Radiation Physics

RADIATION PHYSICS

Lecture (1)

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LECTURE (1) OUTLINE

Introduction to Radiation Physics

- Introduction
- Matter and Energy
- The Atom
- Ionization
- Terminology for Radiology

FUNDAMENTAL PHYSICAL CONSTANTS

Base Units		
Quantity	Unit Name	Symbol
Mass	kilogram	kg
Length	meter	m
Time	second	s
Electric Current	ampere	A
Temperature	kelvin	K
Amount of Substance	mole	mol
Luminous Intensity	candela	cd

FUNDAMENTAL PHYSICAL CONSTANTS

Derived Units			
Quantity	Unit Name	Symbol	British Units
Absorbed Dose	gray	Gy	rad
Charge	coulomb	C	esu
Electric Potential	volt	v	
Dose Equivalent	sievert	Sv	rem
Energy	joule	J	erg
Exposure	coulomb/kilogram	C/kg	roentgen
Frequency	hertz	Hz	cycles/second
Force	newton	N	
Magnetic Flux	weber	Wb	
Magnetic Flux Density	tesla	T	gauss
Power	watt	W	
Radioactivity	bequerel	Bq	curie

MATTER AND ENERGY

Matter

- **Mass:** is a property of physical objects which, roughly speaking, **measure the amount of matter contained in an object.** It is a central concept of classical mechanics and related subjects. In the SI system of measurement, mass is measured in **kilograms.**

Mass vs. Weight

- **Weight:** is the vertical force exerted by a mass as a result of gravity. In the SI system of measurement, weight is measured in **Newton's.**
- **Matter:** **is anything that has mass and occupies space.** One contemporary view on matter takes it as all scientifically observable entities whatsoever. Matter can more accurately be defined as **the energy that has a low vibratory rate, a compressed energy state.**

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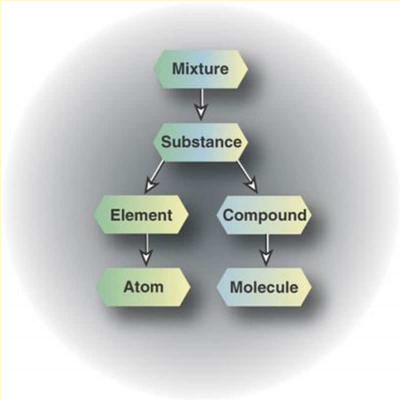
MATTER AND ENERGY CONTINUE

Combinations of Atoms

- **Atom:** is the smallest component of an element having the chemical properties of the element.
- **Molecule:** is the smallest particle of a pure substance that still retains its chemical composition and properties. Molecules can be either **polyatomic** (composed of several atoms) or **monoatomic** (as in noble gases which are composed of single-atom molecules). Polyatomic molecules are electrically neutral clusters of two or more atoms joined by shared pairs of electrons (covalent bonds) that behave as a single particle.
- **Compound:** A compound is a substance formed from two or more elements, with a fixed ratio determining the composition. For example, dihydrogen monoxide (water, H_2O) is a compound composed of two hydrogen atoms for every oxygen atom.



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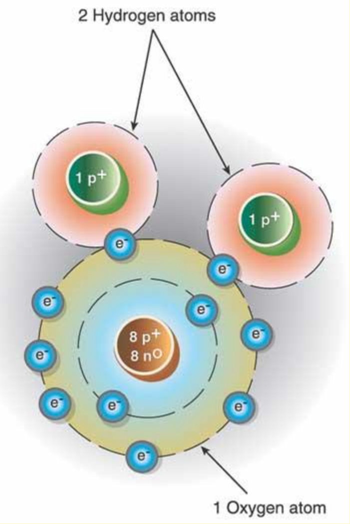
MATTER AND ENERGY CONTINUE

- A molecule is formed when two or more atoms join together chemically. A compound is a molecule that contains at least two different elements. **All compounds are molecules but not all molecules are compounds.**
  1. A molecule is what you get when any atoms join together.
  2. A compound is what you get when atoms of two or more different elements join together.
  3. All compounds are molecules, but not all molecules are compounds.
- Water is a molecule because it is made from atoms that have been chemically combined. It is also a compound because the atoms that make water are not all the same - some are oxygen and some are hydrogen.
- Oxygen in the atmosphere is a molecule because it is made from two atoms of oxygen. It is not a compound because it is made from atoms of only one element - oxygen. This type of molecule is called a diatomic molecule, a molecule made from two atoms of the same type.



MATTER AND ENERGY CONTINUE

Notice that

- Molecular hydrogen (H_2), molecular oxygen (O_2) and molecular nitrogen (N_2) are not compounds because each is composed of a single element. Water (H_2O), carbon dioxide (CO_2) and methane (CH_4) are compounds because each is made from more than one element. The smallest bit of each of these substances would be referred to as a molecule.

For example, a single molecule of molecular hydrogen is made from two atoms of hydrogen while a single molecule of water is made from two atoms of hydrogen and one atom of oxygen.

Energy

Energy is a fundamental quantity that every physical system possesses; it allows us to predict how much work the system could be made to do, or how much heat it can exchange. In the SI system of measurement, energy is measured in **joules** or **electron volts** (eV).

MATTER AND ENERGY CONTINUE

Types of Energy

- **Mechanical Energy:** is the energy which an object possesses due to its motion or its stored energy of position.
- **Potential Energy:** is the energy of a system associated with the spatial configuration of the system's components and their interaction(s) with each other. Or in other words the energy associated where the object is compared to where there would be zero energy.
- **Kinetic Energy:** is the portion of energy associated with the motion of a body.
- **Chemical Energy:** Energy released as a result of chemical reactions. For example, by burning hydro carbons in the presence of oxygen, chemical energy would occur. It can also be thought of the energy stored in the chemical bonds of molecules.
- **Electrical Energy:** is a form of energy related to the position of an electric charge in an electric field. It is also the energy made available by the flow of electric charge through a conductor.
- **Thermal Energy (Heat):** is kinetic energy due to disordered motions and vibrations of microscopic particles such as molecules and atoms, usually associated with temperature.
- **Nuclear Energy:** The energy released in a nuclear reaction, such as fission or fusion.
- **Electromagnetic Energy:** A wave characterized by variations of electric and magnetic fields (for example, short wavelengths such as X-rays through the ultraviolet, visible and infrared regions to longer wavelengths such as radar and radio waves).

EINSTEIN'S MASS-ENERGY EQUIVALENCE

$$E = mc^2$$

where E is energy, m is mass and c is the speed of light in a vacuum $3x10^8$m/s

Example

- What is the rest energy of a 1.00 g particle traveling at $3x10^4$m/s?

Solution:

- Since, it is asking for the rest energy the speed that it is traveling does not matter. Now we will use Einstein's equation.

$$E = (0.001kg)(3x10^8 m/s)^2$$
$$E = 9x10^{13} J$$

RADIATION

- **Radiation:** is energy that comes from a source and travels through some material or through space. **Light, heat and sound are types of radiation.** A person exposed to radiation is said to be **irradiated**.

- **Ionizing Radiation:** Radiation that has enough energy to eject electrons from electrically neutral atoms, leaving behind charge atoms or ions.

  There are four basic types of ionizing radiation: ***Alpha particles*** (helium nuclei), ***beta particles*** (electrons), *neutrons*, and ***gamma rays*** (high frequency electromagnetic waves, **x-rays**, are generally identical to gamma rays except for their place of origin.)

  Neutrons are not themselves ionizing but their collisions with nuclei lead to the ejection of other charged particles that do cause ionization.

FUNDAMENTAL PARTICLES

The fundamental particles of the atom are the electron, proton, and neutron.

Particle	Mass	amu	charge	charge	symbol
Electron	$9.109x10^{-31}$ kg	0.000549	-1	$-1.602x10^{-19}$ C	m_e
Proton	$1.673x10^{-27}$ kg	1.00728	1	$1.602x10^{-19}$ C	m_p
Neutron	$1.675x10^{-27}$ kg	1.00867	none	none	m_n

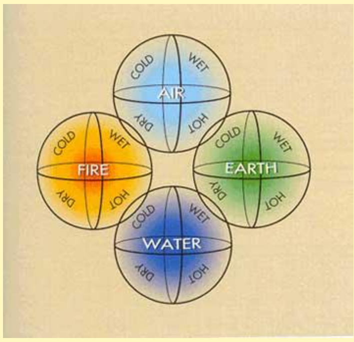
Atomic Mass Units (amu)

A unit of mass equal to 1/12 the mass of an atom of the carbon isotope with mass number 12; approximately **1 amu = $1.66x10^{-27}$kg**.

THE ATOM

Greek Atom

- John Dalton, (1766-1844) wrote *New System of Chemical Philosophy* in 1808.
- Dalton's atomic theory rests on the following postulates.
  1. All matter consists of tiny particles.
  2. Atoms are indestructible and unchangeable.
  3. Elements are characterized by the mass of their atoms.
  4. When elements react, their atoms combine in simple, whole-number ratios.
- Dmitri Mendeleev - Periodic Table, Period Table 2



Brief History of the Atom - Here are links to more information on the atom and atomic theory. Please read each entry.
Wikipedia-This is a link to the Wikipedia entry on the atom.
Vision Learning Atomic Theory I - This is the first part of how the atomic theory developed.
Vision Learning Atomic Theory II - This is the second part of how the atomic theory developed

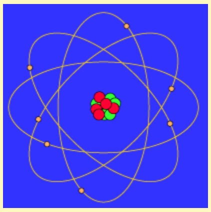
THE ATOM CONTINUE

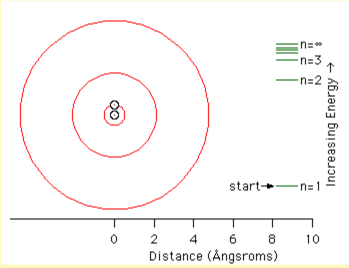
Thomson Atom

- J. J. Thomson (1856 - 1940) with others discovered the electron in the late 1890's.

Bohr Atom

- Neils Bohr (1885-1962), put forth the planetary model of the atom.

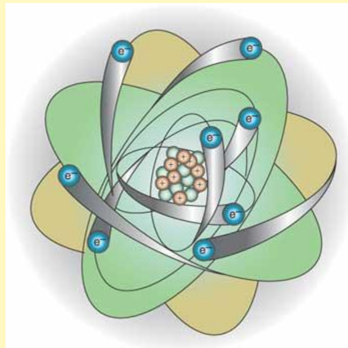




ATOMIC STRUCTURE

- **Chemical Elements:** The number of protons in the atoms of an element is known as the **atomic number** of the element. **For example**, all atoms with 6 protons in their nuclei are atoms of the chemical element carbon, and all atoms with 92 protons in their nuclei are atoms of the element uranium.
- **Isotopes**: are atoms of a chemical element whose nuclei have the same atomic number, Z, but different atomic weights,

A. The word isotope, meaning at the same place, comes from the fact that isotopes are located at the same place on the periodic table. The atomic number corresponds to the number of protons in an atom. Thus, isotopes of a particular element contain the same number of protons. The difference in atomic weights results from differences in the number of neutrons in the atomic nuclei.



ATOMIC NOMENCLATURE

The protocol for representing elements

(Mass Number) A
Chemical Symbol
(Atomic Number) Z

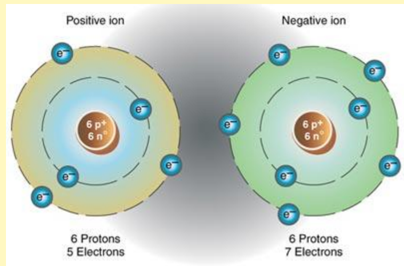
(Mass Number) 6
Li (Chemical Symbol for Lithium)
(Atomic Number) 3

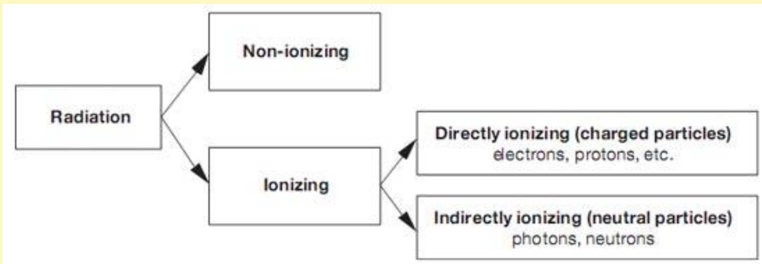
- Barium $^{138}_{56}Ba$
- Ruthenium $^{102}_{44}Ru$
- Aluminum Ion Al^{3+}
- Aluminum Oxide Al_2O_3

IONIZATION

- Ionization: Any process by which a neutral atom gains or loses electrons, thus acquiring a net charge.

High temperatures, electrical discharges or nuclear radiations can cause ionization.





SOURCES OF IONIZING RADIATION

A) Natural Environmental Radiation:

1. *Cosmic Rays*: Highly energetic sub-atomic particles, mostly protons and helium nuclei, which travel across space at close to the speed of light. The lowest energy cosmic rays originate in the Sun; higher energy ones from supernovae and pulsars within the Galaxy, while those with the highest energy of all may be extra galactic in origin, possibly from quasars and active galactic nuclei.
2. *Terrestrial Radiation*: Long wave radiation that is emitted by the earth back into the atmosphere. Most of it is absorbed by the water vapor in the atmosphere, while less than ten percent is radiated directly into space
3. *Internally Deposited Radionuclides*: Internal radiation comes from radioactive materials that occur naturally in the human body. Isotopes of potassium and carbon are the primary sources of internal radiation exposures.

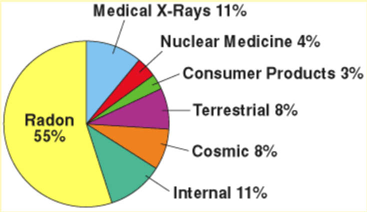
SOURCES OF IONIZING RADIATION

B) Man-Made Radiation:

1. Medical X-Rays: The use of medical radiation accounts for about 11% of our exposure per year.

2. Nuclear Power Generation: The generation of electrical power by nuclear power plants contributes very little to our yearly exposure.

3. Industrial, Research, and Consumer: Also contribute very little.



TERMINOLOGY FOR RADIOLOGY

Customary Units	SI Units
Roentgen	*Air Kerma*
rad	*Gray*
rem	*Seivert*
curie	*Becquerel*

DEFINITIONS

هذه التعريفات سيتم شرحها حين ورودها في المقرر

- *Roentgen*: A basic unit of measurement of the ionization produced in air by gamma or x-rays. One Roentgen (R) is exposure to gamma or x-rays that will produce one electrostatic unit of charge in one cubic centimeter of dry air.

$$1R = 2.58\times10^{-4}\frac{C}{kg}$$

It is a measure of the ionizations of the molecules in a mass of air. The main advantage of this unit is that it is easy to measure directly, but it is limited because it is only for deposition in air, and only for gamma and x rays.

- *rad*: A unit of measurement of any kind of radiation absorbed by humans. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. The unit *rad* can be used for any type of radiation, but it does not describe the biological effects of the different radiations. One *rad* is equal to the absorption of 100 ergs of radiation energy per gram of material.

هذه التعريفات سيتم شرحها حين ورودها في المقرر

- *rem*: The roentgen equivalent man or rem is the unit of effective radiation dose. The rem is a unit used to derive a quantity called **equivalent dose**. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of thousandths of a rem, or mrem. To determine equivalent dose (rem), you multiply absorbed dose (rad) by a quality factor (Q) that is unique to the type of incident radiation.

- *curie*: The original unit used to describe the intensity of radioactivity in a sample of material. One curie equals thirty-seven billion (37,000,000,000) disintegrations per second, or approximately the radioactivity of one gram of radium.

- ***Air Kerma***: means kerma in a given mass of air. The unit used to measure the quantity of air kerma is the Gray (Gy). For X-rays with energies less than 300 kiloelectronvolts (keV), 1 Gy = 100 rad. In air, 1 Gy of absorbed dose is delivered by 114 roentgens (R) of exposure. Kerma means the sum of the initial energies of all the charged particles liberated by uncharged ionizing particles in a material of given mass.

- ***Gray***: radiation energy deposited in material divided by the mass of the material. An often-used unit for absorbed dose is the gray (Gy). One gray is equal to one joule of energy deposited in one kg of a material. The unit gray can be used for any type of radiation, but it does not't describe the biological effects of the different radiations. Absorbed dose is often expressed in terms of hundredths of a gray, or centi-grays. One gray is equivalent to 100 rads. (gray=Gy=J/kg).

هذه التعريفات سيتم شرحها حين ورودها في المقرر

- ***Seivert***: When absorbed dose is adjusted to account for the amount of biological damage a particular type of radiation causes, it is known as **dose equivalent.** This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of millionths of a sievert, or micro-sievert. To determine equivalent dose (Sv), you multiply absorbed dose (Gy) by a quality factor (Q) that is unique to the type of incident radiation. One sievert is equivalent to 100 rem. The SI unit for dose equivalent is called the seivert (Sv).

- ***Becquerel***: The unit of radioactive decay equal to 1 disintegration per second. Often radioactivity is expressed in larger units like: thousands (kBq), one millions (MBq) or even billions (GBq) of a becquerels. 37 billion (3.7×10^{10}) becquerels = 1 curie (Ci)