INTERNATIONAL COLLEGE OF PHARMACEUTICAL INNOVATION

国际创新药学院

Class	Pharm, BioPharm
Course	Fundamentals of Medicinal & Pharmaceutical Chemistry
Code	FUNCHEM.2
Title	Matter: The Basis of Life & Isotopes
Lecturer	Prof. Xinchen Teng
Date	2024-10-09

RECOMMENDED READING

- General Chemistry - The Essential Concepts by Chang and Goldsby (7th edition)
  - Sections 1.3, 2.3, 2.5, 3.1 and 21.7

FUNCHEM.2 Learning Outcomes

- Define ‘matter’, ‘elements’, ‘atom’, ‘mass number’, atomic number’, ‘isotope’.
- Recall the 4 most abundant elements found in the human body and state their functions.
- Identify the number of protons, neutrons and electrons in the first 20 elements of the Periodic Table.
- Discuss diagnostic applications of isotopes using ^{99}Tc, ^{131}I and ^{24}Na as examples.
- Discuss radiation therapy.
- Calculate relative atomic mass of elements.

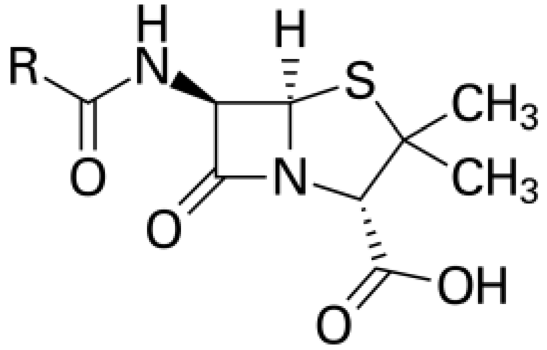
Matter and Chemistry

Chemistry Matters!

To understand how the body works and how the body is affected by disease, you need to know:

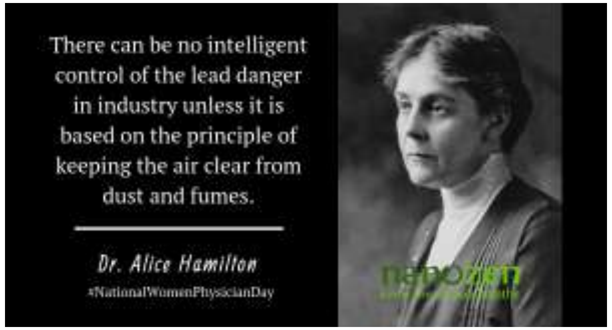
- the composition of matter
- the interactions within matter

Discovery and Development of Penicillin
Alexander Fleming in 1928
Semisynthetic antibiotics

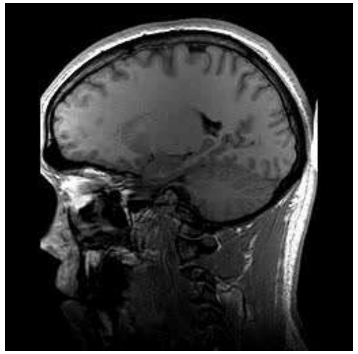


Historic Chemical Landmarks

Alice Hamilton and the Development of Occupational Medicine (1916)
Lead Poisoning



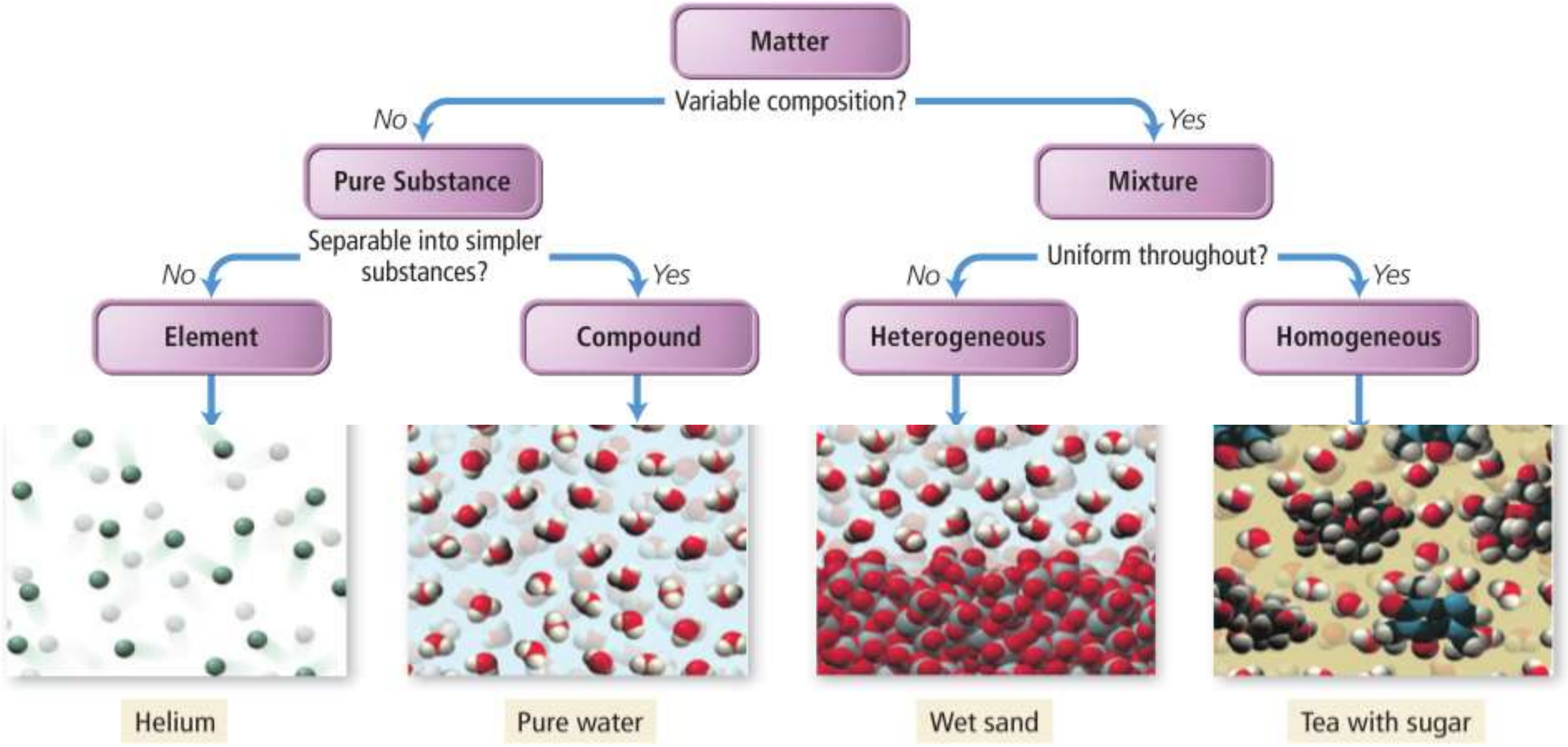
MRI (magnetic resonance imaging) a staple of medical diagnostics



Some Useful Definitions

Chemistry is the study of the *composition, structure and properties* of matter, the *changes* it undergoes and the energy associated with these changes

Matter is anything that occupies space and has mass. Matter can be classified based on its composition.



Elements

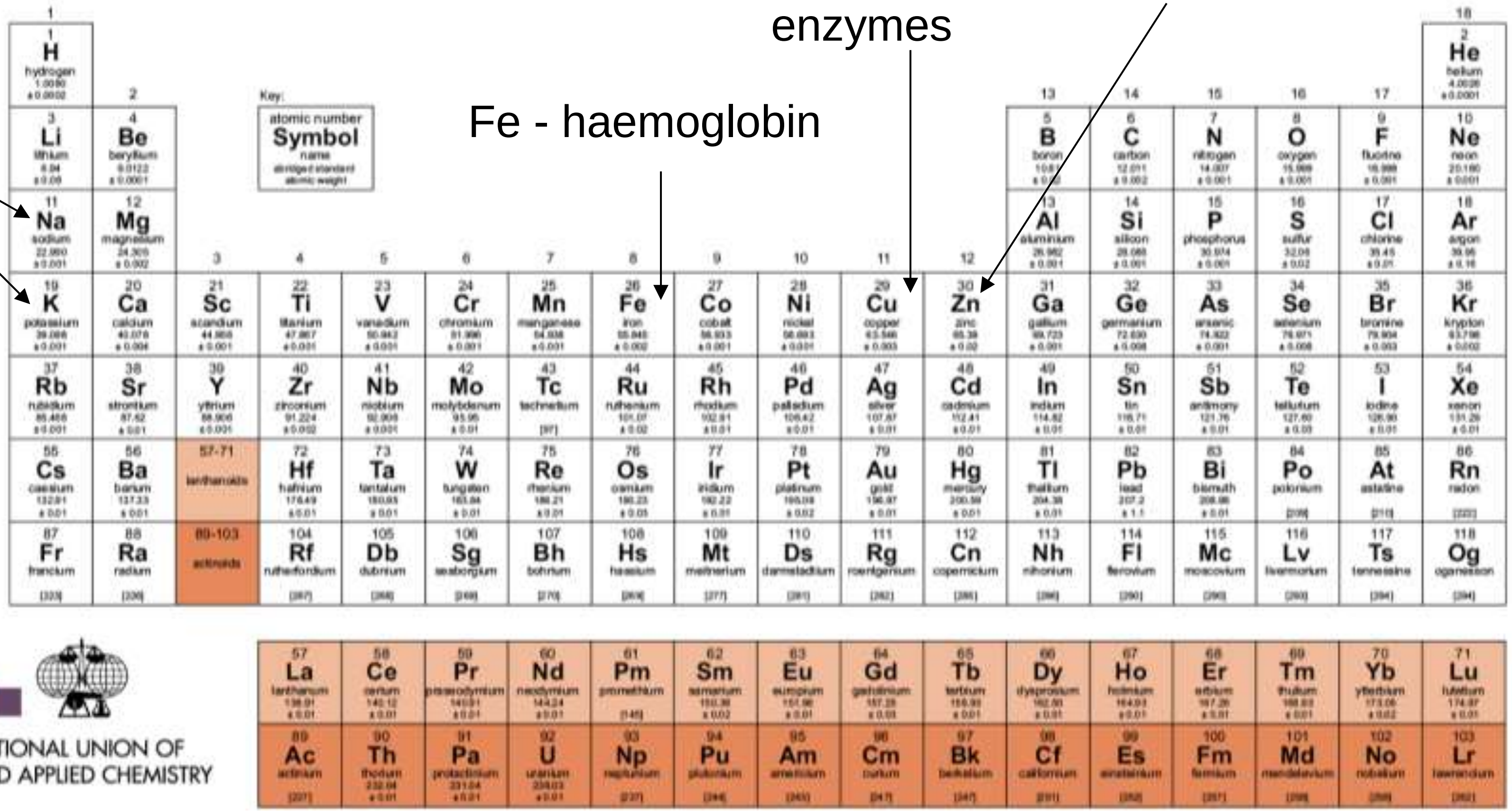
An **element** is a substance that cannot be separated into simpler substances by chemical means. Currently **118** elements have been identified.

Zn – enzymes – longevity, growth, fertility

Cu – oxidative enzymes

Na/K - nervous system

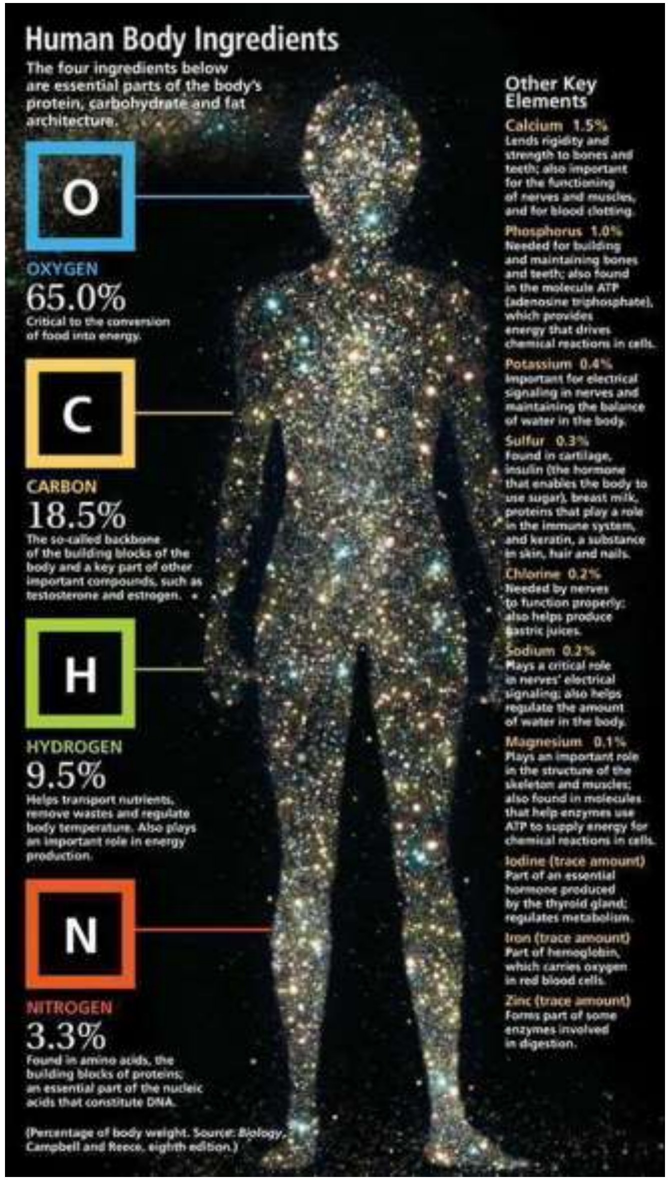
Fe - haemoglobin



INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

https://iupac.org/what-we-do/periodic-table-of-elements/

Fact!



99% of the human body consists of substances made from only 4 elements.

Oxygen	**Cellular Respiration**
Carbon	**Backbone of organic compounds**
Hydrogen	**Component of organic compounds; acid-base balance**
Nitrogen	**Component of proteins, nucleic acids, cell membranes**

What is an atom?

Recall elements are substances made up of the same types of atoms

An atom is the smallest unit of an element.

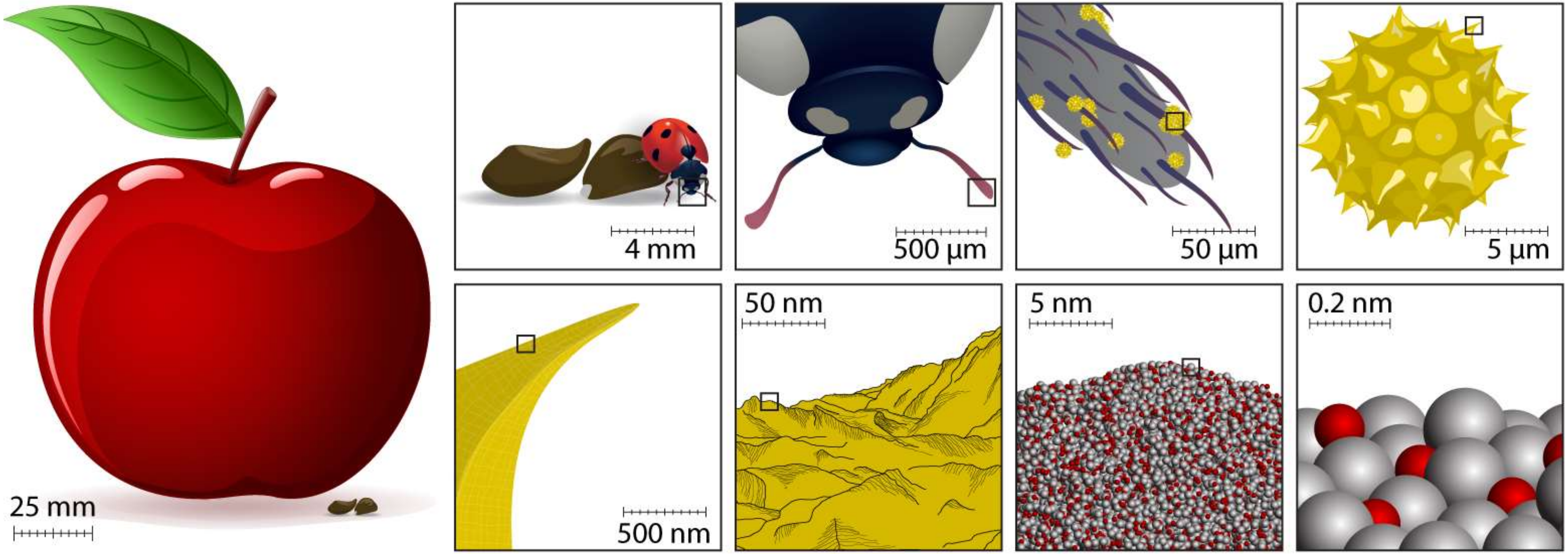
(still retains the properties of the element)

All atoms of an element are identical.

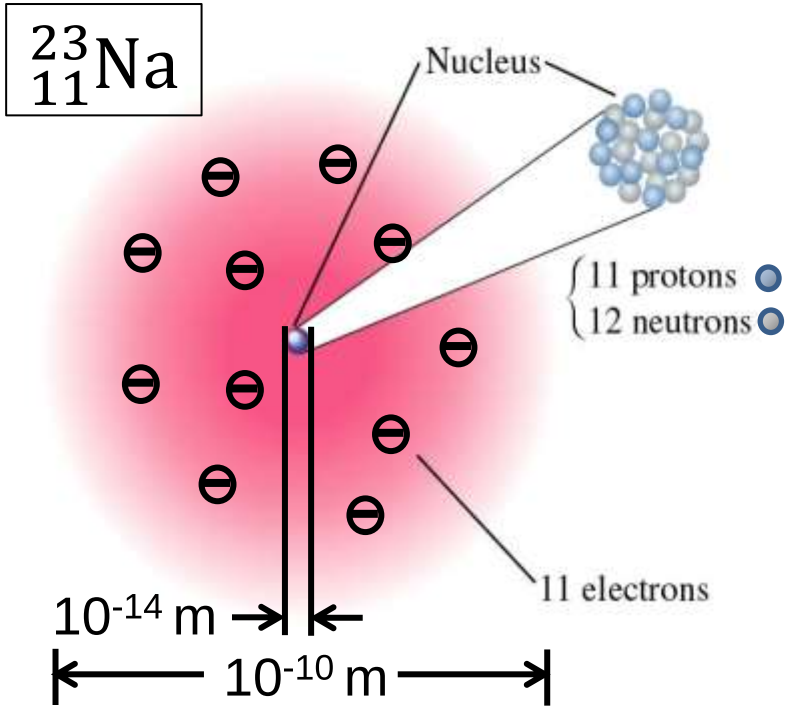
An atom is made up of electrons, protons, and neutrons as well as other particles.

An atom is the smallest part of an element that can undergo a chemical reaction.

Size and Structure of Atoms



Size and Structure of Atoms



Nucleus: at the center of the atom and is small, dense and positively charged

- **Proton:** small particle with a unit positive charge
- **Neutron:** small particle with no charge

Electron: surrounding the nucleus and has a unit negative charge.

The number of electrons are always the same with the number of protons in an atom.

Particle	Symbol	Location	Mass	Charge
Proton	p^+	Nucleus	1.67×10^{-27} kg (1)	+1
Neutron	n	Nucleus	1.68×10^{-27} kg (1)	0
Electron	e-	Orbiting nucleus	9.1×10^{-31} kg	-1

Atomic Number

The **atomic number (Z)** of an element is the number of protons in the nucleus of an atom of that element.

$$^{12}_{6}C$$

atomic number (Z)

The number of **protons** in the nucleus of an atom tell us what type of element the atom is, i.e. the number of protons reveals the **identity** of the atom.

Refer to your periodic table and the atomic no's!

- A hydrogen atom always has **1 proton**
- A carbon atom always has **6 protons**
- A platinum atom always has **78 protons**
- A uranium atom always has **92 protons**

Atomic Number and Electrons

An atom containing an equal number of protons and electrons is electrically neutral, otherwise it has a positive or negative charge and is an **ion**.

Therefore electrically neutral atoms have the same number of protons and electrons

Refer to your periodic table and the atomic no's!

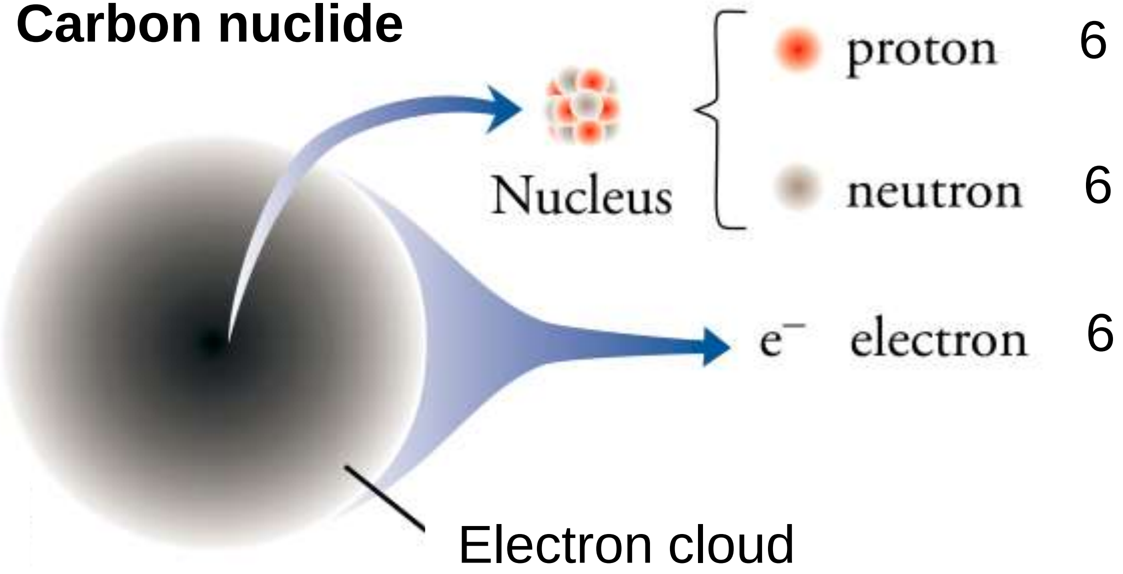
- An electrically neutral hydrogen atom has **1 electron**
- An electrically neutral carbon atom has **6 electrons**
- An electrically neutral platinum atom has **78 electrons**
- An electrically neutral uranium atom has **92 electrons**

Mass Number

- **Mass number (A)**: the total number of protons and neutrons in the nucleus of an atom

mass number (A) = atomic number (Z) + neutron number (N)

Carbon nuclide



Carbon-12

mass number (A)

$^{12}_{6}C$

atomic number (Z)

Atomic Number and Mass Number

The number of neutrons in nucleus = Mass number – Atomic number,
i.e. Number of neutrons (N) = A- Z

	Atomic No.	Mass No.	Protons	Neutrons	Electrons
$^{9}_{4}Be$	4	9	4	**5**	**4**
$^{19}_{9}F$	9	19	9	**10**	**9**
$^{23}_{11}Na$	11	23	11	**12**	**11**
$^{12}_{6}C$	6	12	6	**6**	**6**
$^{14}_{7}N$	7	14	7	**7**	**7**

What are molecules?

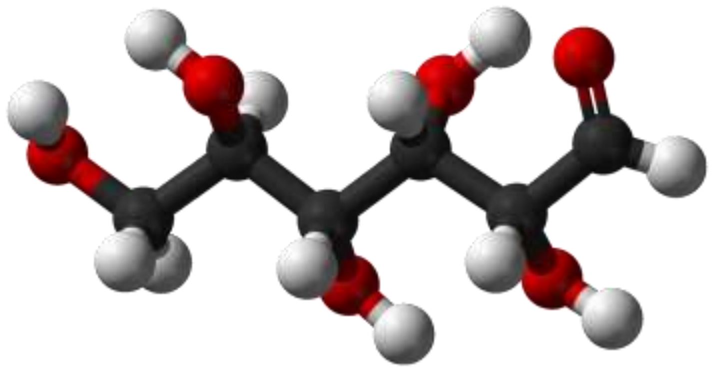
A **molecule** is an aggregate of at least two atoms in a definite arrangement held together by chemical forces (also called chemical bonds).

A molecule can have atoms of the same element such as molecular oxygen $\mathbf{O_2}$ or atoms of different elements (compounds) such as:

Nitric Oxide - **NO**

Water - $\mathbf{H_2O}$

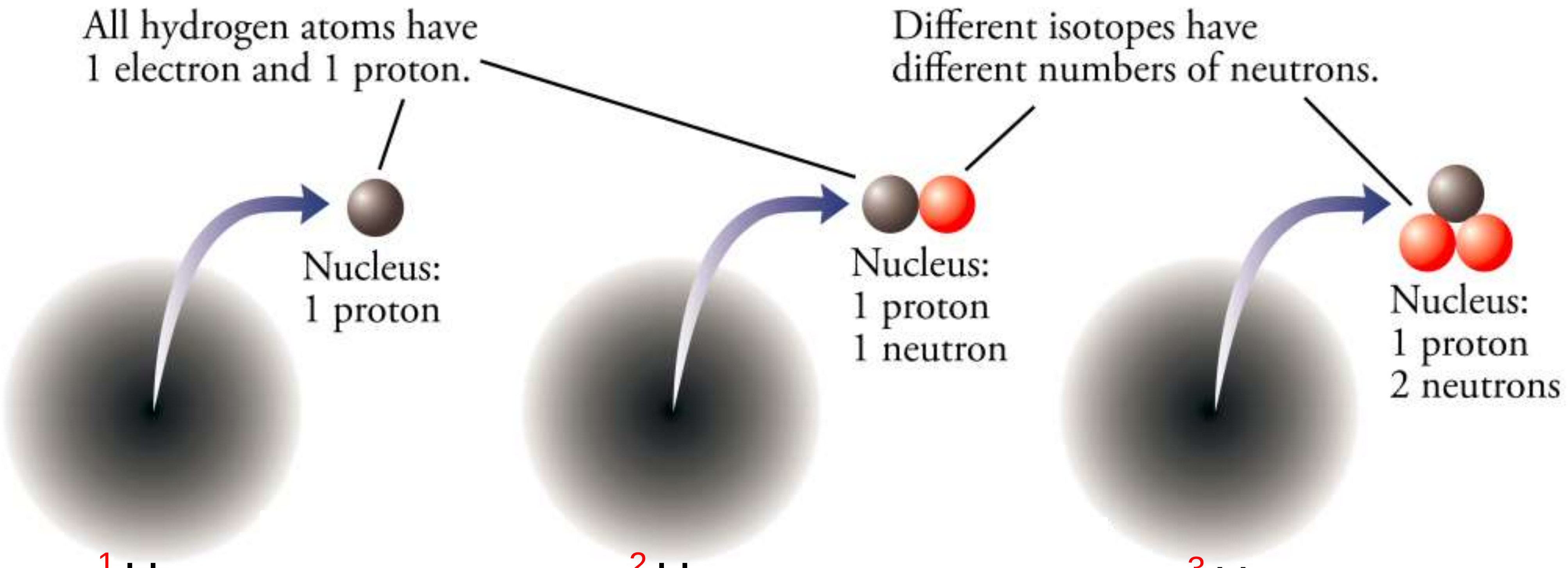
Glucose - $\mathbf{C_6H_{12}O_6}$.



Glucose for example contains carbon (grey) , hydrogen (white) and oxygen (red) atoms

Isotopes

Isotopes are atoms of an element that have the same number of protons (Z) but a different number of neutrons (N), or atoms of an element that have the same atomic number (Z) but different mass number (A)



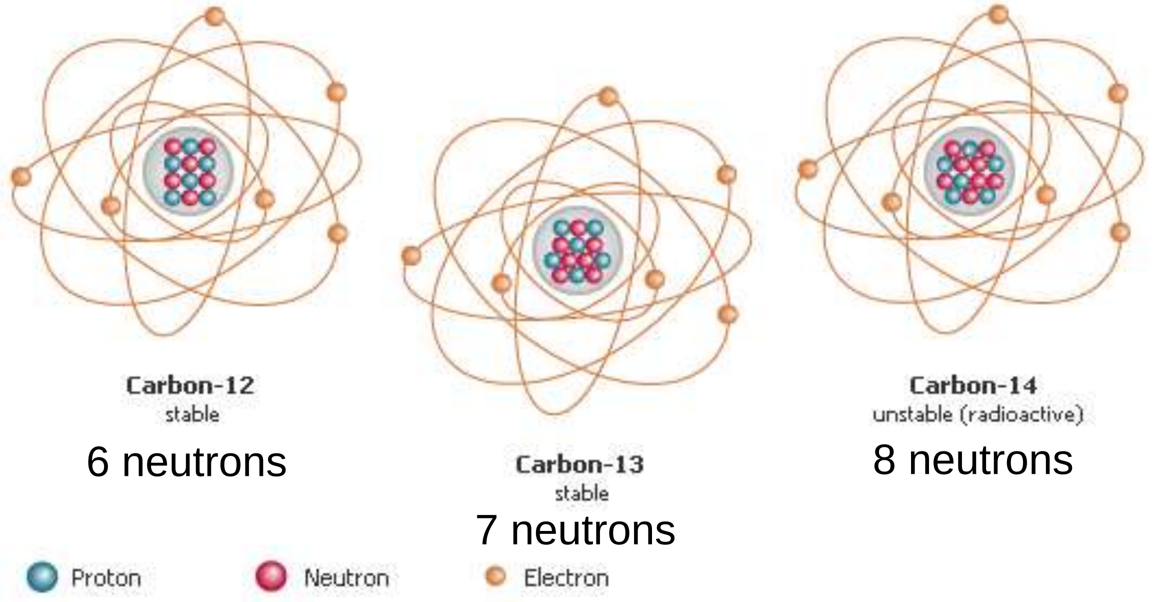
$^{1}_{1}H$ protium

$^{2}_{1}H$ deuterium

$^{3}_{1}H$ tritium

Isotopes

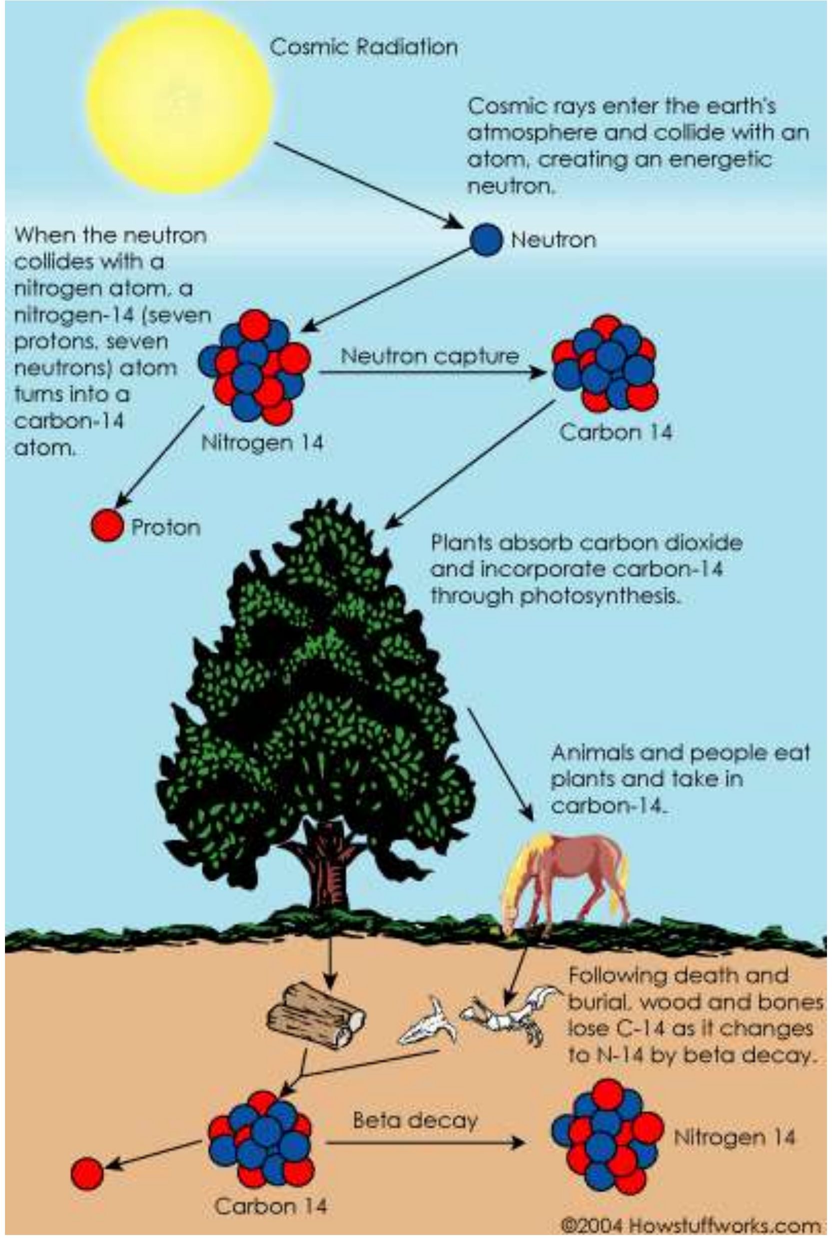
Isotopes of carbon



6 neutrons

7 neutrons

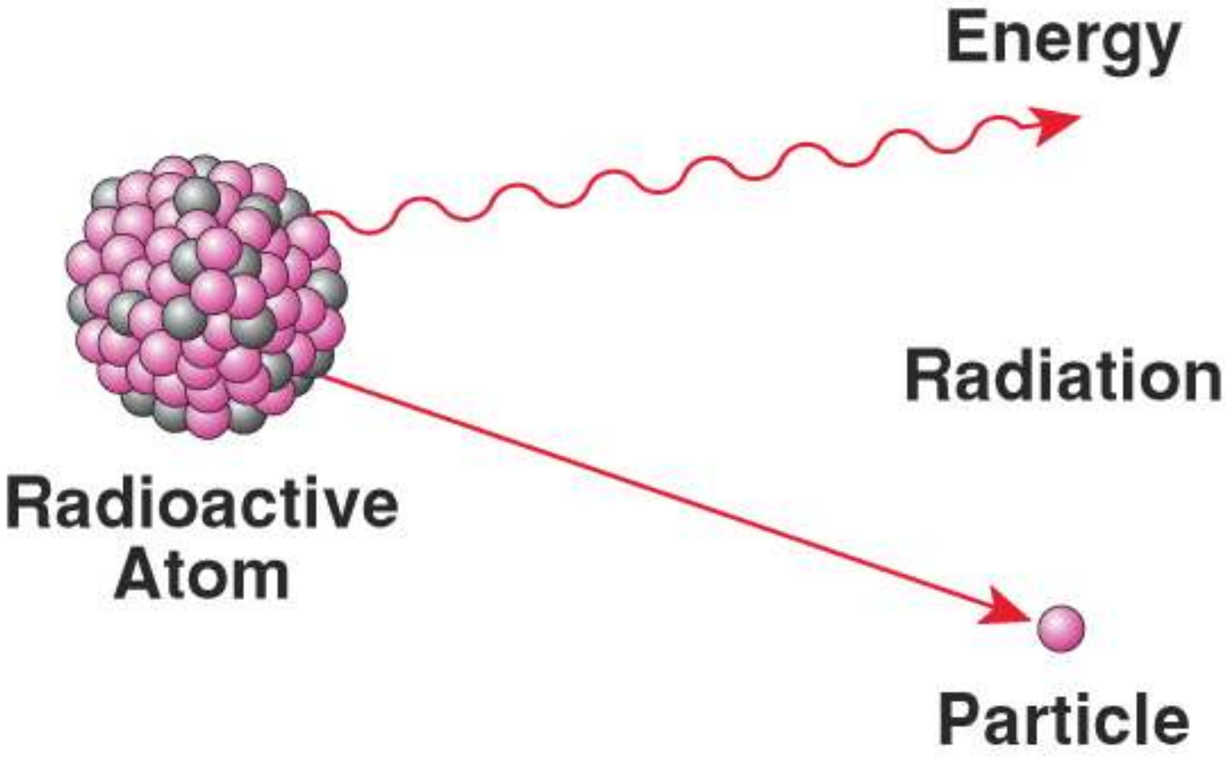
8 neutrons



Carbon Dating:
Method that uses the naturally occurring <u>radioisotope carbon-14</u> to estimate the age of carbon-bearing materials up to about 58,000 to 62,000 years

Isotopes

Unstable isotopes break down
and emit radiation



Medical Applications

Diagnostic - detection
Therapeutic - treatment

Technecium-99

Most widely used isotope in medical diagnosis.

Used to obtain images of the liver, heart, and lungs.

Gaynor, D.; Griffith, D.M. The prevalence of metal-based drugs as therapeutic or diagnostic agents: Beyond platinum. *Dalton Trans.* **2012**, *41*, 13239-13257.

Iodine-131 and Iodine-125

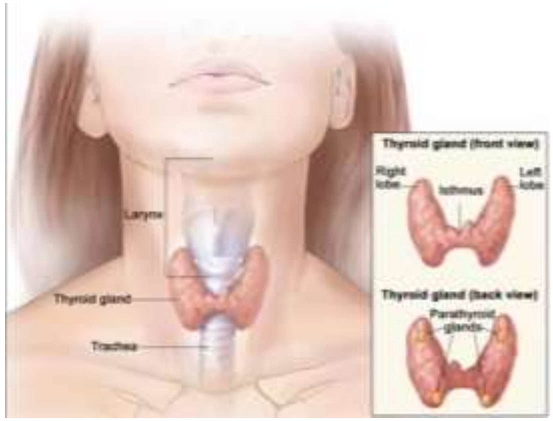
Thyroid gland requires iodine to function properly.

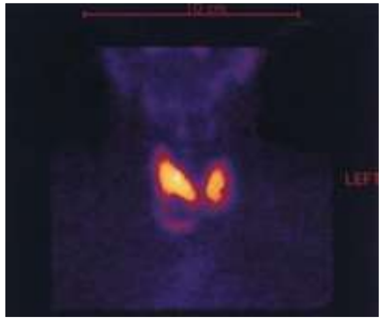
- A malfunctioning thyroid can be detected by administering a solution containing a known amount of:

- **Na^{131}I** and measuring the radioactivity just above the thyroid to see if the iodine is absorbed at the normal rate.

- **Na^{125}I** and image the thyroid gland.

Hypothyroidism
Normal
Hyperthyroidism





Sodium-24

Used to detect blockages in the circulatory system.

Sodium-24, in the form of $^{24}NaCl$,

is injected into the bloodstream as a salt solution.

Trace the flow of blood and detect possible blockages. The progress of blood through the arteries, veins and capillaries can be closely monitored.

Helium-3

To obtain this image, the patient inhaled one standard litre of ^{3}He before the MRI was taken.

Radiation Therapy

Exposure to high energy radiation can induce cancer in humans and other animals.

Cancer cells can be destroyed by proper radiation treatment.

In radiation therapy, a compromise is sought.

Radiation Damage

Somatic

affects organism during its lifetime e.g. sunburn

Genetic

Inherited e.g. a person whose chromosomes have been damaged/altered by radiation may have deformed offspring.

Average Atomic Mass

The **atomic mass** of an element is the mass of an atom of the element relative to one-twelfth the mass of an atom of carbon-12.

By international agreement, 1 **atomic mass unit (amu or u)** is defined as 1/12 of the mass of a single carbon-12 atom

the atomic mass of each carbon-12 atom is 12 u

$$\text{the atomic mass of atom X} = \frac{\text{mass of atom X}}{\frac{1}{12}\,\text{mass of carbon}-12}$$

Most elements have more than one isotope. The atomic masses listed in the periodic table are weighted **average atomic masses** for all of the isotopes of that element.

atomic mass = (isotope1# mass) × (abundance%) + (isotope2# mass) × (abundance%) + …

Average Atomic Mass

Example: Chlorine

2 isotopes: ^{35}Cl and ^{37}Cl

	Natural abundance	Atomic Mass
^{35}Cl	75.77%	34.97
^{37}Cl	24.23%	36.97

Average atomic mass = (0.7577 x 34.97) + (0.2423 x 36.97)

= 35.45 atomic mass units (a.m.u.)

Average Atomic Mass

Another example: Magnesium

3 isotopes: ^{24}Mg, ^{25}Mg and ^{26}Mg

	Natural abundance	Atomic Mass
^{24}Mg	78.70%	23.99
^{25}Mg	10.13%	24.99
^{26}Mg	11.17%	25.99

Average atomic mass = (0.7870 x 23.99) + (0.1013 x 24.99) + (0.1117 x 25.99)

Average atomic mass = 24.31 a.m.u.