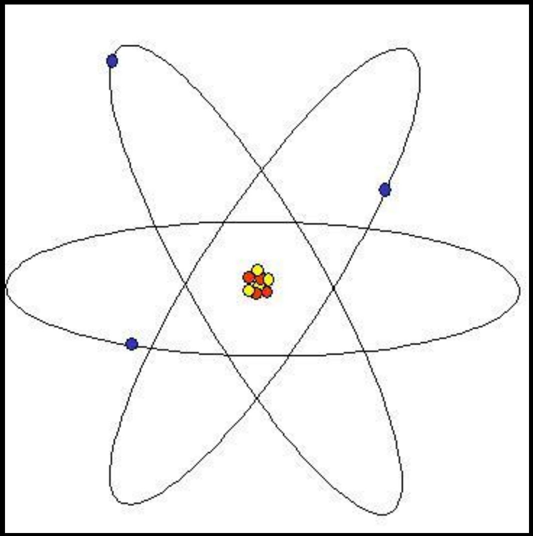
Fisika Inti
Nuclear Physics

Pengertian Modern: Gambar “onion”
Modern understanding: the ``onion’’ picture

Atom



Let’s see what’s inside!

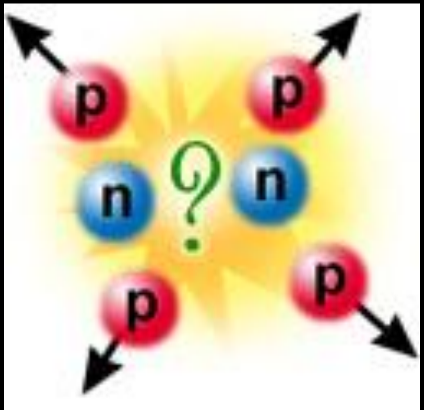
Pengertian Modern: Gambar “onion” Modern understanding: the ``onion” picture

Nucleus

Let’s see what’s inside!

Pengertian Modern: Gambar “onion” Modern understanding: the ``onion” picture

Protons and
neutrons



Let’s see what’s inside!

Next chapter…

Pendahuluan: Perkembangan Fisika Inti
Introduction: Development of Nuclear Physics

- 1896 – the birth of nuclear physics
  - Becquerel discovered radioactivity in uranium compounds
- Rutherford showed the radiation had three types
  - Alpha (He nucleus)
  - Beta (electrons)
  - Gamma (high-energy photons)
- 1911 Rutherford, Geiger and Marsden performed scattering experiments
  - Established the point mass nature of the nucleus
  - *Nuclear force* was a new type of force
- 1919 Rutherford and coworkers first observed nuclear reactions in which naturally occurring alpha particles bombarded nitrogen nuclei to produce oxygen
- 1932 Cockcroft and Walton first used artificially accelerated protons to produce nuclear reactions
- 1932 Chadwick discovered the neutron
- 1933 the Curies discovered artificial radioactivity
- 1938 Hahn and Strassman discovered nuclear fission
- 1942 Fermi achieved the first controlled nuclear fission reactor

29.1 Some Properties of Nuclei

- All nuclei are composed of protons and neutrons
  - Exception is ordinary hydrogen with just a proton
- The *atomic number*, Z, equals the number of protons in the nucleus
- The *neutron number*, N, is the number of neutrons in the nucleus
- The *mass number*, A, is the number of nucleons in the nucleus
  - A = Z + N
  - Nucleon is a generic term used to refer to either a proton or a neutron
  - The mass number is not the same as the mass
- Notation $^{A}_{Z}X$ where X is the chemical symbol of the element
- Example: $^{27}_{13}Al$
    - Mass number is 27
    - Atomic number is 13
    - Contains 13 protons
    - Contains 14 (27 – 13) neutrons
  - The Z may be omitted since the element can be used to determine Z

Muatan dan massa Charge and mass

Charge:

- The electron has a single negative charge, -e ($e = 1.60217733 \times 10^{-19}$ C)
- The proton has a single positive charge, +e
  - Thus, charge of a nucleus is equal to Ze
- The neutron has no charge
  - Makes it difficult to detect

Mass:

- It is convenient to use *atomic mass units,* u, to express masses
  - $1\ u = 1.660559 \times 10^{-27}$ kg
  - Based on definition that the mass of one atom of C-12 is exactly 12 u
- Mass can also be expressed in MeV/c^2
  - From $E_R = m c^2$
  - $1\ u = 931.494$ MeV/c^2

Ringkasan Massa Summary of Masses

	Masses		
Particle	***kg***	***u***	***MeV/c²***
Proton	1.6726×10^{-27}	1.007276	938.28
Neutron	1.6750×10^{-27}	1.008665	939.57
Electron	9.101×10^{-31}	5.486×10^{-4}	0.511

Quick problem: protons in your body

What is the order of magnitude of the number of protons in your body? Of the number of neutrons? Of the number of electrons? Take your mass approximately equal to 70 kg.

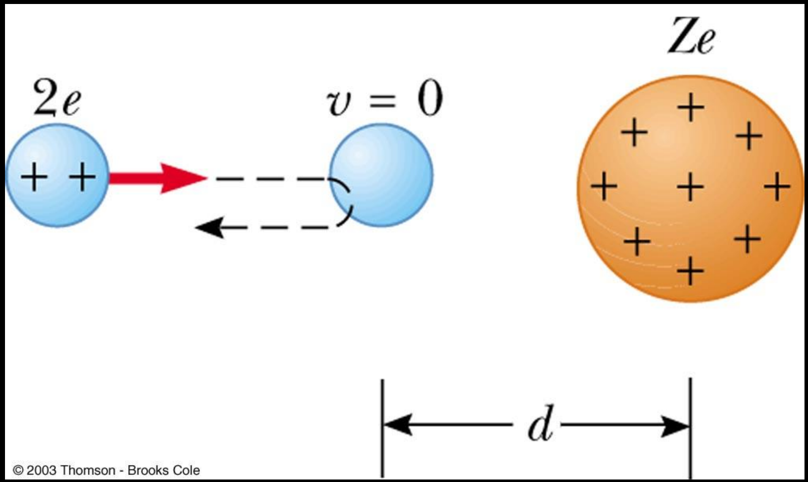
An iron nucleus (in hemoglobin) has a few more neutrons than protons, but in a typical water molecule there are eight neutrons and ten protons. So protons and neutrons are nearly equally numerous in your body, each contributing 35 kg out of a total body mass of 70 kg.

$$N = 35kg\left(\frac{1\,\text{nucleon}}{1.67\times10^{-27}\,kg}\right) \approx 10^{28}\,\text{protons}$$

Same amount of neutrons and electrons.

Ukuran Inti The Size of the Nucleus

- First investigated by Rutherford in scattering experiments
- He found an expression for how close an alpha particle moving toward the nucleus can come before being turned around by the Coulomb force
- The KE of the particle must be completely converted to PE



$$\frac{1}{2}mv^2 = k_e\frac{q_1q_2}{r} = k_e\frac{2e \quad Ze}{d}$$

or

$$\boxed{d = \frac{4k_eZe^2}{mv^2}}$$

- For gold: d = 3.2 x 10^{-14} m, for silver: d = 2 x 10^{-14} m

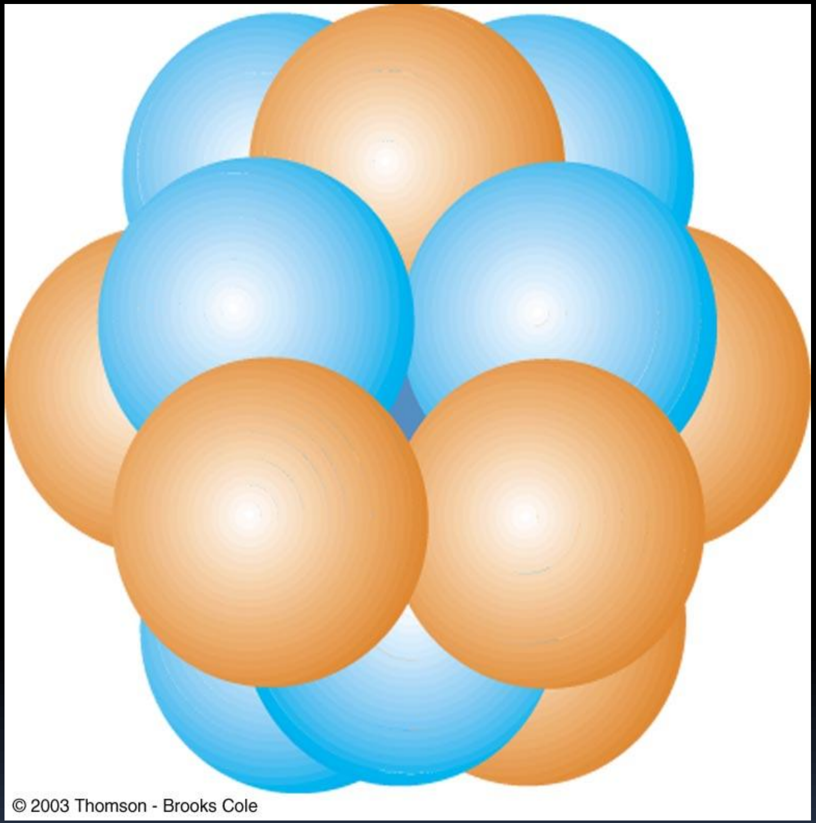
Such small lengths are often expressed in *femtometers* where 1 fm = 10^{-15} m (also called a fermi)

Ukuran Inti Size of Nucleus

- Since the time of Rutherford, many other experiments have concluded the following
  - Most nuclei are approximately spherical
  - Average radius is

$$r = r_o A^{1/3}$$

  - $r_o = 1.2 \times 10^{-15}$ m



Kerapatan Inti Density of Nuclei

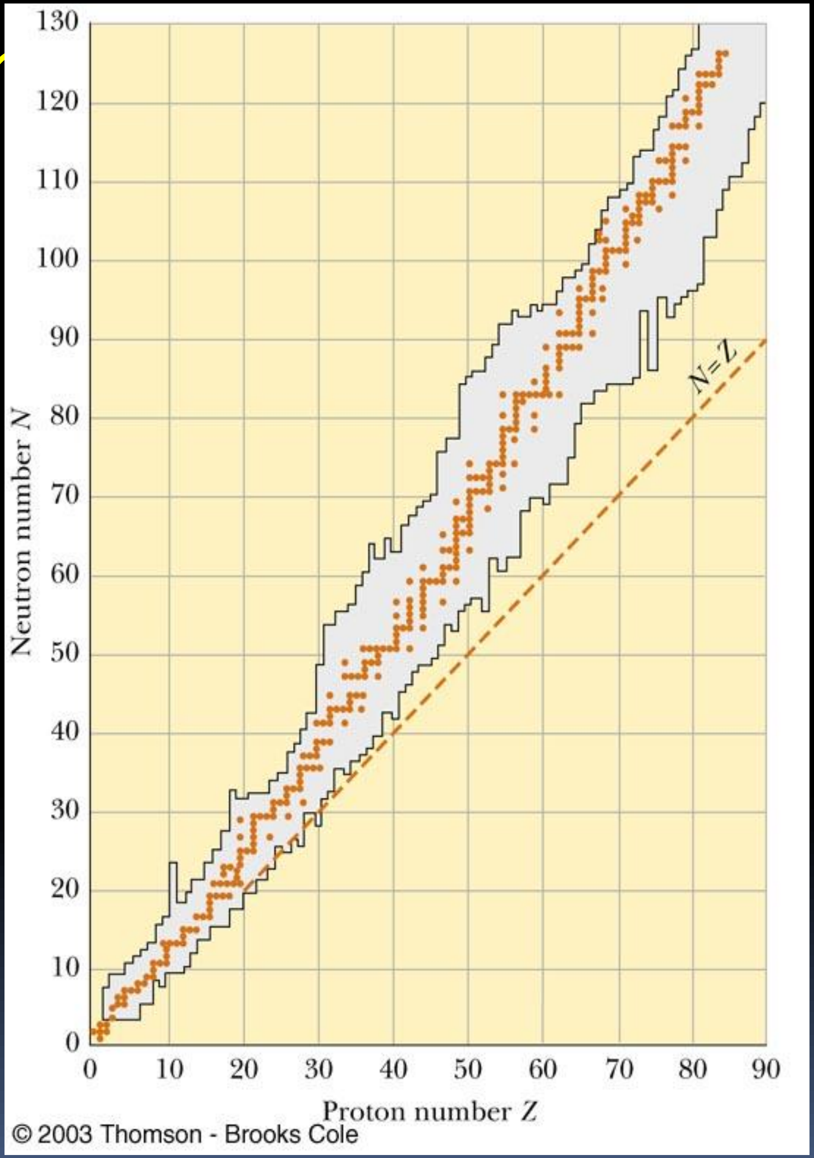
- The volume of the nucleus (assumed to be spherical) is directly proportional to the total number of nucleons
- This suggests that *all nuclei have nearly the same density*
- Nucleons combine to form a nucleus as though they were tightly packed spheres

Kesetabilan Inti Nuclear Stability

- There are very large repulsive electrostatic forces between protons
  - These forces should cause the nucleus to fly apart
- The nuclei are stable because of the presence of another, short-range force, called the *nuclear (or strong) force*
  - This is an attractive force that acts between all nuclear particles
  - The nuclear attractive force is stronger than the Coulomb repulsive force at the short ranges within the nucleus

Grafik Kesetabilan Inti
Nuclear Stability char

- Light nuclei are most stable if N = Z
- Heavy nuclei are most stable when N > Z
  - As the number of protons increase, the Coulomb force increases and so more nucleons are needed to keep the nucleus stable
- No nuclei are stable when Z > 83



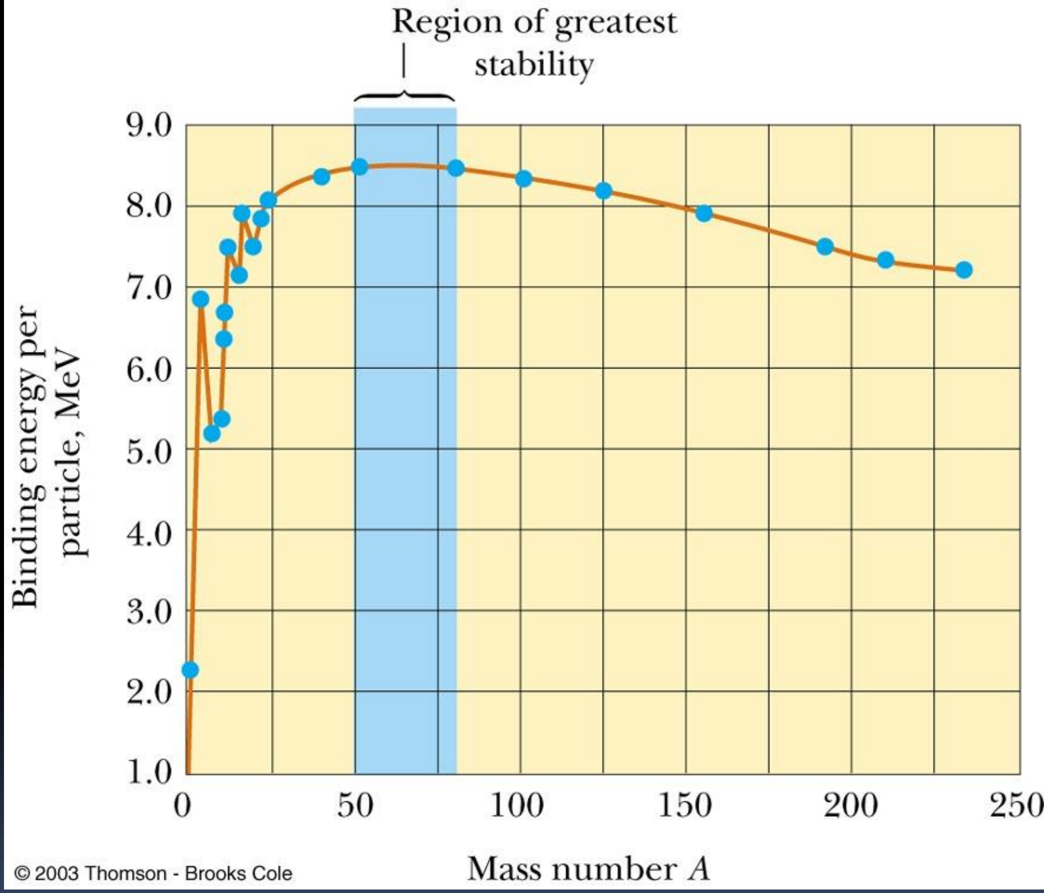
Isotop Isotopes

- The nuclei of all atoms of a particular element must contain the same number of protons
- They may contain varying numbers of neutrons
  - *Isotopes* of an element have the same Z but differing N and A values
  - Example:

$$^{11}_{6}C \quad ^{12}_{6}C \quad ^{13}_{6}C \quad ^{14}_{6}C$$

29.2 Binding Energy

- The total energy of the bound system (the nucleus) is less than the combined energy of the separated nucleons
  - This difference in energy is called the *binding energy* of the nucleus
    - It can be thought of as the amount of energy you need to add to the nucleus to break it apart into separated protons and neutrons



Binding Energy per Nucleon

Binding Energy Notes

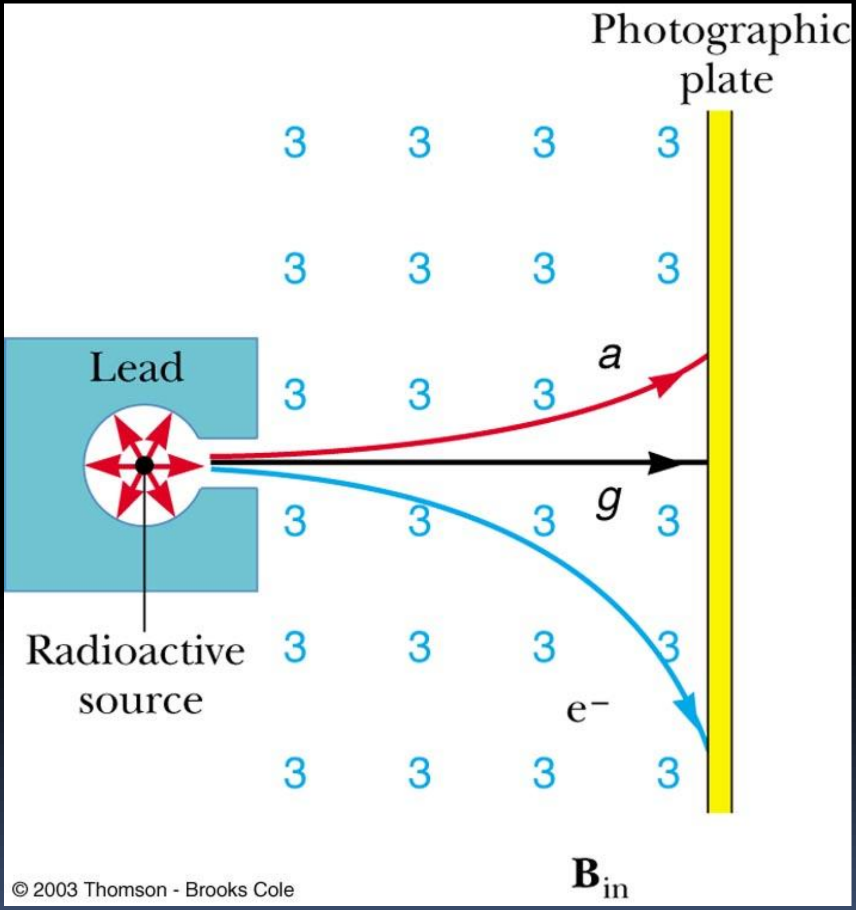
- Except for light nuclei, the binding energy is about 8 MeV per nucleon
- The curve peaks in the vicinity of A = 60
  - Nuclei with mass numbers greater than or less than 60 are not as strongly bound as those near the middle of the periodic table
- The curve is slowly varying at A > 40
  - This suggests that the nuclear force saturates
  - A particular nucleon can interact with only a limited number of other nucleons

29.3 Radioaktiv Radioactivity

- *Radioactivity* is the spontaneous emission of radiation
- Experiments suggested that radioactivity was the result of the decay, or disintegration, of unstable nuclei
- Three types of radiation can be emitted
  - Alpha particles
    - The particles are ^4He nuclei
  - Beta particles
    - The particles are either electrons or positrons
      - A positron is the *antiparticle* of the electron
      - It is similar to the electron except its charge is +e
  - Gamma rays
    - The "rays" are high energy photons

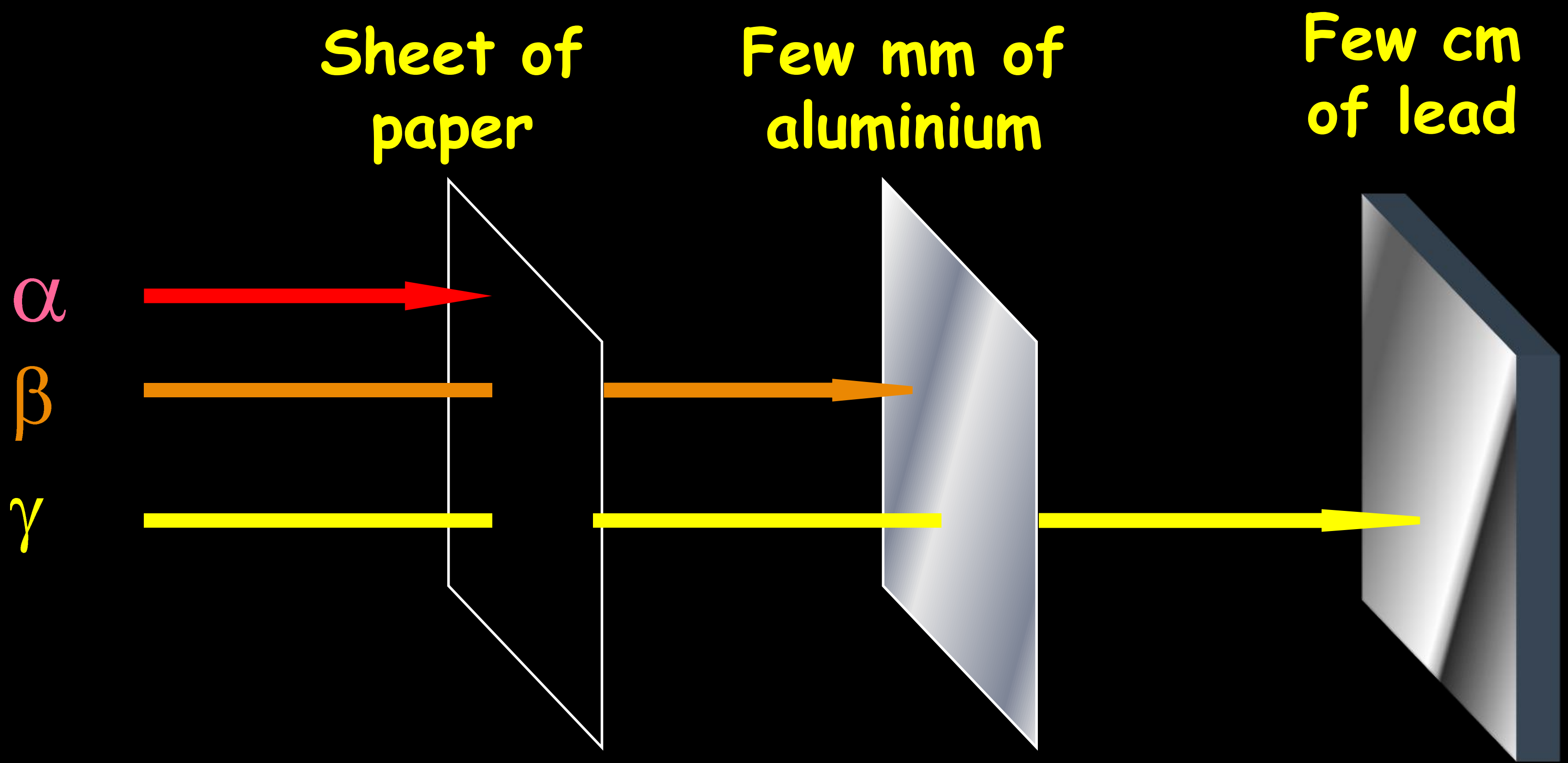
Distinguishing Types of Radiation

- The gamma particles carry no charge
- The alpha particles are deflected upward
- The beta particles are deflected downward
  - A positron would be deflected upward



Penetrating Ability of Particles

- Alpha particles
  - Barely penetrate a piece of paper
- Beta particles
  - Can penetrate a few mm of aluminum
- Gamma rays
  - Can penetrate several cm of lead

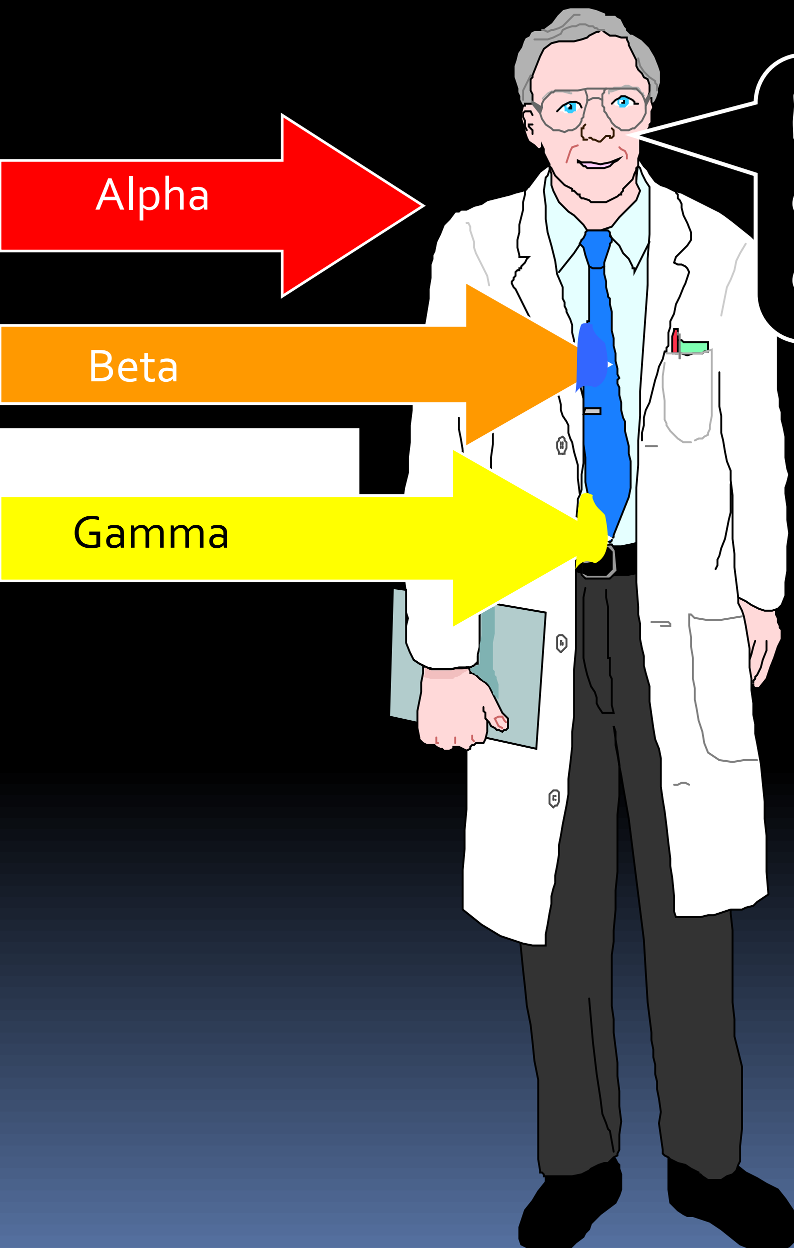


α particles cannot pass through paper

β particles cannot pass through aluminium

γ particles cannot pass through lead

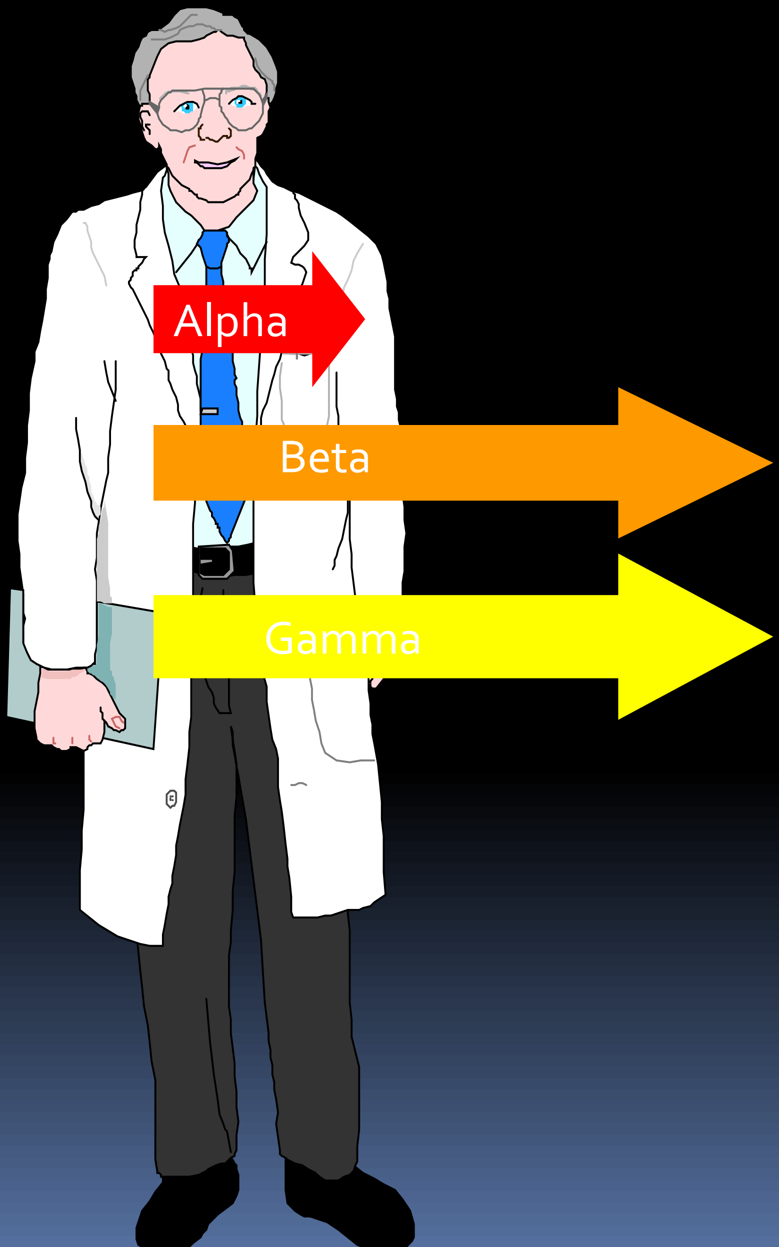
Dangers of radioactivity – OUTSIDE BODY



Radiation will ionise atoms in living cells – this can damage them and cause cancer or leukaemia.

OUTSIDE the body β and γ are more dangerous as they can penetrate the skin into your body to your organs.

Dangers of radioactivity – INSIDE BODY



INSIDE the body an α radiation is the most dangerous because it has not enough energy to pass out of the body and has the greatest ionization power to damage cells.

β and γ are less dangerous because they have enough energy to pass out of the body

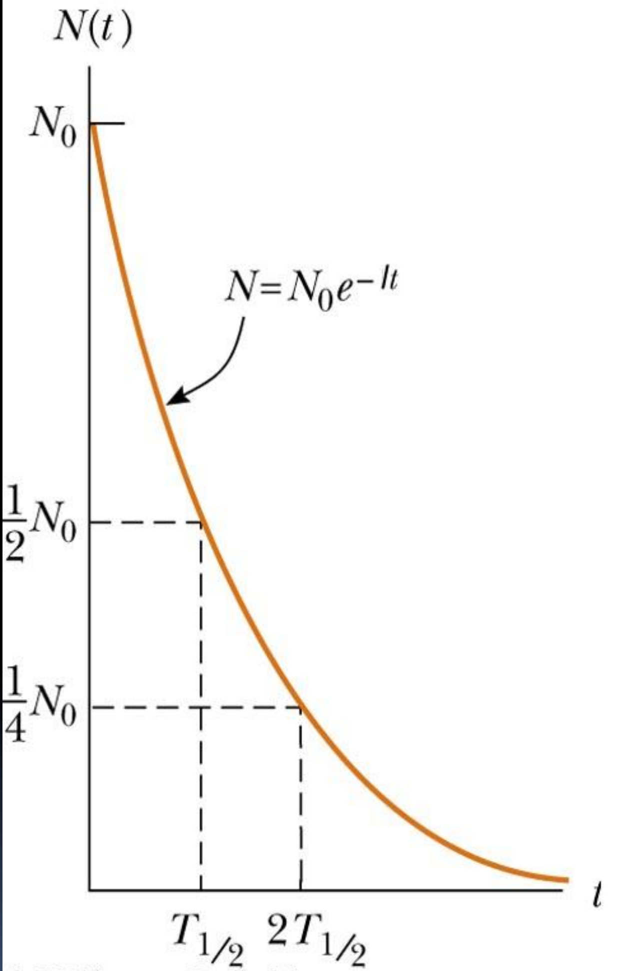
Kurva Decay Curve

- The decay curve follows the equation

$$N = N_0 e^{-\lambda t}$$

- The *half-life* is also a useful parameter
- The half-life is defined as the time it takes for half of any given number of radioactive nuclei to decay

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$



QUICK QUIZ

What fraction of a radioactive sample has decayed after two half-lives have elapsed?

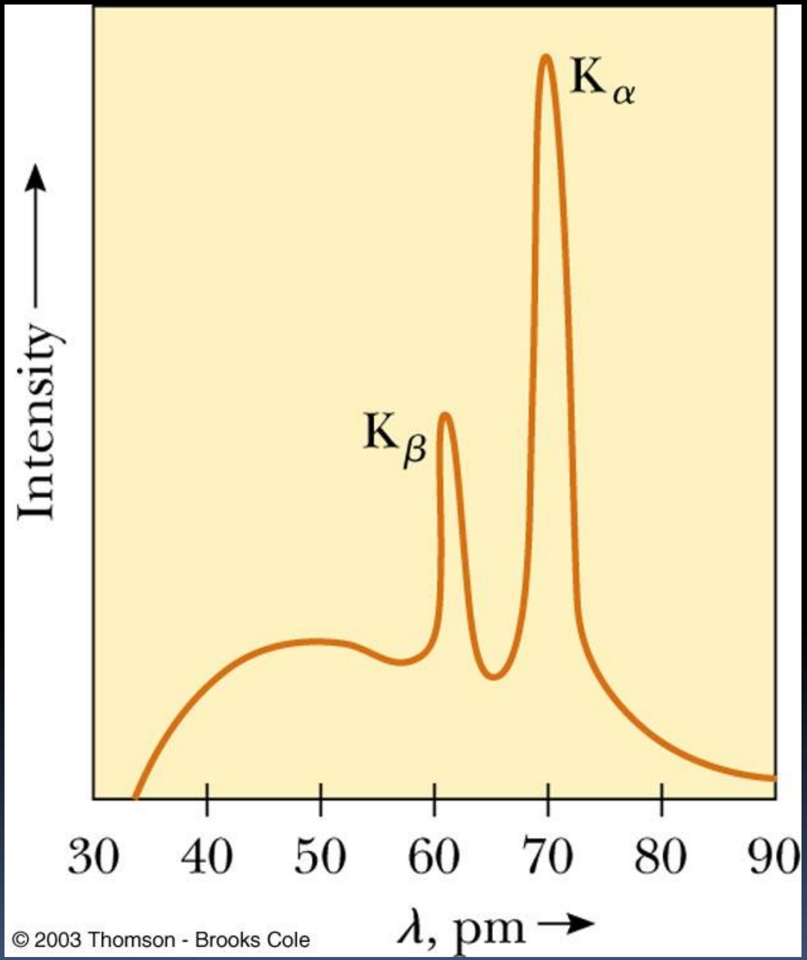
(a) 1/4 (b) 1/2 (c) 3/4
(d) not enough information to say

(c). At the end of the first half-life interval, half of the original sample has decayed and half remains. During the second half-life interval, half of the remaining portion of the sample decays. The total fraction of the sample that has decayed during the two half-lives is:

$$\frac{1}{2}+\frac{1}{2}\left(\frac{1}{2}\right)=\frac{3}{4}$$

Karakteristik Sinar-X
Characteristic X-Rays

- When a metal target is bombarded by high-energy electrons, x-rays are emitted
- The x-ray spectrum typically consists of a broad continuous spectrum and a series of sharp lines
  - The lines are dependent on the metal
  - The lines are called *characteristic x-rays*



Penjelasan Karakteristik Sinar-X Explanation of Characteristic X-Rays

- The details of atomic structure can be used to explain characteristic x-rays
  - A bombarding electron collides with an electron in the target metal that is in an inner shell
  - If there is sufficient energy, the electron is removed from the target atom
  - The vacancy created by the lost electron is filled by an electron falling to the vacancy from a higher energy level
  - The transition is accompanied by the emission of a photon whose energy is equal to the difference between the two levels

Penggunaan Radioaktiv
Uses of Radioactivity

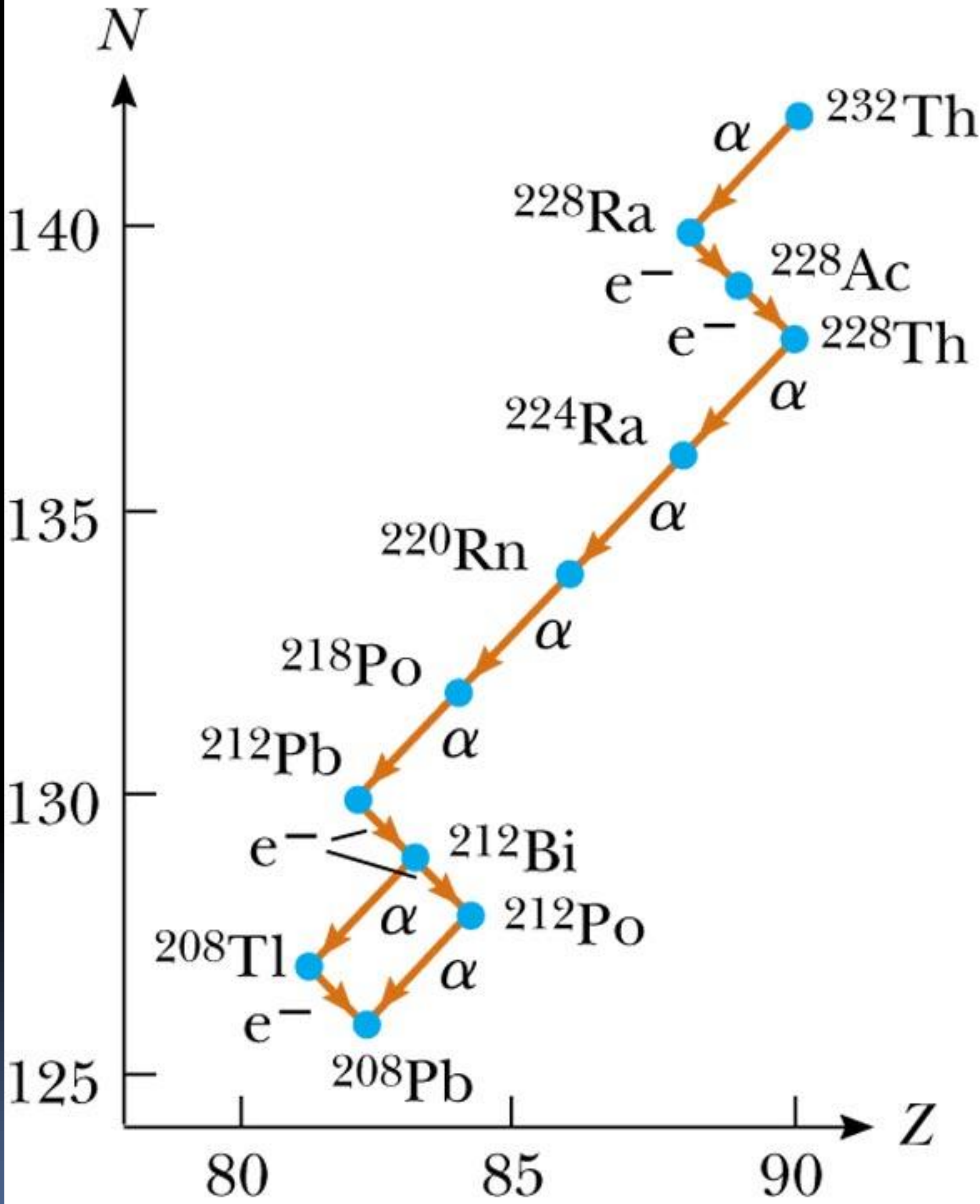
- Carbon Dating
  - Beta decay of ^{14}C is used to date organic samples
  - The ratio of ^{14}C to ^{12}C is used
- Smoke detectors
  - Ionization type smoke detectors use a radioactive source to ionize the air in a chamber
  - A voltage and current are maintained
  - When smoke enters the chamber, the current is decreased and the alarm sounds
- Radon pollution
  - Radon is an inert, gaseous element associated with the decay of radium
  - It is present in uranium mines and in certain types of rocks, bricks, etc that may be used in home building
  - May also come from the ground itself

29.5 Natural Radioactivity

- Classification of nuclei
  - Unstable nuclei found in nature
    - Give rise to *natural radioactivity*
  - Nuclei produced in the laboratory through nuclear reactions
    - Exhibit *artificial radioactivity*
- Three series of natural radioactivity exist
  - Uranium
  - Actinium
  - Thorium

Decay Series of ^{232}Th

- Series starts with ^{232}Th
- Processes through a series of alpha and beta decays
- Ends with a stable isotope of lead, ^{208}Pb



29.6 Nuclear Reactions

- Structure of nuclei can be changed by bombarding them with energetic particles
  - The changes are called *nuclear reactions*
- As with nuclear decays, the atomic numbers and mass numbers must balance on both sides of the equation

Problem

Which of the following are possible reactions?

(a) $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\left(^{1}_{0}n\right)$

(b) $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{132}_{50}Sn + ^{101}_{42}Mo + 3\left(^{1}_{0}n\right)$

(c) $^{1}_{0}n + ^{239}_{94}Pu \rightarrow ^{127}_{53}I + ^{93}_{41}Nb + 3\left(^{1}_{0}n\right)$

(a) and (b). Reactions (a) and (b) both conserve total charge and total mass number as required. Reaction (c) violates conservation of mass number with the sum of the mass numbers being 240 before reaction and being only 223 after reaction.

Q Values

- Energy must also be conserved in nuclear reactions
- The energy required to balance a nuclear reaction is called the *Q value* of the reaction
  - An *exothermic reaction*
    - There is a mass "loss" in the reaction
    - There is a release of energy
    - Q is positive
  - An *endothermic reaction*
    - There is a "gain" of mass in the reaction
    - Energy is needed, in the form of kinetic energy of the incoming particles
    - Q is negative

Threshold Energy

- To conserve both momentum and energy, incoming particles must have a minimum amount of kinetic energy, called the *threshold energy*

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

  - 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

QUICK QUIZ

If the Q value of an endothermic reaction is -2.17 MeV, the minimum kinetic energy needed in the reactant nuclei if the reaction is to occur must be (a) equal to 2.17 MeV, (b) greater than 2.17 MeV, (c) less than 2.17 MeV, or (d) precisely half of 2.17 MeV.

(b). In an endothermic reaction, the threshold energy exceeds the magnitude of the Q value by a factor of $(1 + m/M)$, where m is the mass of the incident particle and M is the mass of the target nucleus.