Topics

- Interactions involving neutrons
- Nuclear Fission
- Nuclear Reactors
- Nuclear Fusion

Interactions Involving Neutrons

- As neutrons are electrically neutral, they do not interact electrically with electrons
- Rate of neutron induced reactions increase as the neutron KE increases
- When a neutron is absorbed by atomic nuclei of matter - decays by nuclear forces

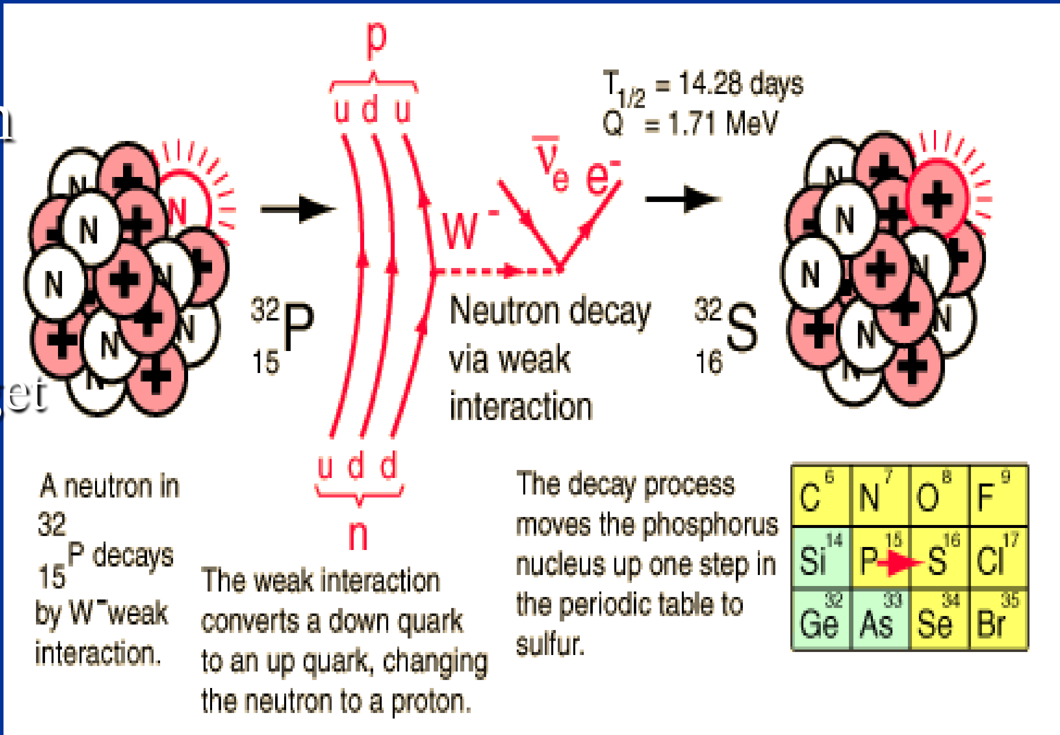
Interactions involving Neutrons

- Neutron Capture
- If a fast neutron (energy> 1MeV) travels through matter – collides with other nuclei
- Loses KE with each collision
- If this KE becomes low – neutron is absorbed by a nucleus
- The nucleus becomes unstable (for a very short time) and emits gamma radiation to stabilize

$$ {}_{0}^{1}n + {}_{Z}^{A}X \rightarrow {}_{Z}^{A+1}X^{*} \rightarrow {}_{Z}^{A+1}X + \gamma $$

Interactions Involving Neutrons

- Neutron Capture $${}^{1}_{0}n + {}^{A}_{Z}X \rightarrow {}^{A+1}_{Z}X^{*} \rightarrow {}^{A+1}_{Z}X + \gamma$$
- The product nucleus is radioactive
- Decays by beta emission
- Rate of capture depends on:
  - Type of atoms in the target matter
  - Energy of the incident neutrons



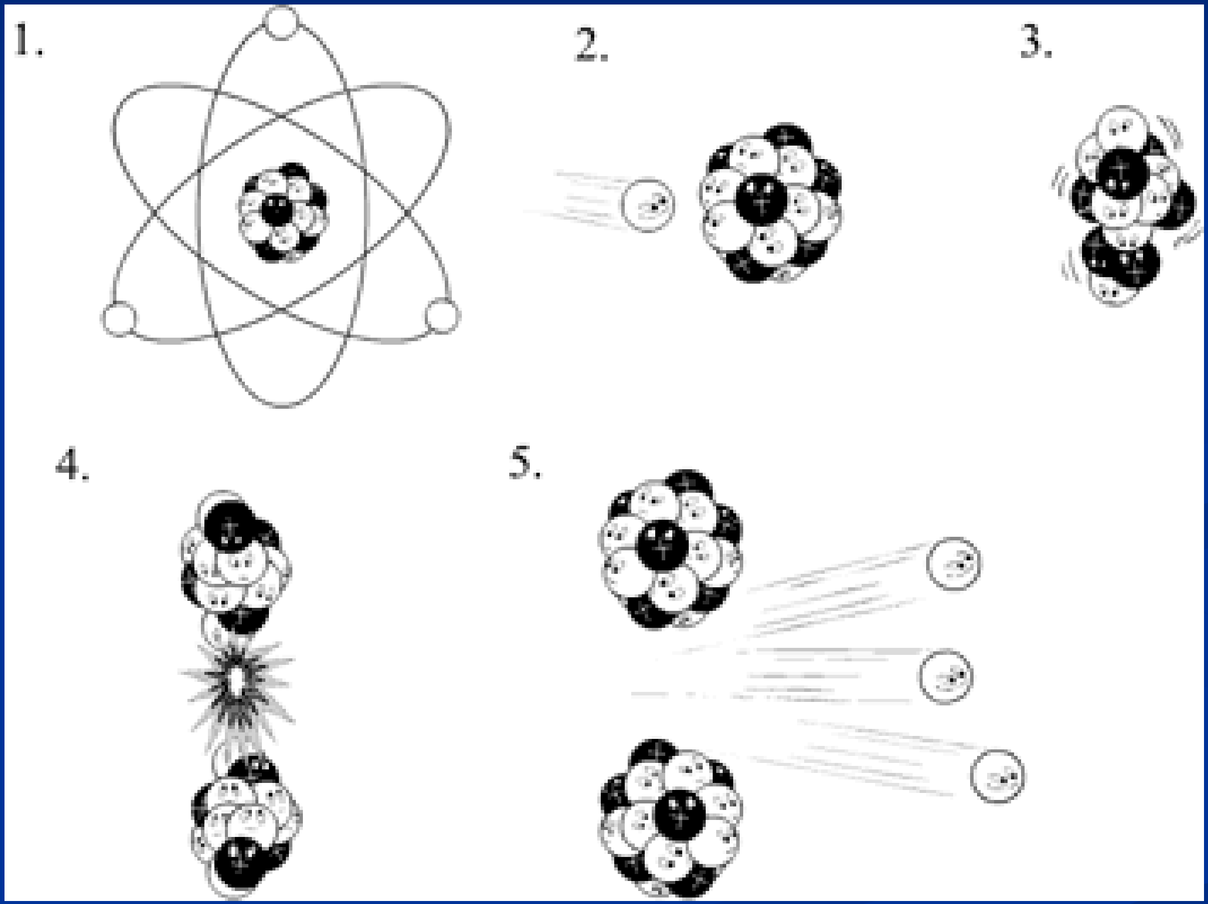
Moderators

- Materials in which the elastic collision between the atoms and neutrons dominate
- They slow down the neutrons effectively
- As the rate of capture increases with decrease in the neutron energy, the material should have low capture tendency
- Moderator nuclei should have low mass
- ……which have abundance of hydrogen (paraffin & water are 2 examples)

Moderators

- Fermi discovered that when some elements were bombarded by neutrons, new radioactive elements were produced.
- He predicted that neutron would be a good projectile. As it is uncharged, it would not experience Coulomb's force while approaching the nucleus
- Neutrons become thermal neutrons
- They are in thermal equilibrium with the moderator material
- As the RMS speed of the thermal neutrons is 2800 m/s, they have a high probability of being captured
- Compare that speed with the speed of the incident neutron whose kinetic energy is of the order of several MeV
- The process is called thermalistation

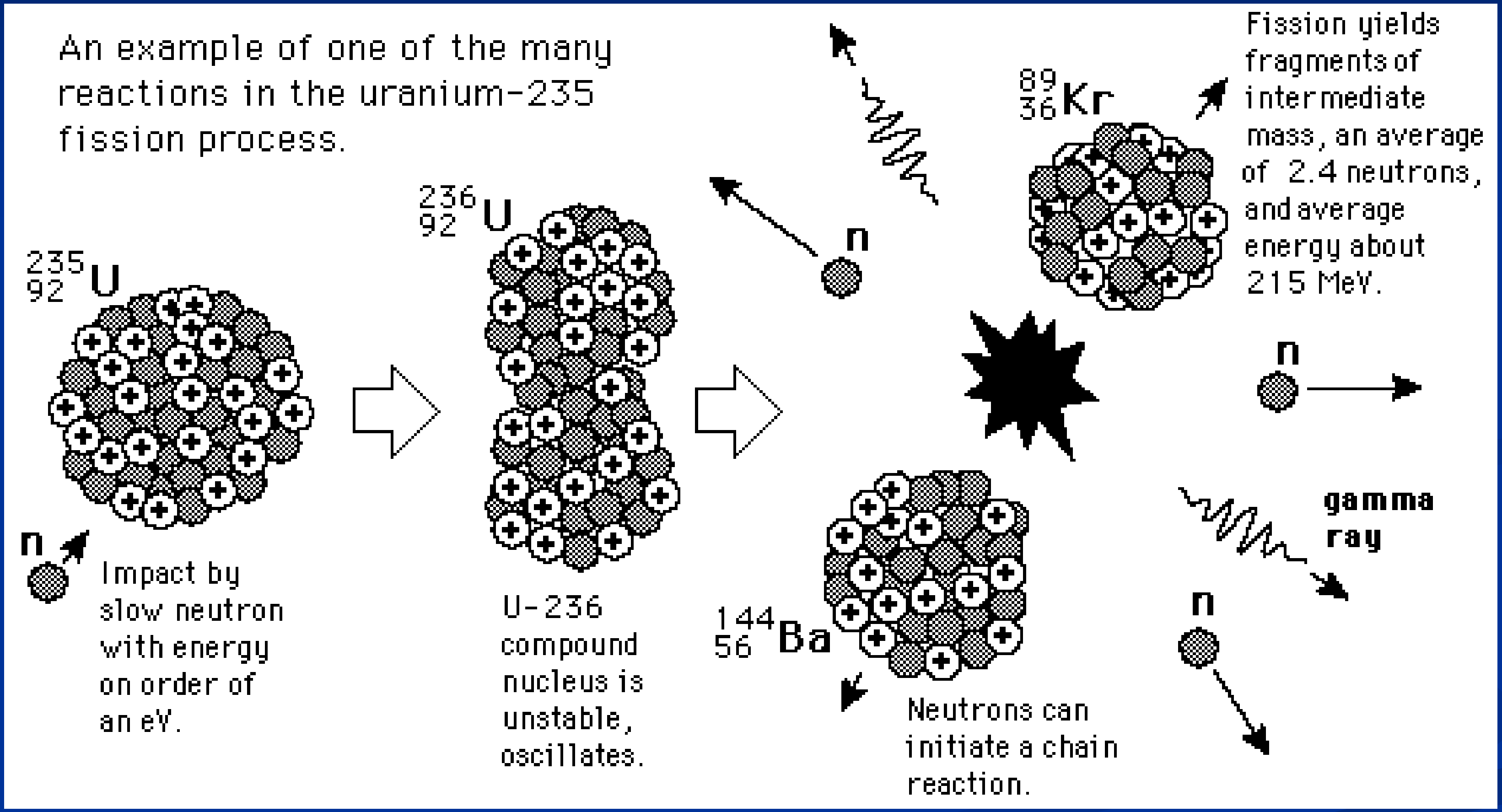
Nuclear Fission



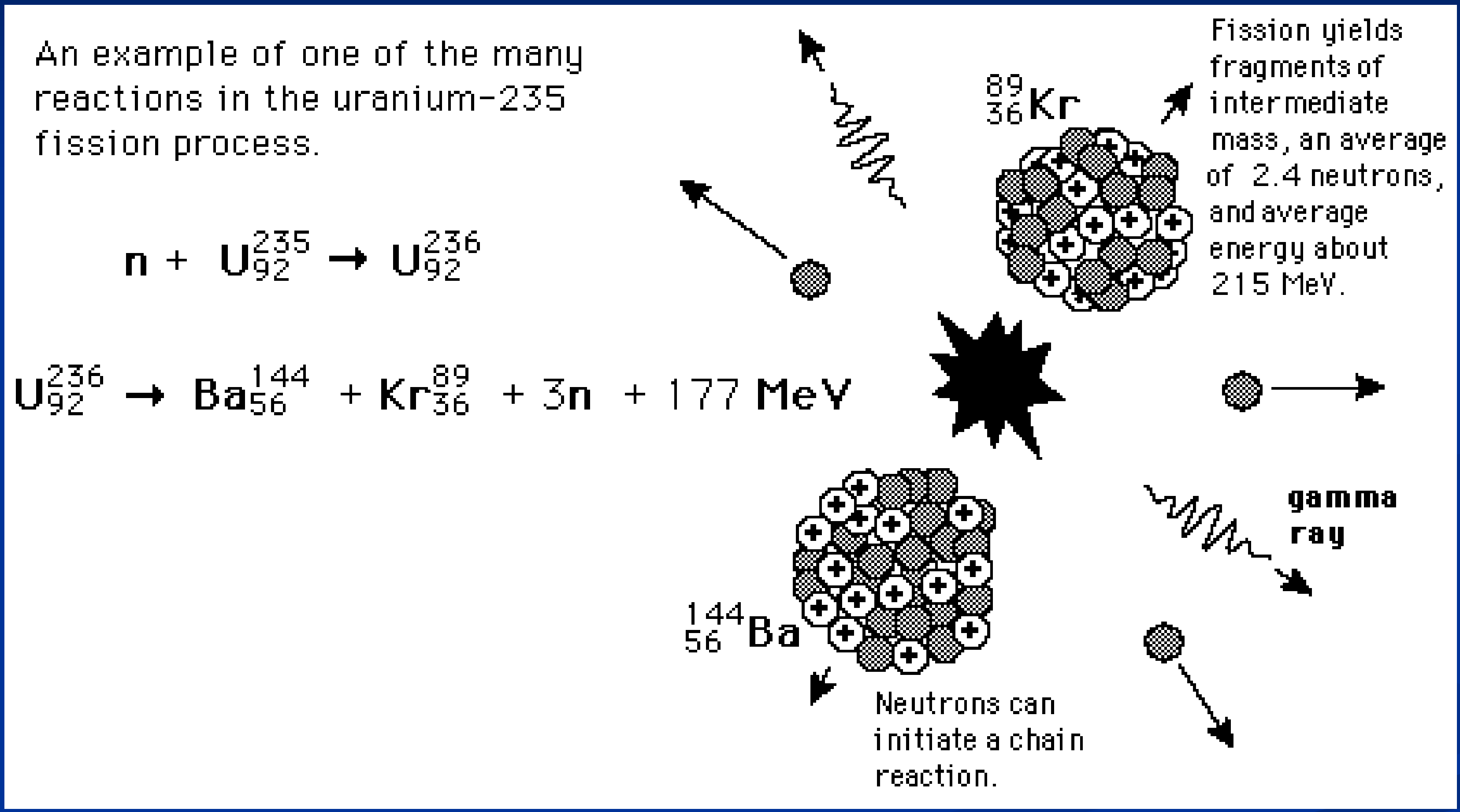
Nuclear Fission

- When a U-235 nucleus absorbs a thermal neutron, it produces a compound nucleus of U-236
- This nucleus undergoes fission, splitting into two fragments

Nuclear Fission



Nuclear Fission



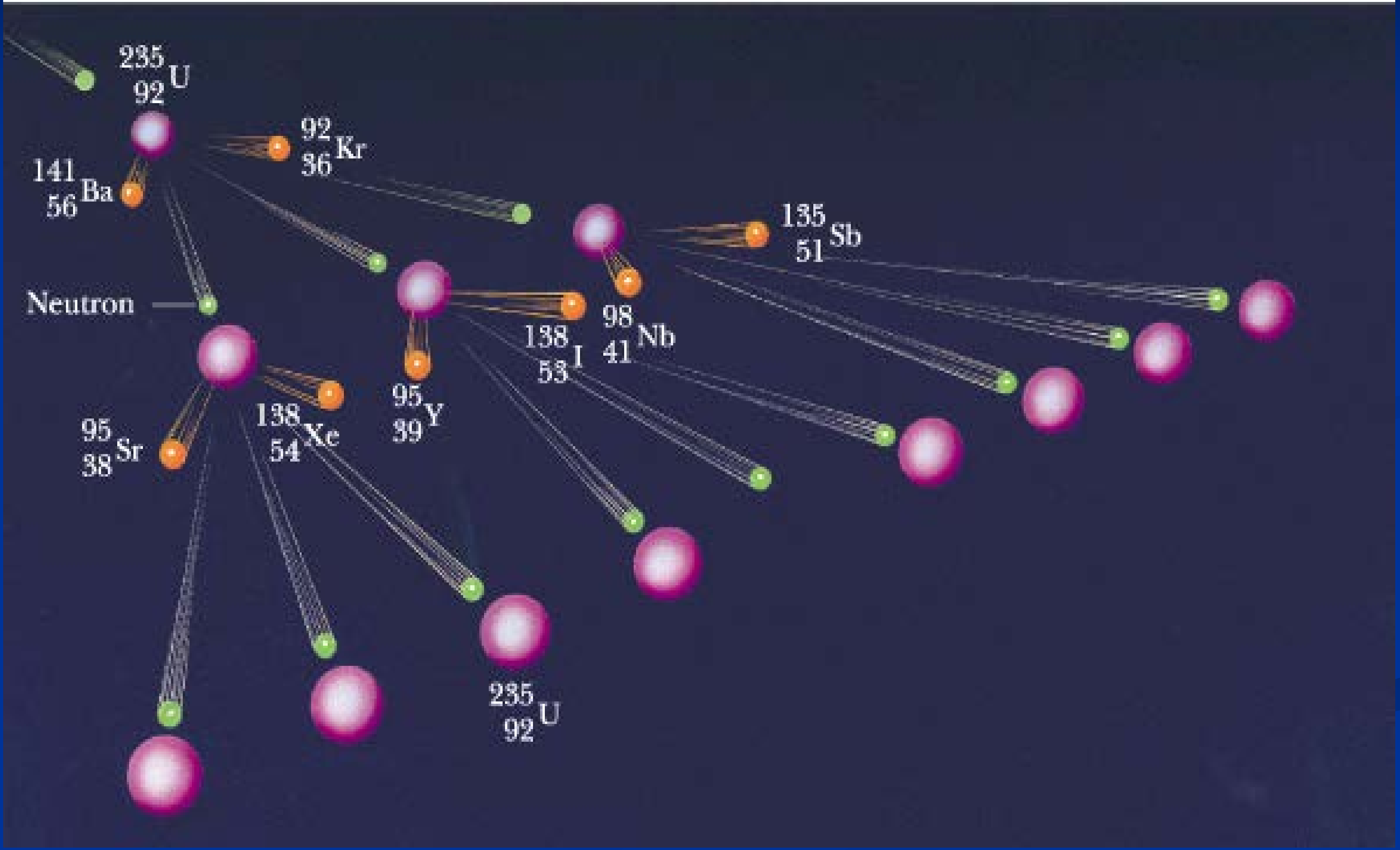
Nuclear Fission (Chain Reaction)

- If an least one neutron from U-235 fission strikes another nucleus and causes it to fission, then the chain reaction will continue
- If the reaction will sustain itself, it is said to be "critical", and the mass of U-235 required to produced the critical condition is said to be a "critical mass”
- A fission chain reaction produces intermediate mass fragments which are highly radioactive and produce further energy by their radioactive decay

Nuclear Fission (Chain Reaction)

- Some of them produce neutrons, called delayed neutrons, which contribute to the fission chain reaction.
- The probability for fission with slow neutrons is greater
- If the neutrons from fission are moderated to lower their speed, a critical chain reaction can be achieved at low concentrations of U-235

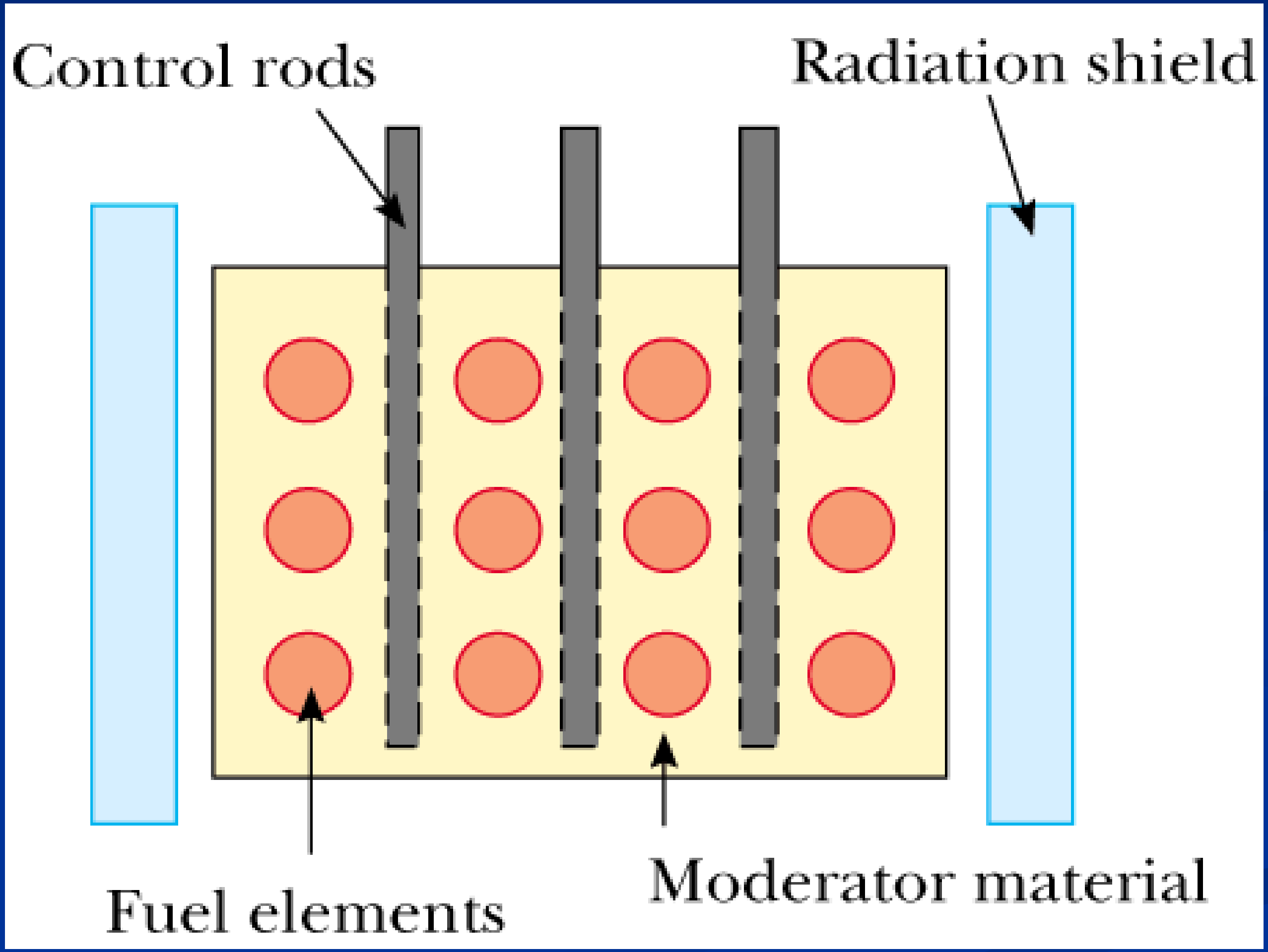
Nuclear Reactors



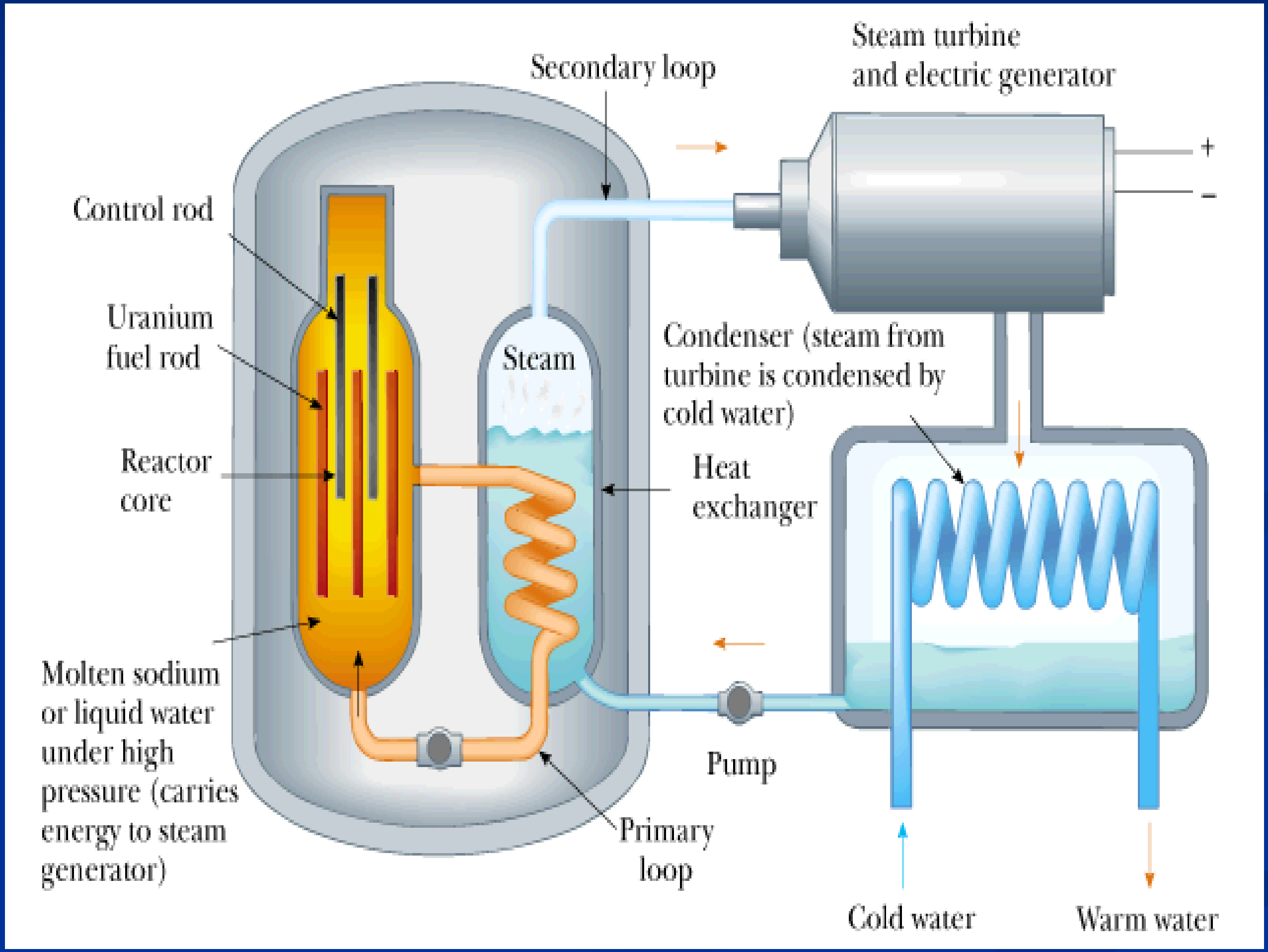
Nuclear Reactors

- Reproduction Constant K:
  - Average number of neutrons from each fission event that causes another fission event
- For normal fission reaction, K = 2.5
- Less because of several factors
- K = 1 gives a self-sustained chain reaction – reactor is called critical
- K < 1, the reactor is sub critical – reaction dies out
- K>1, the reactor is supercritical and a un-stoppable reaction occurs

Nuclear Reactors



Nuclear Reactors

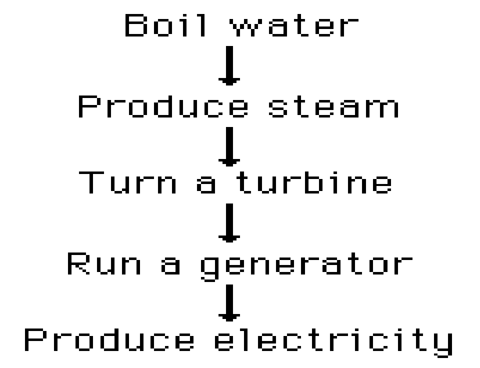


Canada uses heavy-water moderated reactors

U.S. uses light-water moderated reactors

Nuclear Reactors

- Current uses of nuclear energy must rely on nuclear fission, a less-than-ideal energy source, since nuclear fusion has yet to be harnessed for electricity generation. The heat from the nuclear fission is used to:



- This usually done in a Boiling Water Reactor (BWR) or a Pressurized Water Reactor (PWR), but there are other options such as the fast breeder reactor

Nuclear Fusion

- Opposite of nuclear fission
- Energy will be released if two lighter nuclei combine to form a larger nucleus, a process is called nuclear fusion
- This process is hindered by Coulomb repulsive forces
- The Coulomb barrier is broken by raising the temperature of the material until the particles have enough energy (Sun…)

$$ {}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + e^{+} + \nu $$

$$ {}^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + \gamma $$

$$ {}^{1}_{1}H + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + e^{+} + \nu $$

$$ {}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{1}H + {}^{1}_{1}H $$