



Introduction to Nuclei – III

(Reactions with Nuclei)

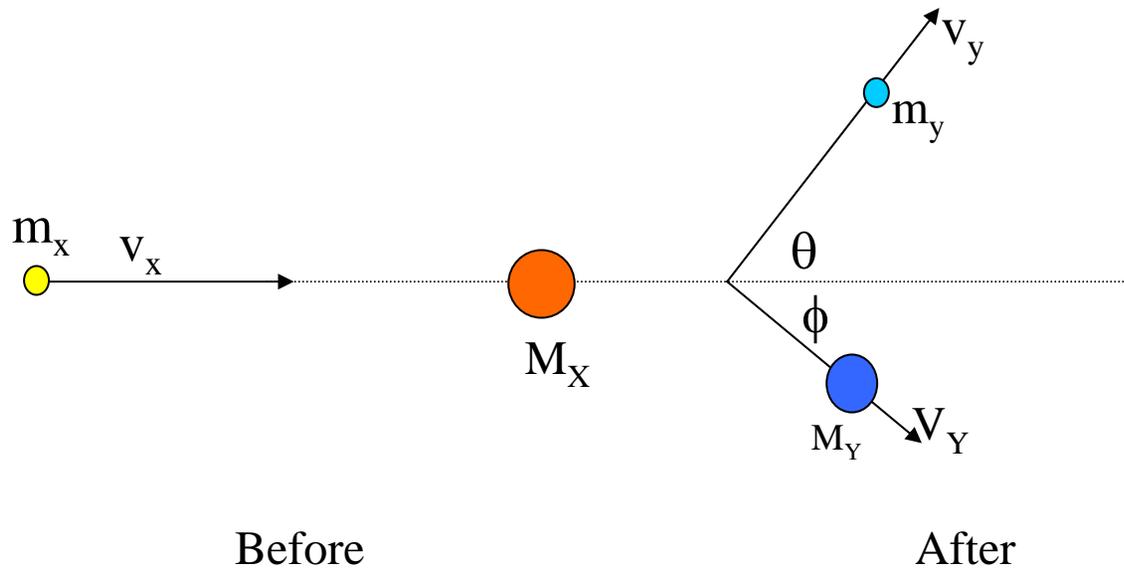
“If our discovery has a commercial future, that is an accident from which we must not profit. And if radium is to be used in the treatment of disease, it seems to me impossible for us to take advantage of that”

- Marie Curie

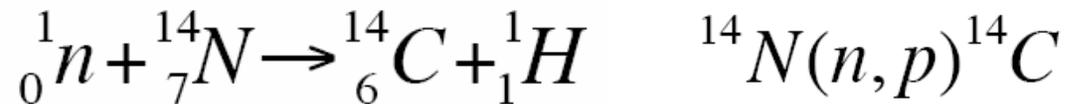
Nuclear Reactions (Notation)

$$x + X = Y + y$$

$$X(x, y)Y$$



Nuclear reaction in laboratory coordinate system.



Q Value of the reaction

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

= final kinetic energy – initial kinetic energy

or

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

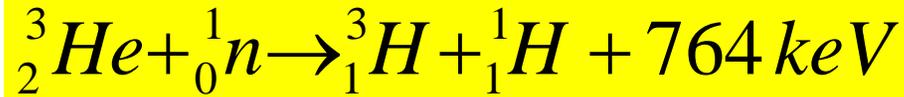
= Initial rest energy – final rest energy.

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**.

If $Q < 0$ the reaction is **endothermic**.

- An example of an exothermic reaction is



- An example of an endothermic reaction is



The Q-value for this reaction is $Q = -1.19 \text{ MeV}$

- 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 $E_{\text{th}} > Q$

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

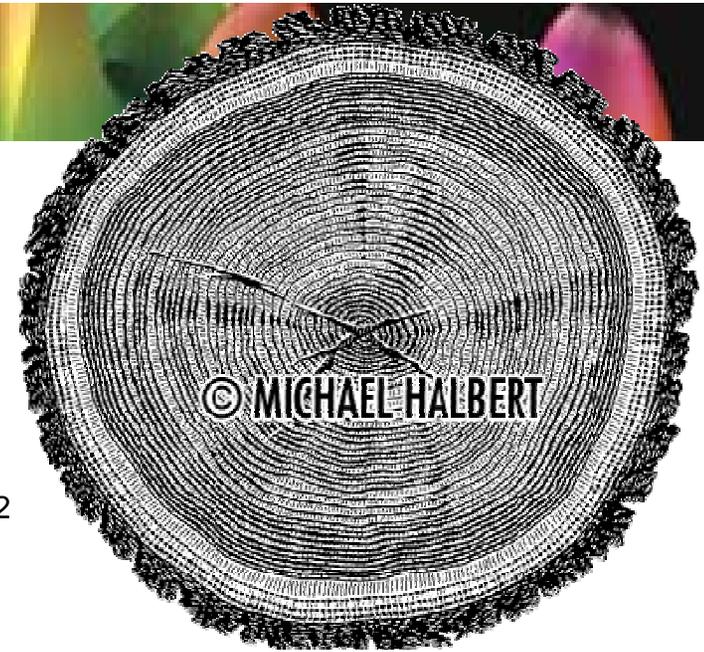
$$KE_{\min} = \left(1 + \frac{m}{M} \right) |Q|$$

- 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

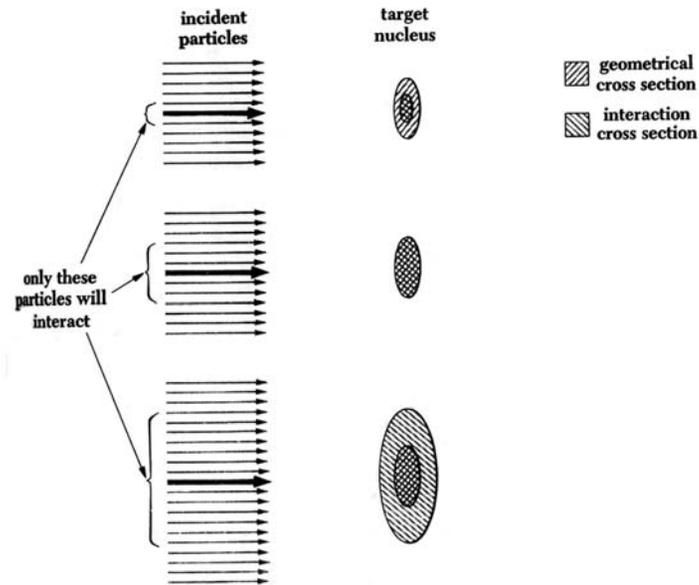
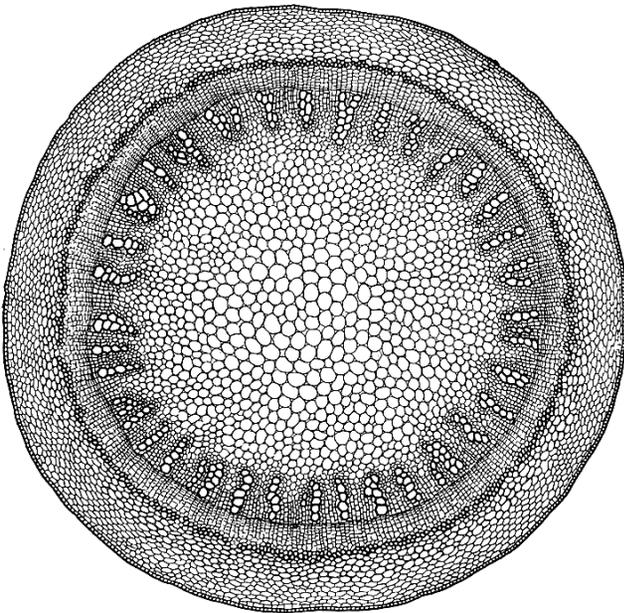
Reaction Cross Section

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} m²



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

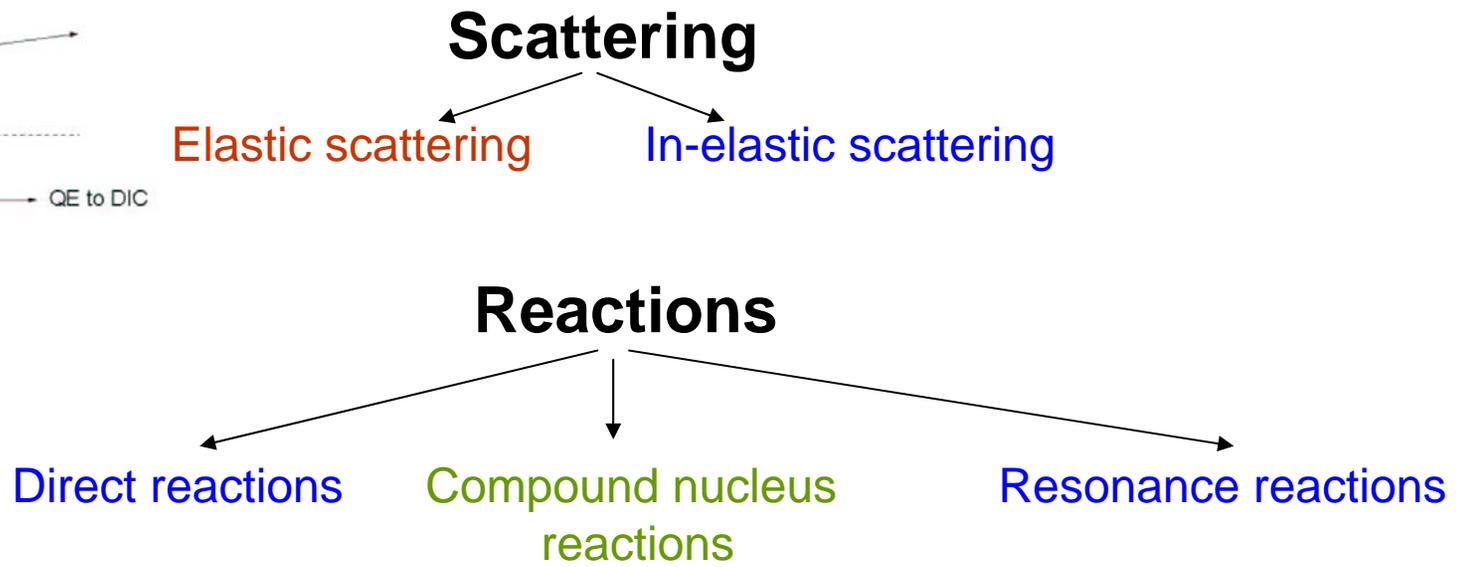
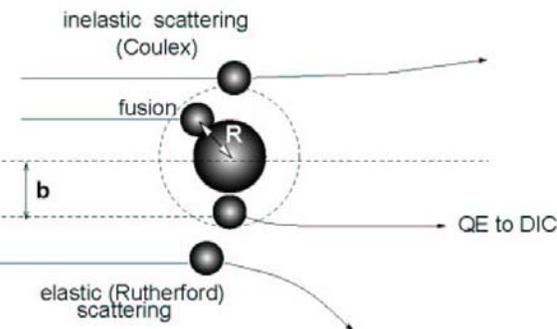


Types of Nuclear process

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



Types of Reactions

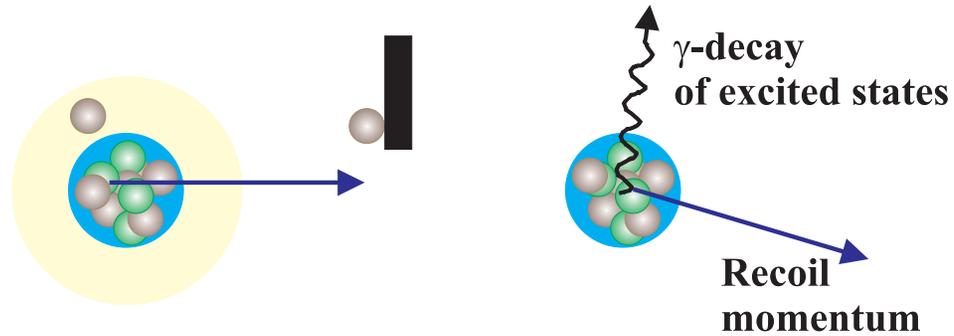
Reaction

Nucleon - nucleon scattering
Elastic scattering of nuclei
Inelastic scattering to excited states
Inelastic scattering to the continuum
Transfer and knockout reactions
Fusion reactions
Fission reactions
Compound nucleus formation
Multifragmentation
Pion reactions
Electron scattering

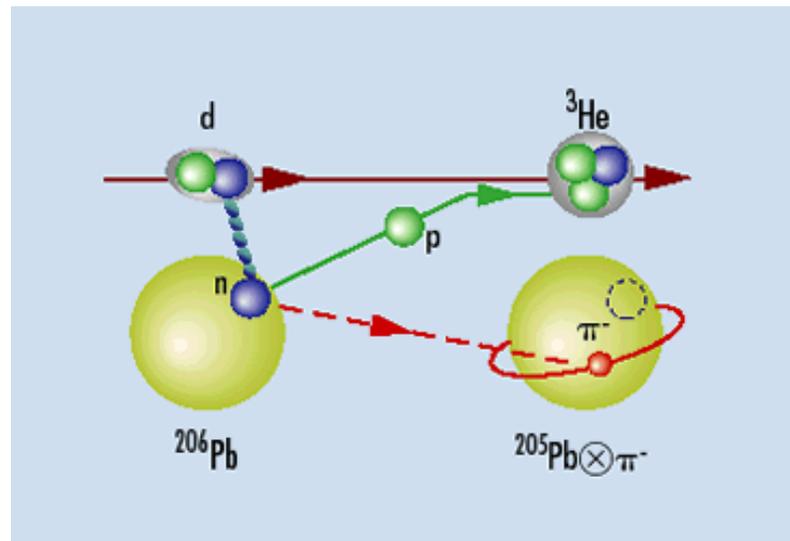
What is Learned

Fundamental nuclear force
Nuclear size and interaction potential
Energy level location and quantum numbers
Giant resonances (vibrational modes)
Details of the Shell Model
Astrophysical processes
Properties of Liquid-drop Model
Statistical properties of the nucleus
Phases of nuclear matter, Collective Model
Investigation of the nuclear “glue”
Quark structure of nuclei

Knockout & Transfer Reactions



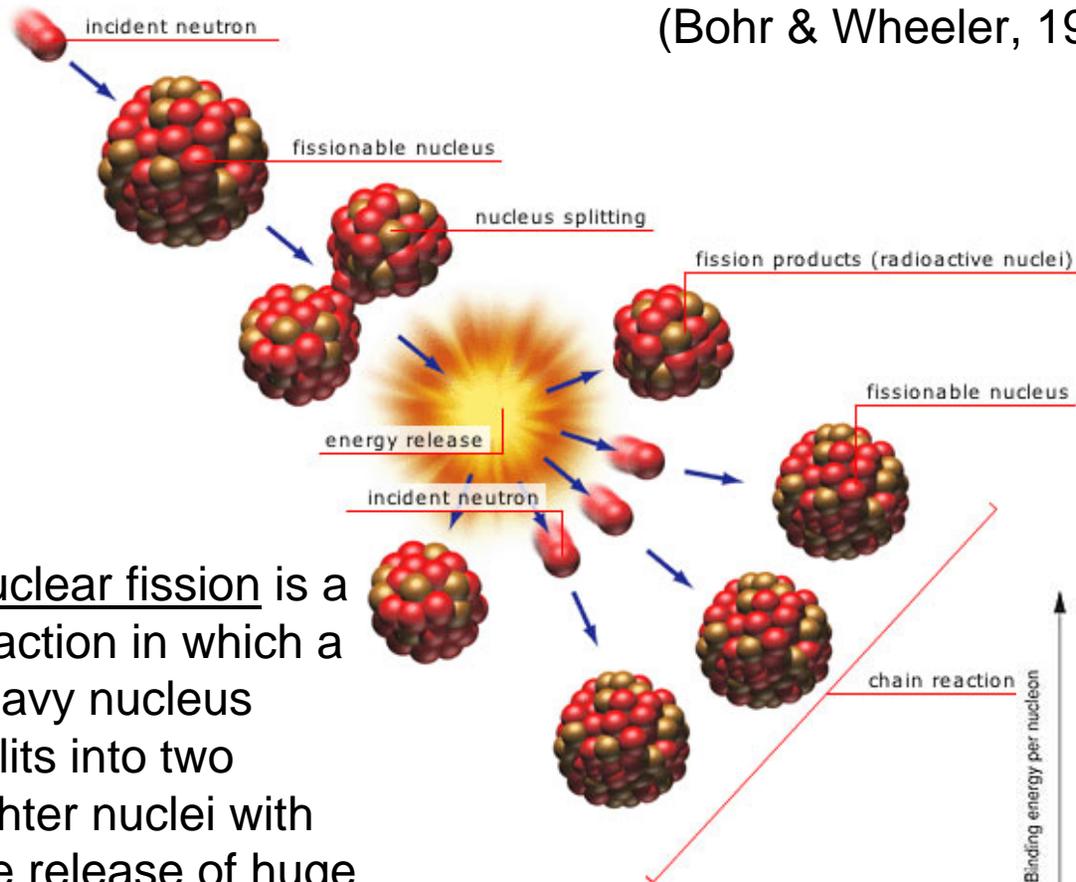
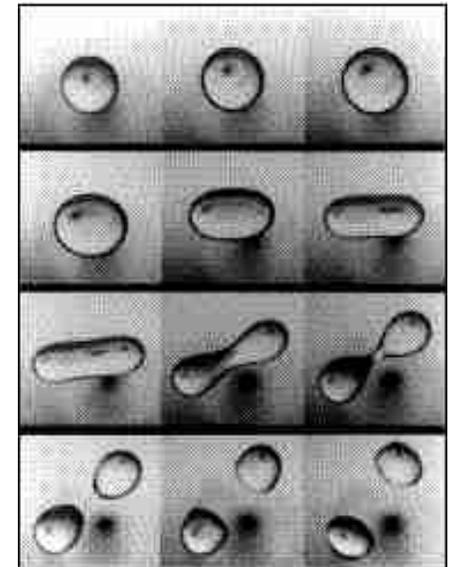
Knockout reaction



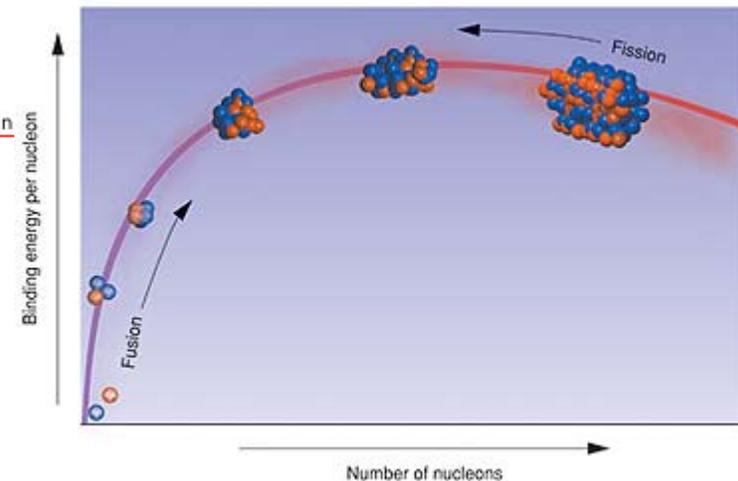
Transfer reaction

Fission Reactions

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

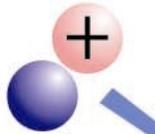


Nuclear fission is a reaction in which a heavy nucleus splits into two lighter nuclei with the release of huge amount of energy

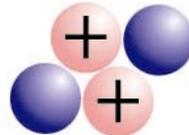


Fusion Reactions

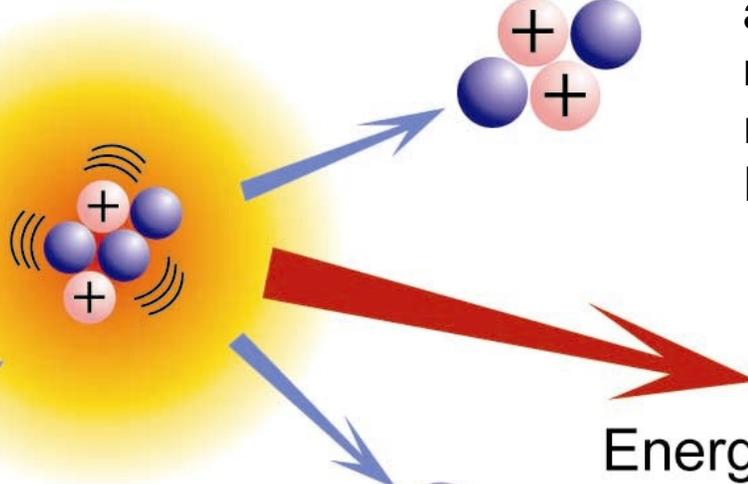
Deuterium



Helium



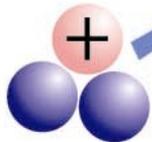
In Nuclear Fusion the nuclei of atoms fuse together, causing much more energy being released than in Nuclear Fission.



This is the process which powers the Sun.

Energy

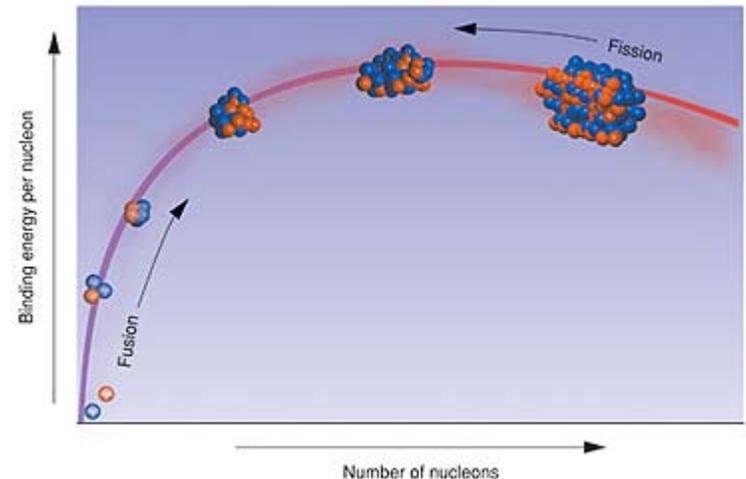
Tritium



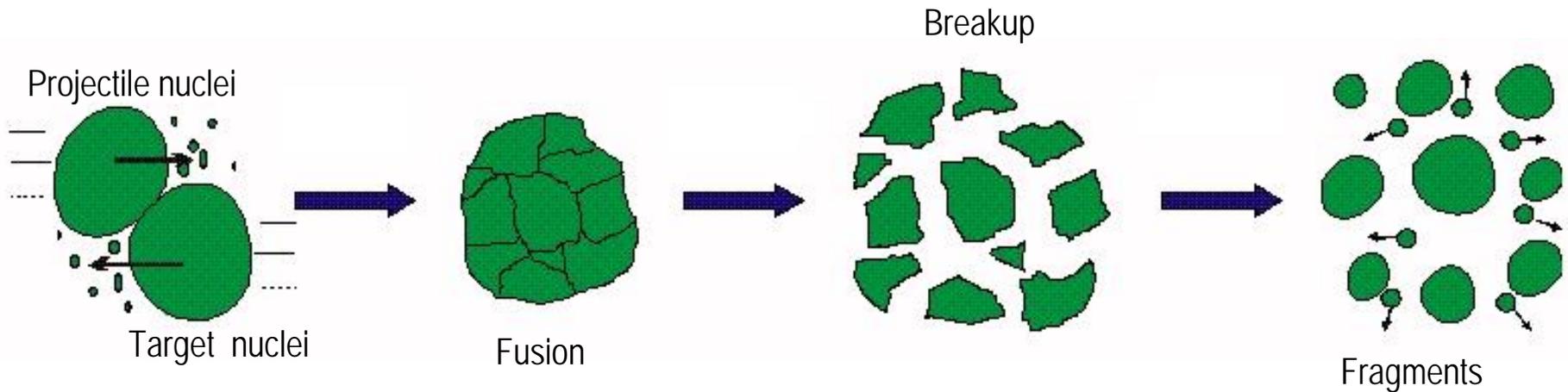
Neutron



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



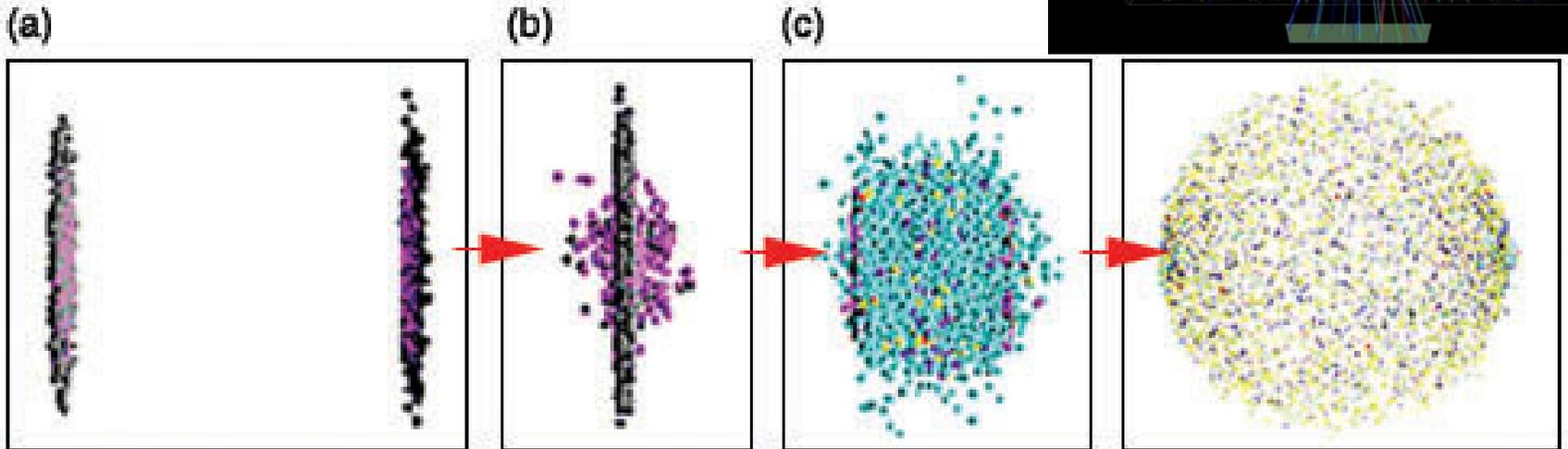
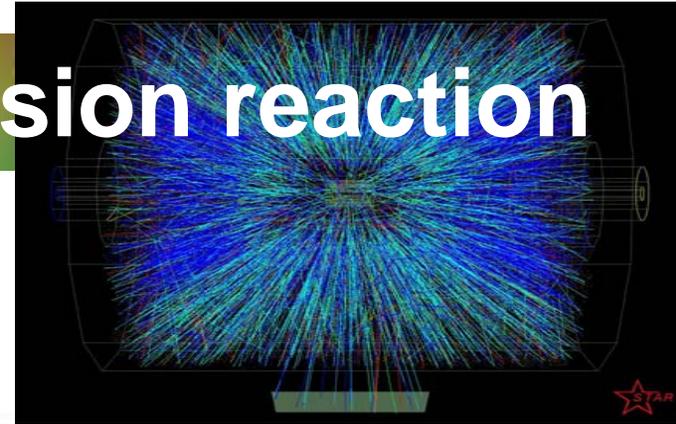
Multifragmentation Reactions



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

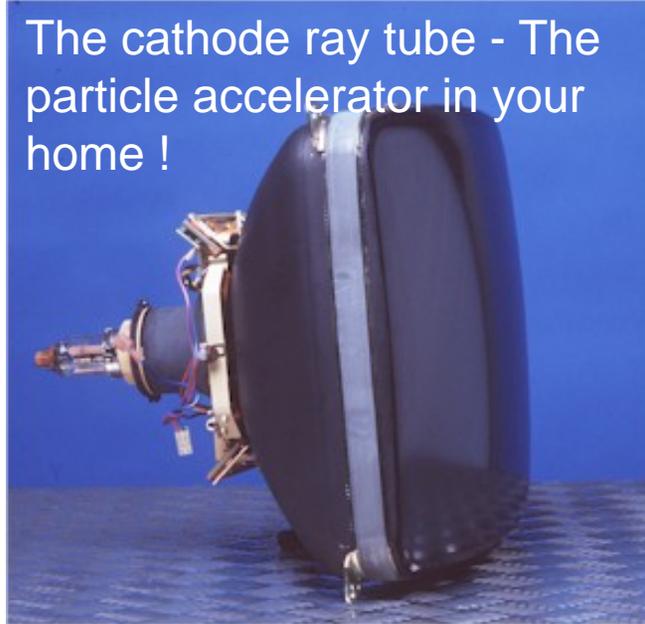
Probing the quark structure of nucleon by colliding two heavy nuclei at relativistic speed



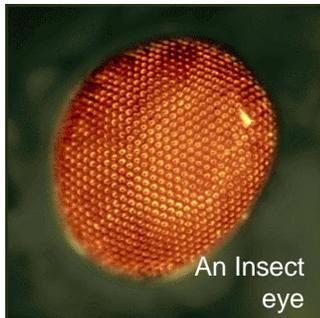
Two gold nuclei approach one another at almost the speed of light. Traveling at relativistic speeds causes them to look flat rather than spherical. (b) As the two nuclei collide and pass through each other, some of the energy they had before the collision is transformed into intense heat and new particles. (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

The cathode ray tube - The particle accelerator in your home !



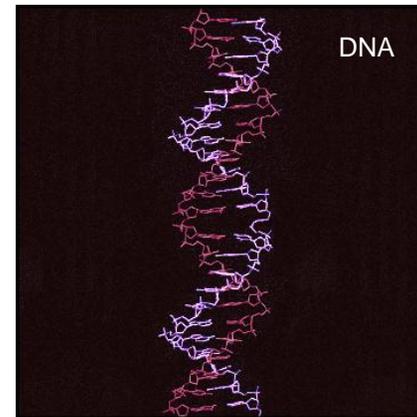
To create new particles and study the structure of atomic nucleus



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

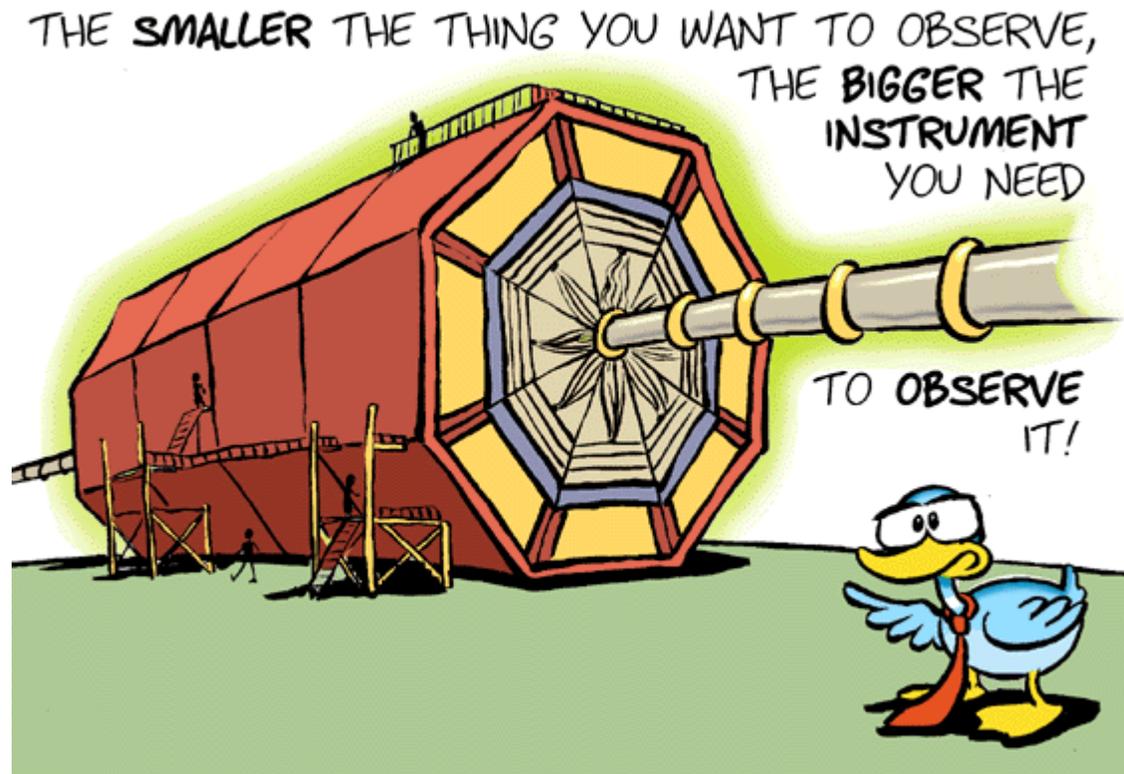


Electron microscopes take us even further, allowing us to see down to the level of atomic structure.



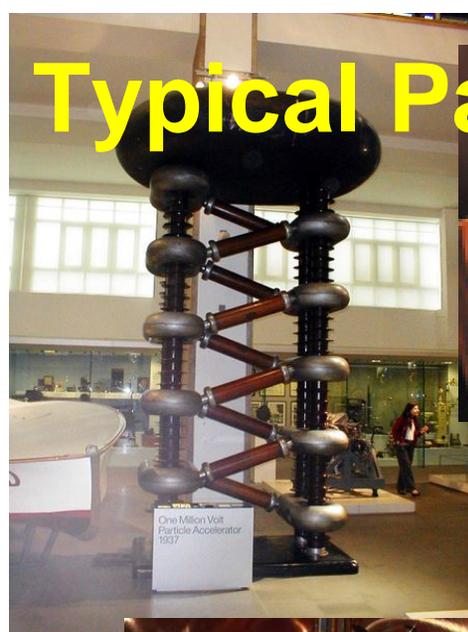
The reason electron microscopes are able to see things so small is because the high energy electrons they use behave like waves, just like light, but their wavelength is much smaller than that of light. The smaller the wavelength, the smaller the objects that can be resolved.

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

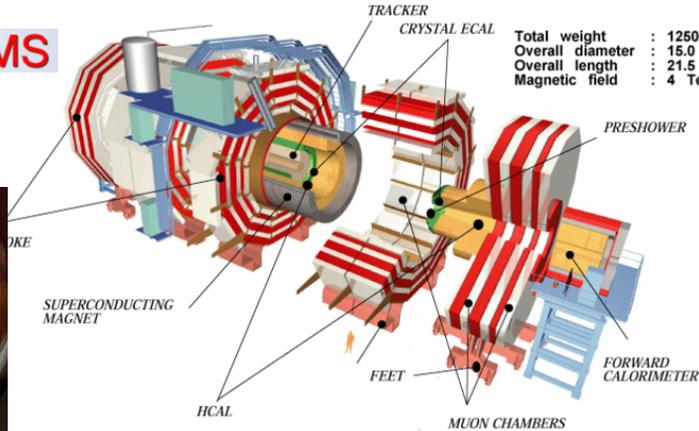


To study things smaller than atoms, physicists take particles like electrons and boost them up to very high energies in machines called particle accelerators.

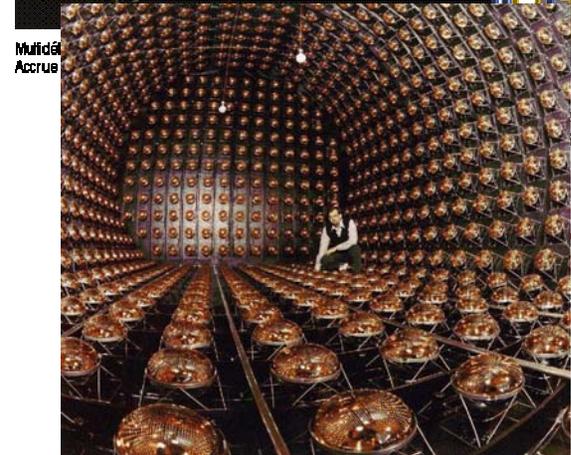
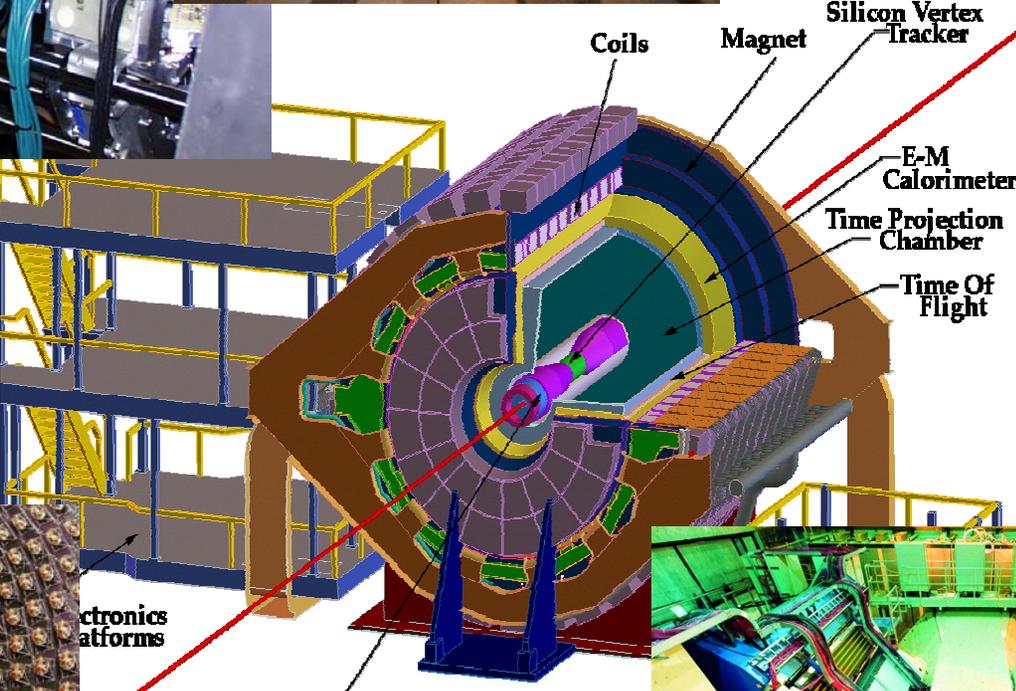
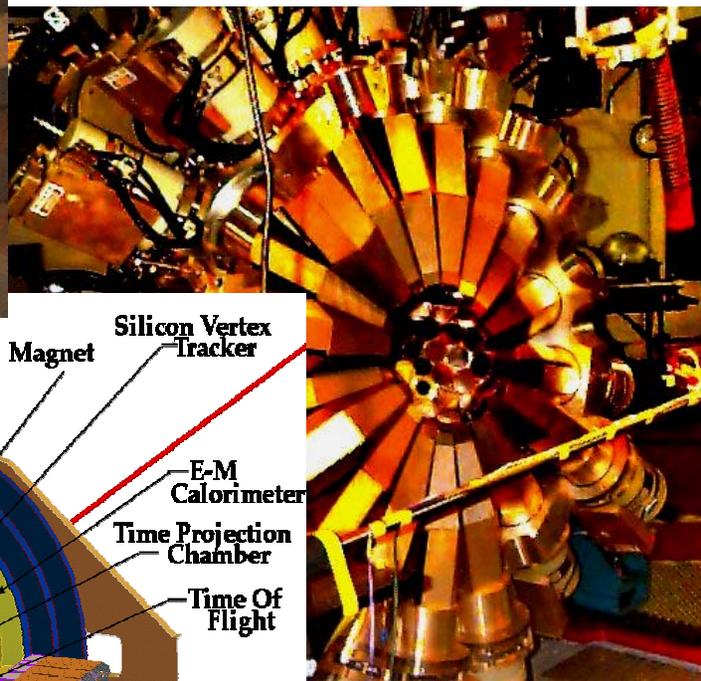
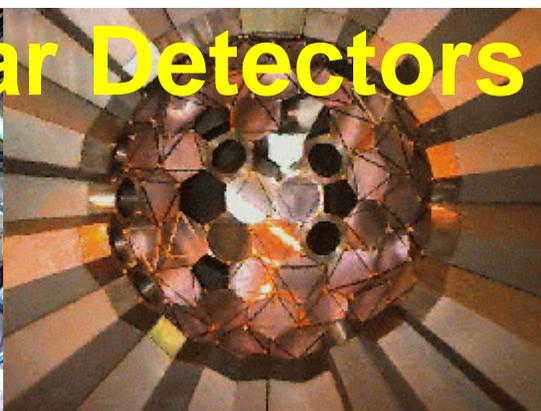
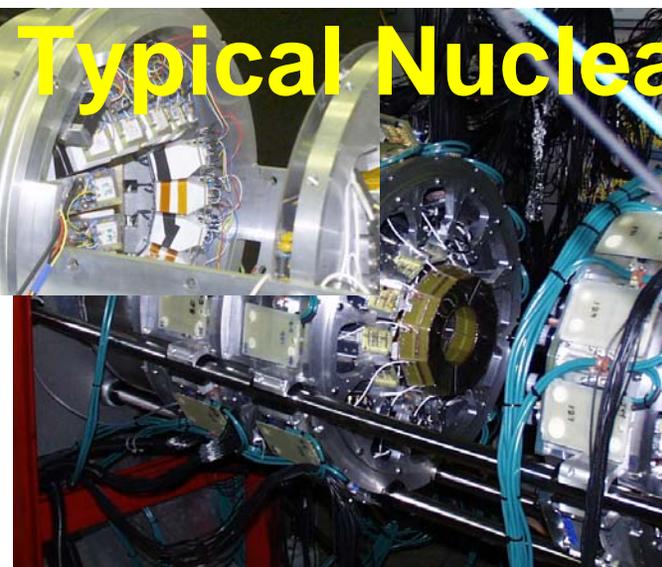
Typical Particle Accelerators



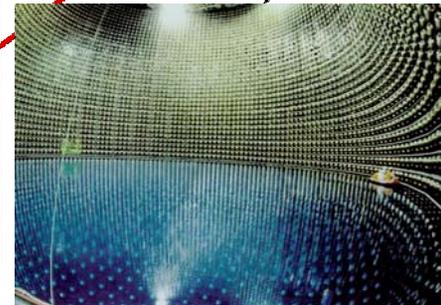
CMS



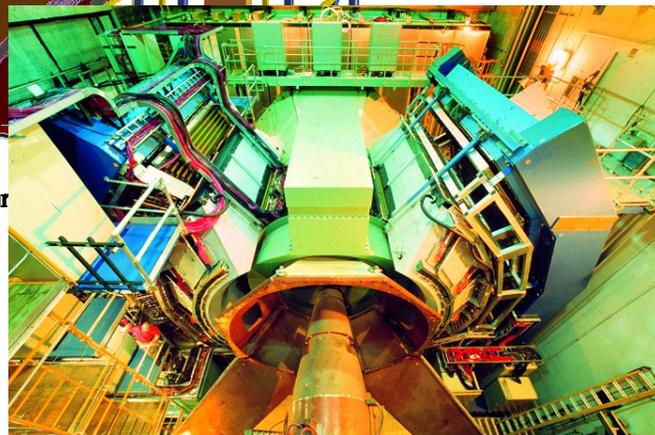
Typical Nuclear Detectors



Multidimensional Accrue



Time Projection



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**

(Click on the image to play the Movie)



(Click on the image to play the Movie)

**RXTE PUFFED ACCRETION DISK
VERSION 2 WITH NO WOBBLE**



ANIMATION BY

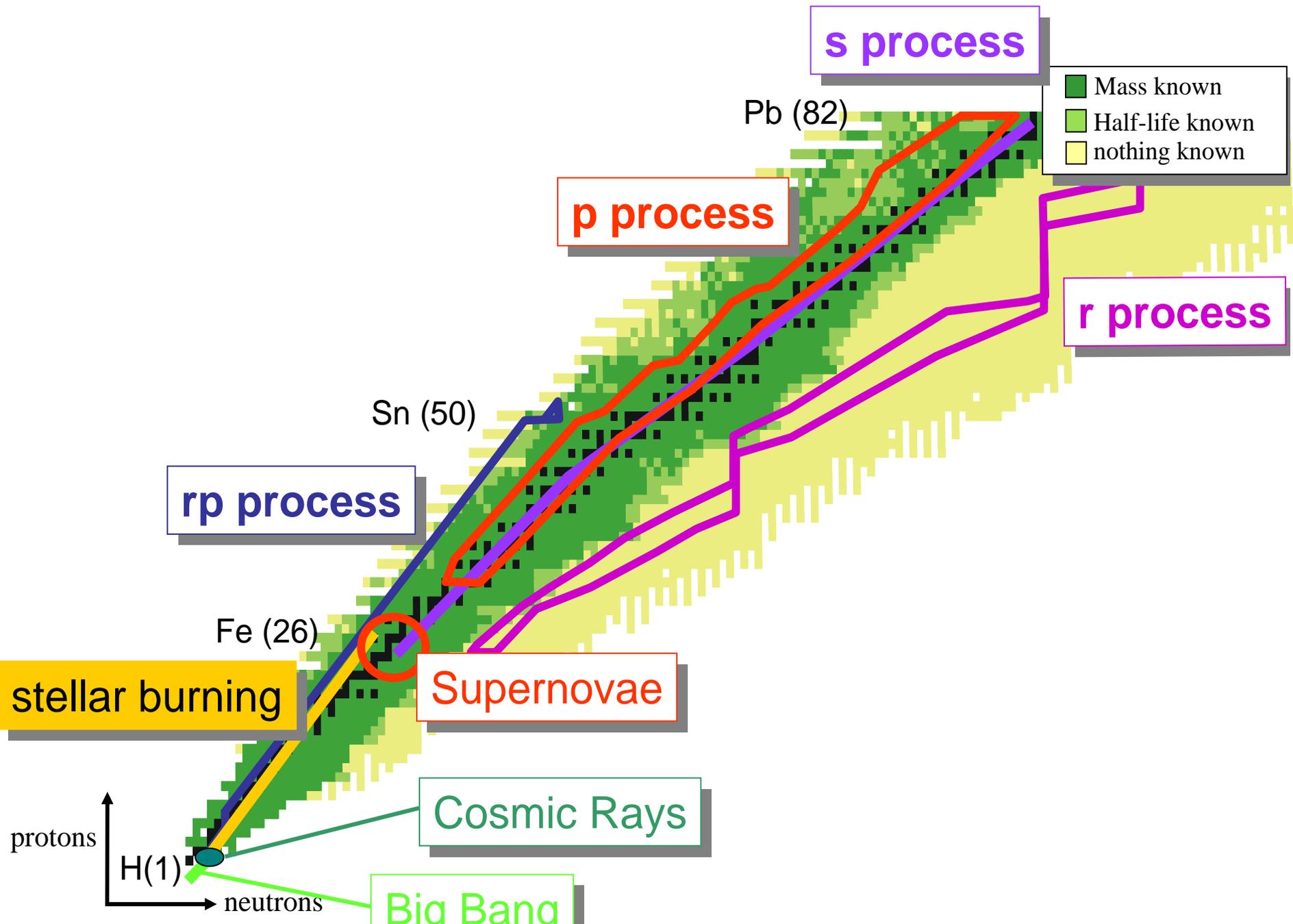
DANA BERRY

SKYWORKS DIGITAL ANIMATION

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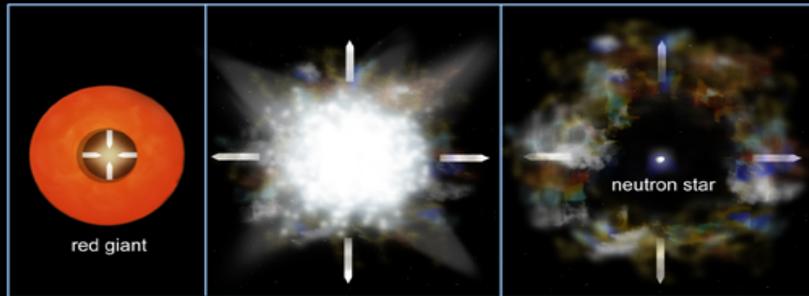
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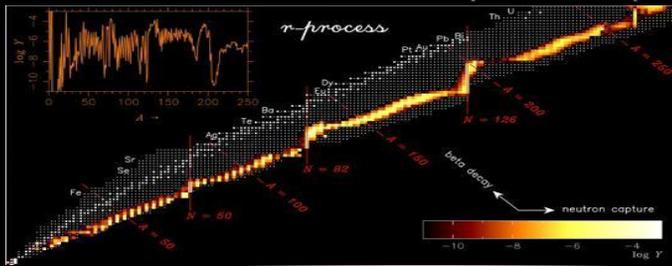
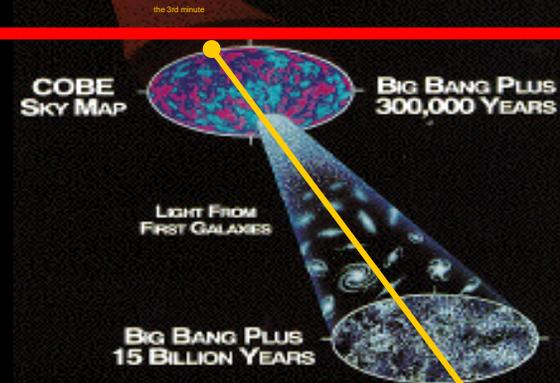


from Atomic Nuclei to Stars

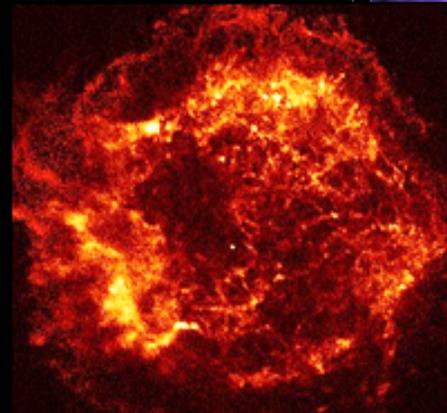
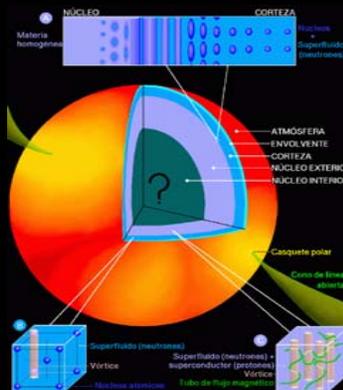
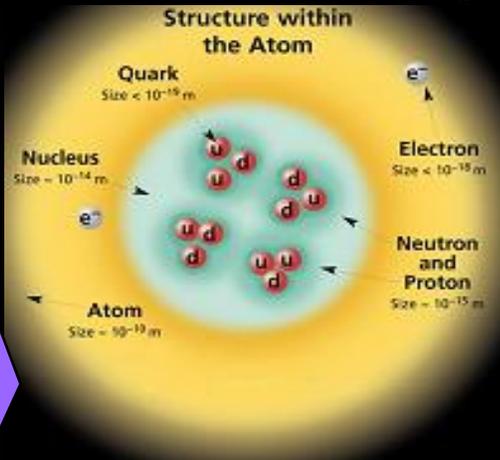
Birth of a Neutron Star and Supernova Remnant
(not to scale)



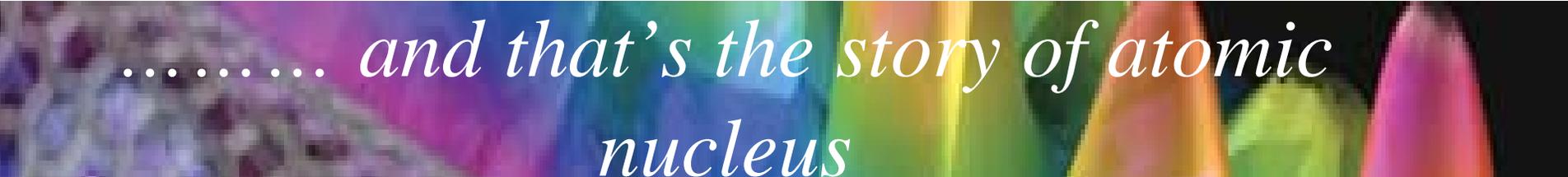
Core Implosion → Supernova Explosion → Supernova Remnant



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