Deflecting radiation with magnetic fields

- Use a source-handling tool to mount a beta source 10 cm from a GM tube and then bring up a magnet as shown in Figure 23.5. Note the change in the count.
- Then move the GM tube into a position like that shown by the dotted lines to find the deflected particles.
- Repeat the experiment with alpha and gamma sources in turn.

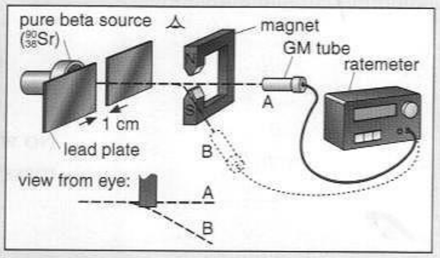
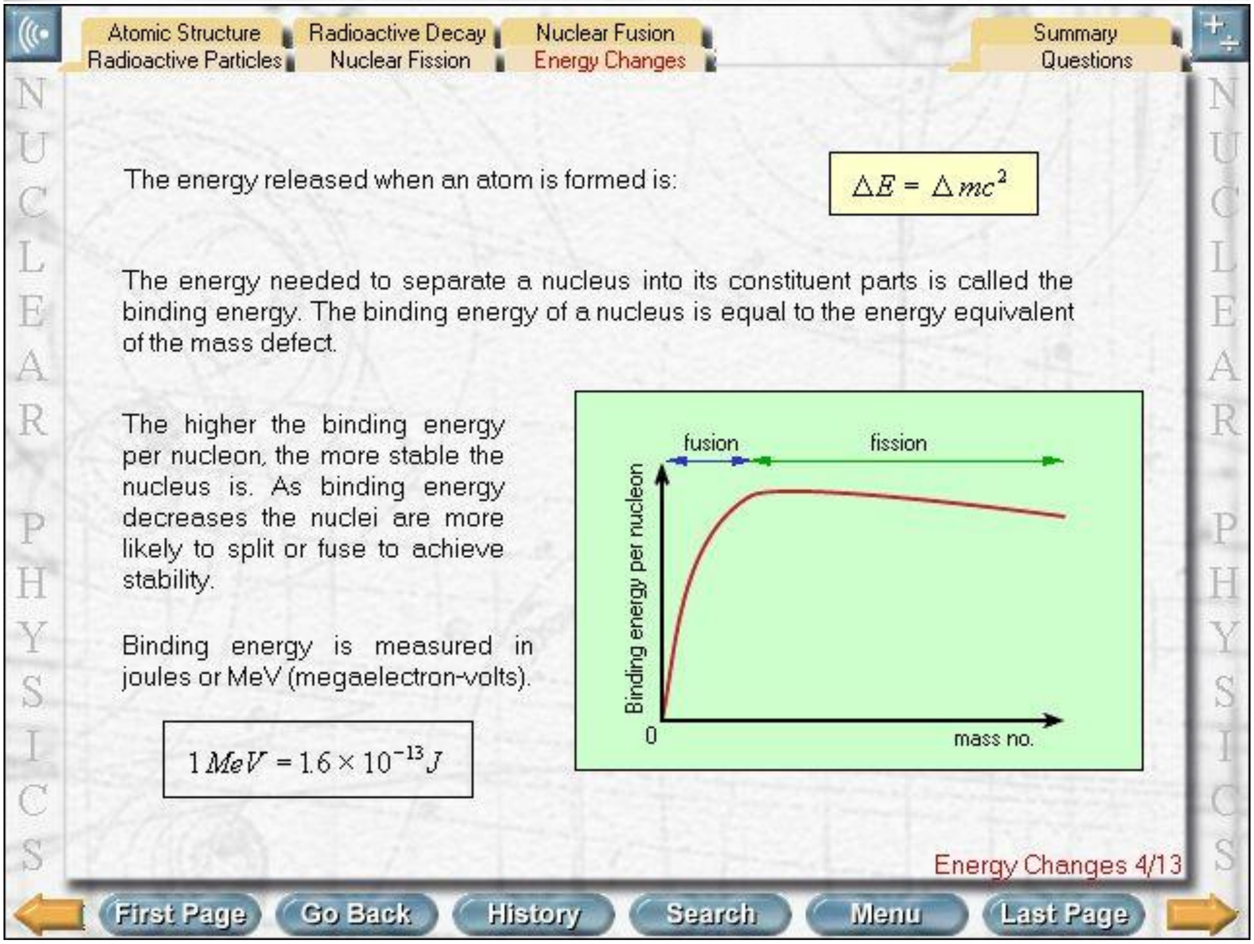


Figure 23.5 Deflecting beta radiation



The energy released when an atom is formed is:

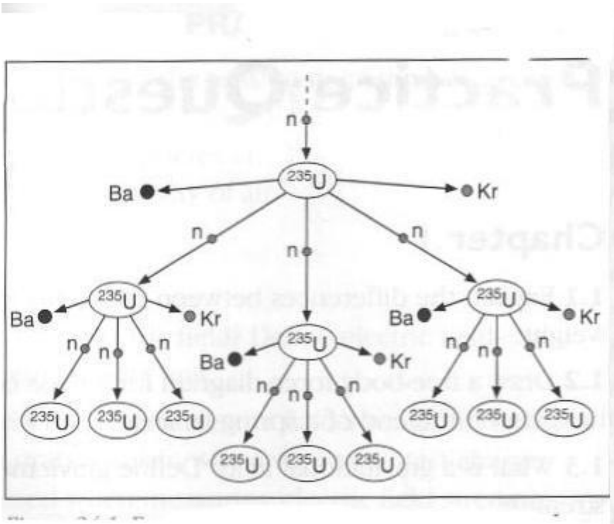
$$\Delta E = \Delta mc^2$$

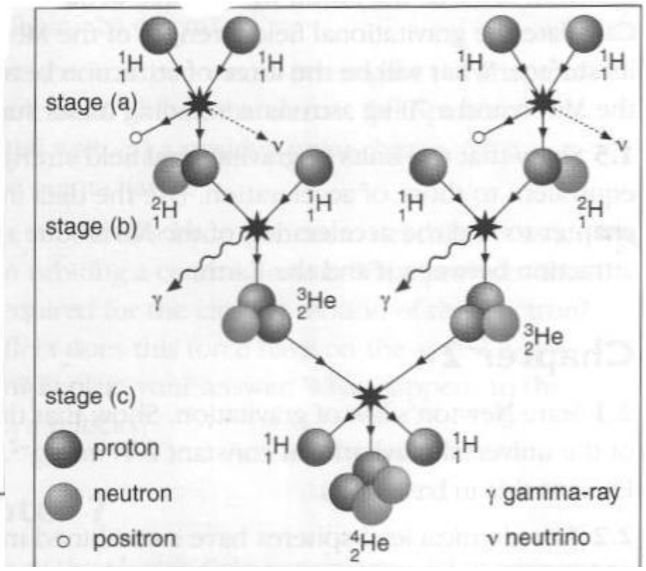
The energy needed to separate a nucleus into its constituent parts is called the binding energy. The binding energy of a nucleus is equal to the energy equivalent of the mass defect.

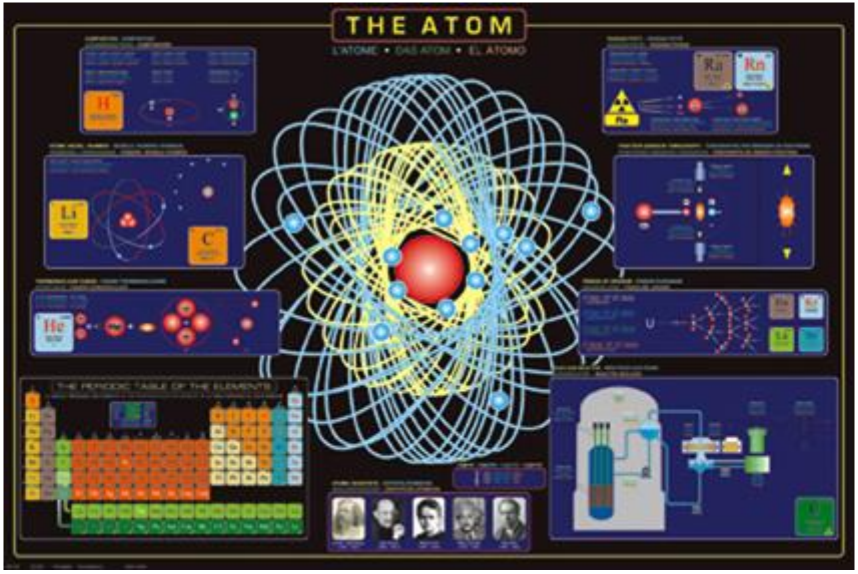
The higher the binding energy per nucleon, the more stable the nucleus is. As binding energy decreases the nuclei are more likely to split or fuse to achieve stability.

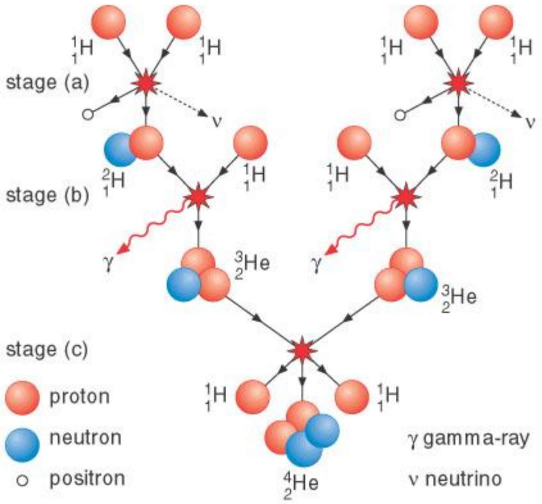
Binding energy is measured in joules or MeV (megaelectron-volts).

$$1\,MeV = 1.6 \times 10^{-13}\,J$$


n
Ba
Kr
^{235}U


stage (a)
stage (b)
stage (c)
^1_1H
^2_1H
^3_2He
^4_2He
γ
ν
proton
neutron
positron
γ gamma-ray
ν neutrino

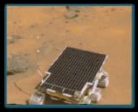

THE ATOM
L'ATOME • DAS ATOM • EL ATOMO
THE PERIODIC TABLE OF THE ELEMENTS



Applications

Radioactive Dating

*N*aturally occurring radioactive isotopes such as $^{14}_{6}$C are used to date objects that were once living, such as wood. For example, from a study of artifacts found at the site, scientists determined that Stonehenge was built nearly 4,000 years ago.



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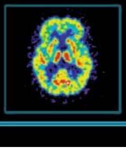

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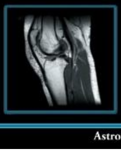
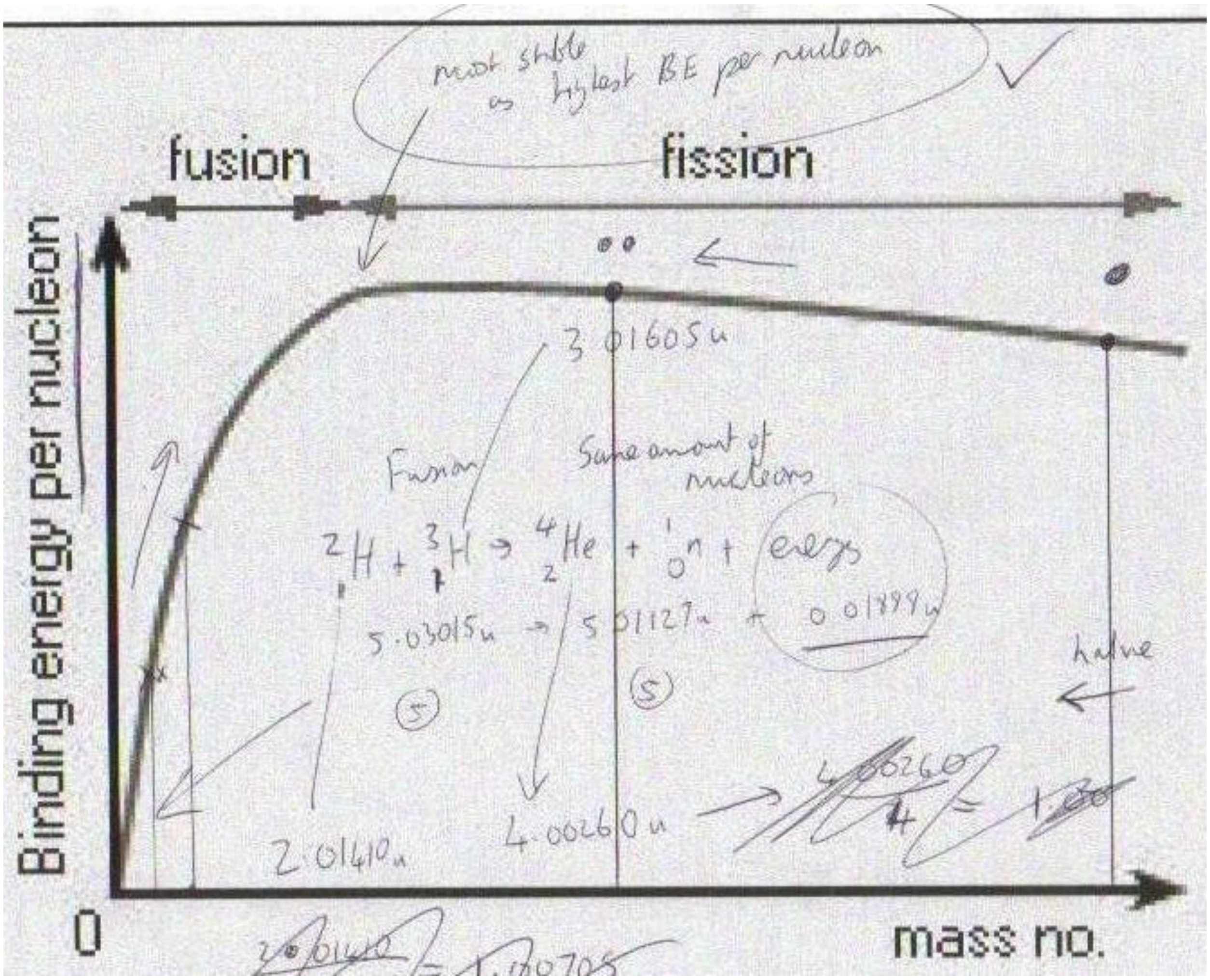


Magnetic Resonance Imaging

*M*agnetic Resonance Imaging (MRI) makes use of atomic transitions involving the magnetic field of a nucleus to study the local chemical environment. This technique accurately maps the density of hydrogen to produce three-dimensional images of the human body.

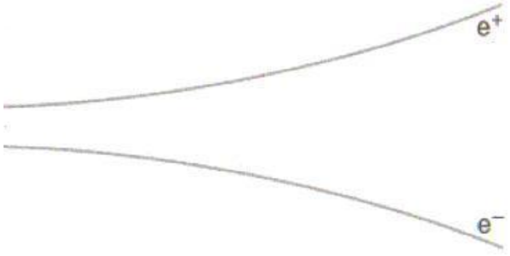
Astrophysical pictures courtesy NASA/JPL/Caltech and AURA/STScI.



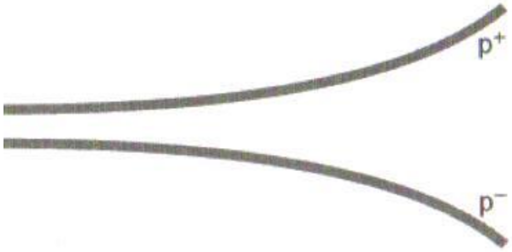
${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + \text{energy}$

$5.03015u \rightarrow 5.01127u + 0.01888u$

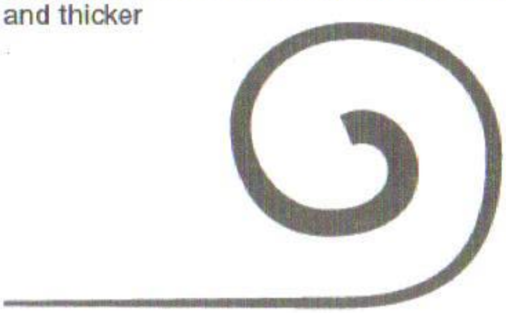
a) Fast particles make a thin curved track



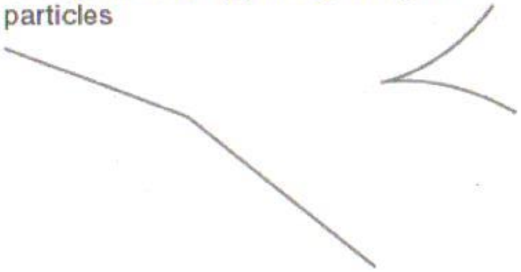
b) Slow particles or massive particles cause more ionisation in a shorter distance and hence thicker tracks



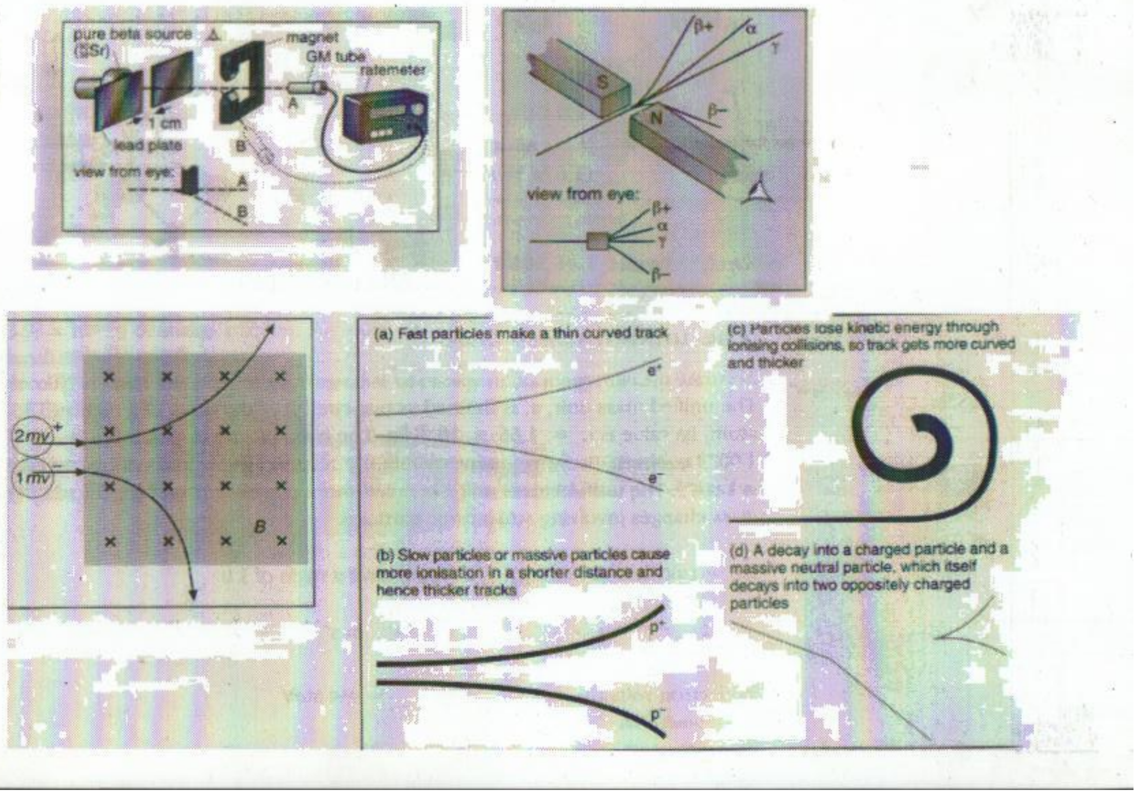
(c) Particles lose kinetic energy through ionising collisions, so track gets more curved and thicker



(d) A decay into a charged particle and a massive neutral particle, which itself decays into two oppositely charged particles

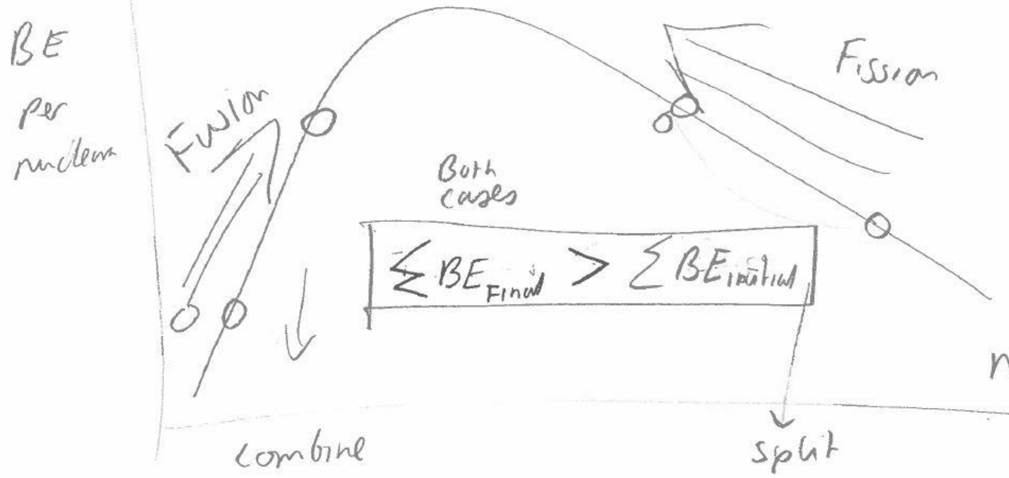


magnetic deflection.JPG



Binding Energy

same number of nucleons ? before + after



Both cases

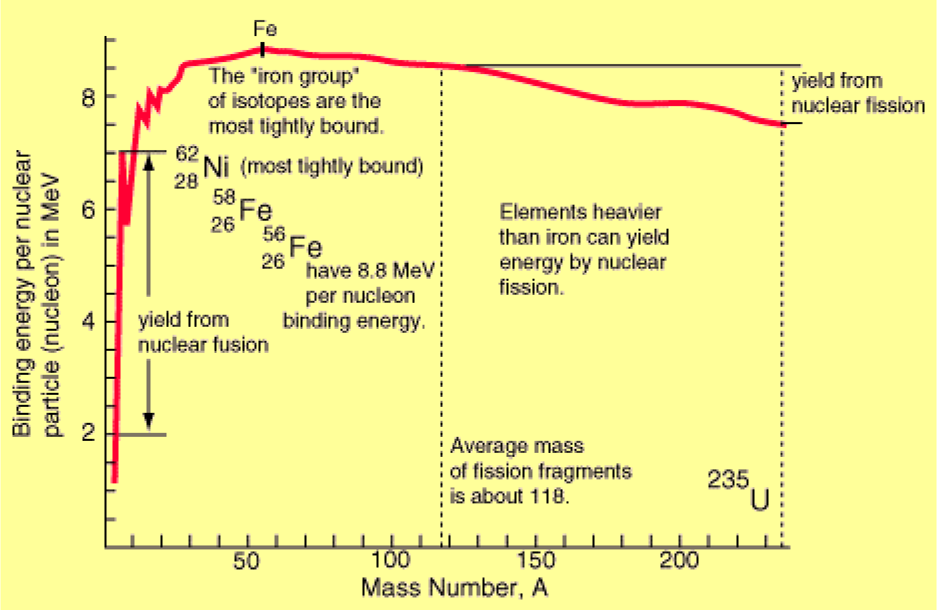
$$\boxed{\sum BE_{Final} > \sum BE_{initial}}$$

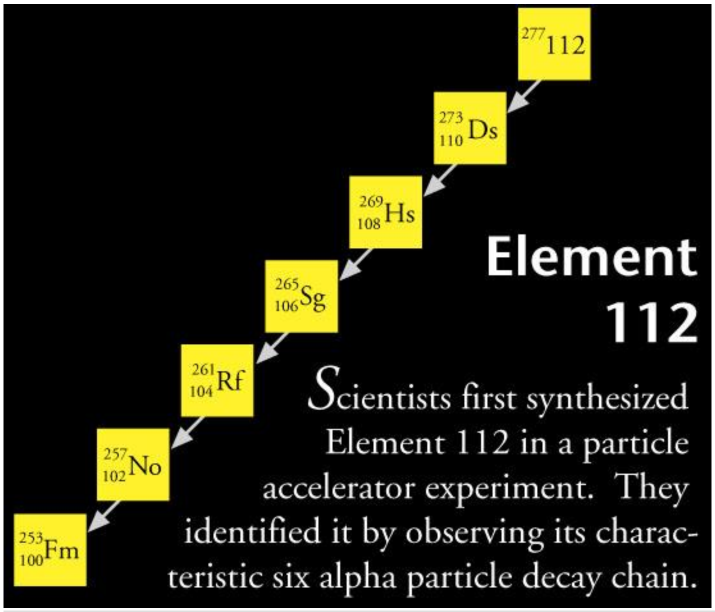
Nuclear Power

End product has greater BE Per nucleon

Conservation of energy + mass

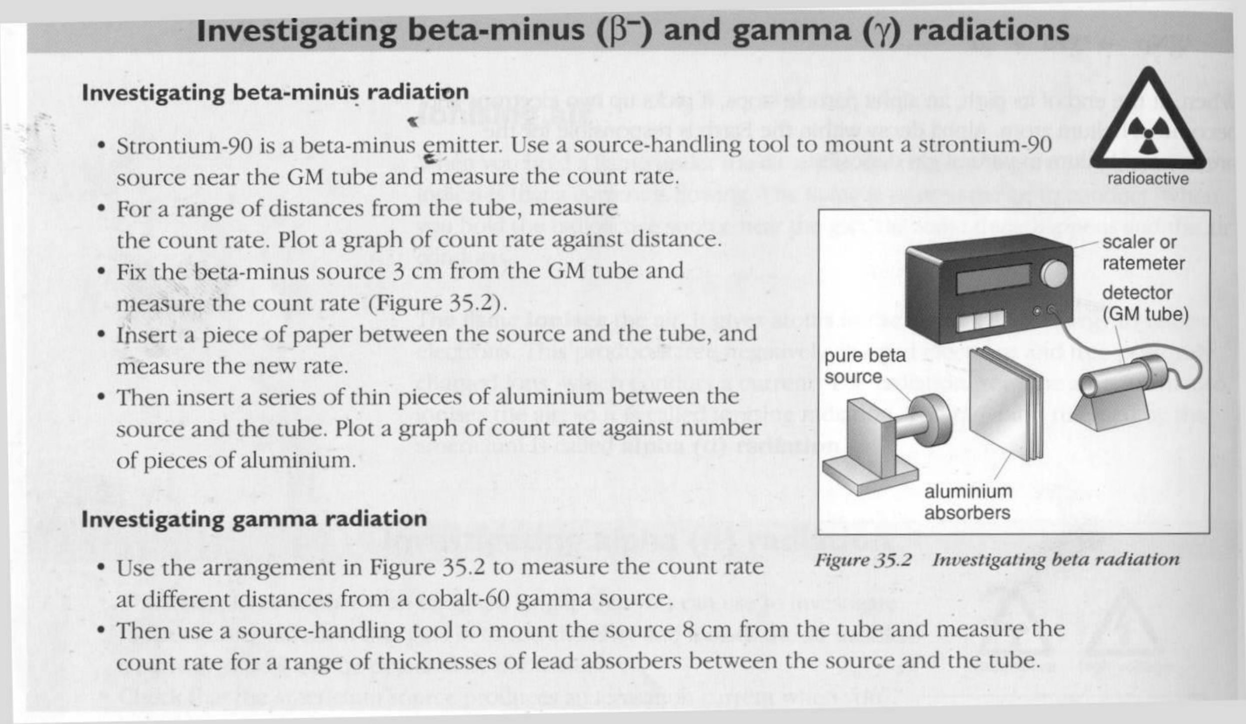
$$\boxed{\text{Total } BE_{initial} = \text{Total } BE_{final} \text{ (greater than before)} - \text{excess energy}}$$





Element 112

Scientists first synthesized Element 112 in a particle accelerator experiment. They identified it by observing its characteristic six alpha particle decay chain.



Investigating beta-minus (β⁻) and gamma (γ) radiations

Investigating beta-minus radiation

- Strontium-90 is a beta-minus emitter. Use a source-handling tool to mount a strontium-90 source near the GM tube and measure the count rate.
- For a range of distances from the tube, measure the count rate. Plot a graph of count rate against distance.
- Fix the beta-minus source 3 cm from the GM tube and measure the count rate (Figure 35.2).
- Insert a piece of paper between the source and the tube, and measure the new rate.
- Then insert a series of thin pieces of aluminium between the source and the tube. Plot a graph of count rate against number of pieces of aluminium.

Figure 35.2 Investigating beta radiation

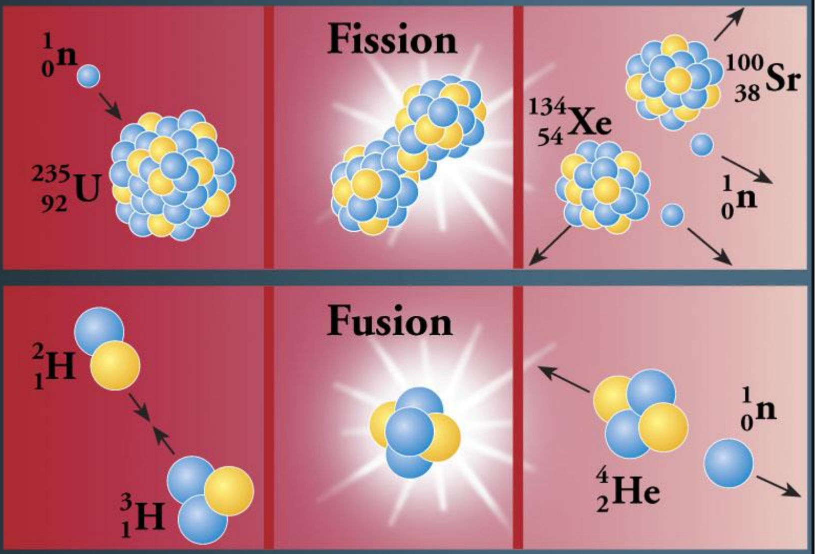
Investigating gamma radiation

- Use the arrangement in Figure 35.2 to measure the count rate at different distances from a cobalt-60 gamma source.
- Then use a source-handling tool to mount the source 8 cm from the tube and measure the count rate for a range of thicknesses of lead absorbers between the source and the tube.

Nuclear Science is the study of the structure, properties, and interactions of the atomic nuclei. Nuclear scientists calculate and measure the masses, shapes, sizes, and decays of nuclei at rest and in collisions. They ask questions, such as: Why do nucleons stay in the nucleus? What combinations of protons and neutrons are possible? What happens when nuclei are compressed or rapidly rotated? What is the origin of the nuclei found on Earth?

Legend
● *proton*
● *neutron*
● *electron* (e^-)
● *positron* (e^+)
● *neutrino* (ν)
● *antineutrino* ($\bar{\nu}$)
● *quark*
gluon field
gluon
● *photon* (γ)
A_{number}^{mass} $^{14}_{6}C$
Z_{number}^{atomic}
$N_{number}^{neutron} = A - Z$

Nuclear Energy



Nuclear reactions release energy when the total mass of the products is less than the sum of the masses of the initial nuclei. The "lost mass" appears as kinetic energy of the products ($E = mc^2$). In fission, a massive nucleus splits into two major fragments that usually eject one or more neutrons. In fusion, low mass nuclei combine to form a more massive nucleus plus one or more ejected particles—neutrons, protons, photons, or alpha particles.

In the early stages of stellar evolution of our sun and other stars, hydrogen fuses to form helium, releasing energy in the form of photons (light) and neutrinos. During the later stages of stellar evolution, more massive nuclei up to and beyond uranium are synthesized by fusion. By measuring the number of neutrinos that come from the Sun, scientists recently have demonstrated that neutrinos must have a mass greater than zero.

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- *electron* (e^-)
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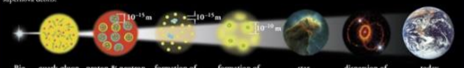
- *neutrino* (ν)
- *antineutrino* ($\bar{\nu}$)
- *quark*
- *gluon field*
- *gluon*
- *photon* (γ)

A mass number, Z atomic number: $^{14}_{6}C$

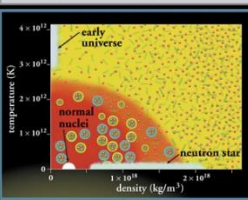
N neutron number = A − Z

Expansion of the Universe

*A*fter the Big Bang, the universe expanded and cooled. At about 10^{-6} second, the universe consisted of a soup of quarks, gluons, electrons, and neutrinos. When the temperature of the Universe, $T_{universe}$, cooled to about 10^{12} K, this soup coalesced into protons, neutrons, and electrons. As time progressed, some of the protons and neutrons formed deuterium, helium, and lithium nuclei. Still later, electrons combined with protons and these low-mass nuclei to form neutral atoms. Due to gravity, clouds of atoms contracted into stars, where hydrogen and helium fused into more massive chemical elements. Exploding stars (supernovae) form the most massive elements and disperse them into space. Our earth was formed from supernova debris.



	Big Bang	quark-gluon plasma	proton & neutron formation	formation of low-mass nuclei	formation of neutral atoms	star formation	dispersion of massive elements	today
$T_{universe}$		$>10^{12}$ K	10^{12} K	10^{9} K	4,000 K	50 K–3 K	<50 K–3 K	3 K
time		10^{-6} s	10^{-4} s	3 min	400,000 yr	3×10^{8} yr	$>3 \times 10^{8}$ yr	14×10^{9} yr

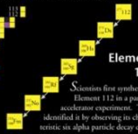


Phases of Nuclear Matter

*N*uclear matter can exist in several phases. When collisions excite nuclei, individual protons and neutrons may evaporate from the nuclear fluid. At sufficiently high temperature or density, a gas of nucleons (red background) forms. At even more extreme conditions, individual nucleons may cease to have meaningful identities, merging into the quark-gluon plasma (yellow background). Current data provide hints that physicists have glimpsed the quark-gluon plasma.

Unstable Nuclei

*S*table nuclides form a narrow white band on the Chart of the Nuclides. Scientists produce unstable nuclides far from this band and study their decays, thereby learning about the extremes of nuclear conditions. In its present form, this chart contains about 2500 different nuclides. Nuclear theory predicts that there are at least 4000 more to be discovered with Z ≤ 113.



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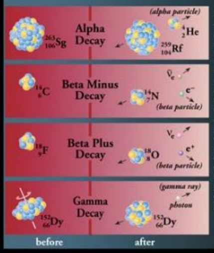
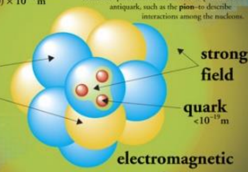


*R*adioactive decay transforms a nucleus by emitting different particles. In **alpha** decay, the nucleus releases a $^{4}_{2}$He nucleus –an alpha particle. In **beta** decay, the nucleus either emits an electron and antineutrino (or a positron and neutrino) or captures an atomic electron and emits a neutrino. A positron is the name for the antiparticle of the electron. Antimatter is composed of antiparticles. Both alpha and beta decays change the original nucleus into a nucleus of a different chemical element. In **gamma** decay, the nucleus lowers its internal energy by emitting a photon–a gamma ray. This decay does not modify the chemical properties of the atom.

The Nucleus

(1-10) × 10^{-15} m

*A*t the center of the atom is a nucleus formed from **nucleons**–protons and neutrons. Each nucleon is made from three **quarks** held together by their strong interactions, which are mediated by gluons. In turn, the nucleus is held together by the **strong** interactions between the gluon and quark constituents of neighboring nucleons. Nuclear physicists often use the exchange of mesons–particles which consist of a quark and an antiquark, such as the **pion**–to describe interactions among the nucleons.



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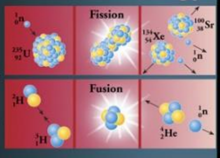
Nuclear Energy



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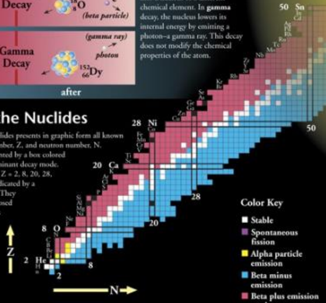

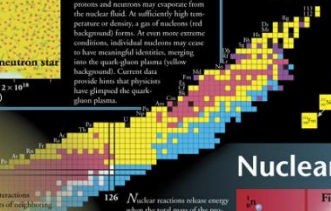

Color Key
- ◻ Stable
- ▨ Spontaneous fission
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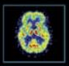

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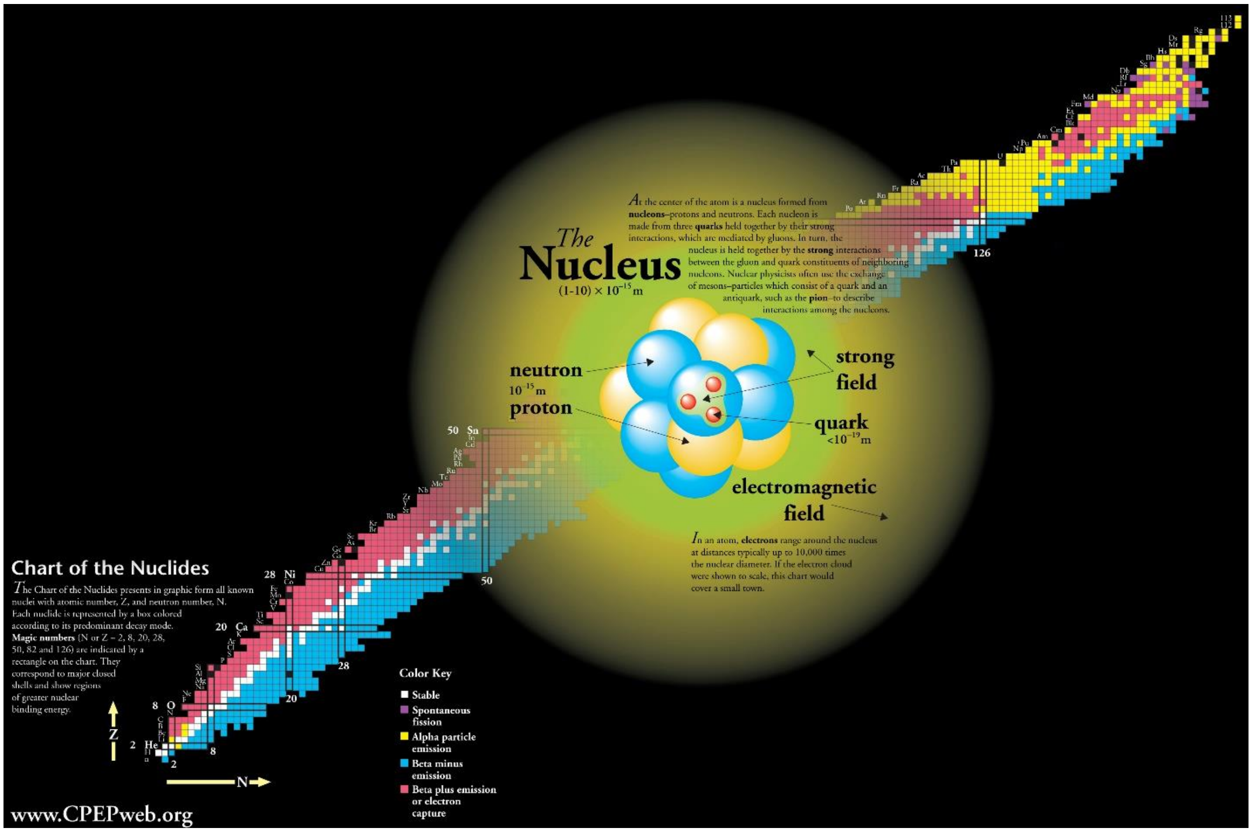

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Color Key

- ■ **Stable**
- ■ **Spontaneous fission**
- 🟨 **Alpha particle emission**
- 🟦 **Beta minus emission**
- 🟥 **Beta plus emission or electron capture**

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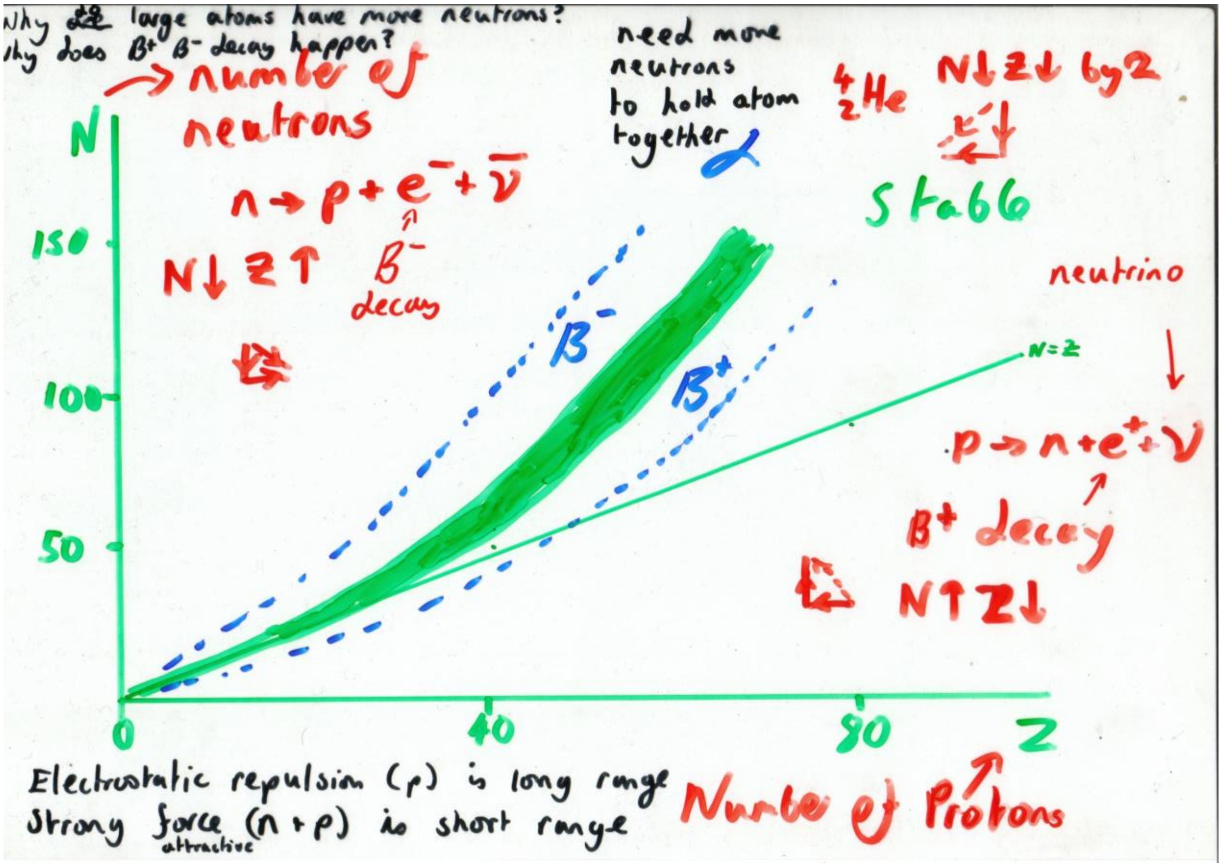
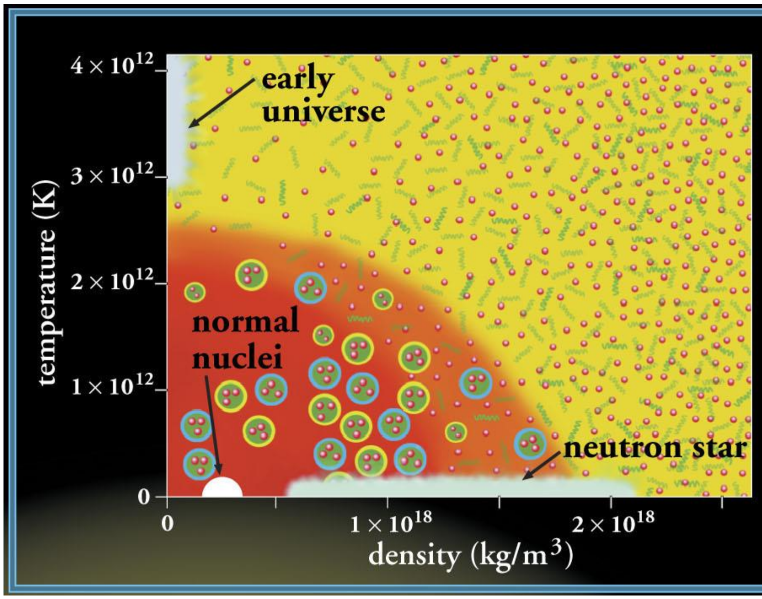


Why do large atoms have more neutrons?
hy does β^+ β^- decay happen?

Electrostatic repulsion (p) is long range
Strong force (n + p) is short range
attractive



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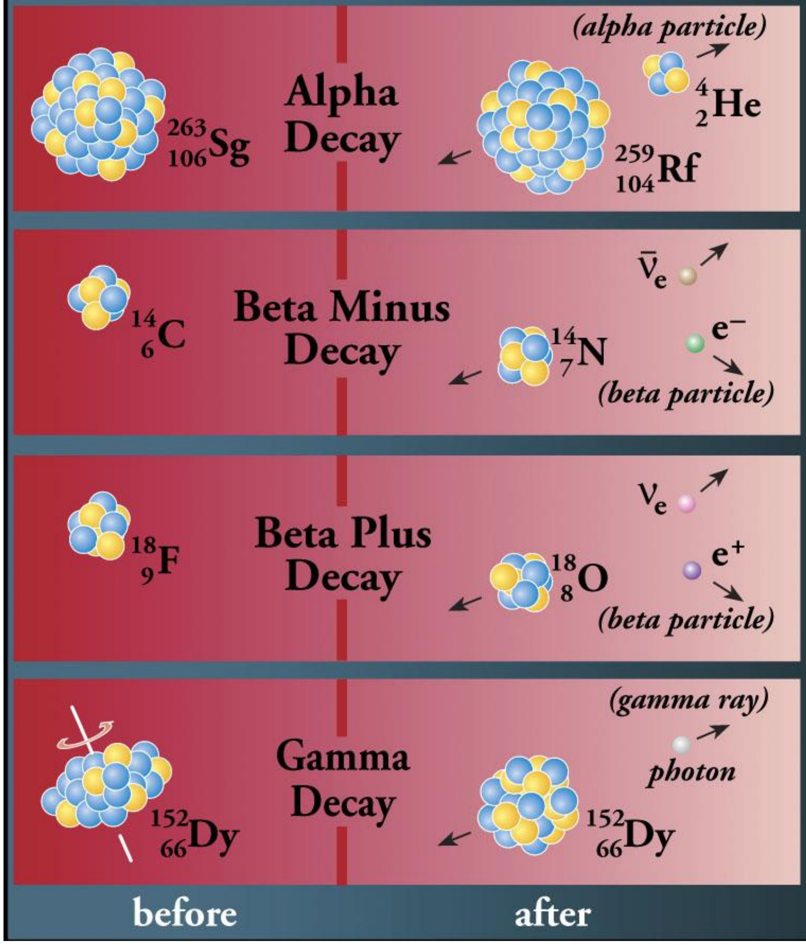

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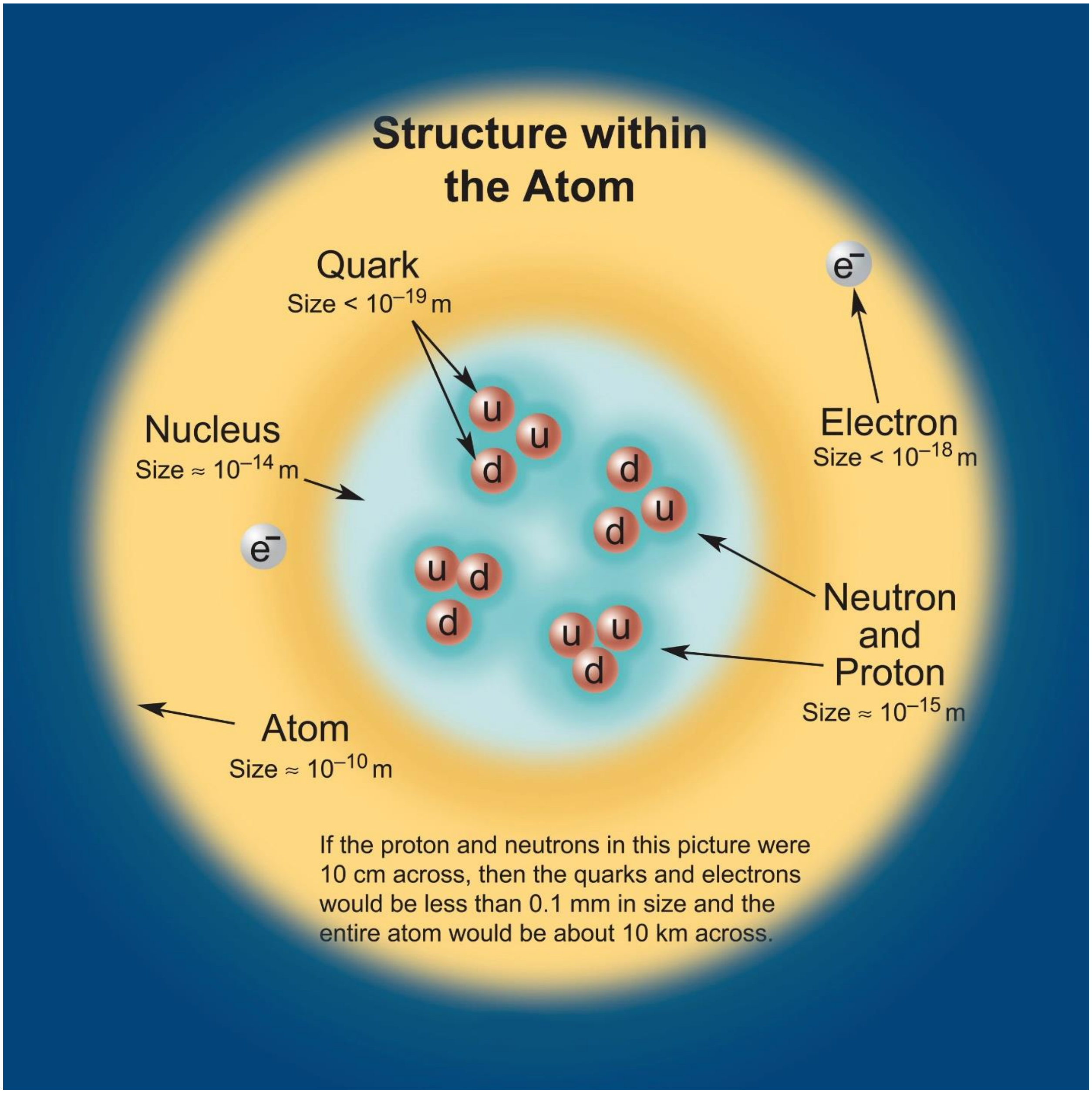
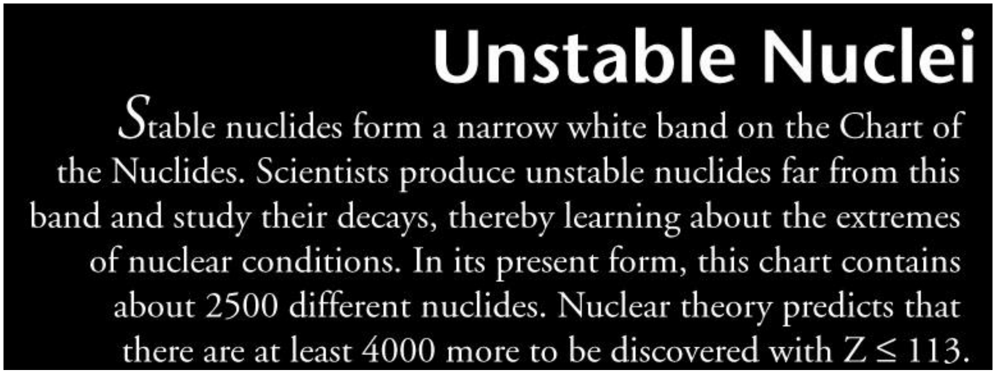


Structure within the Atom

If the proton and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.



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