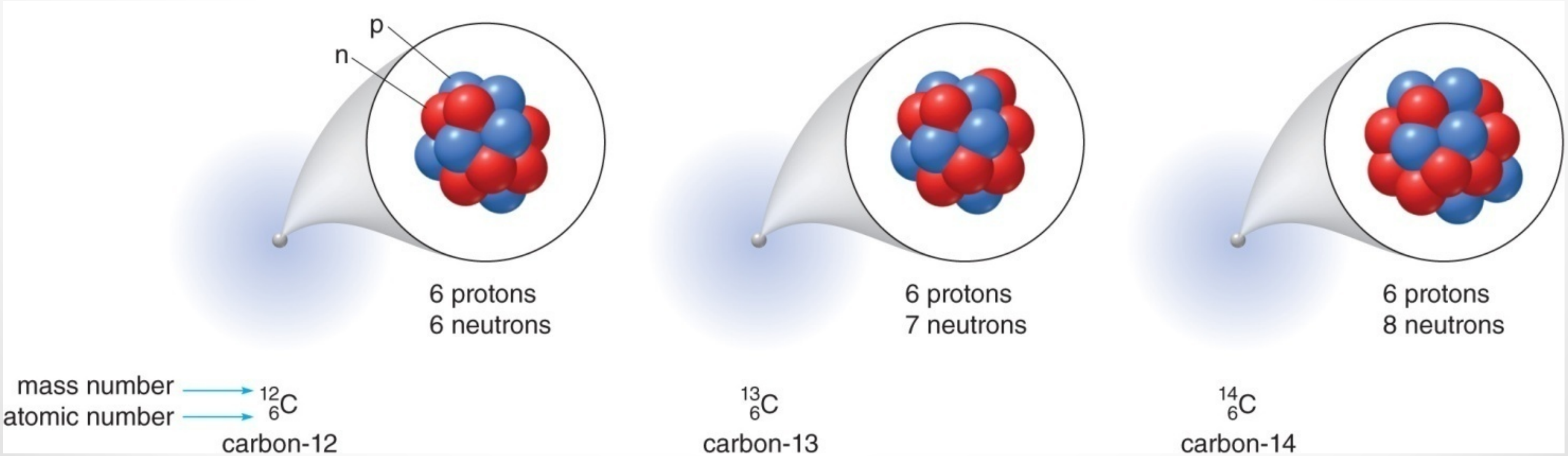
Sections 10.1-10.3

# Isotopes

- Recall isotopes are atoms with different numbers of neutrons
- Not terribly important when dealing with chemical reactions which are based on electron interaction
- More important when dealing with nuclear chemistry – only nucleus interactions
- Protons and neutrons make up the nucleus

# Radioisotope

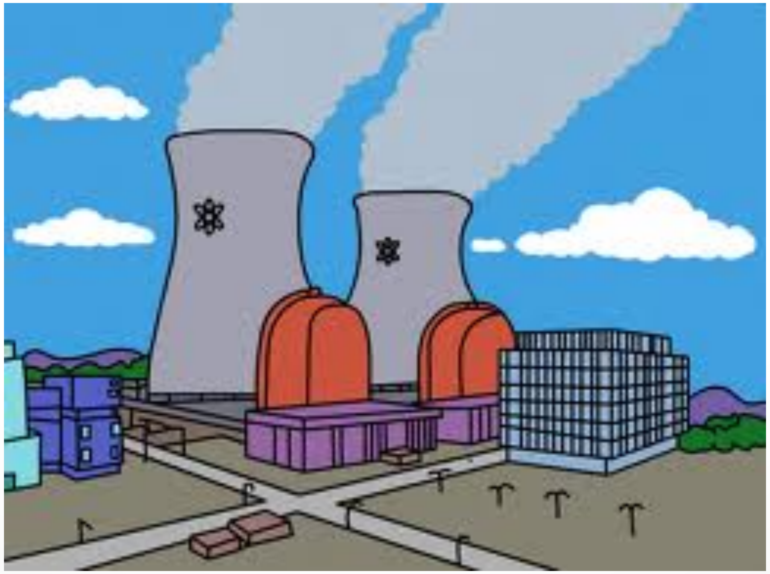
- Also known as radioactive isotope
- Naturally occurring
- Unstable
- Spontaneously undergoes a reaction to reach stability – **radioactive decay**



# Nuclear Reactions

- Different from regular chemical reactions in 3 ways

- Change in atom's nucleus, produces new element
- Isotopes can have drastically different reactivity
- Energy change is significantly higher



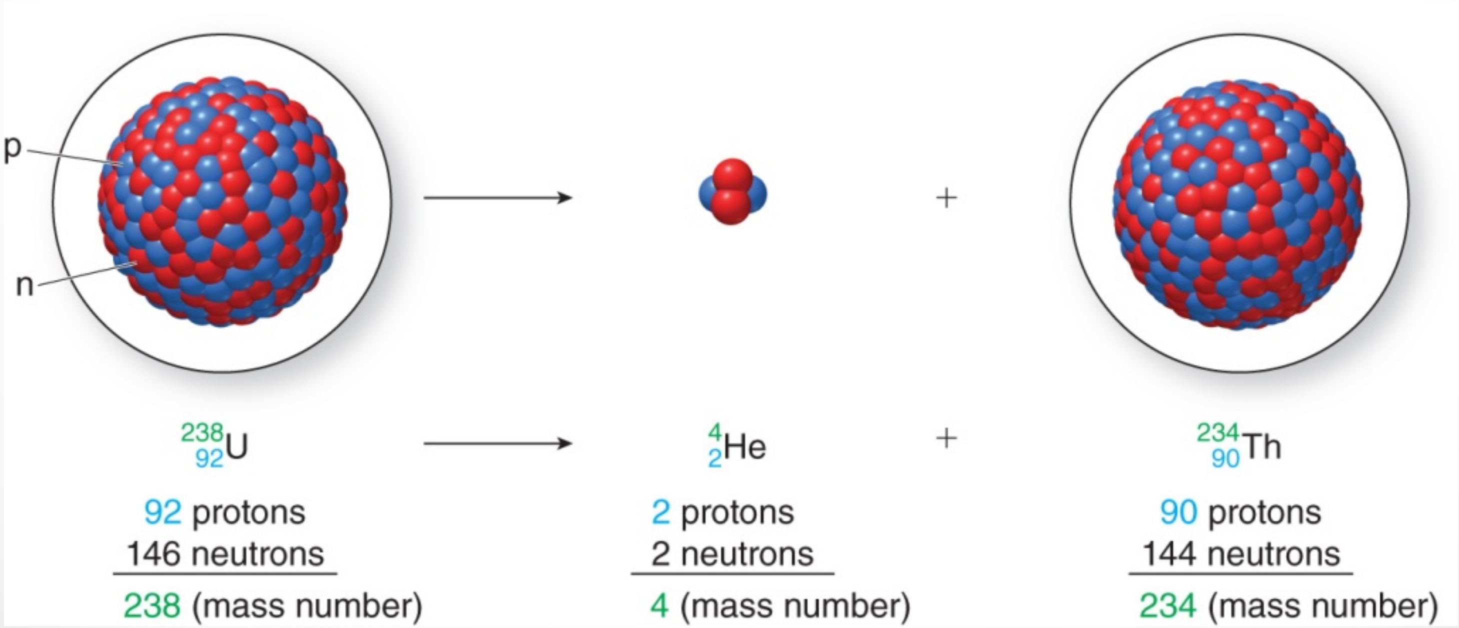
# Radioactivity

- Different forms of radioactivity yield different particles
- Particles are emitted, meaning they are products

- Alpha particles ($\alpha$)
- Beta particles ($\beta$)
- Positrons ($\beta^+$)
- Gamma radiation ($\gamma$)

# Alpha Decay (α)

- An alpha particle is a high energy particle that consists of two protons and two neutrons
- The same as a helium nucleus
  - Remember, no electrons in nuclear chemistry
- Written as α or $^{4}_{2}He$



# Alpha Decay

- New nucleus has two fewer protons and two fewer neutrons
- Overall mass number will decrease by four

- Proton number changes so you will have a new element
- Alpha particle is a product of the reaction

$$241 = 4 + 237$$

$$95 = 2 + 93$$

$$^{241}_{95}\text{Am} \longrightarrow {}^{4}_{2}\text{He} + {}^{237}_{93}\text{Np}$$

# Beta Decay (β)

- A beta particle is formed when a neutron in the nucleus decays into a proton
- In this process an electron is emitted and this is a **beta particle**

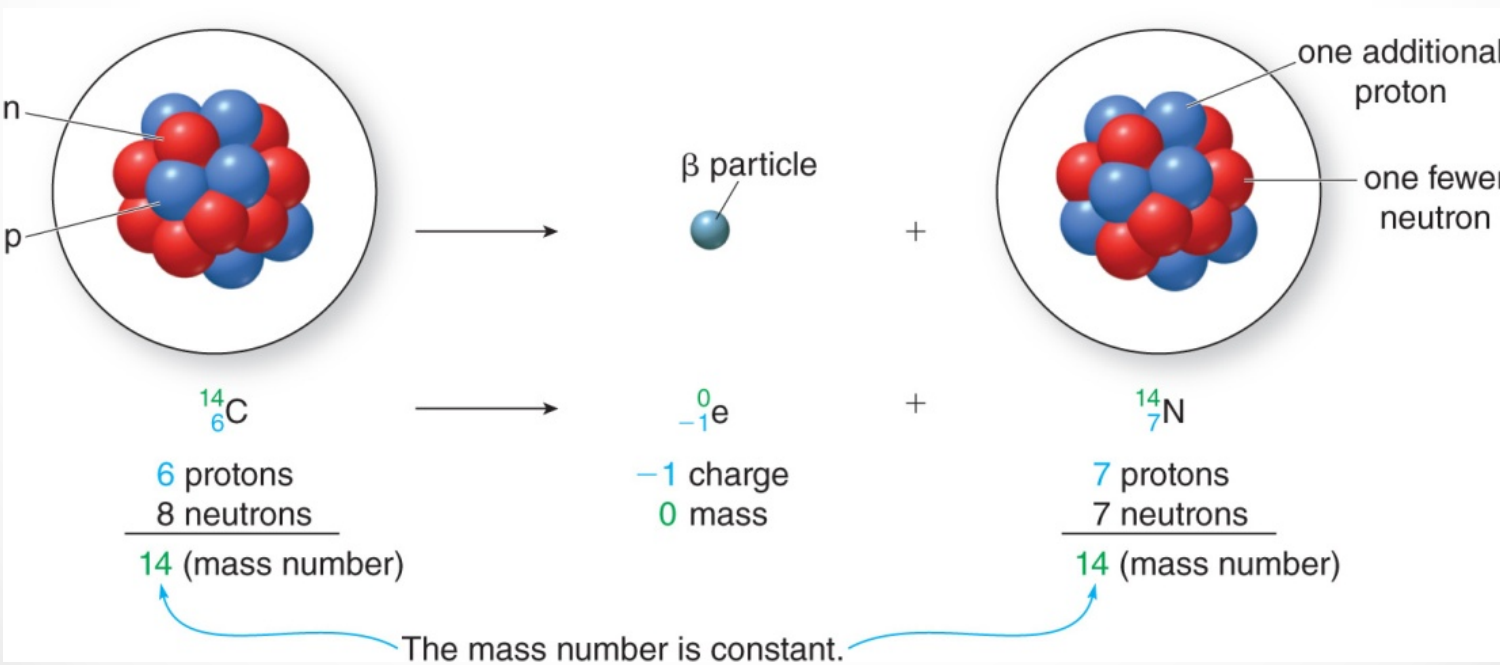
$$^{1}_{0}n \rightarrow \, ^{1}_{+1}p + \, ^{0}_{-1}e$$

beta particle

$$^{32}_{15}P \longrightarrow \, ^{0}_{-1}e + \, ^{32}_{16}S$$

# Beta Decay

- New nucleus has one more proton so it is an all new element
- New nucleus has one fewer neutron, so the overall mass number doesn't change



# Positron Decay ($\beta^+$)

- A positron particle is formed when a proton in the nucleus decays into a neutron
- In this process an positive electron is emitted and this is a **positron particle** (**posi**tive elec**tron**)

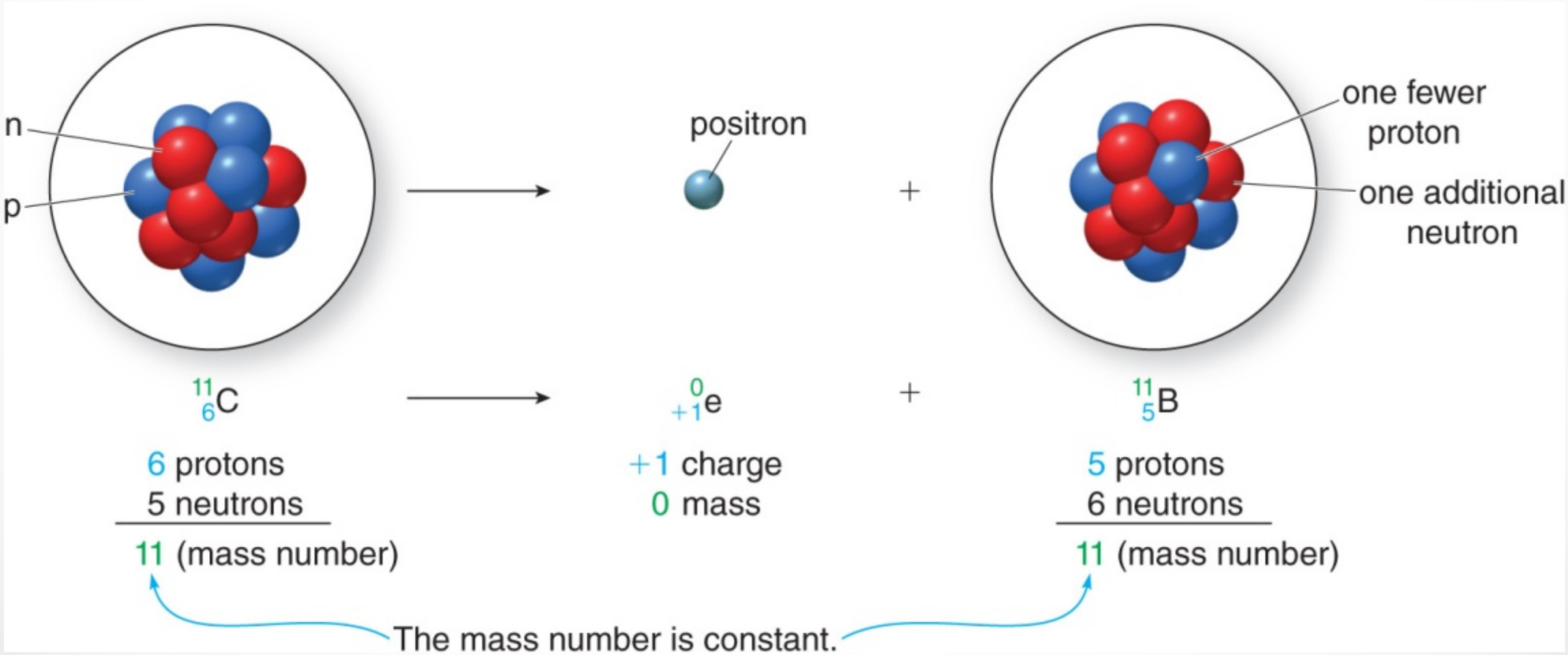
$$^{1}_{+1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e$$

positron particle

$$^{18}_{9}F \longrightarrow {}^{0}_{+1}e + {}^{18}_{8}O$$

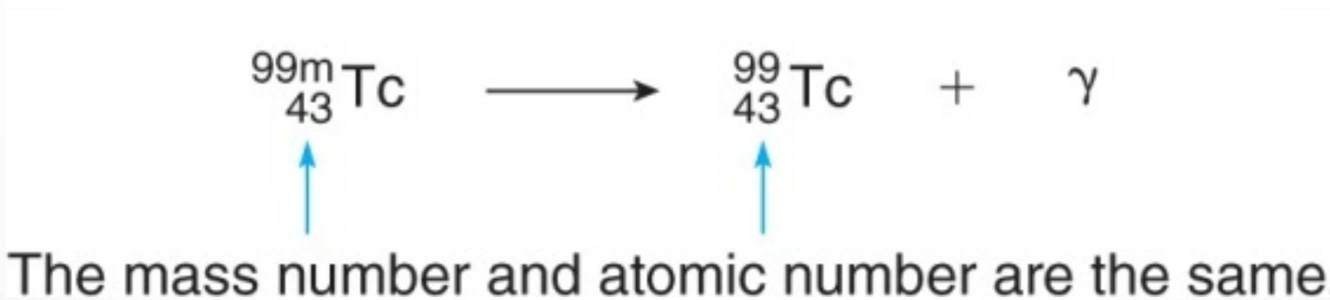
# Positron Decay

- New nucleus has one fewer proton, so it is an all new element
- New nucleus has one more neutron so the overall mass number doesn't change



# Gamma Decay

- A nucleus that undergoes gamma decay gives off energy, not a particle
- Gamma decay has no mass or charge, it is simply a large amount of energy
- No change in atomic number or mass number
- Usually accompanies another type of radiation



# Example #1

Write the equations of the following nuclear reactions:

a. Alpha decay of $^{235}U$
b. Beta decay of $^{20}F$
c. Positron emission of $^{23}Mg$
d. Beta decay of $^{63}Ni$
e. Positron emission of $^{11}C$
f. Alpha decay and gamma emission of $^{14}N$

# Example #1 Solved

a. $^{235}U \rightarrow \alpha + {}^{231}Th$
b. $^{20}F \rightarrow \beta + {}^{20}Ne$
c. $^{23}Mg \rightarrow \beta^{+} + {}^{23}Na$
d. $^{63}Ni \rightarrow \beta + {}^{63}Cu$
e. $^{11}C \rightarrow \beta^{+} + {}^{11}B$
f. $^{14}N \rightarrow \alpha + {}^{10}B + \gamma$

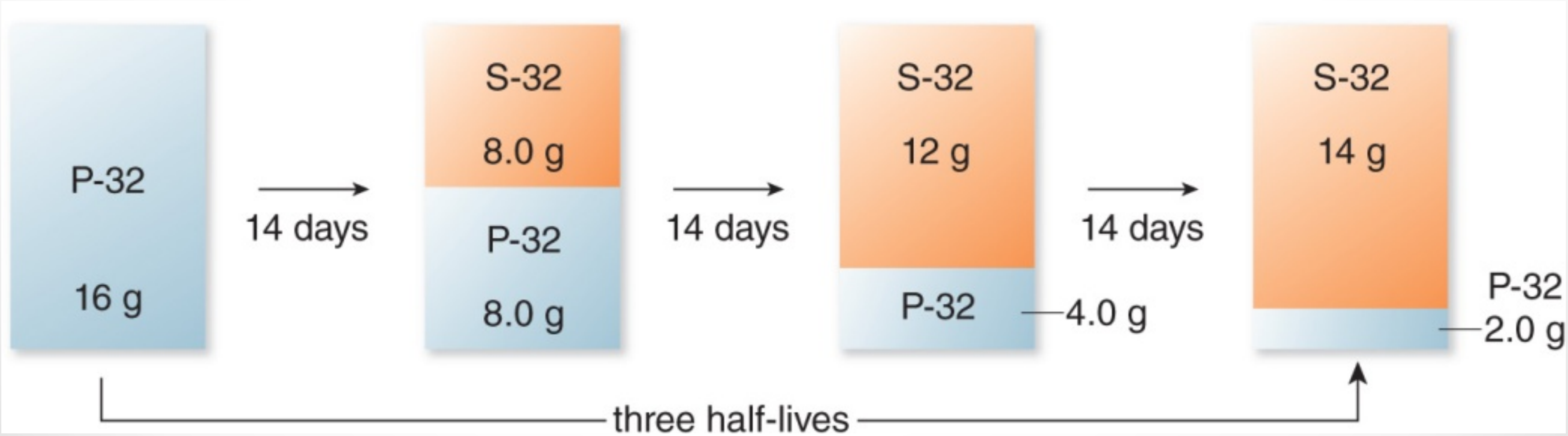
# Half Life

- Given that the radioisotopes decay, it is important to know how long this takes
- Use the idea of **half life** ($t_{1/2}$)to measure decay

- Half life is the time it takes for half of a sample to decay
- Half life is a property of a given isotope and is independent of amount of sample

# Half Life

- Half life is different for each type of isotope
- Half life can range from nanoseconds to thousands of years
- Ex. the half life of $^{32}P$ is 14 days



# Half Life

**Table 10.2** Half-Lives of Some Common Radioisotopes

| Radioisotope | Symbol | Half-Life | Use |
|---|---|---|---|
| Carbon-14 | $^{14}_{6}C$ | 5,730 years | Archaeological dating |
| Cobalt-60 | $^{60}_{27}Co$ | 5.3 years | Cancer therapy |
| Iodine-131 | $^{131}_{53}I$ | 8.0 days | Thyroid therapy |
| Potassium-40 | $^{40}_{19}K$ | $1.3 \times 10^9$ years | Geological dating |
| Phosphorus-32 | $^{32}_{15}P$ | 14.3 days | Leukemia treatment |
| Technetium-99m | $^{99m}_{43}Tc$ | 6.0 hours | Organ imaging |
| Uranium-235 | $^{235}_{92}U$ | $7.0 \times 10^8$ years | Nuclear reactors |

# Example #2

The half life of iodine-131 is 8.0 days. How much of a 250. g sample of iodine-131 remains after 32 days?

# Example #2 Solved

- Determine how many half lives have passed

$$32days \times \frac{1hl}{8.0days} = 4.0hl$$

- For each half life, multiply the initial mass by ½

$$250.g \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = 15.6g$$

# Example #3

Write the equations of the following nuclear reactions:

a. Gamma emission of $^{11}B$
b. Beta decay and gamma emission of $^{40}K$
c. Alpha decay of $^{218}Po$
d. Positron decay of $^{74}As$

# Example #4

If a 160. mg sample of technetium-99m is used for a diagnostic procedure, how much Tc-99m remains after each interval:

a. 6.0 h
b. 18.0 h
c. 24.0 h
d. 2 days