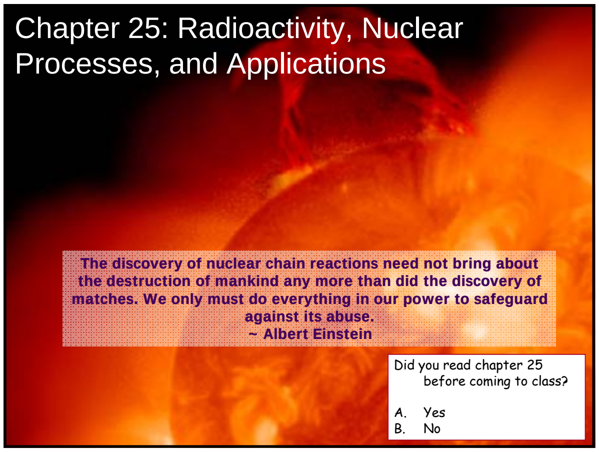


Chapter 25: Radioactivity, Nuclear Processes, and Applications

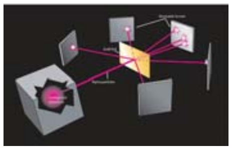
> **The discovery of nuclear chain reactions need not bring about the destruction of mankind any more than did the discovery of matches. We only must do everything in our power to safeguard against its abuse.**
> **~ Albert Einstein**

Did you read chapter 25 before coming to class?

A. Yes
B. No

What do we know about the nucleus?

- Rutherford discovered
  - Contains positively charged protons.
  - Held together by the Nuclear Strong Force.



James Chadwick and the discovery of the neutron

- Scientists in the early 1900's knew that there was too much mass in the nucleus for it to be composed only of protons.
- In the 1930's, Chadwick performed experiments with Beryllium emissions (neutrons) and showed that they were a neutral particle with a mass about the same as a proton. (Their presence could be identified by the momentum of recoiling charged particles)

Modeling the nucleus

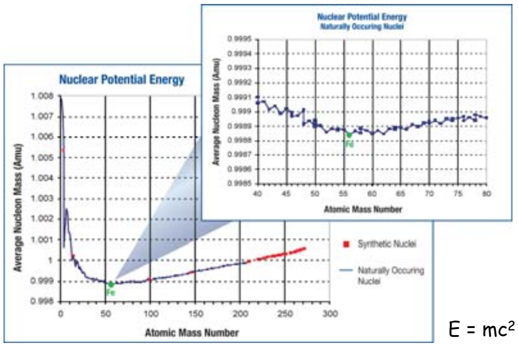
- All of the previously discovered rules still apply.
  - Electric force law – protons will repel each other.
  - Wave-particle duality – protons and neutrons will behave as waves of probability.
  - Pauli exclusion principle – only one proton (or neutron) can have each possible state.

Compare atomic and nuclear models

- Electron energy levels first determined experimentally by measuring discrete emission spectra.
- Rydberg recognized a pattern.
- This led to an understanding of the quantum behavior of electrons.
- Electron energies can now be calculated exactly using electric force laws and equations for wave behavior.

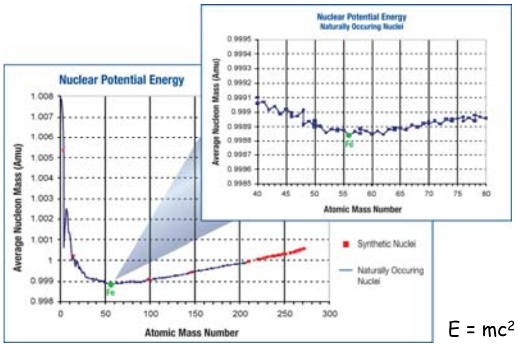
- Nuclear energy levels have been measured experimentally.
- Scientists are still looking for patterns.
- While there is a lot we do understand, there are still some holes.
- Because we still do not know the equation for the nuclear strong force, we cannot calculate exact values for proton and neutron energies.

Where does the mass go? Why does the graph go down so steeply at low atomic mass?



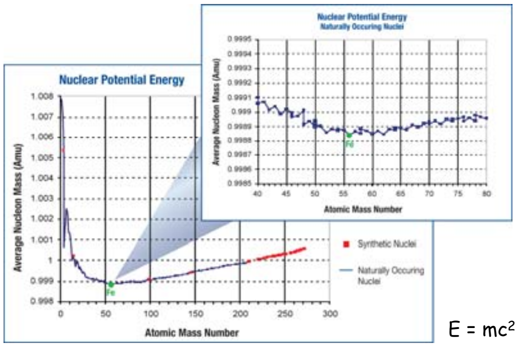
$E = mc^2$

Why would the graph increase at large atomic mass?



$E = mc^2$

The graph abruptly ends. What does this tell us about the range of the nuclear strong force?



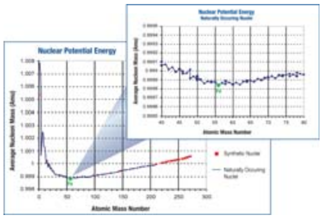
$E = mc^2$

So what is the equation for the nuclear strong force?

- We don't know.
- Here is what we do know:
  - It is much stronger than the electric force at small separations.
  - It is much weaker than the electrical force at large separations.
  - The nucleons are in specific energy levels and obey the exclusion principle

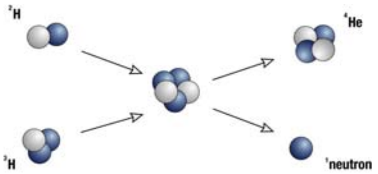
Nuclear energy

- How does the mass of a proton in a hydrogen atom compare to the mass of a proton in a helium atom?
- How do the nuclear potential energies compare?
- How do nuclear forces explain this?



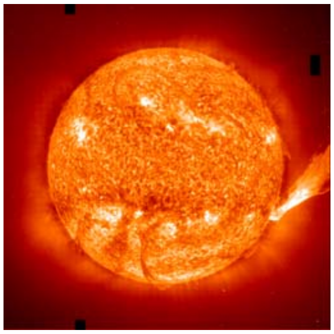
Fusion

- Combining two small nuclei to make a larger one gives off energy.
- Abundant fuel (in sea water) and large energy gain make this a very exciting possibility.
- The catch: Because nuclei are positively charged, you need either extremely hot reactants or large confining forces.
  - What forces do you have available for confinement?

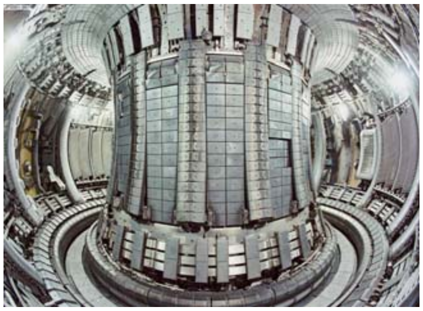


No confinement

Gravitational confinement

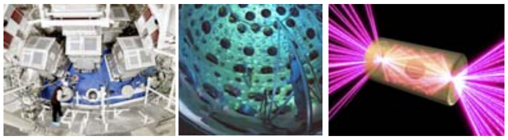


Confinement using magnetic fields: Tocamak



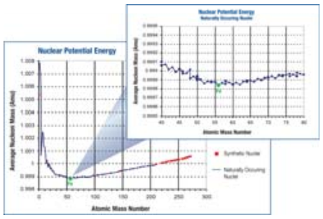
National Ignition Facility (Inertial Confinement)

- the facility is very large, the size of a sports stadium
- the target is very small, the size of a BB-gun pellet
- the laser system is very powerful, equal to 1,000 times the electric generating power of the United States
- each laser pulse is very short, a few billionths of a second



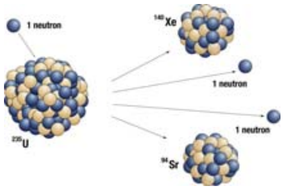
Another way to do nuclear energy

- How does the mass of a proton in a uranium atom compare to the mass of a proton in an iron atom?
- How do the nuclear potential energies compare?
- How do nuclear forces explain this?

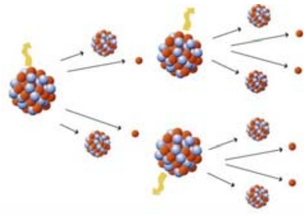


Fission

- Breaking one extremely large nucleus into two smaller ones gives off energy.
- Free neutrons from one fission can trigger another fission, creating a chain reaction.
- This reaction is easy to control simply by changing the number of neutrons that are absorbed by inert atoms.
- This reaction produces isotopes not normally found in nature.



Fission Process



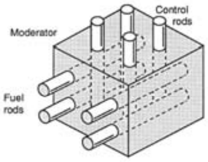
A chain reaction

Video Encyclopedia of Physics Demonstrations

MOUSETRAP "FISSION"

Playing Time: 1:03

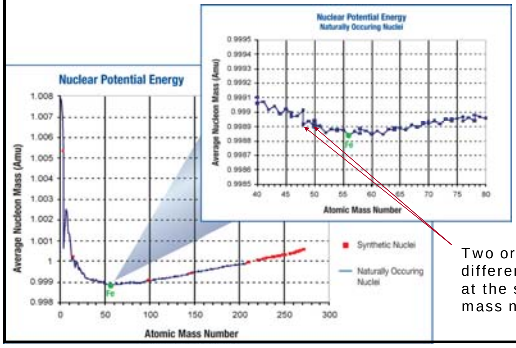
Fission Reactor



- Fissile material (fuel rods)
  - ^{235}U, ^{239}Pu
- Moderator
  - Slow neutrons down
- Control rods
  - Absorb extra neutrons
- Problems
  - radioactive waste
  - fuel is rare
  - fuel can be misappropriated for weapons
  - mistakes are costly

Current applications for fission reactors

When you look in more detail, what do you see? Why don't all possible isotopes occur naturally?



Two or three different nuclei at the same mass number

Missing isotopes

- We don't see something we would expect to see … not all combinations of protons and neutrons occur. We don't even find byproducts of naturally occurring fission. Why not?
- Nature favors the state with the most disorder.

Radioactive Decay

- The missing isotopes must change into atoms with less nuclear potential energy (mass).
- The energy will be released as heat.
- Any change must obey all of the laws

Radioactive decay

- Important laws
  - Conservation of mass-energy … The total mass-energy before is the same as the total mass-energy after the decay . Things decay into atoms with less mass so that energy can be released.
  - Conservation of Charge … the total number of positive - negative charges before and after the reaction must be the same.

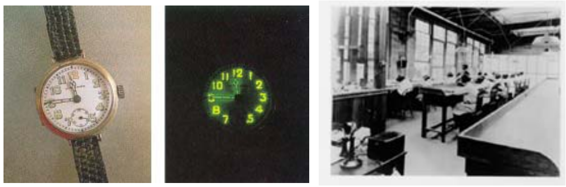
Radioactive decay

- Alpha decay – A nucleus emits 2 protons and 2 neutrons (a helium nucleus).
- Beta decay – A proton changes into a neutron or vice versa
- Gamma decay – Protons or neutrons shift energy levels and emit a photon.

Ionizing Radiation

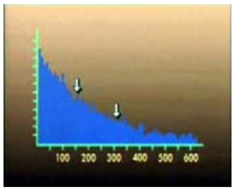
- The particles released in decay carry a lot of energy
  - often a million times typical molecular binding energies
- danger to living cells
  - damage RNA or DNA causing death of cells or mutations
  - disrupt metabolic processes
    - cells with high activity seem more prone to damage than others (cancer therapy)

Radium watches

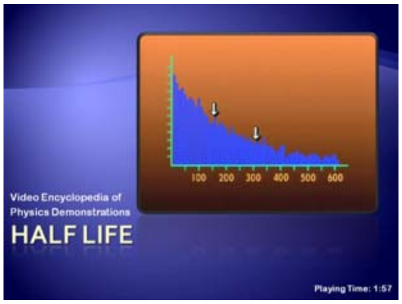


Half Life

- The half life is the time it takes half a sample of radioactive nuclei to decay
- Importance examples
  - ^{14}C --> ^{14}N + e + neutrino (half life of 5730 years)
  - ^{40}K + e --> ^{40}Ar + neutrino (half life of 1.3 billion years)



Half Life



Radioactive Dating

- Each half-life, half of the remaining atoms are left undecayed.
- One half-life--> ½
- Two half-lives--> ½ x ½ = 1/4
- Three half-lives--> ½ x ½ x ½ = 1/8
- If the original number of atoms is known, the age of the sample can be determined by the fraction of atoms left.
- This process is known as radioactive dating

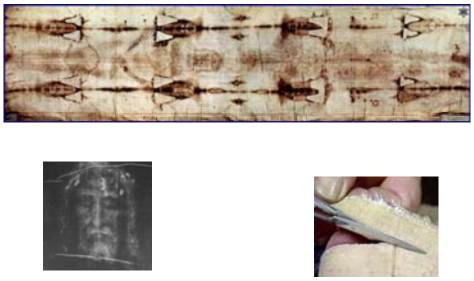
A sample of radioactive gas is produced. After 20 minutes, only ¼ of the original gas remains. What is the half life of the gas?

a) 5 minute
b) 10 minutes
c) 15 minutes
d) 20 minutes

A sample of radioactive material with a half-life of 6 hours sits for a day (24 hrs). How much of the original material remains?

a) A half
b) A quarter
c) An eighth
d) A sixteenth

A famous example: Shroud of Turin



Result: AD 1260 - 1390