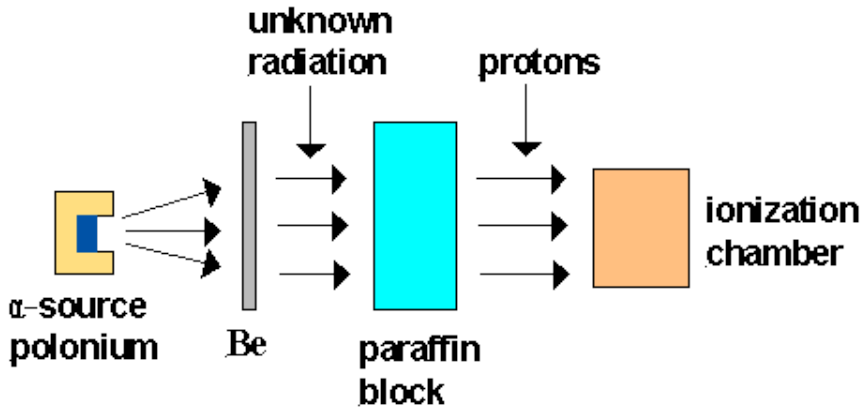
9.8.D
Artificial Transmutations

Year 12 Physics

9.8 – Quanta to Quarks

Chadwick's Discovery of the Neutron

- Alpha particles caused beryllium to produce an unknown radiation thought to be gamma photons
- Chadwick showed by conservation of momentum and energy that they had to have a much larger mass
- Chadwick calculated the mass and confirmed Rutherford's prediction of the existence of neutrons in the nucleus

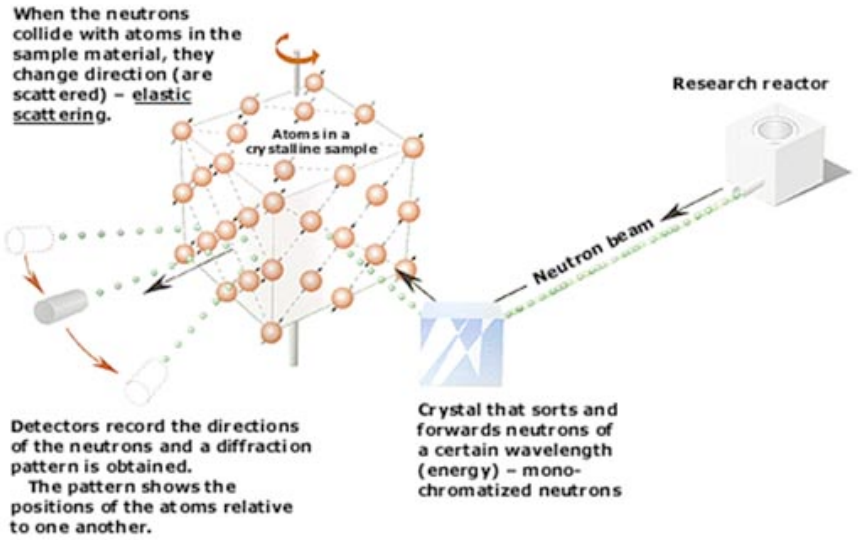


Schematic of the Joliots' Experiment

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{12}_{6}C + ^{1}_{0}n$$

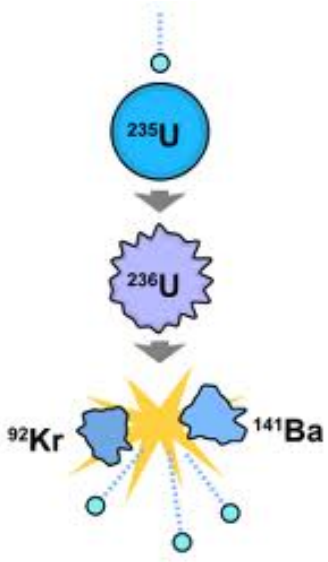
Neutron Scattering

- Neutrons can be used to probe the inner structure of solids
- They are neutral and can therefore penetrate deeply into matter.
- The de Broglie wavelength of thermal neutrons is comparable to the spacing of the atoms in an atomic lattice.
- The neutrons collide with atomic nuclei and scatter in directions determined by the neutron's wavelength and the structure of the material under study.
- From the diffraction patterns obtained, physicists can deduce the internal structure of the material.



Fermi and Fission

- After the discovery of the neutron which was large and uncharged, Fermi tried to extend the number of known elements through transmutation
- In 1934 he bombarded uranium-235 (Z=92) with neutrons expecting to produce an isotope of neptunium (Z=93)
- Two lighter nuclei were actually produced as fission products in an artificial transmutation

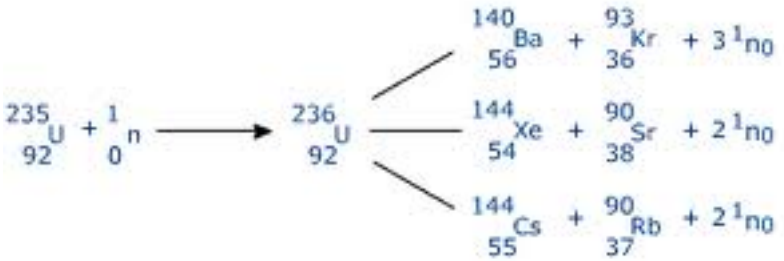


$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{93}Np + ^{0}_{-1}e + \bar{\nu}$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3^{1}_{0}n$$

Artificial Transmutations

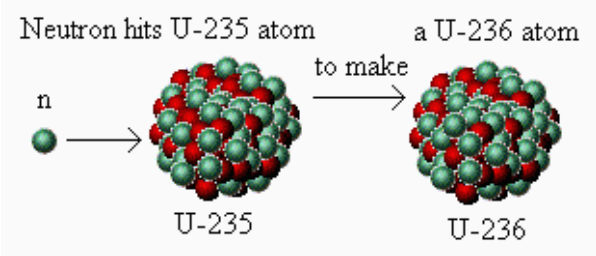
- Some nuclei can be made unstable by firing other particles at them.
- Fermi demonstrated this in 1934. Nowadays, nuclear reactors are used to bombard nuclei with neutrons
- Particle accelerators are used to bombard nuclei with charged particles

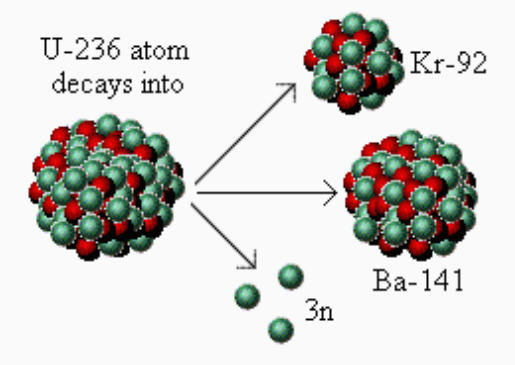


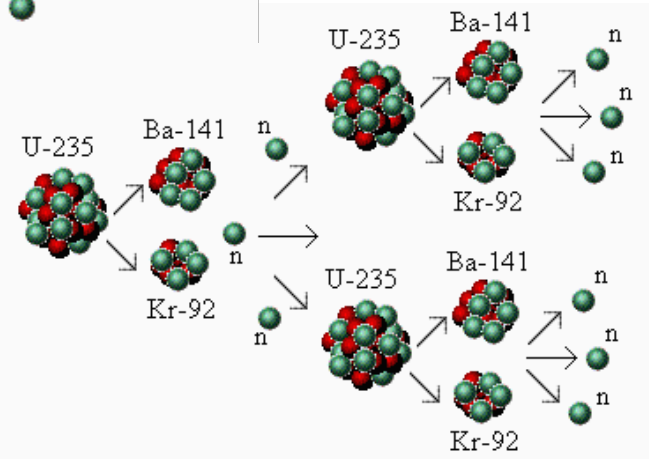
$$^{239}_{94}Pu + ^{4}_{2}He \longrightarrow ^{242}_{96}Cm + ^{1}_{0}n$$

Nuclear Chain Reactions

- Chain reactions occur when fission products cause further transmutation (fission)
- For fission to occur:
  - The fission material must be **larger** than a certain critical mass
  - **Slow** neutrons are better at causing fission (too fast and they escape without causing a fission).
  - The fission material must have enough atoms capable of undergoing fission

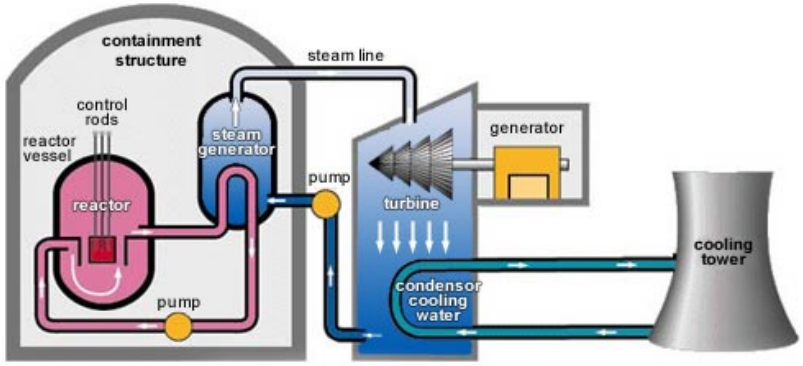






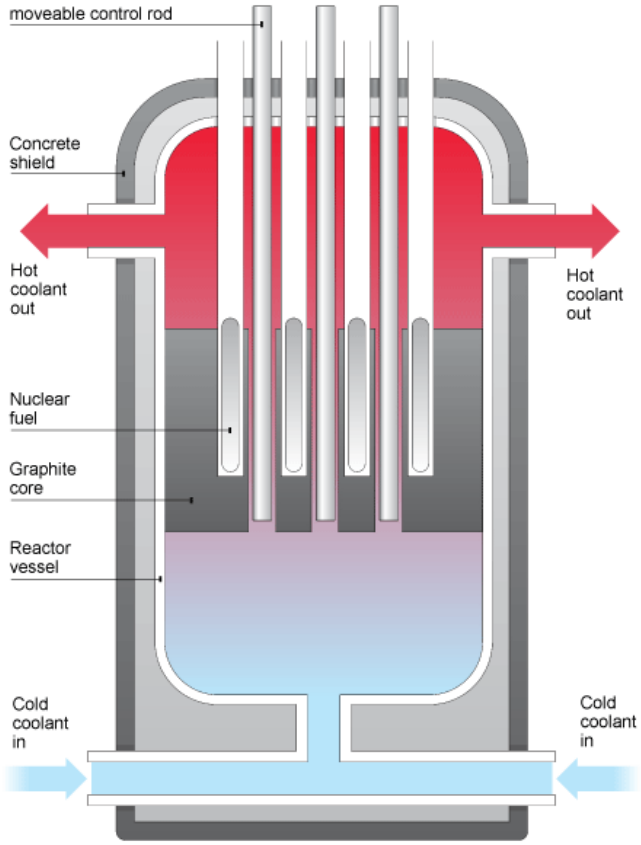
Nuclear Reactors

- Controlled chain reactions take place in nuclear reactors
- The heat energy produced is used to generate electricity
- Other reactors are used to make radioisotopes for medicine or industry
- These isotopes are usually made through neutron uptake



Nuclear Reactors

- **Nuclear fuel:** fissionable material such as uranium-235
- **Moderator:** Designed to slow neutrons (thermal) neutrons for uptake by fuel and made from graphite or heavy water (D_2O)
- **Control rods:** Absorb neutrons to slow chain reaction as needed
- **Coolant:** Removes heat from the reactor core



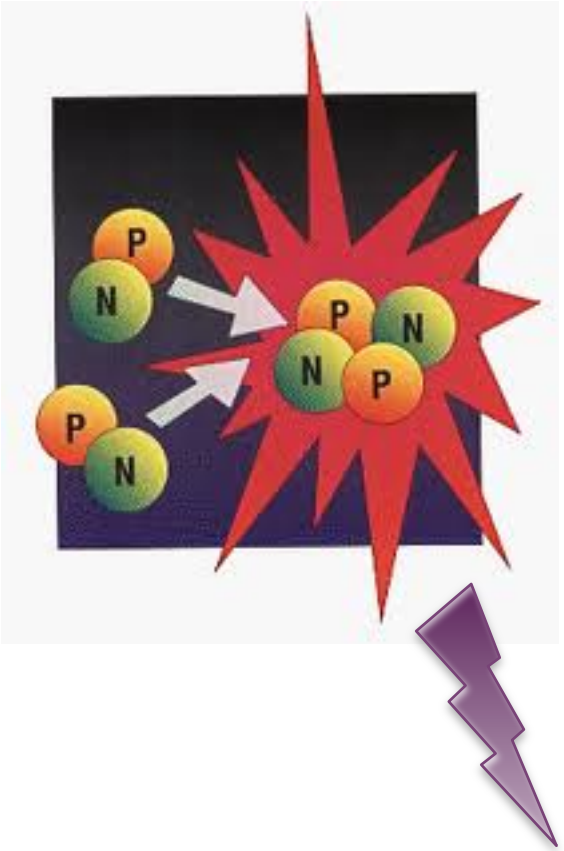
Unified Mass Units

- The unified atomic mass unit (u) is a small unit of mass used to express atomic masses
- It is defined to be 1/12 of the mass of one atom of carbon-12.
- 1 u = 1.66053886 x 10^{-27} kg
- 1 u = 931.5 MeV

Particle	Mass (u)
Electron, m_e	0.000549
Proton, m_p	1.007277
Neutron, m_n	1.008665
Hydrogen atom, m_H	1.007825

Binding Energy

- The mass of a nucleus is always less than the sum of the mass of each particle
- The binding energy is the amount of energy released when a nucleus is assembled from its component nucleons
- The binding energy is also the energy required to break the nucleus apart



Mass Defect

- Radioactive decay is an exothermic process and therefore produces energy at the expense of mass
- The energy comes from mass according to $E=mc^2$
- The mass of the products is always less than the reactants
- The difference is called **MASS DEFECT**
- 1 kg of mass is equivalent to 9×10^{16} J of energy.
- 1 u is equivalent to 931.5 MeV of energy.