Introduction to Nuclei – III

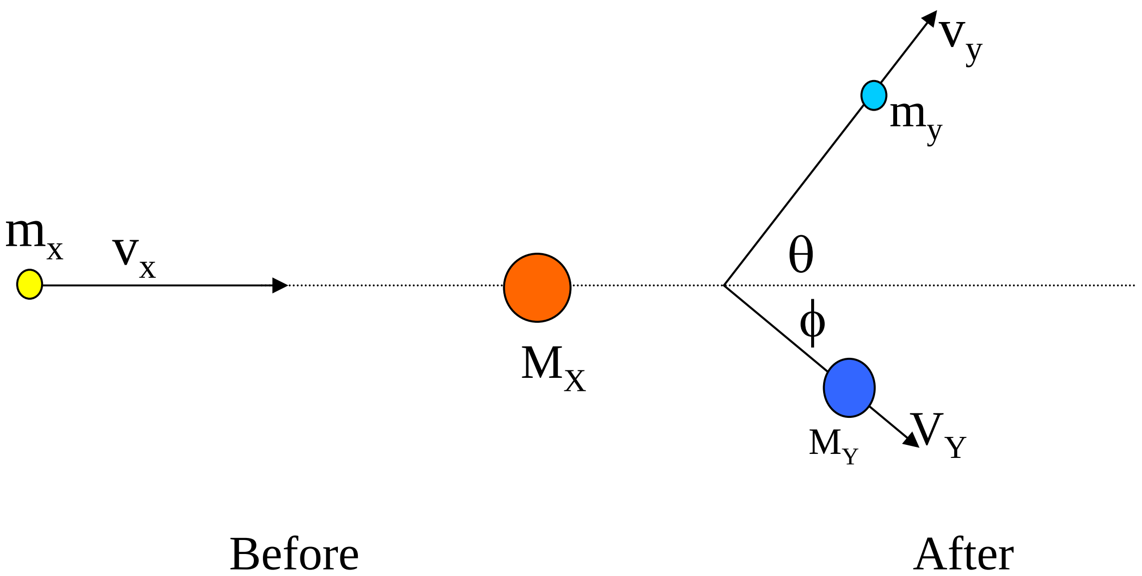
(Reactions with nuclei)

"If our discovery has a commercial future, that is an accident from which we must not profit. And if radium is to be used in the treatment of disease, it seems to me impossible for us to take advantage of that"

- Marie Curie

Nuclear Reactions (Notation)

$$x + X = Y + y \qquad X(x, y)Y$$



Nuclear reaction in laboratory coordinate system.

$$_0^1n + _7^{14}N \rightarrow _6^{14}C + _1^1H \qquad ^{14}N(n,p)^{14}C$$

Q Value of the reaction

$Q = (K_y + K_Y) - (K_x + K_X)$

= final kinetic energy – initial kinetic energy

or

$Q = (M_X + m_x)\,c^2 - (M_Y + m_y)\,c^2$

= Initial rest energy – final rest energy.

In most experiments the target is at rest and therefore $K_X = 0$.

If $Q > 0$ i.e. final kinetic energy is greater than initial kinetic energy the reaction is exothermic (exoergic).

If $Q < 0$ the reaction is endothermic (endoergic).

- An example of an exothermic reaction is

$$^{3}_{2}He + ^{1}_{0}n \rightarrow ^{3}_{1}H + ^{1}_{1}H + 764\,keV$$

- An example of an endothermic reaction is

$$^{4}_{2}He + ^{14}_{7}N \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

The Q-value for this reaction is Q = -1.19 MeV

- An endothermic reaction can proceed only if the incident particle energy exceeds the threshold energy E_{th}.

- Note that Q only supplies the energy required to balance the rest energy of the products. In order to conserve the momentum extra energy is required. Thus $E_{th} > Q$

Threshold Energy

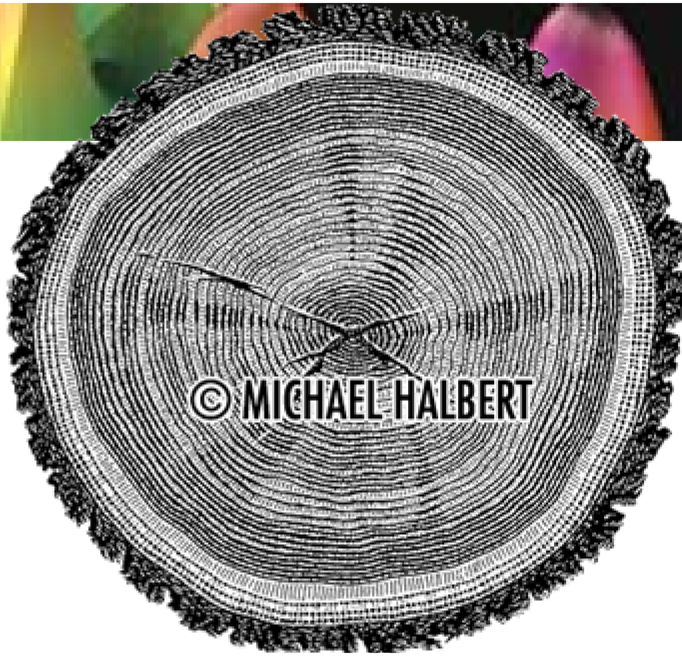
It requires certain minimum amount of energy to start an endothermic reaction

- The smallest value of projectile energy (bombarding energy) at which an endothermic reaction can take place is called the threshold energy for that reaction

$$KE_{min} = \left(1 + \frac{m}{M}\right)|Q|$$

  - m is the mass of the incoming particle
  - M is the mass of the target particle
- If the energy is less than this amount, the reaction cannot occur

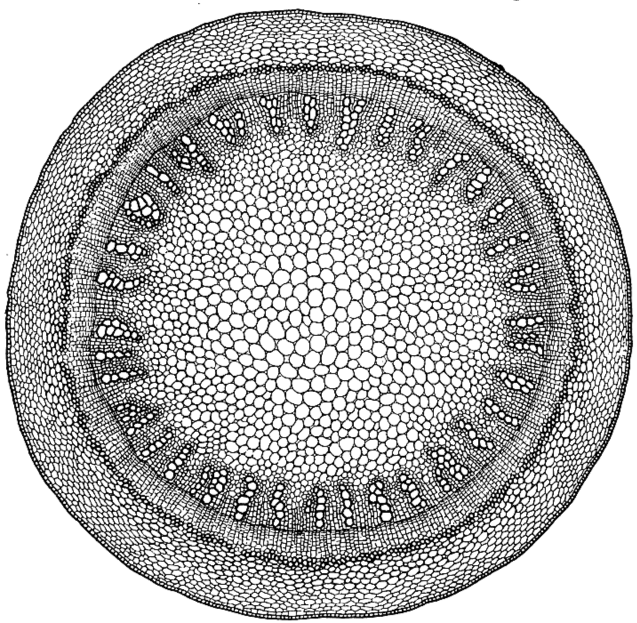
Reaction Cross Section

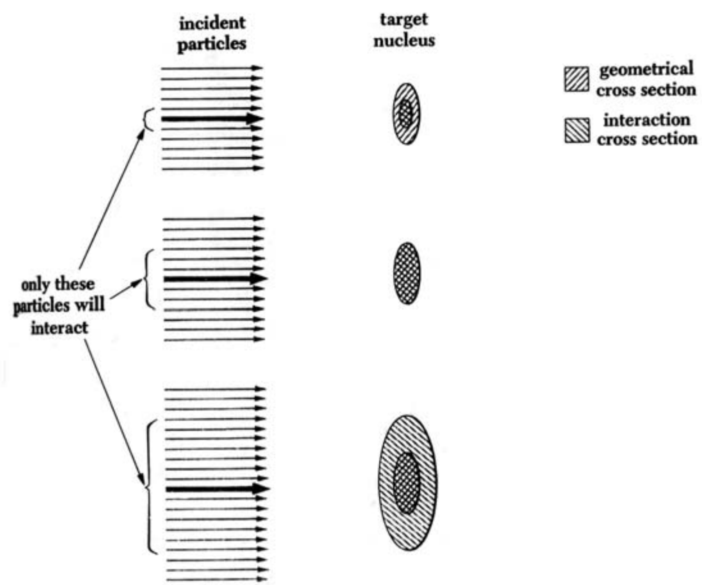


The cross section (σ) is a measure of the probability for a particular reaction to occur. It has the dimension of area.

A commonly used unit is the barn : 1 barn = 10^{-28} m^2

$$\sigma = \frac{\text{number of reaction particles emitted}}{(\text{number of beam particles per unit area})(\text{number of target nuclei within the beam})}$$

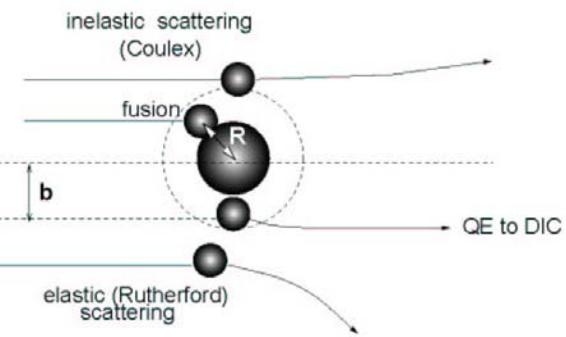




Types of Reactions

Nuclear processes can be divided into two categories :

Scattering : The incident particle and the emitted particle are the same
Reactions : The incident and the emitted particles are different



Scattering

- Elastic scattering
- In-elastic scattering

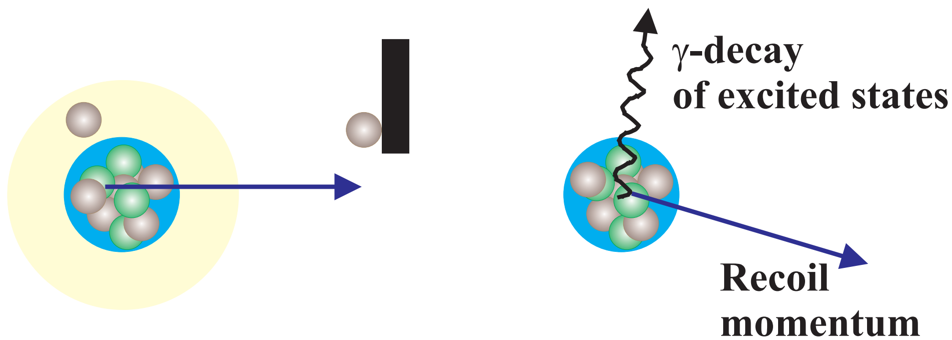
Reactions

- Direct reactions
- Compound nucleus reactions
- Resonance reactions

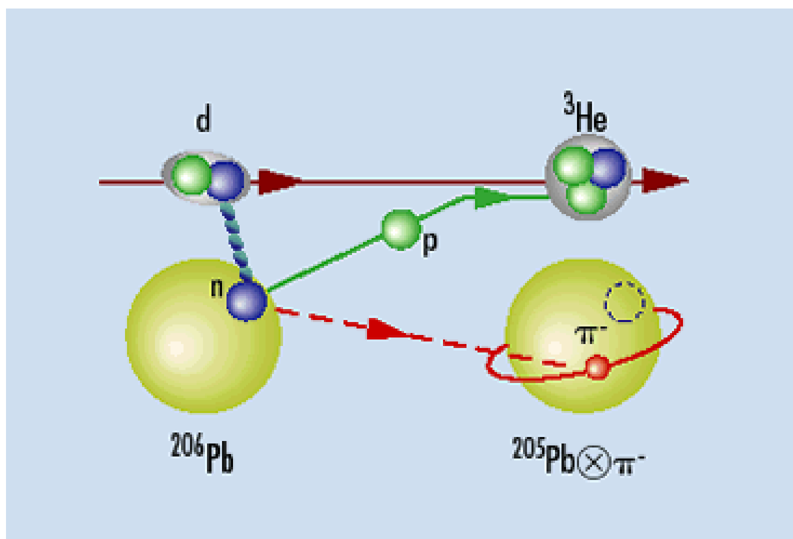
Types of Reactions

Reaction	What is Learned
Nucleon - nucleon scattering	Fundamental nuclear force
Elastic scattering of nuclei	Nuclear size and interaction potential
Inelastic scattering to excited states	Energy level location and quantum numbers
Inelastic scattering to the continuum	Giant resonances (vibrational modes)
Transfer and knockout reactions	Details of the Shell Model
Fusion reactions	Astrophysical processes
Fission reactions	Properties of Liquid-drop Model
Compound nucleus formation	Statistical properties of the nucleus
Multifragmentation	Phases of nuclear matter, Collective Model
Pion reactions	Investigation of the nuclear "glue"
Electron scattering	Quark structure of nuclei

Knockout & Transfer Reactions



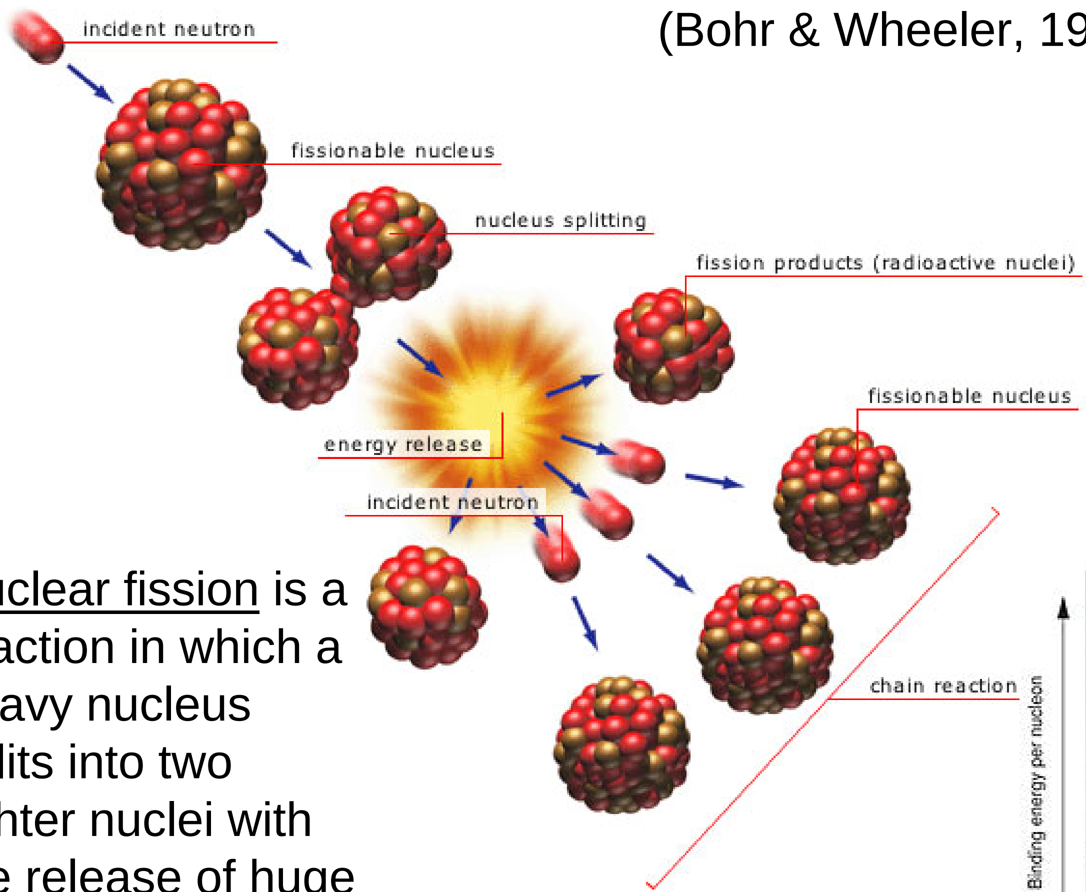
Knockout reaction

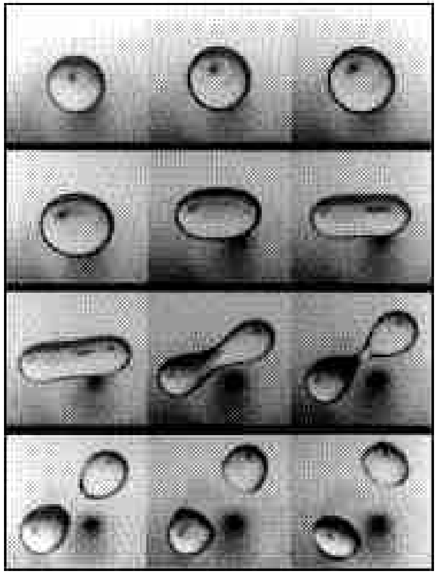


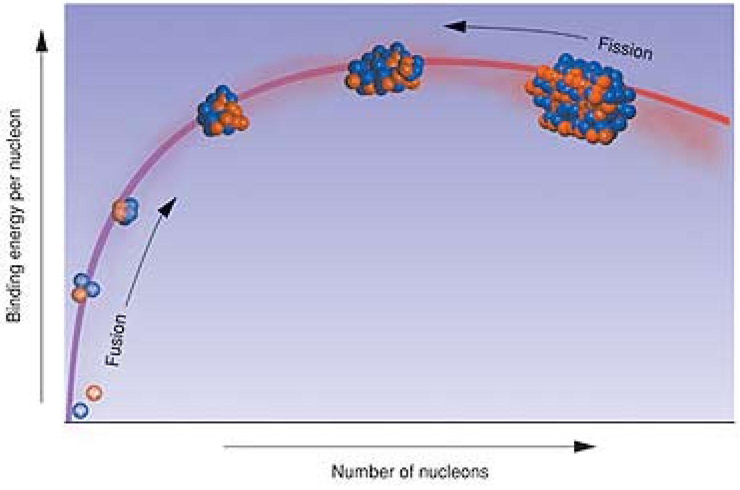
Transfer reaction

Fission Reactions

Liquid drop picture of fission
(Bohr & Wheeler, 1938)

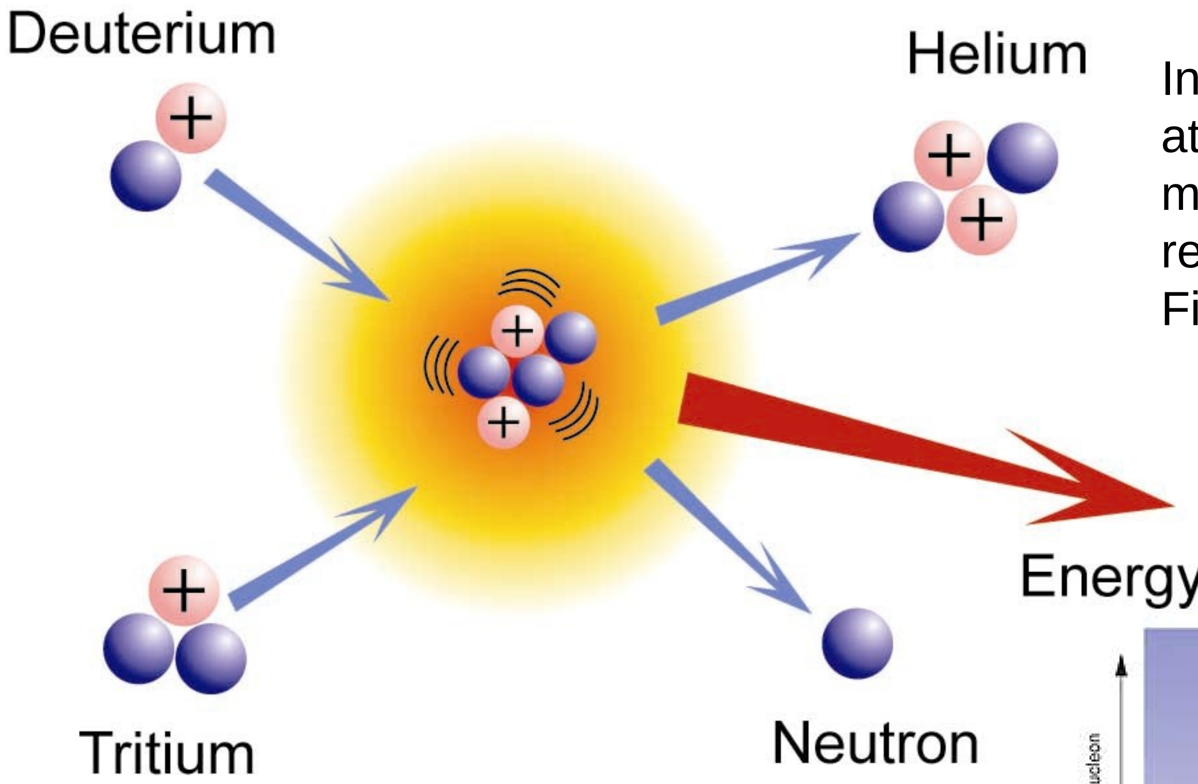






Nuclear fission is a reaction in which a heavy nucleus splits into two lighter nuclei with the release of huge amount of energy

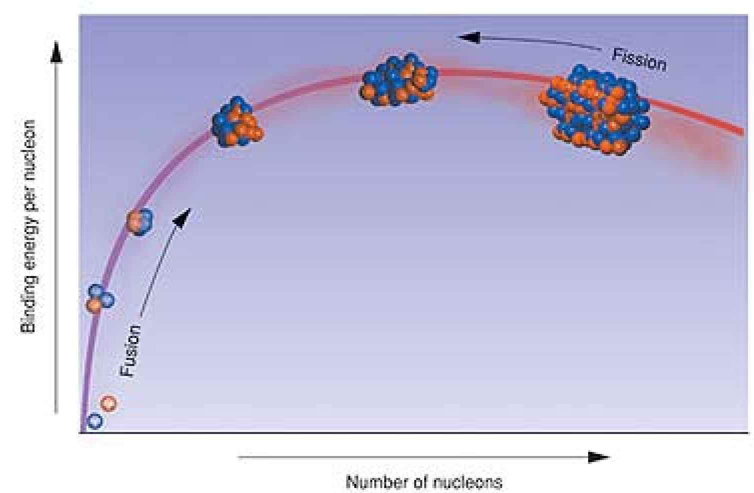
Fusion Reactions



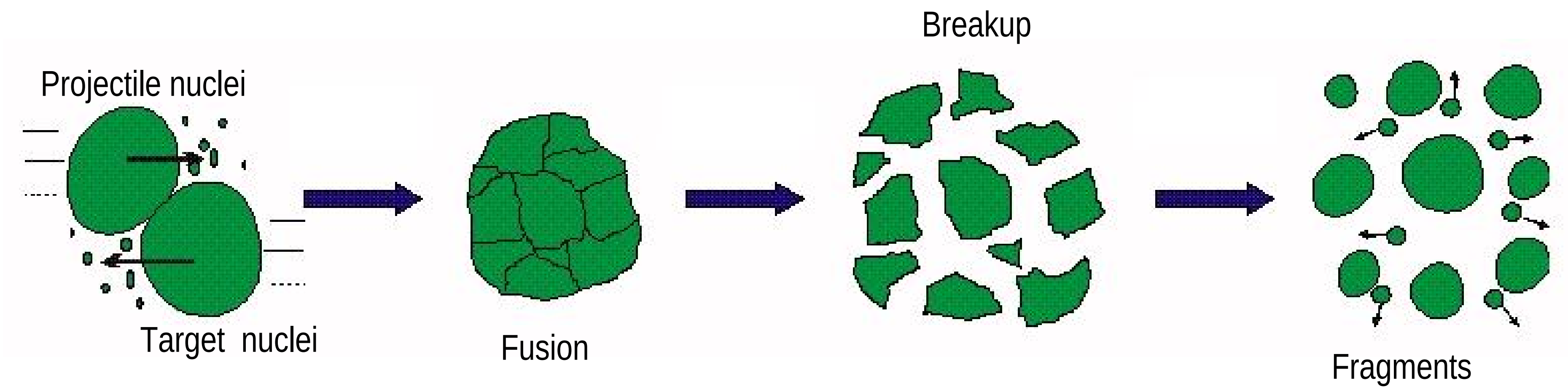
In Nuclear Fusion the nuclei of atoms fuse together, causing much more energy being released than in Nuclear Fission.

This is the process which powers the Sun.

Energy is released due to a difference in mass between He atom and the sum of the Deuterium and Tritium atoms



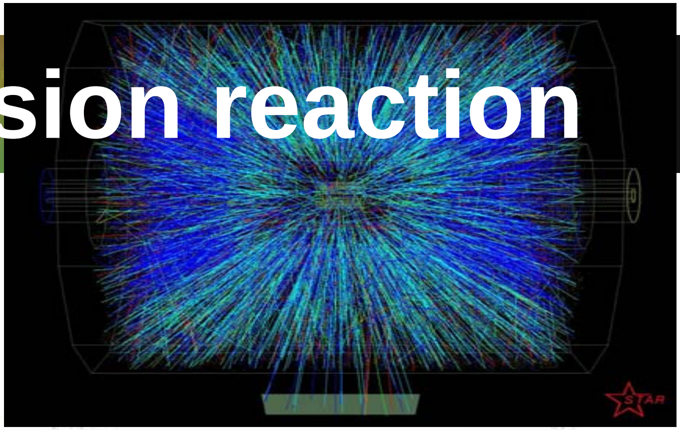
Multifragmentation Reactions

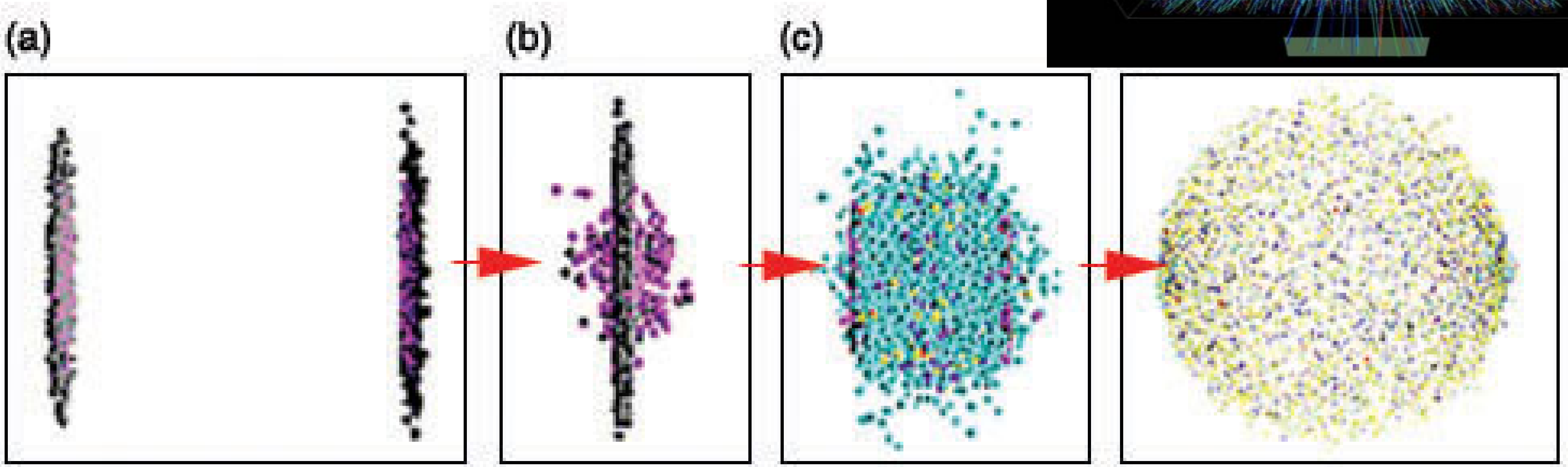


Multifragmentation is a process in which two nuclei collide to form a highly excited composite system, which then expand to low density and breaks into several fragments

Relativistic heavy ion collision reaction

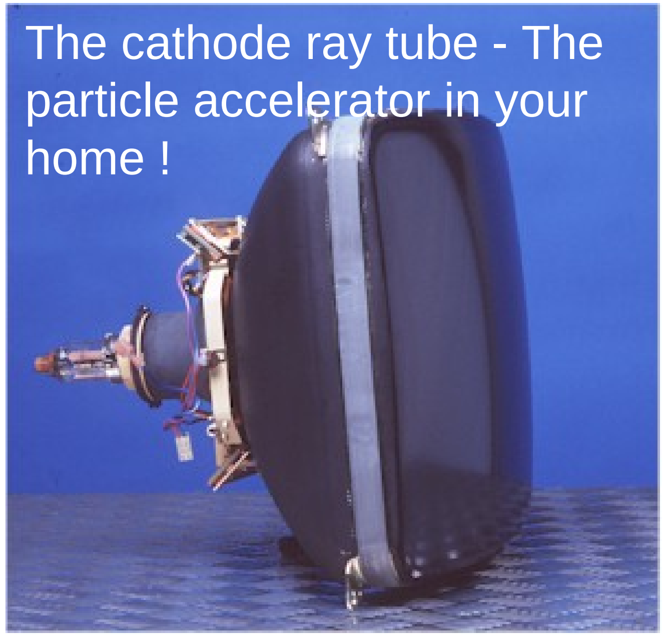
Probing the quark structure of nucleon by colliding two heavy nuclei at relativistic speed



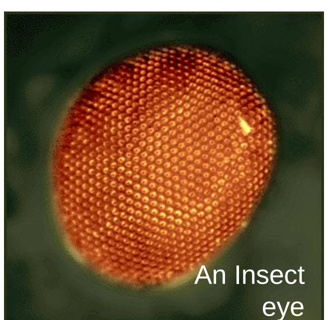


Two gold nuclei approach one another at almost the speed of light. Traveling at relativistic speeds causes them to look flat rather than spherical. (b) As the two nuclei collide and pass through each other, some of the energy they had before the collision is transformed into intense heat and new particles. (c) If conditions are right, the collision liberates the quarks and gluons in the nuclei to form a quark–gluon plasma.

Need for a charged particle accelerator

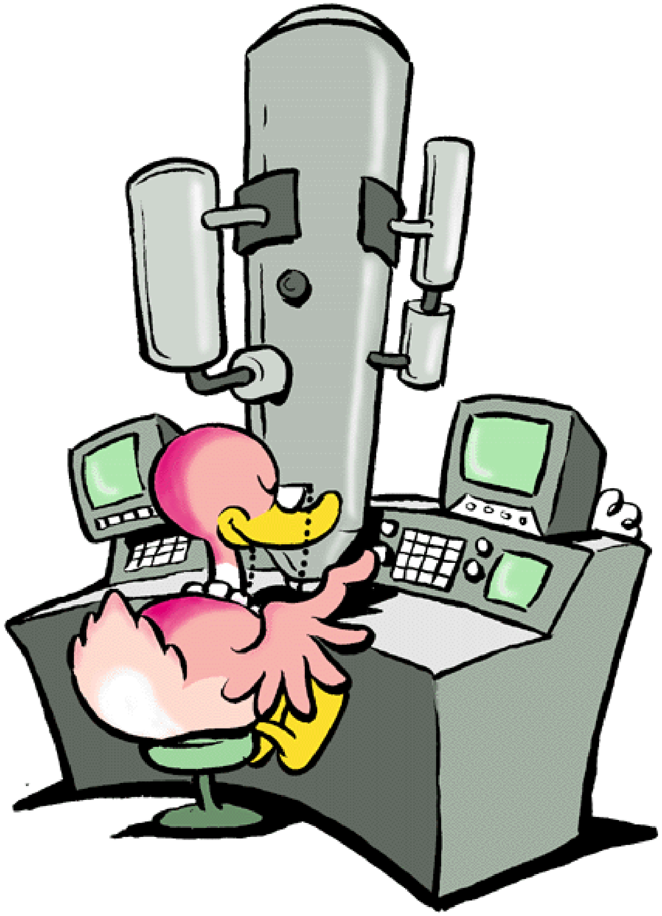


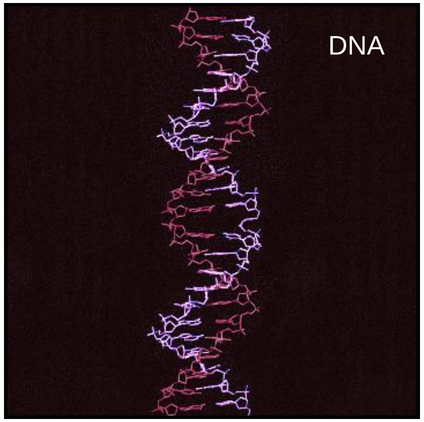
To create new particles and study the structure of atomic nucleus



Nuclear detectors and accelerators are to a nuclear physicist, what a microscope is to a biologist and a telescope is to an astronomer

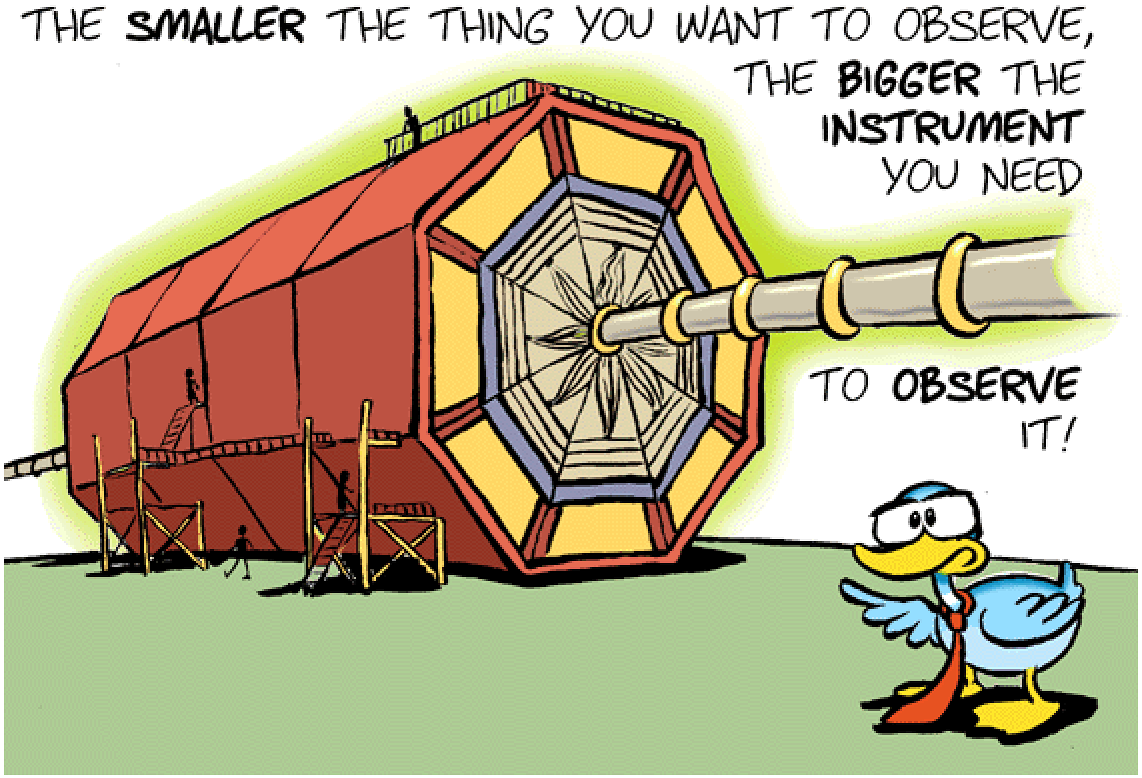
Electron microscopes take us even further, allowing us to see down to the level of atomic structure.





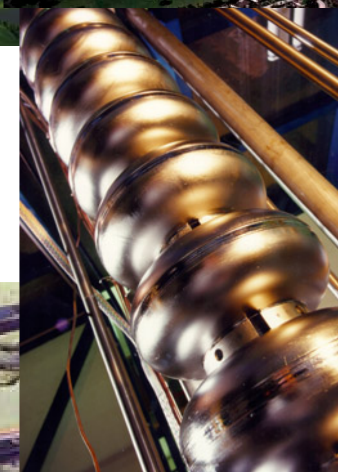
The reason electron microscopes are able to see things so small is because the high energy electrons they use behave like waves, just like light, but their wavelength is much smaller than that of light. The smaller the wavelength, the smaller the objects that can be resolved.

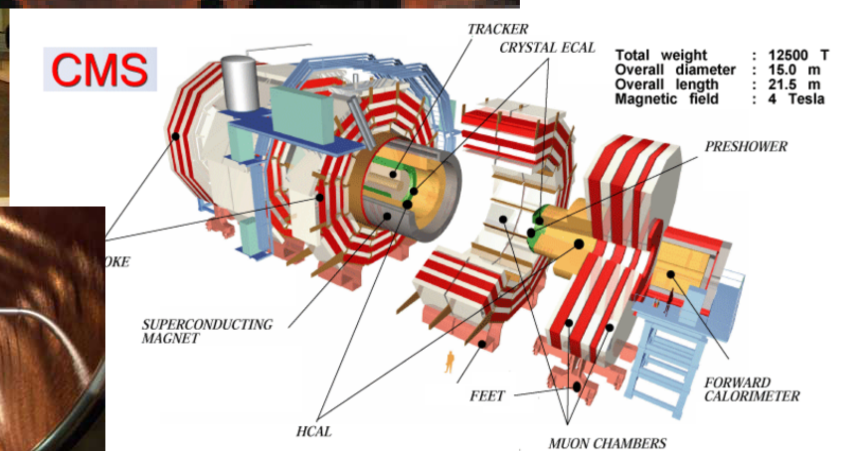
The smaller the object we want to study, the shorter the wavelength and the higher the energy of the probe we need to use.



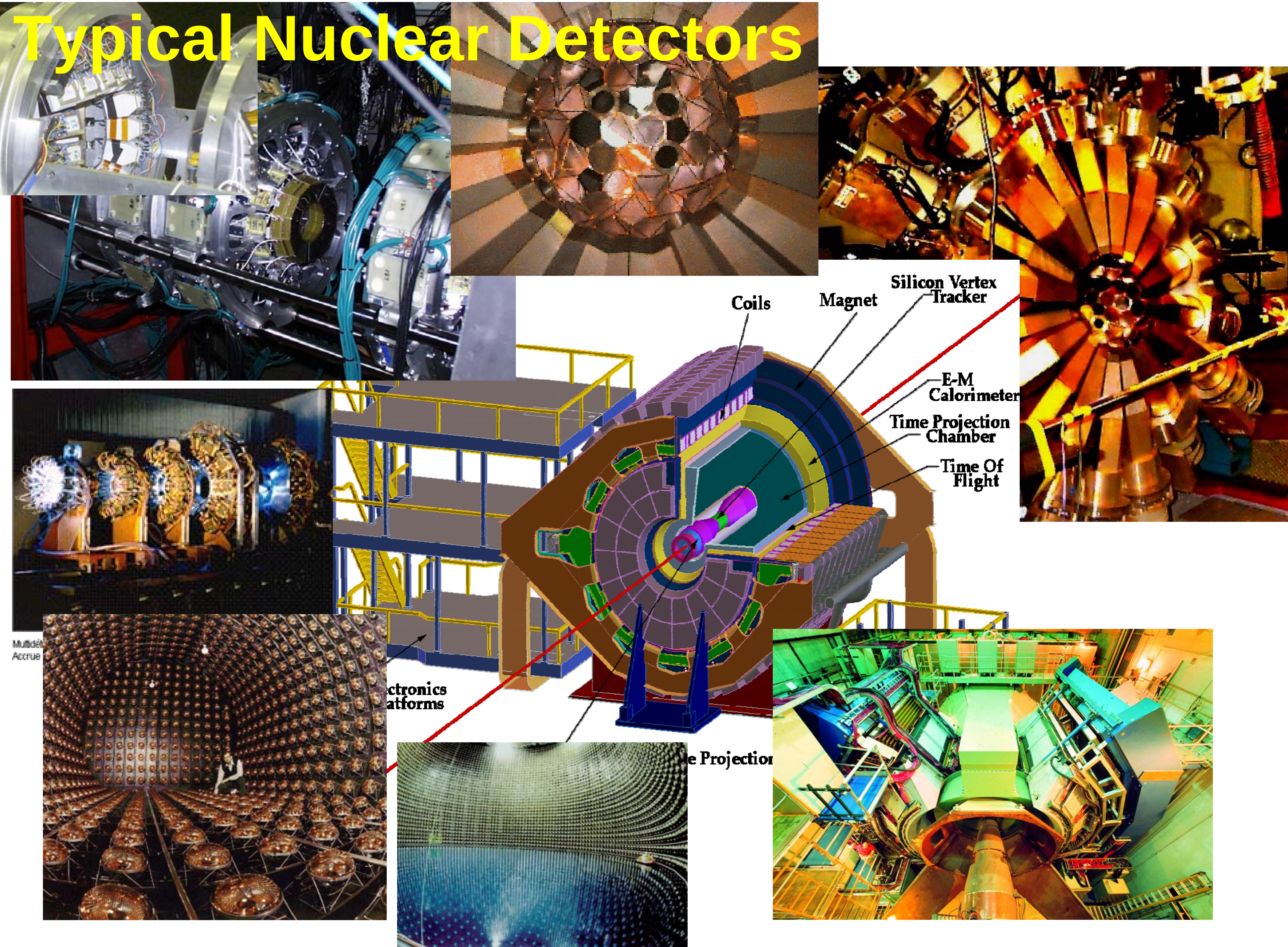
To study things smaller than atoms, physicists take particles like electrons and boost them up to very high energies in machines called particle accelerators.

Typical Particle Accelerators





Typical Nuclear Detectors



Why study Nuclear Physics ?

Practically all heavy elements are due to stars

We owe our very existence to SN explosions

The heaviest elements -- such as gold, lead and uranium -- were produced in a supernova explosion during the cataclysmic end of a huge star's life,

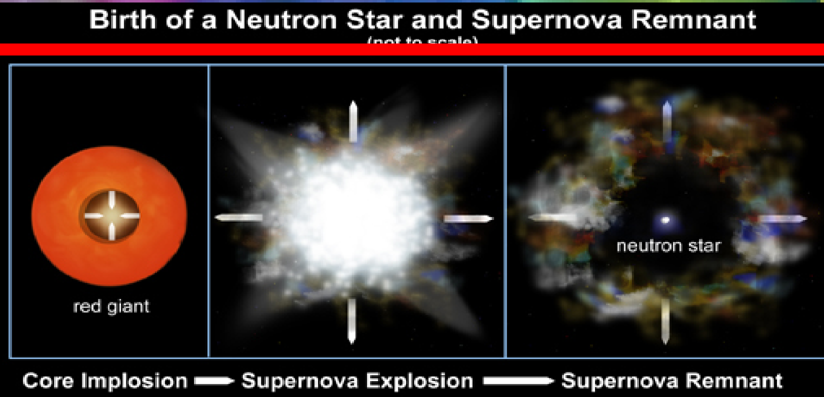
These elements were ejected into space by the force of the massive explosion, where they mixed with other matter and formed new stars, some with planets such as earth. That's why the earth is rich in these heavy elements. The iron in our blood and the calcium in our bones were all forged in such stars. We are made of stardust

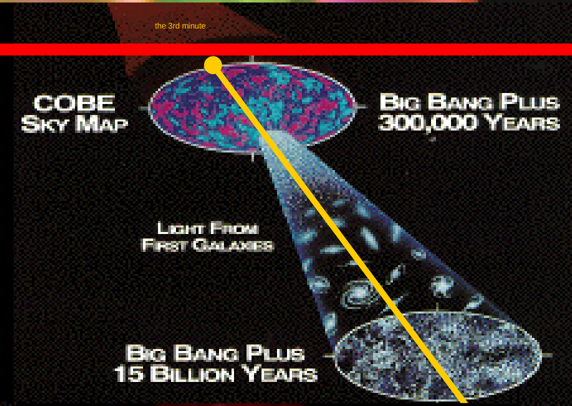
Why study Nuclear Physics ?

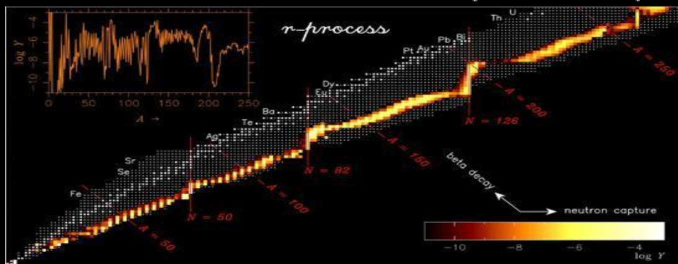
We are made of stardust—and so is all life as we know it. All the chemical elements on earth except hydrogen—including the ones in our bodies—have been processed inside stars, scattered across the universe in great stellar explosions, and recycled to become new stars, planets, and parts of us.

Stardust
Supernovae and Life -- The Cosmic Connection
John Gribbin and Mary Gribbin

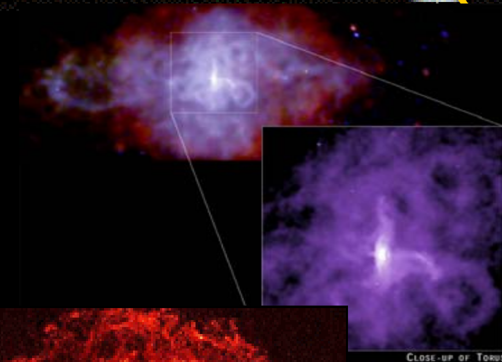
from Atomic Nuclei to Stars

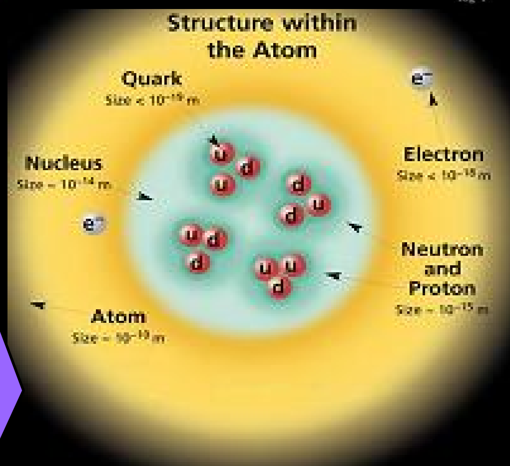


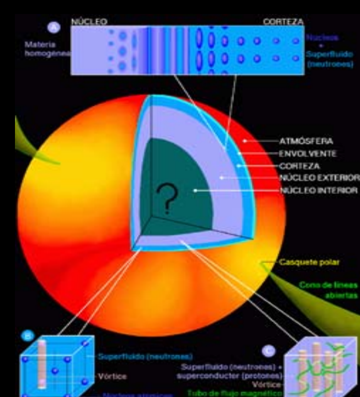


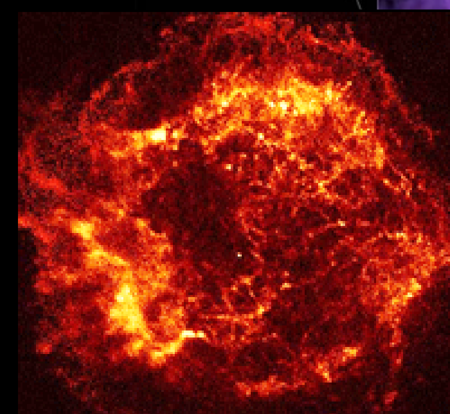


Nuclear Physics









Origin and fate of the elements in our universe

Origin of radiation and energy in our universe

Physics under extreme conditions

……….. *and that's the story of atomic nucleus*

"Imagination will often carry us to worlds that never were. But without it we go nowhere"

- Carl Sagan