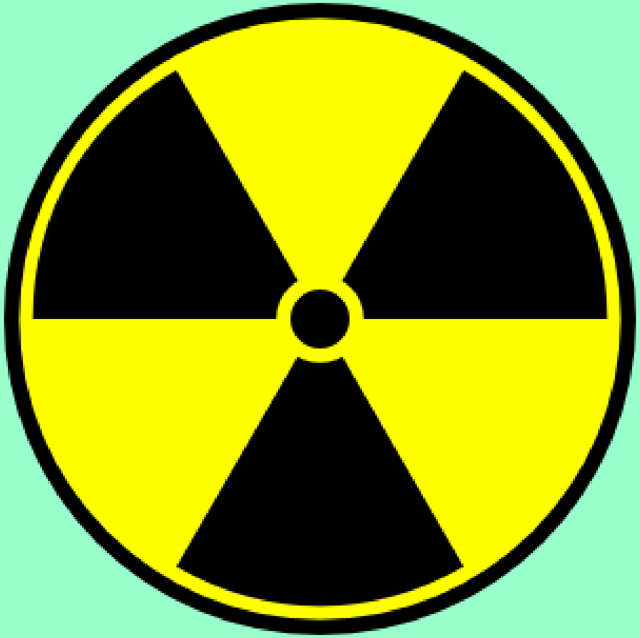
Chapter 10
Nuclear Chemistry



Standards Addressed in this Chapter

SPS3. Students will distinguish the characteristics and components of radioactivity.

- Differentiate among alpha and beta particles and gamma radiation.
- Differentiate between fission and fusion.
- Explain the process half-life as related to radioactive decay.
- Describe nuclear energy, its practical application as an alternative energy source, and its potential problems.

SPS5. Students will compare and contrast the phases of matter as they relate to atomic and molecular motion.

- Compare and contrast the atomic/molecular motion of solids, liquids, gases and plasmas.

10.1 Radioactivity

- Radioactivity is the process in which an unstable atomic nucleus emits charged particles and energy.
- Radioisotope is short for radioactive isotopes, which is any atom containing an unstable nucleus.
- Radioisotopes spontaneously change into other isotopes over time and is said to undergo nuclear decay.
- **During nuclear decay, atoms of one element can change into atoms of a different element altogether.**

Types of Nuclear Radiation

- Nuclear radiation is charged particles and energy that are emitted from the nuclei of radioisotopes
- **Common types of nuclear radiation include alpha particles, beta particles and gamma rays**

1. Alpha Decay

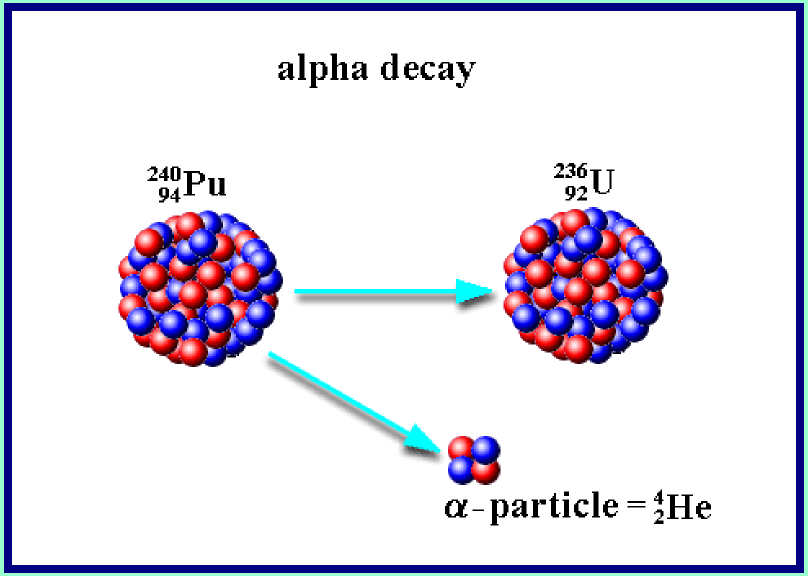
- Alpha particle is a positively charged particle made up of two protons and two neutrons (the same as helium nucleus)
- Alpha particles are the least penetrating type of nuclear radiation.
- They can be stopped by a sheet of paper of by clothing.
- The alpha particle has no electrons so it has a 2+ charge.
- $^{4}_{2}He$ is the symbol for an alpha particle

Alpha Decay

- Alpha decay is expressed as an equation

$$^{208}_{84}Po \longrightarrow\ ^{4}_{2}He + {}^{204}_{82}Pb$$

$$^{222}_{88}Ra \longrightarrow\ ^{4}_{2}He + {}^{218}_{86}Rn$$



2. Beta Decay

- Beta particle is an electron emitted by an unstable nucleus
- Beta particles are abbreviated β or $^{0}_{-1}e$
- Beta particles are more penetrating than alpha particles.
- Beta particles pass through paper but can be stopped by a thin sheet of metal.

2. Beta Decay

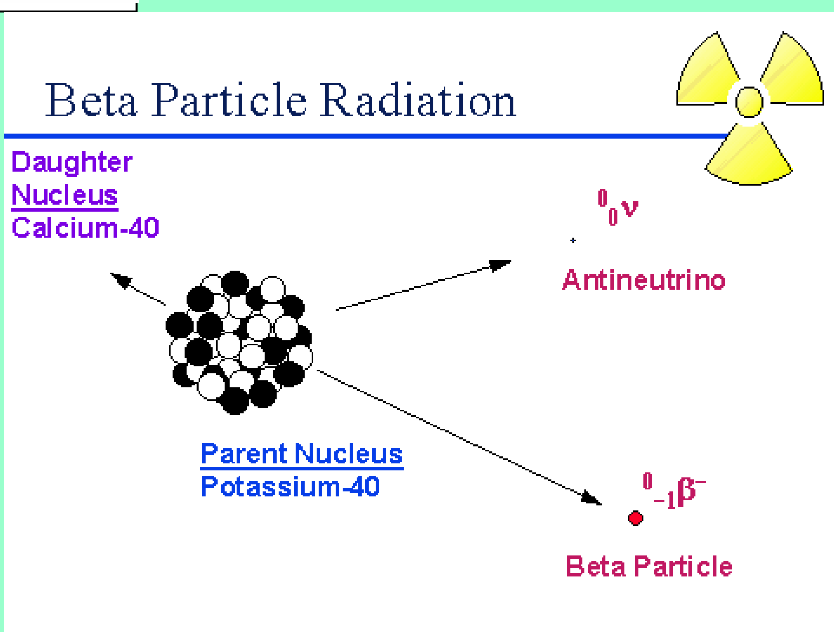
- The beta particle has no mass
- During beta decay a neutron decomposes into a proton and an electron
- The proton stays trapped in the nucleus while the electron is released

Beta Decay

- Beta decay is expressed as an equation

$$ {}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e $$

$$ {}^{131}_{53}I \longrightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e $$



3. Gamma Decay

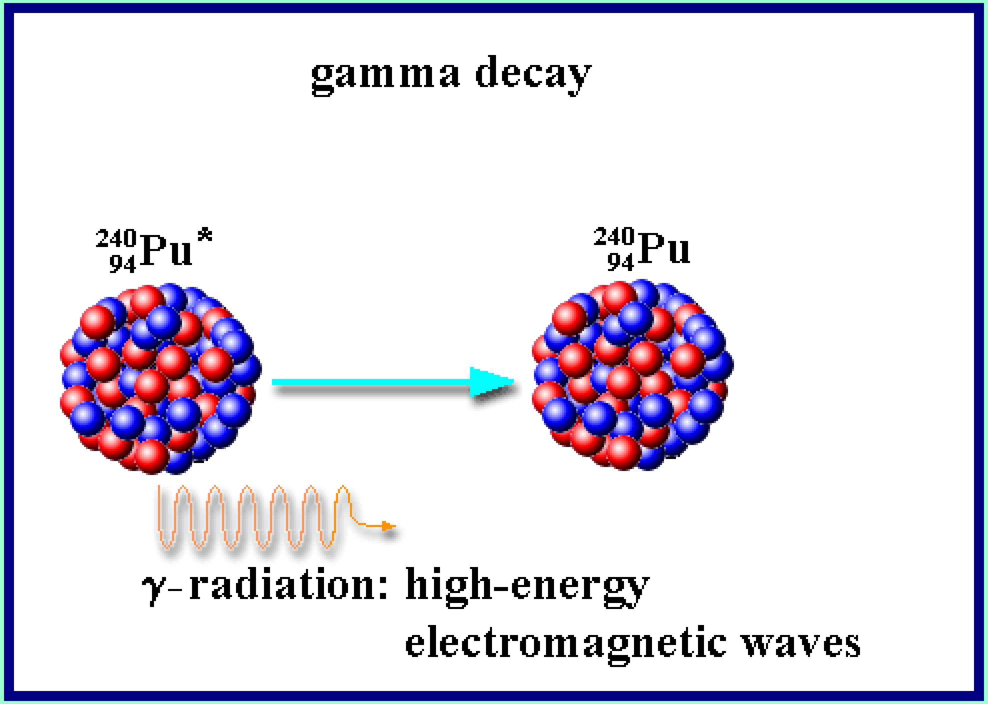
- Gamma ray is a penetrating ray of energy emitted by an unstable nucleus.
- The symbol for a gamma ray is γ
- The gamma radiation has no mass and no charge
- During gamma decay the atomic number and mass number of the atom remain the same but the energy of the nucleus decreases

Gamma Decay

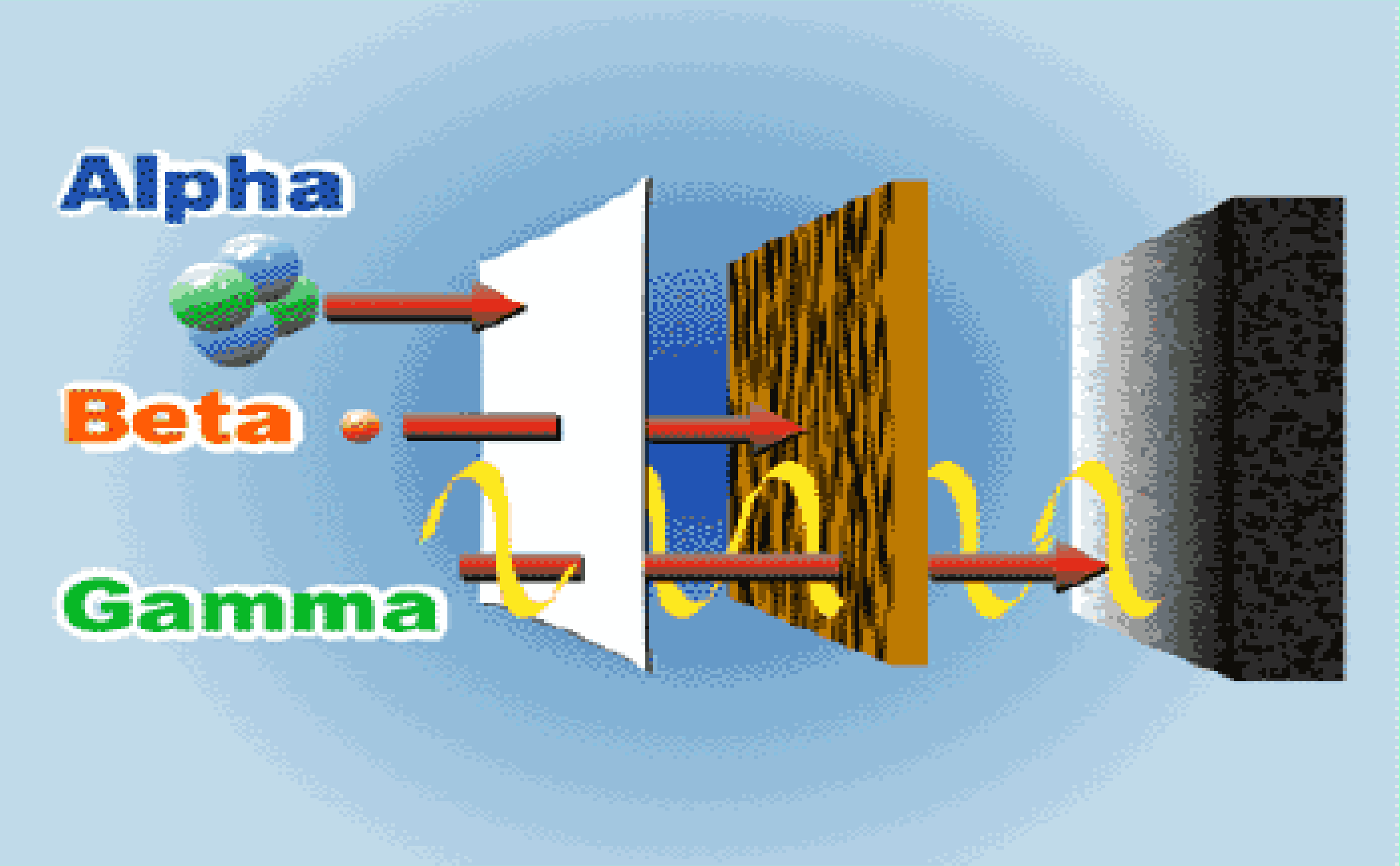
- Gamma decay often accompanies alpha or beta decay.
- Gamma rays have the most energy of the three,
- gamma rays can pass through paper and aluminum but is stopped by thick concrete or lead

Gamma Decay

- Gamma decay



Comparing Strength of Nuclear radiation



Nuclear Ration Summary

Alpha Particles

- Symbol ^4_2He
- 2 protons & 2 neutrons
- Has a charge +2 and mass of 4 atm
- Weakest
- Stopped by paper

Beta Particles

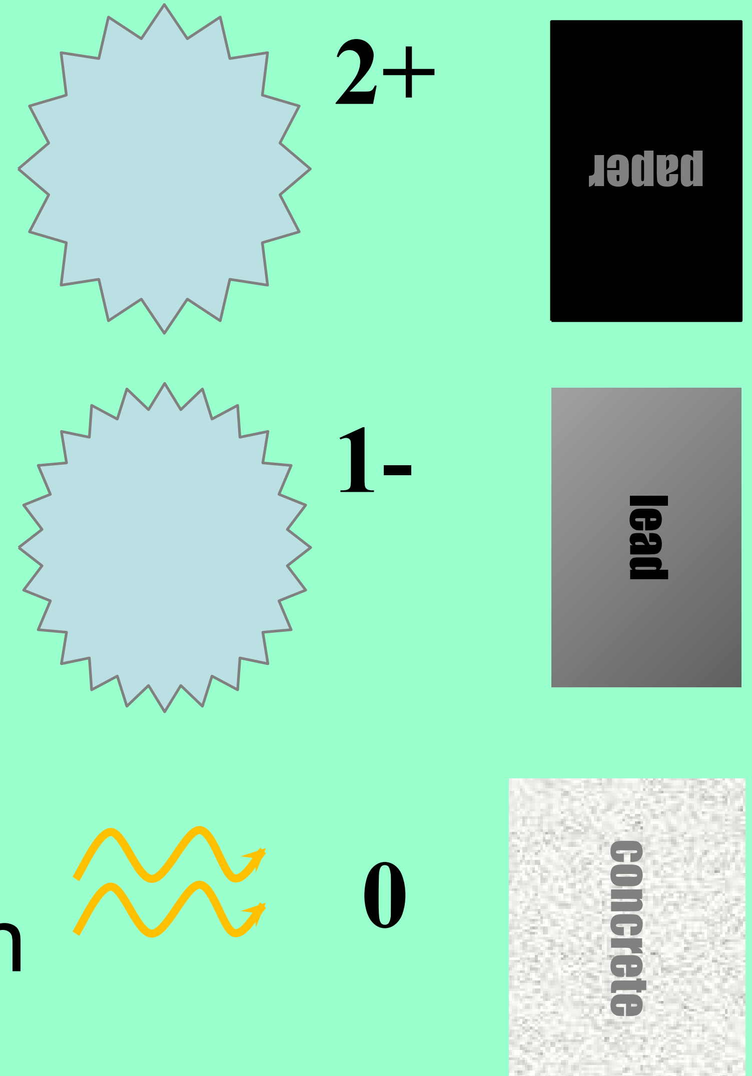
- Symbol β or $^0_{-1}e$
- An electron
- Has no mass
- Stronger than Alpha
- Stopped by sheet of metal

Gamma Ray

- Symbol γ
- Only energy
- No mass, No charge
- Strongest
- Stopped by thick lead or thick concrete

Types of Radiation

- **Alpha (α)**
  - helium nucleus
- **Beta-minus (β-)**
  - electron
- **Gamma (γ)**
  - high-energy photon



10.2 Rates of Nuclear Decay

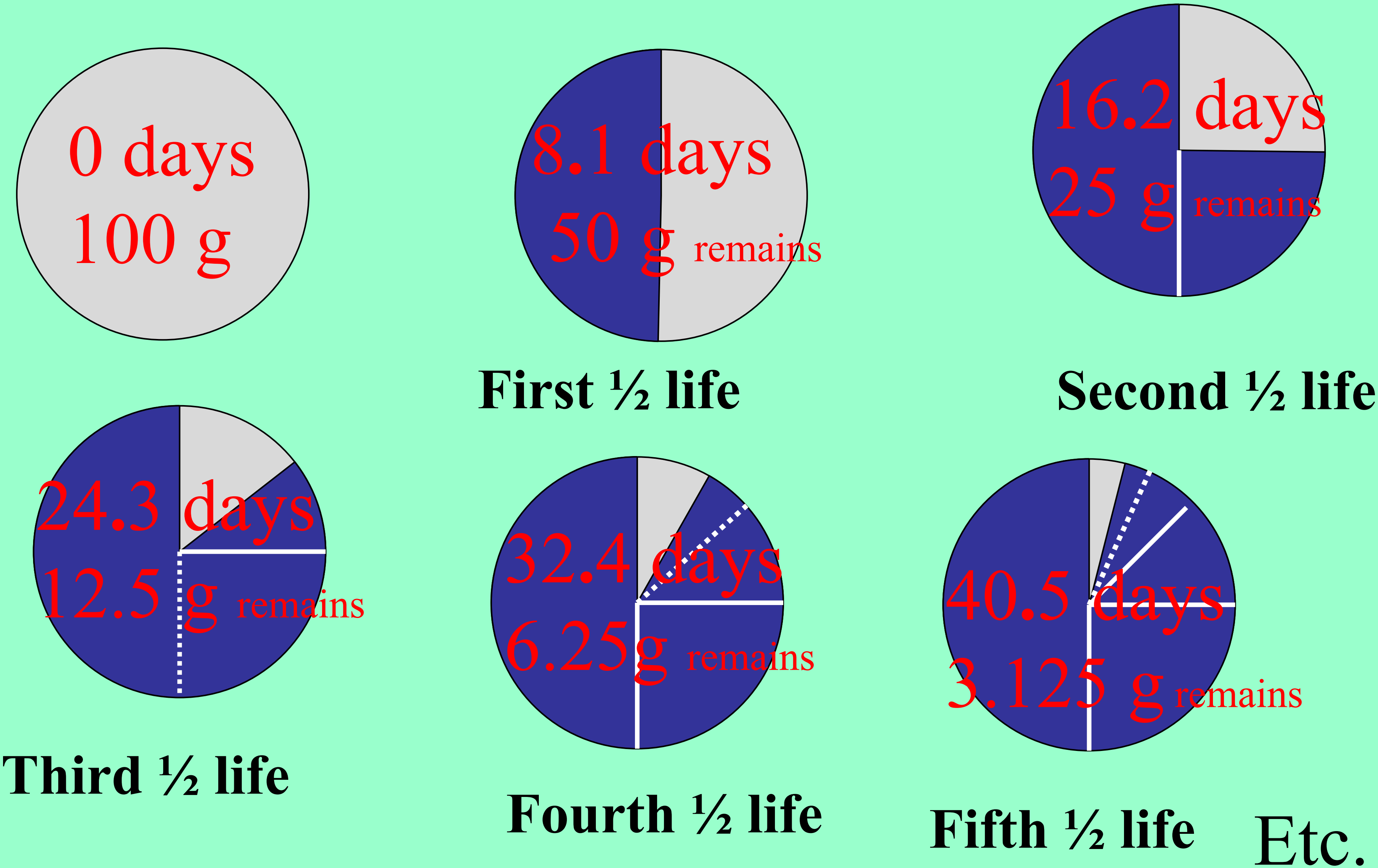
- Half-life is the time required for one half of a sample of radioisotope to decay
- After one half-life, half of the atoms in a sample have decayed, while the other half remains unchanged.
- Half-lives can vary from fractions of a second to billions of years
- Time in which ½ of the original isotopes decay

A. Half-Life

- First Half-life ½ original isotopes remain
  ½ decayed
- Second Half-life ¼ original isotopes remain
  ¾ decayed
- Third Half-life 1/8 original isotopes remain
  7/8 decayed
- **Unlike chemical reaction rates, which vary with the conditions of a reaction, nuclear decay rates are constant.**

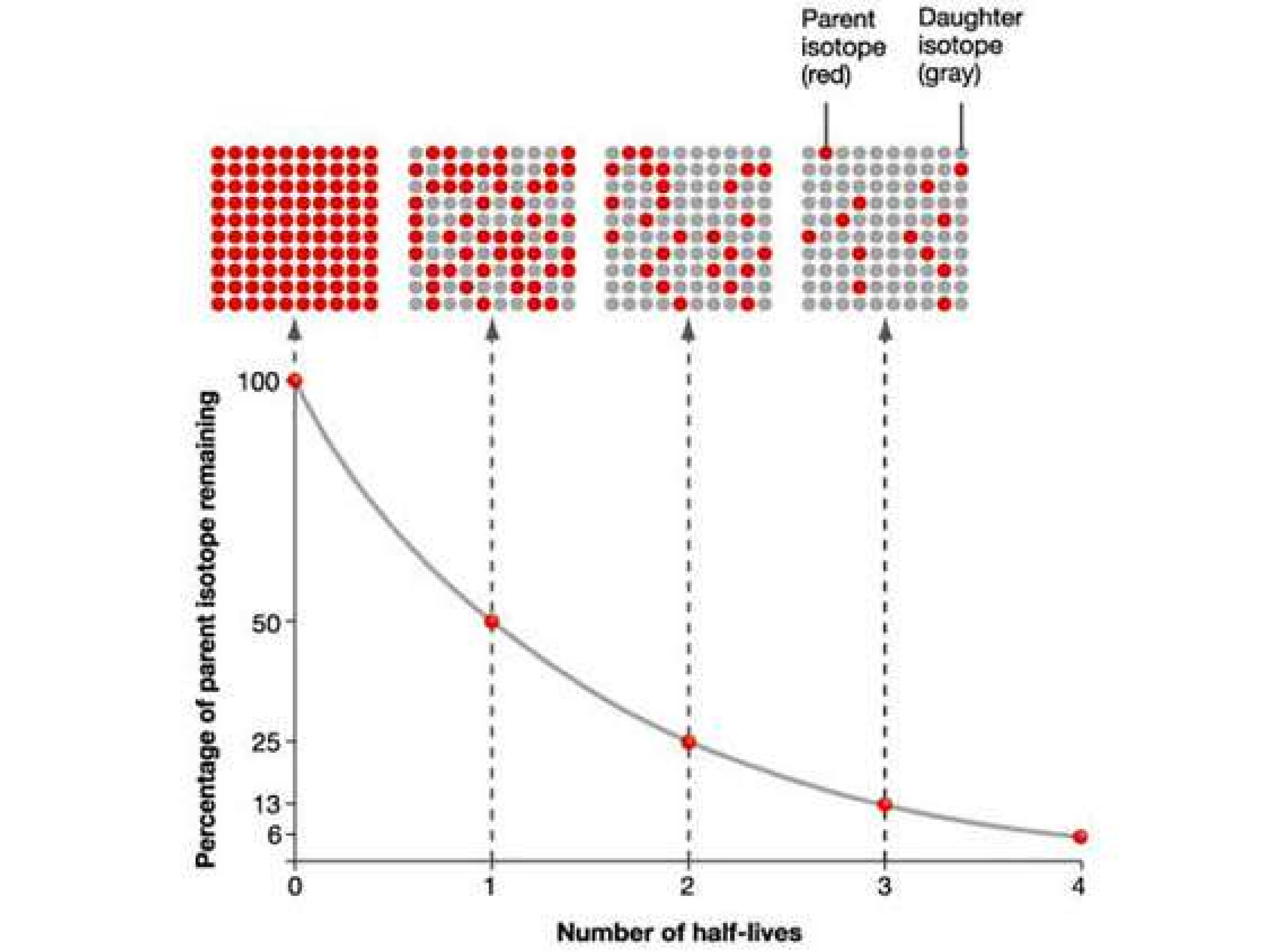
Half-Life progression of Iodine-131

100 gram sample with 8.1 day ½ life



•http://einstein.byu.edu/~masong/htmstuff/Radioactive2.html

Half-life graph



½ life calculations

- Amount of sample divide by two for each ½ life that passed
- Amount of time = (# of ½ lives) X (length of one ½ life)

A. Half-Life Practice

1. If we start with 800 atoms of a radioactive substance,

   how many would remain after one half-life? **400 atoms**

   after two half-lives? **200 atoms**

   after three half-lives? **100 atoms**

2. If we start with 48 g of a radioactive substance with a 2 hour ½ life ,

   how much is left after two half-lives? **12 g**

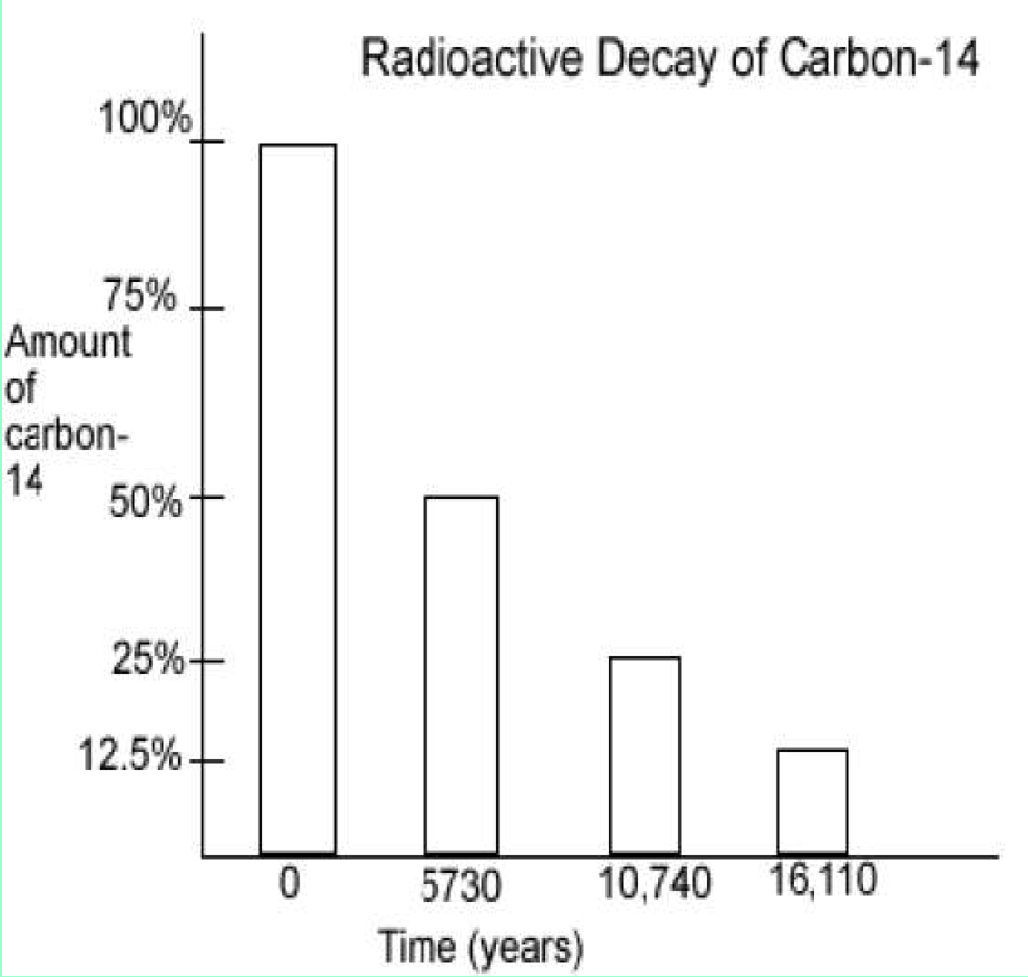
   after four half-lives? **3 g**

   how much time has passed for 4 ½ lives? **8 hours**

3. If we start with 16 grams of a radioactive substance that has a 6 day ½ life,

   How much will remain after three half-lives? **2 grams**

   How much time would have passed? **18 days**



4. How much of the sample has decayed after zero years? zero ________

5. If only 25% of the carbon-14 remains, how old is the material containing the carbon-14? 10740 years old ____________

6. If a sample originally had 150 grams of carbon-14, how many atoms will remain after 16,110 years? 12.5 grams ________

10.4 Fission and Fusion

- Strong nuclear force is the attractive force that binds protons and neutrons together in the nucleus.
- **Over very short distances the strong nuclear force is much great than the electric forces among protons.**

1. The effect of size on Nuclear Forces

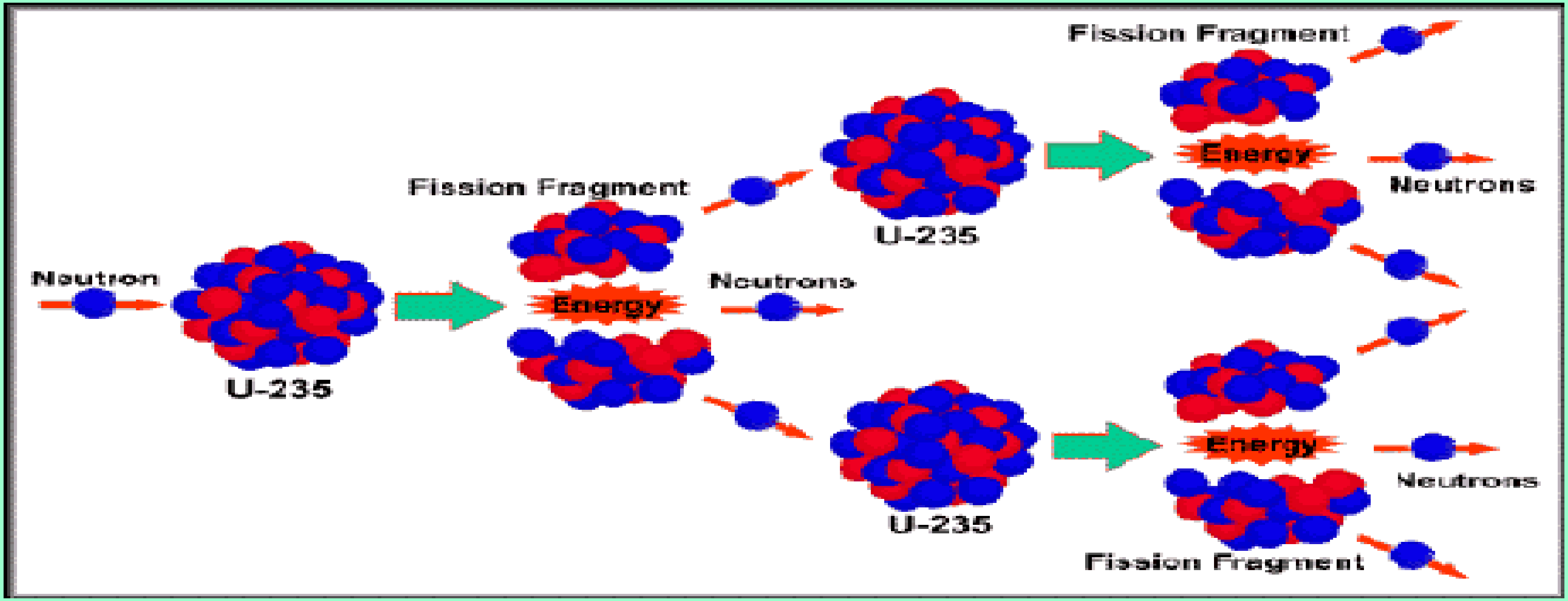
- The greater the number of protons in a nucleus the greater is the electric force that repels those protons.
- In larger nuclei, the repulsive electric force is stronger than in smaller nuclei
- Larger numbers of electric forces make larger nucleus less stable

2. Unstable Nuclei

- A nucleus becomes unstable (radioactive) when the strong nuclear force can no longer overcome the repulsive electric forces among protons.
- All nuclei with more than 83 protons are radioactive

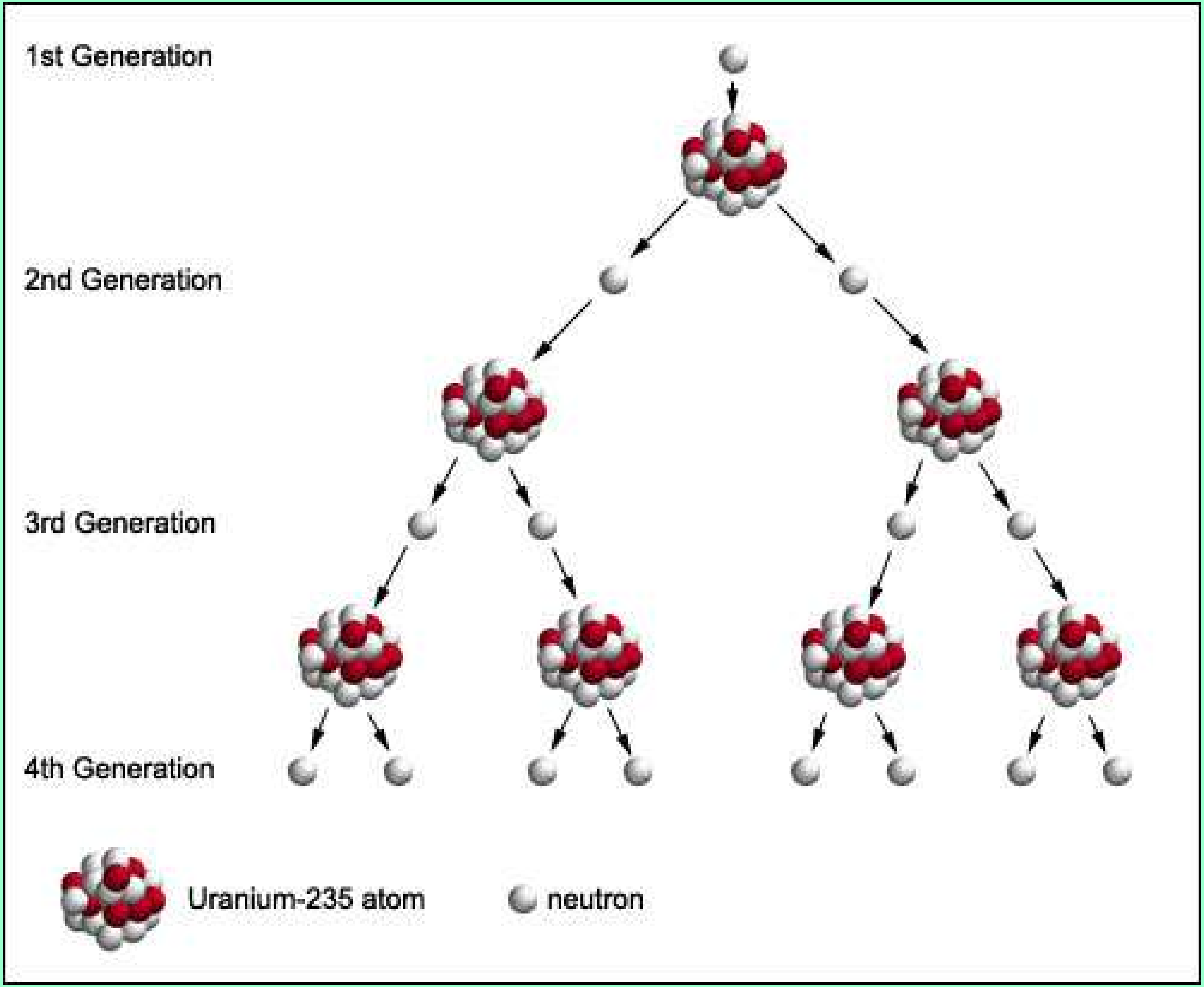
Fission

- Fission is the splitting of an atomic nucleus into two smaller parts.
- **In nuclear fission, tremendous amounts of energy can be produced from very small amounts of mass.**



Chain Reaction

- A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus.
- This nucleus in turn produces neutrons, and the process repeats.
- The process may be controlled (nuclear power) or uncontrolled (nuclear weapons).


1st Generation
2nd Generation
3rd Generation
4th Generation
Uranium-235 atom
neutron

Critical Mass

- The minimum amount of a substance that can sustain a chain reaction.
- It takes very little Uranium-235 to reach critical mass.

Fusion

- Fusion is a process in which the nuclei of two atoms combine to form a larger nucleus.
- During fusion a small fraction of the reactant mass is converted into energy.
- Inside the sun an estimated 600 millions tons of hydrogen undergo fusion each second
- Fusion requires extremely high temperatures (10,000,000◦C).
- At these temperature matter can exist as plasma

C. Fusion

- Plasma is a state of matter in which atoms have been stripped of their electrons.
- Fusion reactions produce much more energy per gram of fuel and produce less radioactive waste than fission.
- Two main problems in designing a fusion rector
  - 1st they need to achieve high temperatures required to start the reaction
  - It requires a heat of about 10 million degrees Celsius. Scientist have to find a way of producing and containing that much heat.
  - 2nd they must contain the plasma
  - Fusion can occur only in the plasma state of matter (super-heated gas).

Fission

- Splitting a larger atom into smaller atoms
- Releases two or three neutrons
- Releases large amounts of energy
- Used as a source for electricity

Fusion

- Combining small atoms into a larger atom
- Requires very high temperatures
- Releases large amounts of energy

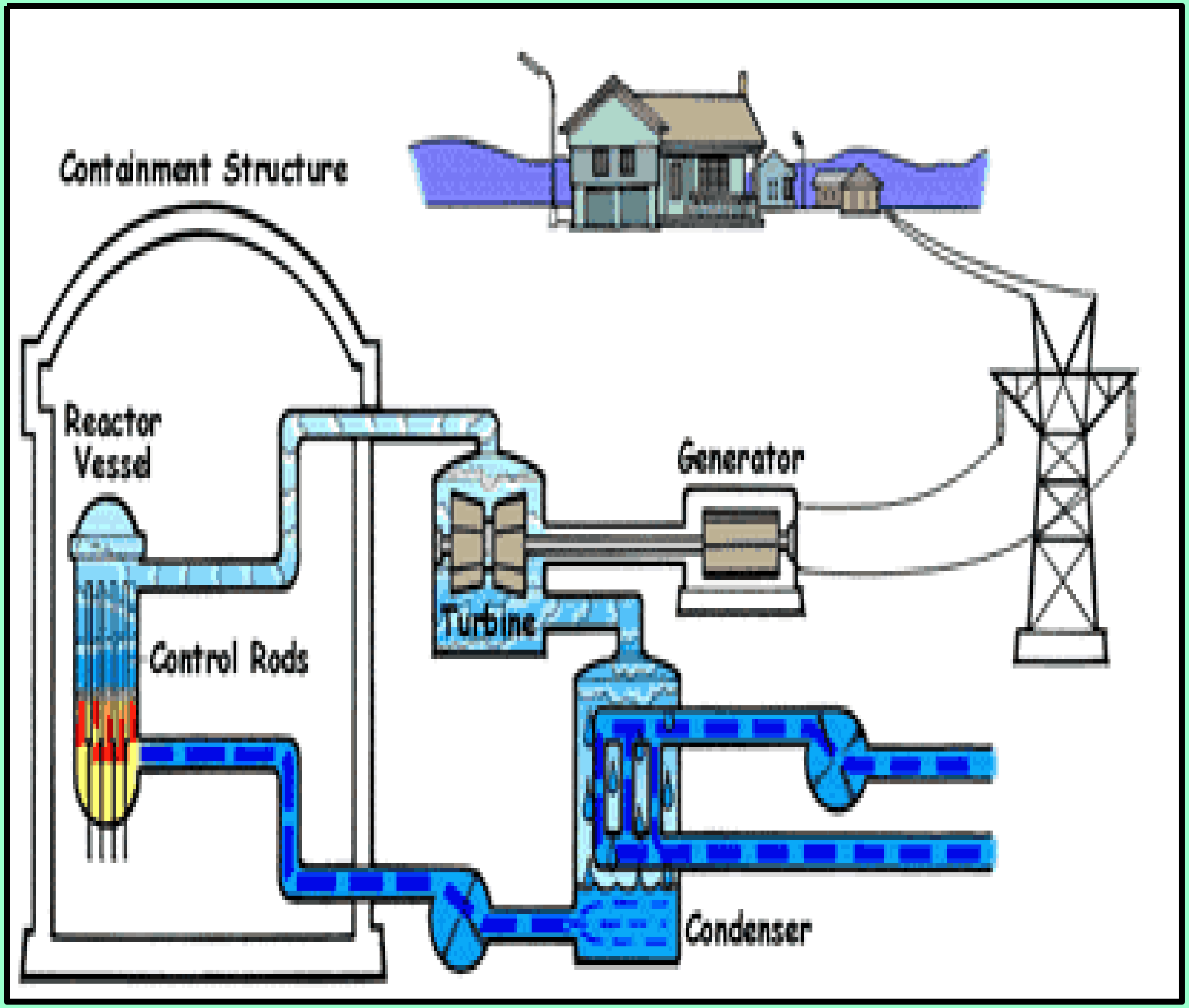
3. Nuclear Energy from Fission

- Nuclear power plants generate about 20% of the electricity in the US
- Nuclear power plant do not emit air pollutants
- But workers are made to wear protective clothing to recue their exposure to nuclear radiation.

- Nuclear power plants produce radioactive waste that must be isolated and stored so that it does not harm people or the environment.
- If the reactors cooling systems failed a meltdown might occur
- During a meltdown the core of the reactor melts and radioactive material may be released.

Nuclear Power

- **Fission Reactors**

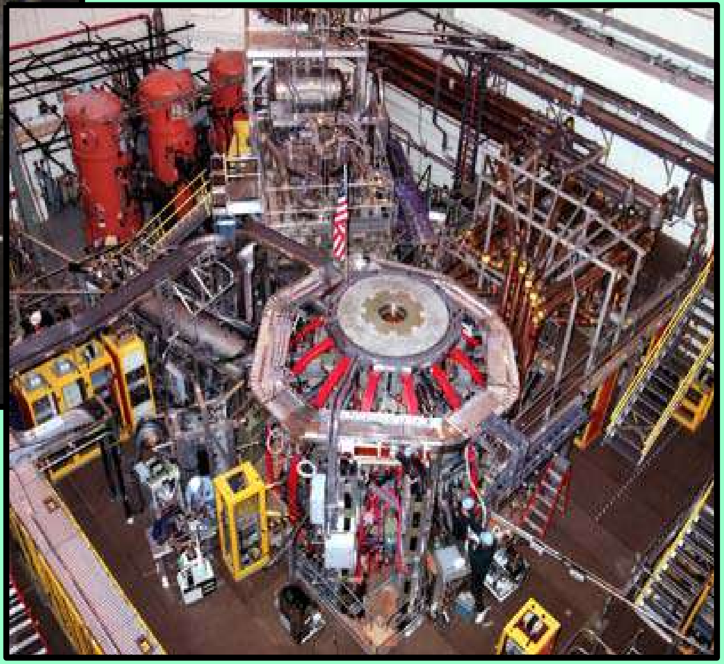


Nuclear Power

- **Fusion Reactors** (not yet sustainable)

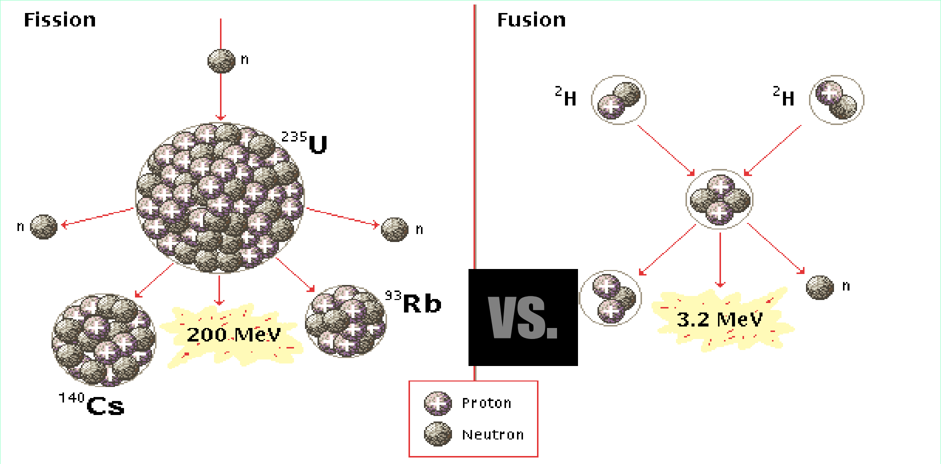
Tokamak Fusion Test Reactor

National Spherical Torus Experiment



Nuclear Power

FISSION



FUSION

- ^{235}U is limited
- danger of meltdown
- toxic waste
- thermal pollution

- Hydrogen is abundant
- no danger of meltdown
- no toxic waste
- not yet sustainable

- Dangers Nuclear Decay –
  - nuclear waste
  - Nuclear radiation
- Benefits –
  - Medical
    - Cancer Treatment
    - Radioactive tracers
  - Nuclear Power

Other Uses of Radiation

– Irradiated Food (p.676)

– Radioactive Dating (p.683)

– Nuclear Medicine (p.692-693)

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- **# 1-10 Question & Answer**
- **#11-20 only Answer**
- **Answer on Separate sheet of paper for grade**