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General Concept in Thermodynamic

Definitions and Fundamental Ideas of Thermodynamics

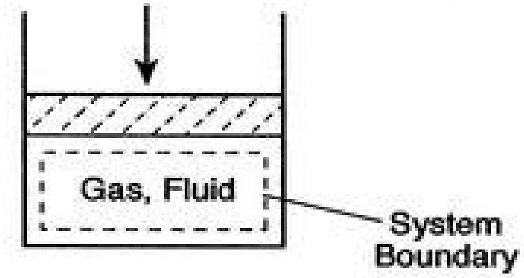
Thermodynamics deals with the quantitative relationship of interconversion of the various forms of energy. Any system, physical or chemical or even biological, can be considered as a thermodynamical system.

The Concept of a ``System“

A thermodynamic system is a quantity of matter of fixed identity, around which we can draw a boundary (see figure 1.1 for an example).

The system boundary

The boundaries may be fixed or moveable. Work or heat can be transferred across the system boundary. Everything outside the boundary is the surroundings.



Types of thermodynamics system

Isolated system

a system is said to be isolated when there is no exchange of energy or matter with the surroundings.

Closed system

when there is an exchange of energy but not of matter then the system is said to be closed.

Open system

when both matter and energy can be freely exchanged with the environment, then the system is an open one.

Properties of a system

Properties of a system are a measurable characteristic of a system that is in equilibrium. Properties may be intensive or extensive.

Intensive – Are independent of the amount of mass: e.g: Temperature, Pressure, and Density, ….etc

Extensive – varies directly with the mass e.g: mass, volume, energy, enthalpy

Specific properties – The ratio of any extensive property of a system to that of the mass of the system is called an average specific value of that property (also known as intensives property)

For example:

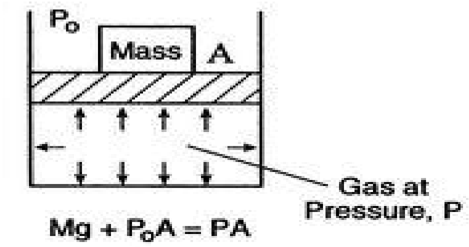
$$\text{specific volume} = V/m = v.$$

The Concept of a ``State"

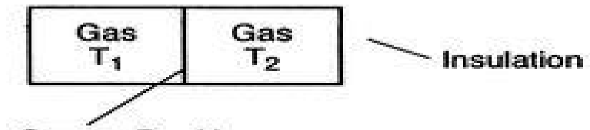
The **thermodynamic state** of a system is defined by specifying values of a set of measurable **properties** sufficient to determine all other properties. For fluid systems, typical properties are pressure, volume and temperature.

The Concept of ``Equilibrium"

The state of a system in which properties have definite, unchanged values as long as external conditions are unchanged is called an equilibrium state.



[Mechanical Equilibrium]



[Thermal Equilibrium]

Thermodynamics Equilibrium•

No spontaneous change in macroscopic property (i.e. isolated system) A system in thermodynamic equilibrium satisfies:

1-mechanical equilibrium (No pressure gradient within the system and also between system & surroundings i.e. δP=0, or no unbalance force)

2-thermal equilibrium (No transfer of heat across the boundary of system when it is separated from universe by means of Diathermic wall- that allows the heat or δT=0)

3-chemical equilibrium. (No transfer of mass by any chemical process across the boundary of system i.e. diffusion and no unbalanced chemical reaction within the system)

Equations of state

It is an experimental fact that two properties are needed to define the state of any pure substance in equilibrium or undergoing a steady or quasi-steady process

The Concept of a ``Process“

- If the state of a system changes, then it is undergoing a **process**.

- At the end of the process if the properties have returned to their original values, the system has undergone a **cyclic process** or a **cycle**.

Note that even if a system has returned to its original state and completed a cycle, the state of the surroundings may have changed.

Adiabatic process - a process with no heat transfer into or out of the system.
Isochoric process - a process with no change in volume, in which case the system does no work.
Isobaric process - a process with no change in pressure.
Isothermal process - a process with no change in temperature.

Irreversible process - a process that cannot return both the system and surrounding to their original conditions

Reversible process - it is defined as a process that, once having take place it can be reversed. In doing so, it leaves no change in the system or boundary.

Cyclic process - when a system in a given initial state goes through various processes and finally return to its initial state, the system has undergone a cyclic process or cycle.

process path

is the series of states that a system passes through as it moves from an initial state to a final state.

- **Work** is a transfer of energy that can be used to change the height of a weight somewhere in the surroundings.

- **Heat** may be defined as energy in transit from a high temperature object to a lower temperature object.

- Internal energy is the microscopic energy in an object is . The internal energy may be increased by transferring energy to the object from a higher temperature (hotter) object - this is properly called heating.

Zeroth Law of Thermodynamics

If two systems in thermal equilibrium with a third system then they are in thermal equilibrium with each other.

Equation of state

By

States of Matter:

Gases, liquid and crystalline solid are the three primary state of matter or phase. Solid with high vapor pressure, such as iodine and camphor, can pass directly from the solid to the gaseous state without melting at room temperature. This process is known as sublimation

The Gaseous State

a pressure ʼn a force per unit area ʼn expressed in $dynes/cm^2$.Pressure is also recorded in atmospheres or in millimeters of mercury Another important characteristic of a gas, its volume, is usually expressed in liters or cubic centimeters (1 cm^3 = 1 mL) The temperature involved in the gas equations is given according the absolute or Kelvin scale. Zero degrees on the centigrade scale is equal to 273.15 Kelvin (K).

The Ideal Gas Law

the gas laws formulated by Boyle, Charles, and Gay-Lussac an ideal situation where no intermolecular interactions exist and collisions are perfectly elastic, and thus no energy is exchanged upon collision. Boyle's law relates the volume and pressure of a given mass of gas at constant temperature,

$$P \alpha \frac{1}{V}$$

or

$$PV = \qquad (2\_2)$$

The law of Gay-Lussac and Charles states that the volume and absolute temperature of a given mass of gas at constant pressure are directly proportional,

$$P \alpha T$$

$$V = KT \qquad (2\_3)$$

These equations can be combined to obtain the familiar relationship

$$\frac{P_1 V_1}{T} = \frac{P_2 V_2}{T} \qquad (2\_4)$$

In equation (2-4), P_1, V_1, and T_1 are the values under one set of conditions and

P_2, V_2, and T_2 the values under another set.

Example (2-1)

The Effect of Pressure Changes on the Volume of an Ideal Gas

In the assay of ethyl nitrite spirit, the nitric oxide gas that is liberated from a definite quantity of spirit and collected in a gas burette occupies a volume of 30.0 mL at a temperature of 20°C and a pressure of 740 mm Hg. Assuming the gas is ideal, what is the volume at 0°C and 760 mm Hg? Write

Answer//

$$\frac{740 \times 30}{273 + 20} = \frac{760 \times V_2}{273} \quad ′n \quad V_2 = 27.2 \text{ ml}$$

From equation (2-4) it is seen that PV/T under one set of conditions is equal to

PV/T under another set, and so on. Thus, one reasons that although P, V, and T Change, the ratio PV/T is constant and can be expressed mathematically as

$$\frac{PV}{T} = R$$

or

$$PV = \qquad (2-5)$$

in which R is the constant value for the PV/T ratio of an ideal gas. This equation is correct only for 1 mole (i.e., 1 g molecular weight) of gas; for n moles it becomes

$$PV = nRT \qquad (2\text{–}6)$$

Equation (2-6) is known as the general ideal gas law, and because it relates the specific conditions or state, that is, the pressure, volume, and temperature of a given mass of gas, it is called the equation of state of an ideal gas.

Real gases do not interact without energy exchange, and therefore do not follow the laws of Boyle and of Gay-Lussac and Charles as ideal gases are assumed to do. To obtain a numerical value for R

If 1 mole of an ideal gas is chosen, its volume under standard conditions of temperature and pressure (i.e., :**0°C** and **760 mm Hg**) has been found by experiment to be **22.414** liters. Substituting this value in equation (2-6), we obtain

$$1\ \text{atm} \times 22.414\ \text{liters} = 1\ \text{mole} \times R \times 273.16\ \text{K}$$

$$R = 0.08205\ \text{liter}\ atm/mole\ \text{K}$$

The molar gas constant can also be given in energy units by expressing the pressure in dynes/cm^2(**1 atm = 1.0133 x 10° dynes/cm²**) and the volume in the corresponding units of cm° (**22.414 liters = 22,414** cm^2). Then

$$R = \frac{PV}{T} = \frac{(1.0133 \times 10^6) \times}{273.}$$

$$= 8.314 \times 10^6 erg$$

or, because $1\ joule = 10^7 ergs$,

$$R = 8.314\ joules/mole\ K$$

The constant can also be expressed in $cal/mole\ dag$, employing 1 cal = 4.184 $joules$

$$R = \frac{8.314\ joule/}{mole\ deg} = 1.987\ cal/m$$

Example 2-2

Calculation of Volume Using the Ideal Gas Law What is the volume of 2 moles of an ideal gas at 25°C and 780 mm Hg?

Answer//

$$(780\ mm/760\ mm\ atm^{-1}) \times V$$

$$= 2\ moles \times (0.08205\ liter\ atm/mole\ deg) \times 298\ K$$

$$V = 47.65\ liter$$

Molecular Weight

The approximate molecular weight of a gas can be determined by use of the ideal gas law. The number of moles of gas n is replaced by its equivalent g/M in which g is the number of grams of gas and M is the molecular weight:

$$PV = \frac{g}{M} RT \qquad (2-7)$$

or

$$\underset{T}{M} = \frac{gR}{P} \qquad (2-8)$$

Example 2-3

Molecular Weight Determination by the Ideal Gas Law

If 0.30 g of ethyl alcohol in the vapor state occupies 200 mL at a pressure of 1 atm and a temperature of 100°C, what is the molecular weight of ethyl alcohol? Assume that the vapor behaves as an ideal gas. Write

Answer//

$$M = \frac{0.30 \times 0.082 \times 373}{1 \times 0.2}$$

$$M = 46\ g/mole$$

Kinetic Molecular Theory

some of the more important statements of the theory:

1/ Gases are composed of particles called atoms or molecules, the total volume of which is so small as to be negligible This condition is approximated in actual gases only at low pressures and high temperatures.

2/ The particles of the gas do not attract one another; this statement applies only at low pressures.

3/ The particles exhibit continuous random motion owing to their kinetic energy. The average kinetic energy. *E*. is directive proportional to the absolute temperature of the gas. or $E = (3/2)R\,T$.

4/The molecules exhibit perfect elasticity; that is, there is no net loss of speed or transfer of energy after they collide with one another and with the molecules in the walls of the confining vessel, which latter effect accounts for the gas pressure.

From these and other postulates, the following fundamental kinetic equation is derived:

$$P\ V = \frac{1}{3}\ n\ m\ c^{2} \qquad (2-9)$$

where P is the pressure and V the volume occupied by any number n of molecules of mass m having an average velocity [C with bar above].

$$\mu\!\!\!V = \sqrt{\frac{3\ R}{n}} \qquad (2-10)$$

Restricting this case to 1 mole of gas, we find that $P\ V$ becomes equal to $R\ T$ from the equation of state (2-5), n becomes Avogadro's number N_A, and N_A multiplied by the mass of one molecule becomes the molecular weight M.

The root mean square velocity is therefore
given by

$$\mu\!\!\!T = \sqrt{\frac{3\ R}{M}} \qquad (2-11)$$

Example 2-4

Calculation of Root Mean Square Velocity What is the root mean square velocity of oxygen (molecular weight, 32.0) at 25°C (298 K)?

Answer//

$$\mu = \sqrt{\frac{3 \times 8.314 \times 10^{7} \times 298}{32}} = 4.82 \times 10^{4}\ \mathrm{cm/sec}$$

Because the term $n\ m / V$ is equal to density, we can write equation (2-10) as

$$\mu = \frac{3}{d} \qquad (2-12)$$

Remembering ◊

that density is defined as a mass per unit volume, we see that the rate of diffusion of a gas is inversely proportional to the square root of its density.

The van der Waals Equation for Real Gases

The fundamental kinetic equation (2-9) is found to compare with the ideal gas equation because the kinetic theory is based on the assumptions of the ideal state. However, real gases are not composed of infinitely small and perfectly elastic nonattracting spheres. They are composed of molecules of a finite volume that tend to attract one another.

A number of such expressions have been suggested, the *van der Waals equation* being the best known of these. For 1 mole of gas, the van der Waals equation is written as

$$\left(P+\frac{a}{V^2}\right)(V-b)=RT \qquad (2-13)$$

For the more general case of moles of gas in a container of volume V ,

equation (2-13) becomes:

$$\left(P+\frac{an^2}{V^2}\right)(V-nb)= \qquad (2-14)$$

The term a/V^2 accounts for the internal pressure per mole resulting from the intermolecular forces of attraction between the molecules b accounts for the incompressibility of the molecules. When the volume of a gas is large, the molecules are well dispersed. Under these conditions, a/V^2 and become insignificant with respect to P and V ,respectively. Under these conditions, the van der Waals equation for 1 mole of gas reduces to the ideal gas equation, $PV=RT$.

Example 2-5

Application of the van der Waals Equation

A 0.193-mole sample of ether was confined in a 7.35-liter vessel at 295 K. Calculate the pressure produced using (a) the ideal gas equation and (b) the van der Waals equation. The van der Waals a value for ether is 17.38 liter atm/mole; the b value is 0.1344 liter/mole. To solve for pressure, the van der Waals equation can be rearranged as follows:

Answer//

$$P = \frac{nRT}{V - nb} - \frac{an^2}{V^2}$$

a

$$P = \frac{0.193\ \text{mole} \times 0.0821\ \text{liter atm/deg mole} \times 295\ \text{deg}}{7.35\ \text{liter}}$$

$$= 0.636\ atm$$

b)

$$P = \frac{(0.193\ \text{mole} \times 0.0821\ \text{liter atm/deg mole} \times 295\ \text{deg}}{7.35\ \text{liter} - (0.193\ \text{mole}) \times (0.1344\ \text{liter/mole})} - \frac{17.38\ \text{liter}^2\ \text{atm/mole}^2\ (0.193\ \text{mole})^2}{(7.35\ \text{liter})^2}$$

$$= 0.626\ atm$$

Example 2-6

Calculation of the van der Waals Constants

Calculate the pressure of 0.5 mole of CO_2 gas in a fire extinguisher of 1-liter capacity at 27°C using the ideal gas equation and the van der Waals equation. The van der Waals constants can be calculated from the critical temperature T_C and the critical pressure P_C (see the section Liquefaction of Gases for definitions):

Answer//

$$a = \frac{27 R^2 T^2_C}{64 P_C} \quad \text{and} \quad b = \frac{R T_C}{8 P_C}$$

The critical temperature and critical pressure of CO_2 are 31.0°C and 72.9 atm, respectively. Using the ideal gas equation, we obtain

$$P = \frac{nRT}{V} = \frac{0.5\,mole \times 0.0821\,liter\ atm/\text{deg}\,mole \times 300.15\,deg}{1\,liter}$$

$$= 12.32\,atm$$

Using the van der Waals equation, we obtain

$$a = \frac{27 \times (0.0821\,liter\ atm/\text{deg}\,mole)^2 \times (304.15\,\text{deg})^2}{64 \times 72.9\,atm} = 3.608\,liter^2\,atm/mole^2$$

$$b = \frac{(0.0821\,liter\ atm/deg\ mole) \times 304.15\,deg}{8 \times 72.9\,atm} = 0.0428\,liter/mole$$

$$P = \frac{nRT}{V - nb} - \frac{an^2}{V^2}$$

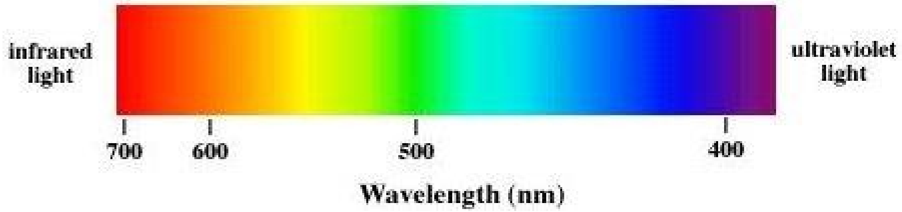
$$= \frac{(0.5\,mole \times 0.821\,liter\ atm/deg\ mole) \times 300.15\,deg}{1\,liter - (0.5\,mole \times 0.042882\ \ 1\,liter/mole)}$$

$$93.608\ liter^2\,atm/mole^2 \quad - \frac{}{(1\ liter)^2}$$

$$= 11.69\ atm$$

The EM spectrum

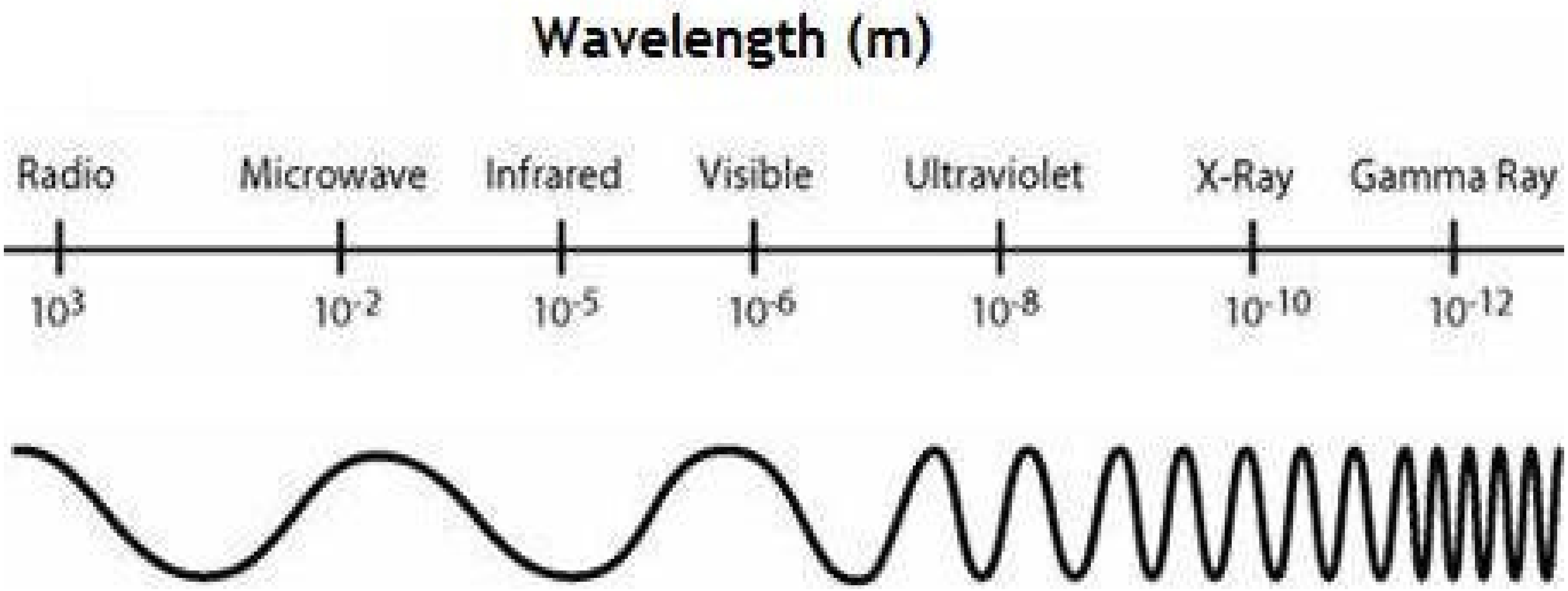
Electromagnetic waves are categorized according to their frequency f or, equivalently, according to their wavelength λ = c/f. Visible light has a wavelength range from ~400 nm to ~700 nm. Violet light has a wavelength of ~400 nm, and a frequency of ~$7.5*10^{14}$ Hz. Red light has a wavelength of ~700 nm, and a frequency of ~$4.3*10^{14}$ Hz.



Visible light makes up just a small part of the full electromagnetic spectrum. Electromagnetic waves with shorter wavelengths and higher frequencies include ultraviolet light, X-rays, and gamma rays. Electromagnetic waves with longer wavelengths and lower frequencies include infrared light, microwaves, and radio and television waves.

Type of Radiation	Frequency Range (Hz)	Wavelength Range
gamma-rays	10^{20} - 10^{24}	< 10^{-12} m
x-rays	10^{17} - 10^{20}	1 nm - 1 pm
ultraviolet	10^{15} - 10^{17}	400 nm - 1 nm
visible	4 - $7.5*10^{14}$	750 nm - 400 nm
near-infrared	$1*10^{14}$ - $4*10^{14}$	2.5 μm - 750 nm
infrared	10^{13} - 10^{14}	25 μm - 2.5 μm
microwaves	$3*10^{11}$ - 10^{13}	1 mm - 25 μm

radio waves	< 3*10^{11}	> 1 mm


Wavelength (m)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-Ray
Gamma Ray
10^3
10^{-2}
10^{-5}
10^{-6}
10^{-8}
10^{-10}
10^{-12}

The for laws of radiation:

For electromagnetic radiation, there are four "laws" that describe the type and amount of energy being emitted by an object. The four laws which explain radiation are Kirchhoff’s law, Stefan-Boltzmann’s law,
Planck’s law and Wien’s displacement law.

Now when we talk about radiation, one thing which we need to understand is that all bodies radiate energy. The form in which they radiate energy is known as photons, and when these particles reach another surface they either get absorbed, reflected back or transmitted. Absorptivity (a) is a term which is also referred to as a particular fraction of incident radiation which is absorbed. Reflectivity (r) can also be known as the fraction of incident radiation which is reflected back. And lastly, we have transmissivity (t) which is also known as the fraction of incident radiation which is transmitted.The sun emits visible light

, infrared waves, and ultraviolet waves , but did you know that the sun also emits microwaves, radio waves, and X-rays.

Kirchhoff's Law: Kirchhoff's Law describes the linkage between an object's ability to emit at a particular wavelength with its ability to absorb radiation at that same wavelength. *Kirchhoff's Law states that for an object whose temperature is not changing, an object that* ***absorbs radiation well at a particular wavelength will also emit radiation well*** *at that wavelength.*

Kirchoff’s Law states that the emissivity of a surface is equal to its absorptance, where the absorptance (α) of a surface is the ratio of the radiant power absorbed to the radiant power incident on the surface.

$$\int_T \alpha(\lambda,T)\,d\lambda = \int_T \varepsilon(\lambda,T)\,d\lambda$$

$$\alpha = \varepsilon$$

Planck's Law:

Planck's Law can be generalized as such: ***Every** object emits radiation at **all** times and at **all** wavelengths.* This law gives the spectral distribution of radiant energy inside a blackbody.

$$W_{e\lambda}(\lambda, T) = 8\pi hc\lambda^{-5}(e^{ch/k\lambda T}-1)^{-1}$$

Where:

T = Absolute temperature of the blackbody

h = Planck’s constant (6.626 x 10^{-34} Js)

c = Speed of light (2.998 x 10^{8} m s^{-1})

k = Boltzmann's constant (1.381 x 10^{-23} JK^{-1})

λ = Wavelength in m

Wein's Law:

All matter emits radiation at all wavelengths, it does not do so *equally*. *Wein's Law states that the **wavelength of peak emission is inversely proportional to the temperature** of the emitting object.* but another way, the hotter the object, the shorter the wavelength of max emission. This law relates the wavelength of peak excitance, λ_m, and blackbody temperature, T:

this relation can be written as:

$$\lambda_{max} \propto \frac{1}{T}$$

$$\lambda_{max} T = 2.9 \times 10^{-3}\ \mathrm{m\ K}$$

Where:

λ_{max} = peak wavelength emitted by the body (m)
T = temperature of the body (K)

This equation shows:

The **higher** the **temperature** of a body, the **shorter** the **wavelength** it emits at the peak intensity. The **higher** the **temperature** of a body, the **greater** the **intensity** of the radiation at each wavelength

Stefan–Boltzmann Law:

The Stefan-Boltzmann Law states that the ***total amount of energy*** *per unit area emitted by an object is* ***proportional to the 4th power of the temperature****.*

Integrating the spectral radiant excitance over all wavelengths gives:

$$\int M_{e\lambda}(\lambda, T)\,d\lambda = M_e(T) = \sigma T^4$$

σ is called the Stefan-Boltzmann constant

This is the Stefan-Boltzmann law relating the total output to temperature. If $M_e(T)$ is in W m^{-2}, and T in kelvins, then σ is 5.67 x 10 -8 Wm^{-2} K^{-4}.

At room temperature a 1 mm^2 blackbody emits about 0.5 mW into a hemisphere.

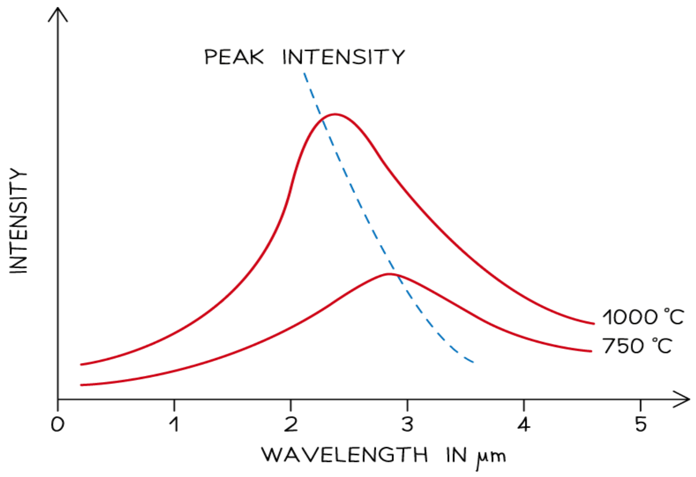
At 3200 K, the temperature of the hottest tungsten filaments, the 1 mm^2, emits 6 W.

Black-Body Radiation:

Black body radiation is the name given to the **thermal radiation** emitted by all bodies

(objects) All objects, emit black body radiation in the form of electromagnetic waves

These electromagnetic waves usually lie in the **infrared** region of the spectrum
Black-body radiation can also be emitted in the form of visible light or other wavelengths, depending on the temperature. The **hotter** object, the **more** infrared radiation it radiates in a given time . A perfect black body is defined as:
An object that absorbs all of the radiation incident on it and does not reflect or transmit any radiation
Since a good absorber is also a good emitter, a perfect black body would be the best possible emitter too
As a result, an object which perfectly absorbs all radiation will be black, this is because the colour black is what is seen when **all** colours from the visible light spectrum are absorbed
The **intensity** and **wavelength** distribution of any emitted waves depends on the **temperature** of the body.
This is represented on a black body radiation curve. As the temperature increases, the peak of the curve moves. This moves to a **lower** wavelength and a **higher** intensity



Black body spectrum for objects of different temperatures

From the electromagnetic spectrum, waves with a **smaller** wavelength have **higher** energy (e.g. UV rays, X-rays) When an object gets hotter, the amount of **thermal radiation** it emits increases

This increases the thermal energy emitted and therefore the **wavelength** of the emitted radiation **decreases**

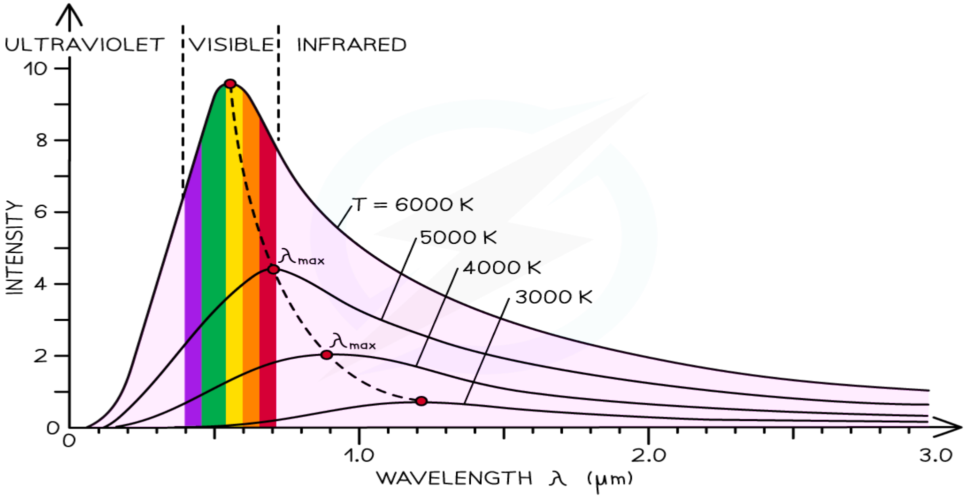
At room temperature objects emit thermal radiation in the infrared region of the spectrum At around 1000 °C an object will emit a significant amount of **red light** At 6000 °C an object will mainly emit **white** or **blue light** (and some ultraviolet) At even higher temperatures objects will emit **ultraviolet** or even **X-rays**

A black body is an object which:

Absorbs all the radiation that falls on it, and is also a good emitter Does not reflect or transmit any radiation

A black body is a theoretical object, however, stars are the best approximation there is

The radiation emitted from a black body has a **characteristic spectrum** that is determined by the temperature alone



The intensity-wavelength graph shows how thermodynamic temperature links to the peak wavelength for four different bodies

- **Albedo:**
  albedo, fraction of light that is reflected by a body or surface and measured on a scale from 0, corresponding to a black body that absorbs all incident radiation, to 1, corresponding to a body that reflects all incident radiation. If albedo decreases in the surface, increased heat absorption at the surface. spectrum includes visible light (0.4–0.7 μm), which explains why surfaces with a low albedo appear dark , whereas surfaces with a high albedo appear bright . Albedo is usually differentiated into two general types: normal albedo and Bond albedo.
- **How do you calculate albedo?**
- Albedo can be measured using a pyranometer device, it can detect the reflection of shortwave solar radiation in the form of watts per square meter (W/sq m). Simply, albedo can be calculated using the basic equation:
- Albedo = Reflected Light / Incoming Light.

Heat transfer – radiation, convection and conduction:

Any matter which is made up of atoms and molecules has the ability to transfer heat. The atoms are in different types of motion at any time. The motion of molecules and atoms is responsible for heat or thermal energy and every matter has this thermal energy. The more the motion of molecules, more will be the heat energy.

What is Heat Transfer?

to thermodynamic systems, heat transfer is defined as

"The movement of heat across the border of the system due to a difference in temperature between the system and its surroundings." Interestingly, the difference in temperature is said to be a 'potential' that causes the transfer of heat from one point to another.

Unit of Heat Transfer

SI system	Joule
MKS system	cal
Rate of transfer of heat	KW

How is Heat Transferred?

Heat can travel from one place to another in several ways. The different modes of heat transfer include:

Conduction

Convection

Radiation

Meanwhile, if the temperature difference exists between the two systems, heat will find a way to transfer from the higher to the lower system.

What is Conduction?

Conduction is defined as

The process of transmission of energy from one particle of the medium to another with the particles being in direct contact with each other.

An area of higher kinetic energy transfers thermal energy towards the lower kinetic energy area. High-speed particles clash with particles moving at a slow speed, as a result, slow speed particles increase their kinetic energy. This is a typical form of heat transfer and takes place through physical contact. Conduction is also known as thermal conduction or heat conduction.

Conduction Equation: ***The rate of conduction can be calculated by the following equation:***

$$Q = [K.\ A.\ (T_{hot} - T_{cold})] / d$$

Where,

Q is the transfer of heat per unit time

K is the thermal conductivity of the

body A is the area of heat transfer

T_{hot} is the temperature of the hot

region T_{cold} is the temperature of the

cold region d is the thickness of the

body

The coefficient of thermal conductivity shows that a metal body conducts heat better when it comes to conduction.

Following are the examples of conduction:

Ironing of clothes is an example of conduction where the heat is conducted from the iron to the clothes.

Heat is transferred from hands to ice cube resulting in the melting of an ice cube when held in hands.

Heat conduction through the sand at the beaches. This can be experienced during summers. Sand is a good conductor of heat.

What is Convection?

Convection is defined as
The movement of fluid molecules from higher temperature regions to lower temperature regions.

Convection Equation

As the temperature of the liquid increases, the liquid's volume also has to increase by the same factor and this effect is known as displacement.

The equation to calculate the rate of convection is as follows:

$$Q = h_c \cdot A \cdot (T_s - T_f)$$

Where,

Q is the heat transferred per unit time

h_c is the coefficient of convective heat

transfer A is the area of heat transfer

T_s is the surface

temperature T_f is the fluid

temperature **Convection Examples**

Examples of convection include:

Boiling of water, that is molecules that are denser move at the bottom while the molecules which are less dense move upwards resulting in the circular motion of the molecules so that water gets heated.

Warm water around the equator moves towards the poles while cooler water at the poles moves towards the equator.

Blood circulation in warm-blooded animals takes place with the help of convection, thereby regulating the body temperature.

What is Radiation?

Radiant heat is present in some or other form in our daily lives. Thermal radiations are referred to as radiant heat. Thermal radiation is generated by the emission of electromagnetic waves. These waves carry away the energy from the emitting body. Radiation takes place through a vacuum or transparent medium which can be either solid or liquid. Thermal radiation is the result of the random motion of molecules in matter. The movement of charged electrons and protons is responsible for the emission of electromagnetic radiation. Let us know more about radiation heat transfer.
Radiation heat transfer is measured by a device known as thermocouple. A thermocouple is used for measuring the temperature. In this device sometimes, error takes place while measuring the temperature through radiation heat transfer.

Radiation Equation

As temperature rises, the wavelength in the spectra of the radiation emitted decreases and shorter wavelengths radiations are emitted.

Thermal radiation can be calculated by Stefan-Boltzmann law:

$P = e \cdot \sigma \cdot A \cdot (Tr - Tc)^4$

Where,

P is the net power of

radiation A is the area of

radiation

Tr is the radiator temperature

Tc is the surrounding temperature

e is emissivity and σ is Stefan’s constant ($\sigma = 5.67 \times 10^{-8} Wm^{-2}K^{-4}$

Radiation Example

Following are the examples of radiation:

Microwave radiation emitted in the oven is an example of radiation.

UV rays coming from the sun is an example of radiation.

The release of alpha particles during the decaying of Uranium-238 into Thorium-234 is an example of radiation.

Ultraviolet radiation:

Ultraviolet Radiation, that portion of the electromagnetic spectrum extending from the violet, or short-wavelength, end of the visible light range to the X-ray region. Ultraviolet (UV) radiation is undetectable by the human eye, although, when it falls on certain materials, it may cause them to fluorescence—i.e., emit electromagnetic radiation of lower energy, such as visible light.

Ultraviolet radiation lies between wavelengths of about 400 nanometres (1 nanometre [nm] is 10−9 metre) on the visible-light side and about 1 nm on the X-ray side. In physics, ultraviolet radiation is traditionally divided into four regions: near (400–300 nm), middle (300–200 nm), far (200–100 nm), and extreme (below 100 nm). Based on the interaction of wavelengths of ultraviolet radiation with biological materials, three divisions have been designated: UVA (400–315 nm), also called black light; UVB (315–280 nm), responsible for the radiation's best-known effects on organisms; and UVC (280–100 nm), which does not reach Earth's surface.

Ultraviolet radiation is produced by high-temperature surfaces, such as the Sun, in a continuous spectrum and by atomic excitation in a gaseous discharge tube as a discrete spectrum of wavelengths. Most of the ultraviolet radiation in sunlight is absorbed by oxygen in Earth’s atmosphere, which forms the ozone layer of the lower stratosphere. Of the ultraviolet that does reach Earth’s surface, almost 99 percent is UVA radiation.

When the ozone layer becomes thin, however, more UVB radiation reaches Earth’s surface and may have hazardous effects on organisms.

ultraviolet radiation has a low power of penetration; hence, its direct effects on the human body are limited to the surface skin. The direct effects include reddening of the skin (sunburn), pigmentation development (suntan), aging, and carcinogenic changes. Ultraviolet sunburns can be mild, causing only redness and tenderness, or they can be so severe as to produce blisters, swelling, seepage of fluid, and sloughing of the outer skin. The blood capillaries (minute vessels) in the skin dilate with aggregations of red and white blood cells to produce the red coloration. Tanning is a natural body defense relying on melanin to help protect the skin from further injury. Melanin is a chemical pigment in the skin that absorbs ultraviolet radiation and limits its penetration into tissues. A suntan occurs when melanin pigments in cells in the deeper tissue portion of the skin are activated by ultraviolet radiation, and the cells migrate to the surface of the skin. When these cells die, the pigmentation disappears. Persons of light complexion have less melanin pigment and so experience the harmful effects of ultraviolet radiation to a greater degree. The application of sunscreen to the skin can help to block absorption of ultraviolet radiation in such persons.

Constant exposure to the Sun’s ultraviolet radiation induces most of the skin changes commonly associated with aging, such as wrinkling, thickening, and changes in pigmentation. There is also a much higher frequency of skin cancer, particularly in persons with fair skin. The three basic skin cancers, basal- and squamous-cell carcinoma and melanoma, have been linked to long-time exposure to ultraviolet radiation and probably result from changes generated in the DNA of skin cells by ultraviolet rays.

Ultraviolet radiation also has positive effects on the human body, however. It stimulates the production of vitamin D in the skin and can be used as a therapeutic agent for such diseases as psoriasis. Because of its bactericidal capabilities at wavelengths of 260–280 nm, ultraviolet radiation is useful as both a research tool and a sterilizing technique. Fluorescent lamps exploit the ability of ultraviolet radiation to interact with materials known as phosphors that emit visible light.

Infrared Radiation

Sometimes known as infrared light IR, is electromagnetic radiation (EMR) with wavelengths longer than those of visible light. Hence, it is undetectable by the human eye. Infrared light extends from the suggested red edge of the visible spectrum at 700 nanometers to 1 mm. Most of the thermal radiation emitted by objects near room temperature is infrared. As with all EMR, IR carries radiant energy and behaves both like a wave and like its quantum particle (the photon). Depending on the wavelength and frequency, infrared is commonly divided into five categories as near-wavelength, short-wavelength, mid-wavelength, long- wavelength and far-infrared.

Infrared radiations is also referred to as thermal waves or electromagnetic waves. This is because they have a heat-inducing property. Sometimes infrared rays are used in applications where heat production is required, like for therapeutic purposes where a patient requires physical therapy.

Sometimes infrared rays are classified as near-infrared and far-infrared.

Near-infrared rays are used in electronic applications like TV remote sensors and photography. Their applications can be similar to visible light applications since their wavelength ranges are close.

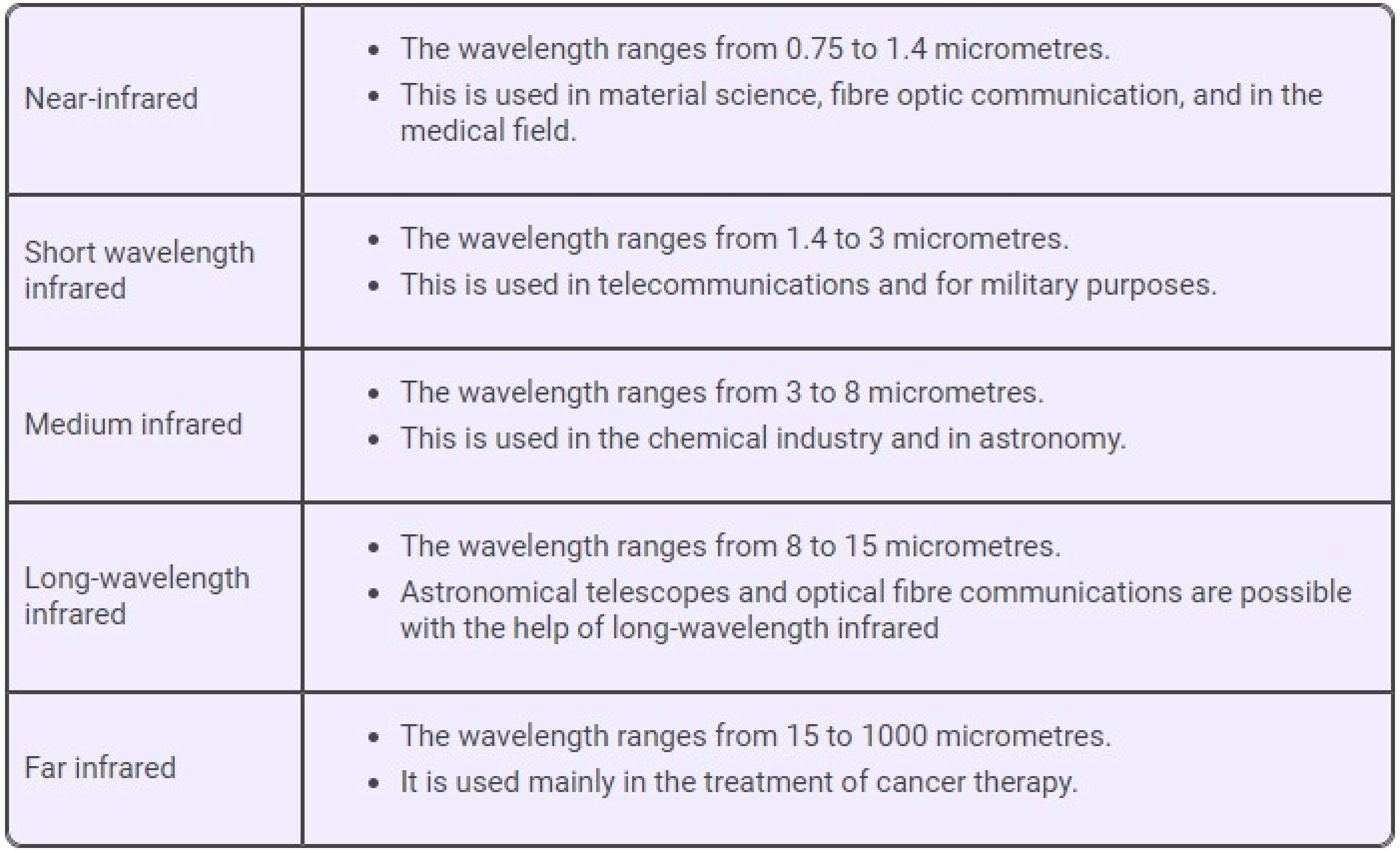
Far infrared rays are more thermal. Anything generating heat gives out far-infrared radiation. Even the human body at 37°C gives far infrared radiations of around 800 nm wavelength.

The wavelength of Infrared Radiation

The following is the classification of bands based on the spectral range 1μm and 50μm:

- 1μm to 3μm, which is known as Band I or Short Wave Infrared
- 3μm to 8μm, which is known as the Band II or Middle Wave Infrared
- 8μm to 15μm, which is known as the Band III or Long Wave Infrared

Characteristics of Regions of Infrared



Near-infrared	• The wavelength ranges from 0.75 to 1.4 micrometres. • This is used in material science, fibre optic communication, and in the medical field.
Short wavelength infrared	• The wavelength ranges from 1.4 to 3 micrometres. • This is used in telecommunications and for military purposes.
Medium infrared	• The wavelength ranges from 3 to 8 micrometres. • This is used in the chemical industry and in astronomy.
Long-wavelength infrared	• The wavelength ranges from 8 to 15 micrometres. • Astronomical telescopes and optical fibre communications are possible with the help of long-wavelength infrared
Far infrared	• The wavelength ranges from 15 to 1000 micrometres. • It is used mainly in the treatment of cancer therapy.

Applications of Infrared Waves

Infrared radiation finds application as a heating source. There are infrared saunas used to treat high blood pressure and rheumatoid arthritis. Infrared radiation is considered to be one of the methods of physiotherapy.

Infrared rays are widely used for cosmetic applications such as treating skin injuries, smoothing wrinkles, reducing the occurrence of dandruff, blackheads, etc. Infrared rays are used because they can penetrate the skin up to 3-4 mm. They also warm the skin resulting in improved blood circulation and a continuous supply of oxygen and other nutrients to the skin.

Infrared rays are used for warming the skin and for relaxing the muscles. Infrared rays are preferred because of their penetration quality through the skin.

List a few medicinal effects of infrared radiation.

A few medicinal effects of infrared radiation are as follows:

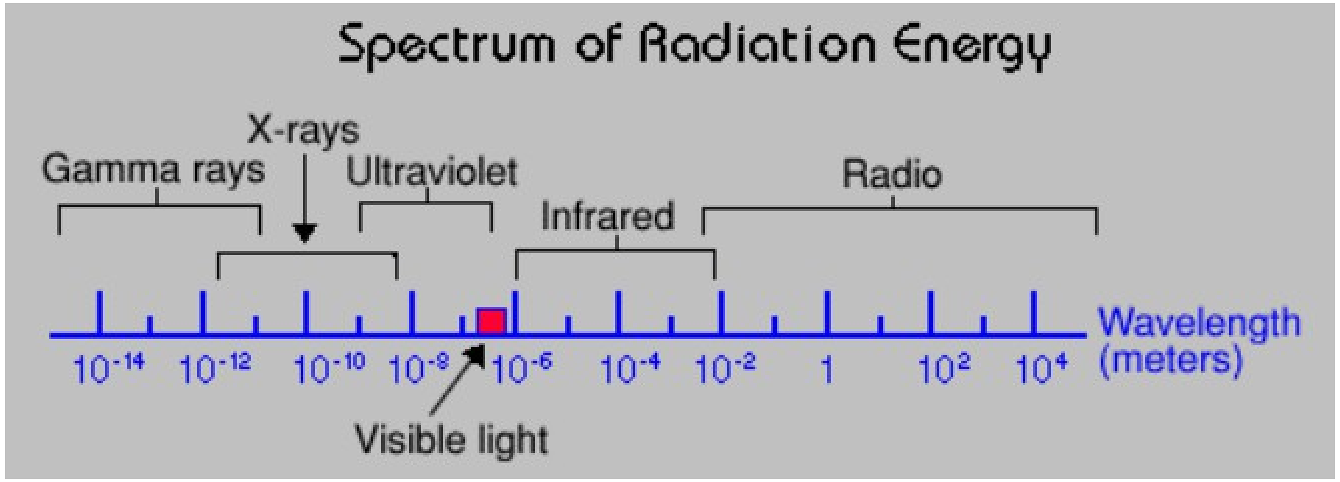
- Used to reduce the inflammation of the throat, ear and nose
- Used as an aid in stress management
- Reduces pain arthritis
- It eases kidney function

Is Infrared radiation Carcinogenic?

Radiation is generally famous for causing cellular damage. However, Infrared radiation is not potent enough to cause the development of malignancy. But, studies show that this radiation can reduce the efficiency of DNA repair as a result of increased skin temperature. In some rare cases, there have been signs of discrepancy in the skin thickness which happens due to Infrared radiation exposure.

Is Red light therapy and Infrared same?

No, both of them are entirely different. While red light is visible to naked eyes, Infrared light is not. We cannot feel the red light on the skin. However, since Infrared light generates heat, there will be a sensation of temperature rise on the skin when we expose it to Infrared.



X-ray radiation:

X-ray beam has a mix of energies

Maximum energy in a beam = kVp

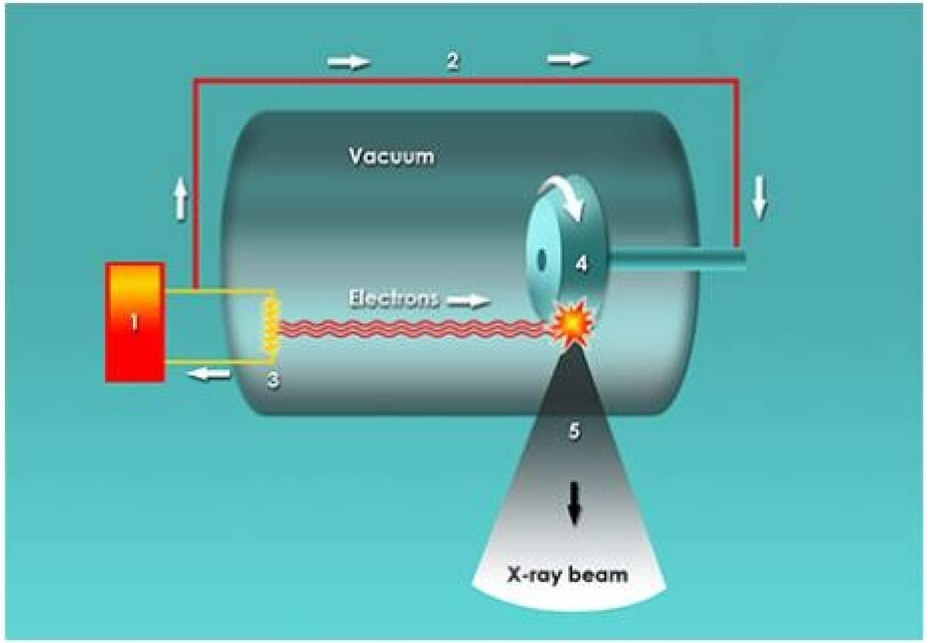
Diagnostic X-ray range 20-150 kVp

X-ray production:

X-rays are produced within the X-ray machine, also known as an X- ray tube. No external radioactive material is involved. Radiographers can change the current and voltage settings on the X-ray machine in order to manipulate the properties of the X-ray beam produced. Different X-ray beam spectra are applied to different body parts.

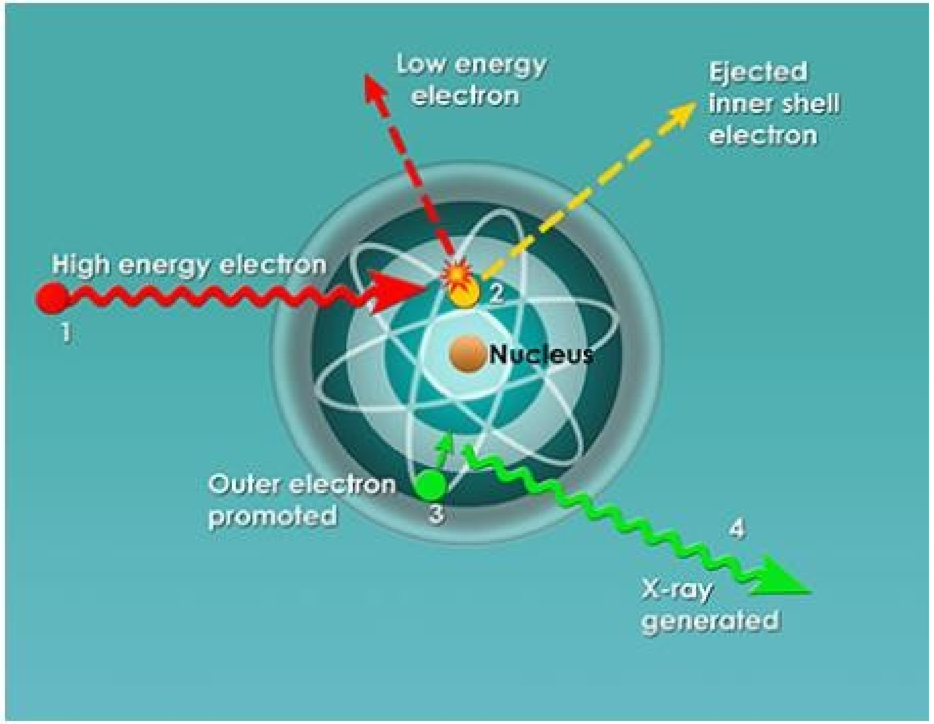
The X-ray tube:

A small increase in the filament voltage (1) results in a large increase in tube current (2) which accelerates high speed electrons from the very high temperature filament negative cathode (3) within a vacuum, towards a positive tungsten target anode (4). This anode rotates to dissipate heat generated. X-rays are generated within the tungsten anode and an X-ray beam (5) is directed towards the patient. X-rays are generated via interactions of the accelerated electrons with electrons of tungsten nuclei within the tube anode. There are two types of X-ray generated: characteristic radiation and bremsstrahlung radiation.



Characteristic X-ray generation:

When a high energy electron (1) collides with an inner shell electron (2) both are ejected from the tungsten atom leaving a 'hole' in the inner layer. This is filled by an outer shell electron (3) with a loss of energy emitted as an X-ray photon (4) (K X-ray photon emitted). When an electron falls from the L level to the K level, the emitted radiation is called a Kα characteristic X-ray and emitted when an electron falls from the M shell to the K shell is called a Kβ X-ray.

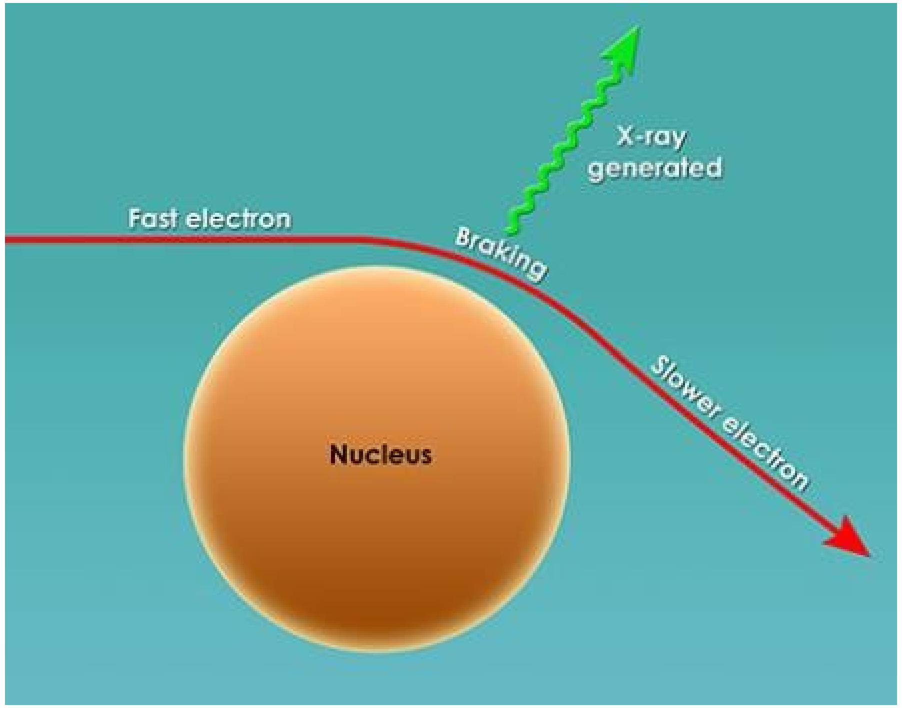


Bremsstrahlung/Braking X-ray generation:

When an electron passes near the nucleus it is slowed and its path is deflected. Energy lost is emitted as a bremsstrahlung X-ray photon.

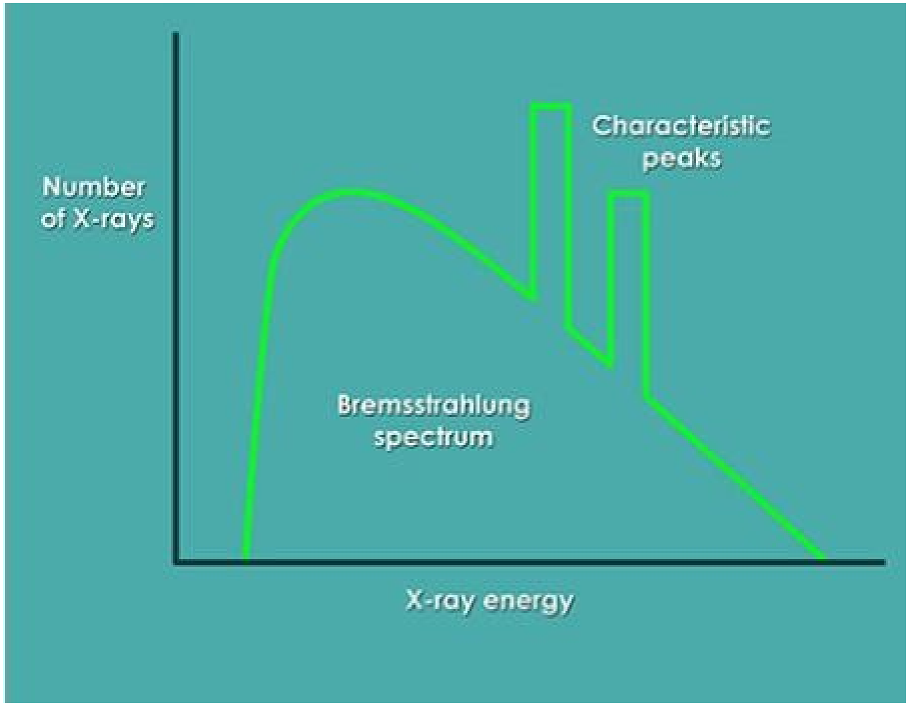
Bremsstrahlung = Braking radiation

Approximately 80% of the population of X-rays within the X-ray beam consists of X-rays generated in this way.



The X-ray spectrum:

As a result of characteristic and bremsstrahlung radiation generation a spectrum of X-ray energy is produced within the X-ray beam.
This spectrum can be manipulated by changing the X-ray tube current or voltage settings, or by adding filters to select out low energy X-rays. In these ways radiographers are able to apply different spectra of X-ray beams to different body parts.

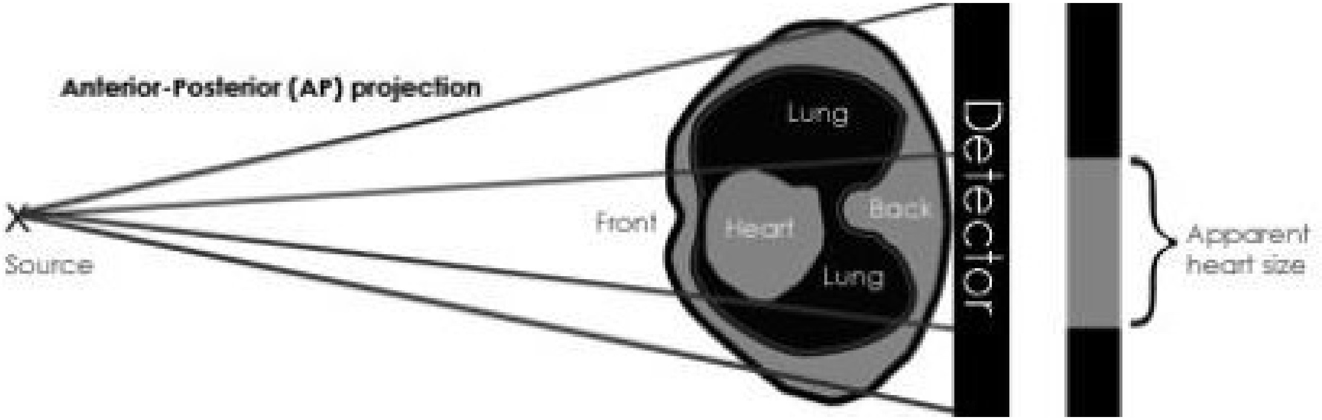


The X-ray beam:

X-rays travel in straight lines and a beam of X-rays diverges from its source. Structures the beam hits first will be magnified in relation to those which are nearer the detector. To reduce magnification the X-ray source can be moved further away from the subject. Structures that need to be measured accurately should be placed closer to the detector, Occasionally magnification can be helpful in localizing abnormalities

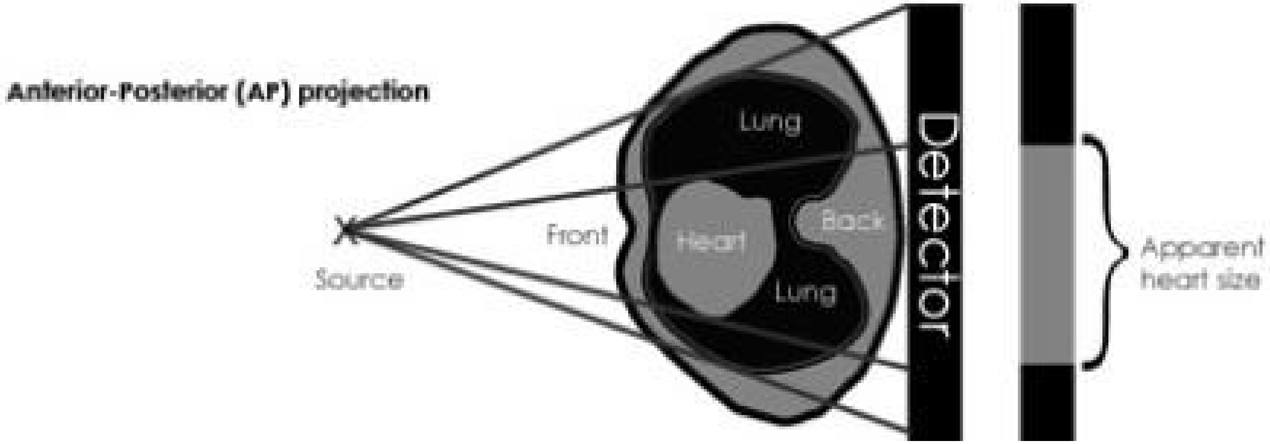
Anterior-Posterior (AP) magnification:

The X-ray beam for an anterior-posterior (AP) view of the chest exaggerates heart size as the heart is relatively near to the beam source.



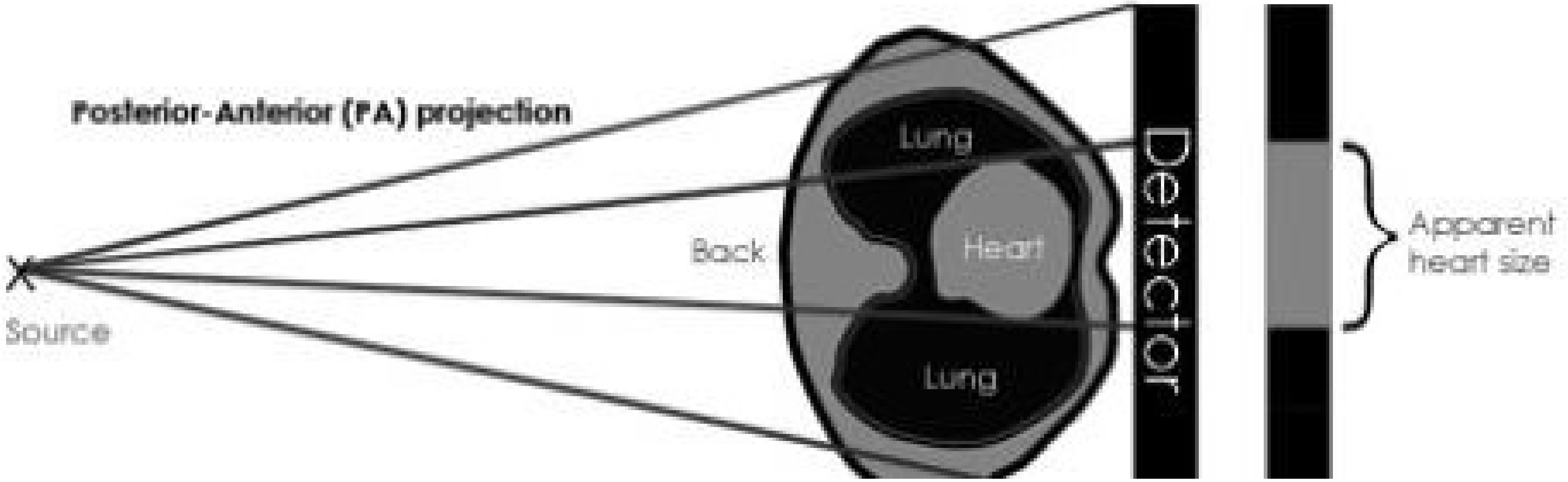
Near beam magnification:

A source that is too near the patient will further exaggerate the size of structures nearest to that source.



Posterior-Anterior (PA) projection:

A posterior-anterior(PA) beam view of the chest allows more accurate representation of heart size as the heart is positioned closer to the detector and is therefore less magnified.



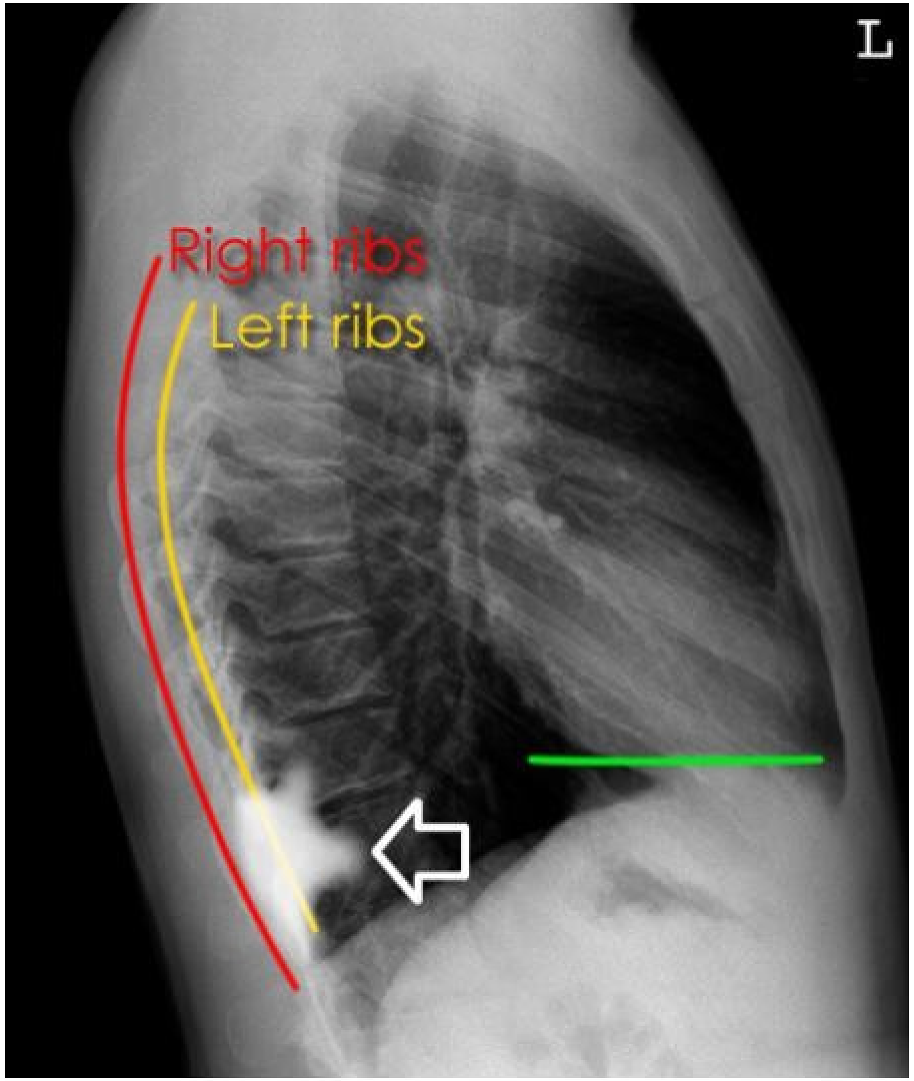
Helpful magnification:

Knowledge of the magnifying properties of an X-ray beam is sometimes helpful.

In this image there is a simulated abnormality (arrow) located in the posterior part of the chest, not visible on a PA view as it lies below the top of the diaphragm (green line).

This is a LEFT lateral image, that is, the LEFT side of the body is closest to the detector and the X-ray beam has passed from RIGHT to LEFT. Body structures such as the RIGHT ribs therefore appear bigger and are more posteriorly placed in relation to their counterparts on the LEFT which are less magnified.

It is possible to locate this abnormal shadow (arrow) on this lateral view because it extends behind the line formed by the LEFT ribs. Assuming it lies within the rib cage at all, it must be located on the RIGHT.



Tissue densities:

An X-ray image is a map of X-ray attenuation. Attenuation of X-rays is variable depending on density and thickness of tissues. Describing X-ray abnormalities in terms of density may help in determining the tissue involved

A radiographic image is composed of a 'map' of X-rays that have either passed freely through the body or have been variably attenuated (absorbed or scattered) by anatomical structures. The denser the tissue, the more X-rays are attenuated. For example, X-rays are attenuated more by bone than by lung tissue.

Describing densities:

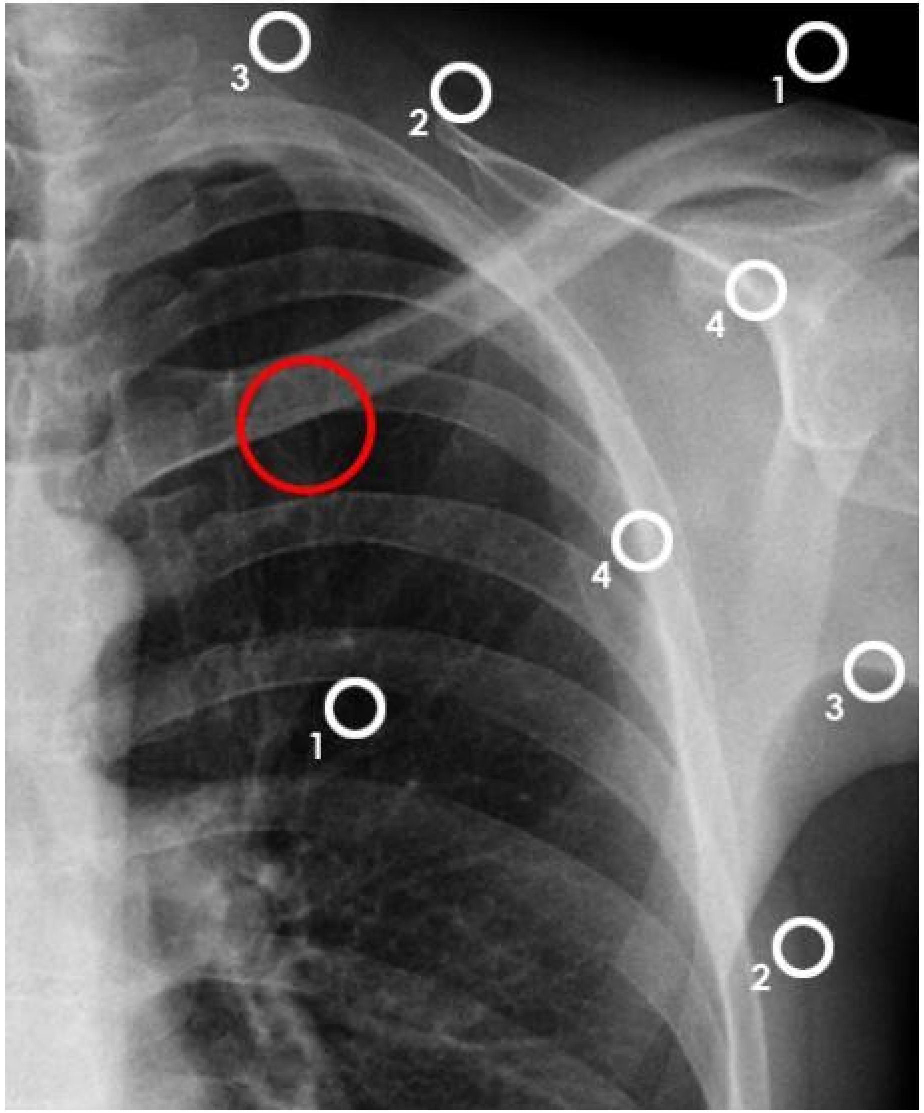
Contrast within the overall image depends on differences in both the density of structures in the body and the thickness of those structures. The greater the difference in either density or thickness of two adjacent structures leads to greater contrast between those structures within the image. For descriptive purposes there are five different densities that can be useful to determine the nature of an abnormality. If there is an unexpected increase or decrease in the density of a known anatomical structure then this may help determine the tissue structure of the abnormality.

The 5 X-ray densities:

Low density material such as air is represented as black on the final radiograph. Very dense material such as metal or contrast material is represented as white. Bodily tissues are varying degrees of grey, depending on density, and thickness.

X- ray tissue densities:

Here are the four natural tissue densities seen on a chest radiograph. Note there is a range of greyness, depending on the thickness of each tissue.



Natural tissue densities:

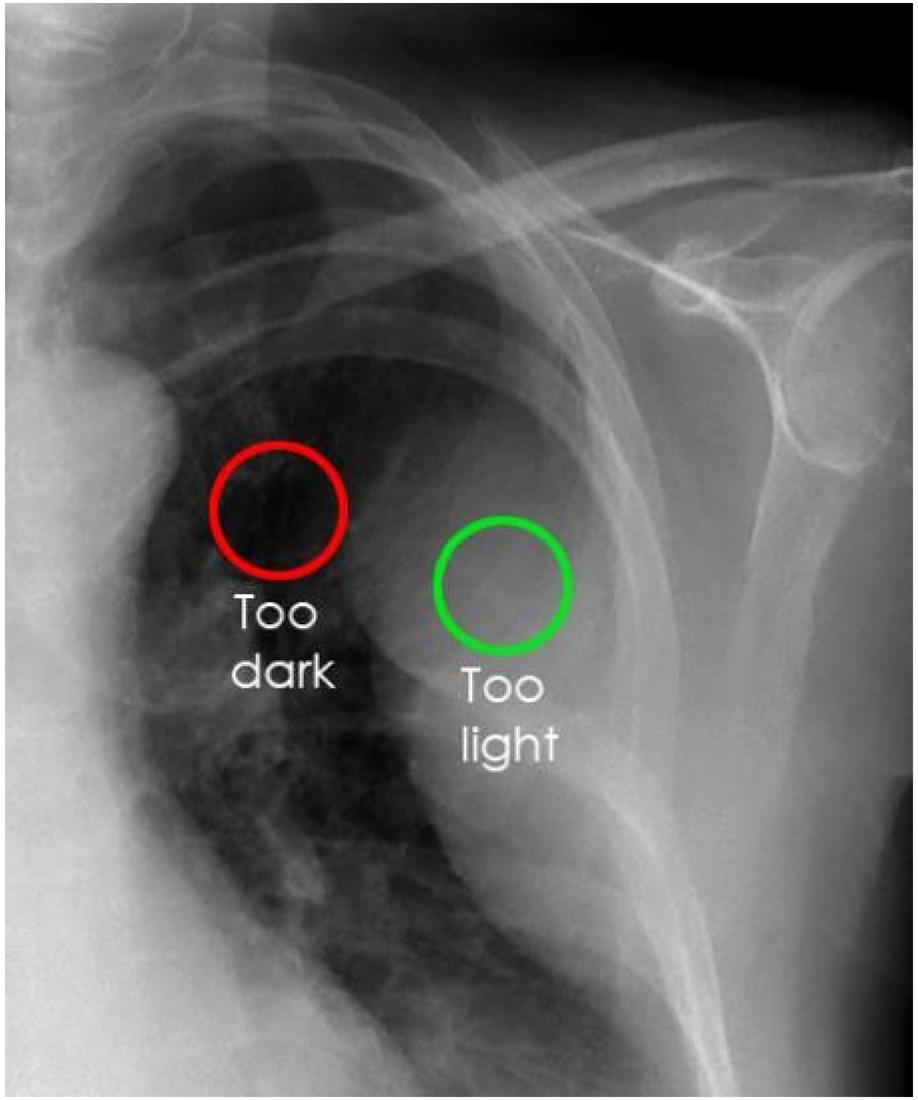
1 - Air/Lung
2 - Fat (layer between soft tissues)
3 - Soft tissue
4 - Bones

X-ray tissue densities:

The greatest contrast is found in areas of greatest difference in density of adjacent structures (red circle).

Abnormal X-ray densities:

There is a large area of increased density on the left side of the chest. This has increased the density (increased whiteness) of this area (green circle). This is a soft tissue density mass that has destroyed a rib which is missing. The posterior rib has lost density and therefore this area appears blacker than normal (red circle).



Biological effects of X-ray exposure:

Some biological effects such as skin damage are dose dependent, whereas others, such as development of cancer, are random . Dose dependent biological effects become measurable above 50mSv (millisieverts) and a whole body dose of greater than 10Sv (sieverts) is universally lethal.
Diagnostic investigations typically involve doses between 0.02mSV (chest X-ray) to 10mSv (CT abdomen). These are generally tissues with rapidly dividing cells, for example, radiation dose to the stomach is over 20 times more likely to result in a fatal cancer than the same dose to bone.
Children are more radiosensitive than adults and irradiation of a fetus should be avoided wherever possible.
Knowledge of the 'inverse square law' helps in reducing dose.

inverse square law:

The strength of the X-ray beam is inversely proportional to the square of distance from the source (X). Standing back by double the distance from a source of radiation (d to 2d) will quarter the dose to the radiologist or radiographer.

How x-rays are absorbed:

X-ray are not absorbed equally well by all materials. Heavy elements such as calcium are much better absorbers of x-rays than light elements such as
Carbon. To understand the absorption of x-ray, we need to study the properties of the x-ray.

1- The attenuation:

It's the reduction of an x-ray beam due to the absorption and scattering of some of the out the beam. To measure the attenuation beam intensity I_o we use:

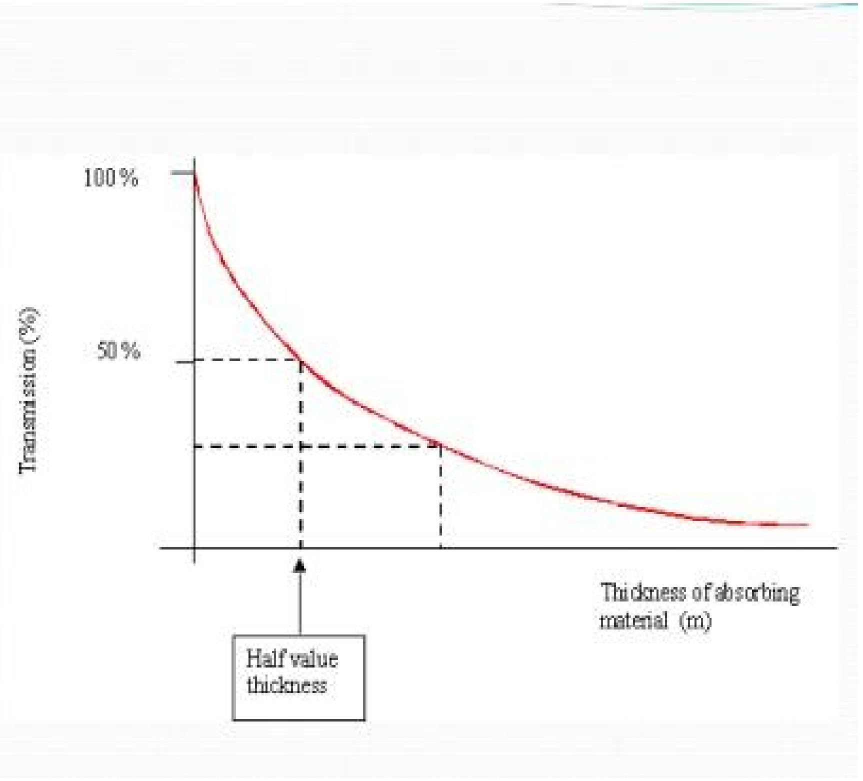
$$I = I_o e^{-\mu x}$$

where:

e: Base of natural logarithm = 2.7

I: The final intensity of x-rays beam.

I_o: attenuated intensity. (original



intensity). x: Thickness of the attenuator
(The target).
μ: The linear attenuation coefficient of the attenuator
(which is depend on the energy of x-ray

The linear attenuation coefficient of the attenuator (μ) was related with half-value layer according to this

equation: $\mu = 0.693 / HVL$

HVL: The thickness of a given material that will reduce the beam intensity by one half.

Mass attenuation coefficient: it's used to remove the effect of density when comparing attenuation in several materials.

Mass attenuation coefficient= Linear atten. coeff. density of material

$$\mu_m = \mu / \rho$$

μm will be in cm^2 /gm

Then $I = I_o e^{-(\mu/\rho)\rho x}$

Therefore $I = I_o e^{-\mu_m \rho x}$

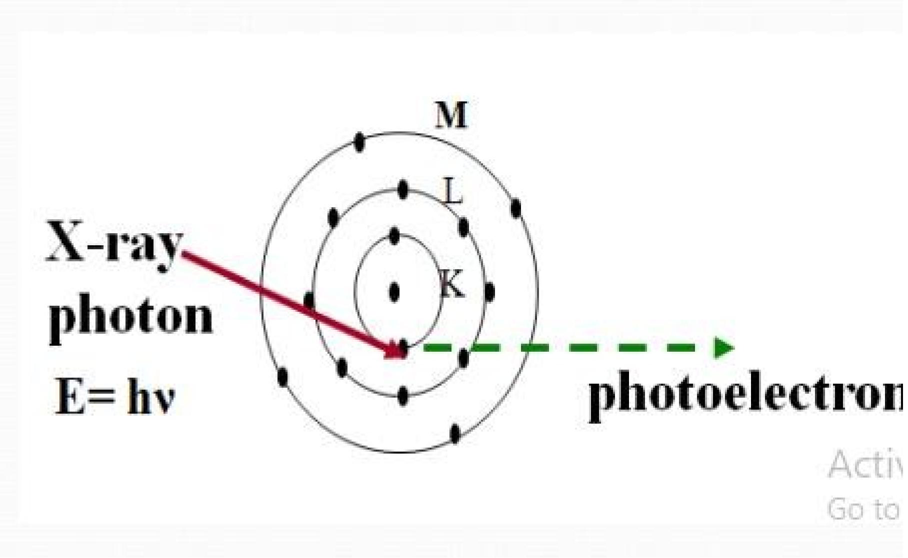
X- ray interaction with matter:

There are three types of interaction between the x-rays and matter. Or x-rays lose energy in three ways:

1-Photoelectric effect
2- Compton effect
3- Pair-production

1- Photoelectric effect:

Its occurs when the incoming x-ray photon transfer all of its energy to an electron which then escapes from the atom.


M
L
K
X-ray photon
E= hν
photoelectron

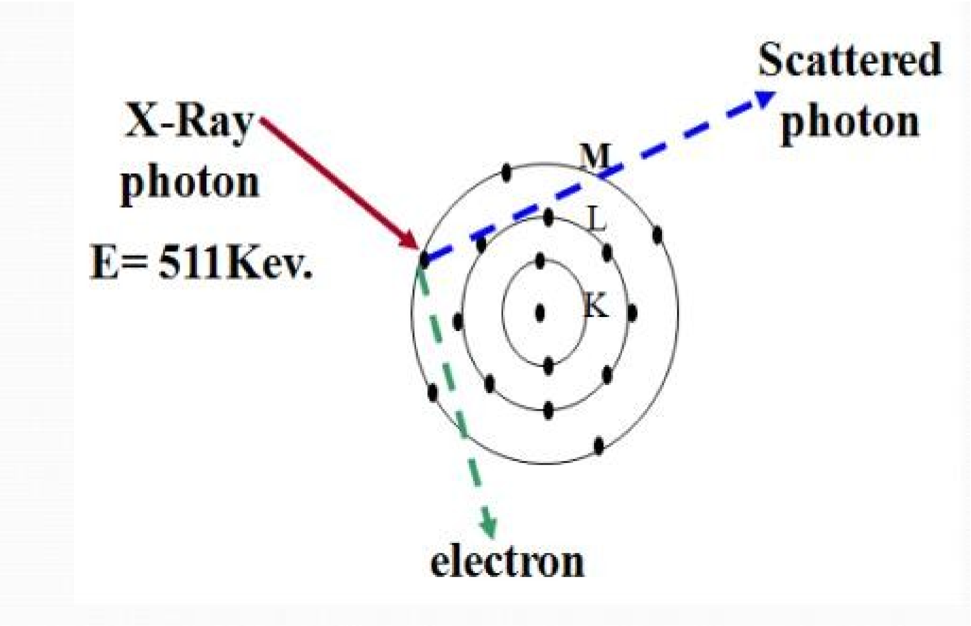
Characteristics of Photoelectric effect:

1. It's more apt to occur in the intense electric field near the nucleus.
2. It's more common in elements with high Z than in those with low Z.
3. The photoelectron uses some of its energy (the binding energy) to get away from the positive nucleus and the reminder will be as a kinetic energy for the electron.
4. The energy used about 30 Kev of x-ray photons.
5. Used more than Compton effect in diagnosis.

Especially the bones and heavy materials such as bullets in the body.

2- Compton effect:

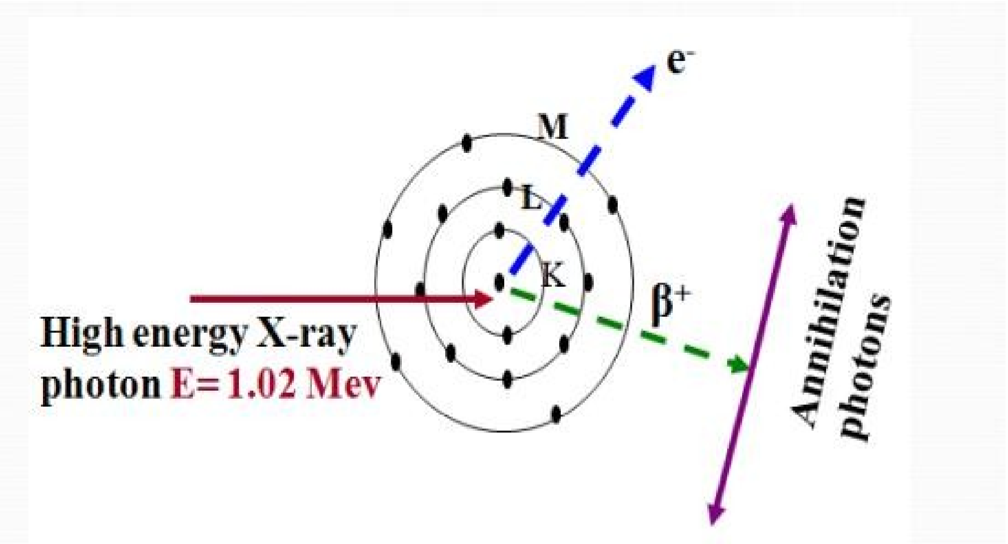
1. It occurs by collision of an x-ray photon with an loosely bounded electron.
2. More apt to occurs at the outer electrons.
3. The energy used usually more than 100 Kev.
4. It usually done at low atomic number (Z) mater
5. Used also in diagnosis especially the soft tissu



3- Pair-production:

Its occur when:

1. A very energetic photon enters the intense field of the nucleus, and converted into two particles: an
electron and a positron (β+), or positive electron.
2. This energetic photon providing the mass for the two particles requires a photon with energy of at least 1.02 Mev and the remainder of the energy over
1.02 Mev is given to the particles as a kinetic energy.
3. The positron is a piece of antimatter. After it has spent its kinetic energy in ionization it does death dance with an electron.
4. Both then vanish, and their mass energy usually appears as two photons of 511 kev each called (annihilation radiation).
5. Pair-production is more apt to occur in high Z elements than in low Z elements.



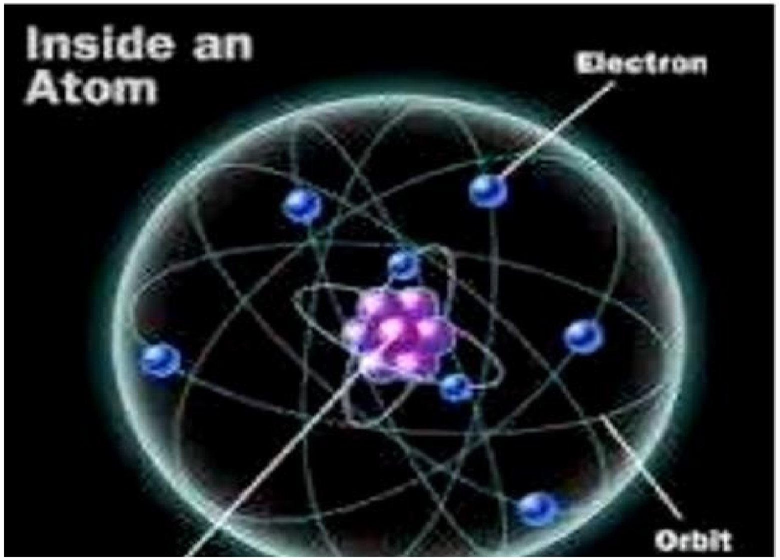
Radiation

Some Properties of Nuclei

All nuclei are composed of protons and neutrons except hydrogen with a single proton. The atomic number Z equals the number of protons in the nucleus. Sometimes called the charge number.

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



$${}^{A}_{Z}X$$

- X is the chemical symbol of the element.

Example: ${}^{27}_{13}Al$

- Mass number is 27

☐ Atomic number is 13

☐ Contains 13 protons. Contains (27 – 13)= 14 neutrons

Charge

- The proton has a single positive charge, e.
- The electron has a single negative charge, - e.
- $e = 1.6 \times 10^{-19}$ C

- The neutron has no charge.

Mass

It is convenient to use ***atomicmass units***, **u**, to express masses.

- $1\ u = 1.660\ 539 \times 10^{-27}$ kg
- From $E_R = mc^2$
- $1\ u = 931.494\ MeV/c^2$
- Includes conversion 1 eV = 1.602 176 x 10-19 J

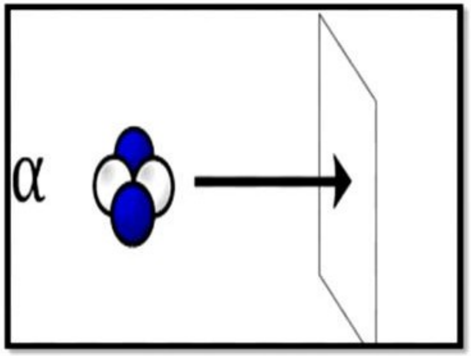
Radioactivity

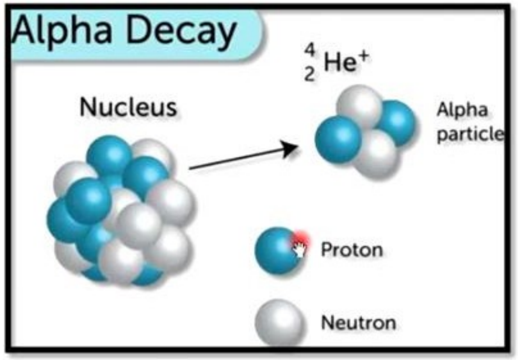
Radioactivity is the spontaneous emission of radiation. Discovered by Becquerel in 1896.

Experiments suggested that radioactivity was the result of the decay, or disintegration, of unstable nuclei. Three types of radiation can be emitted.

1) Alpha particles

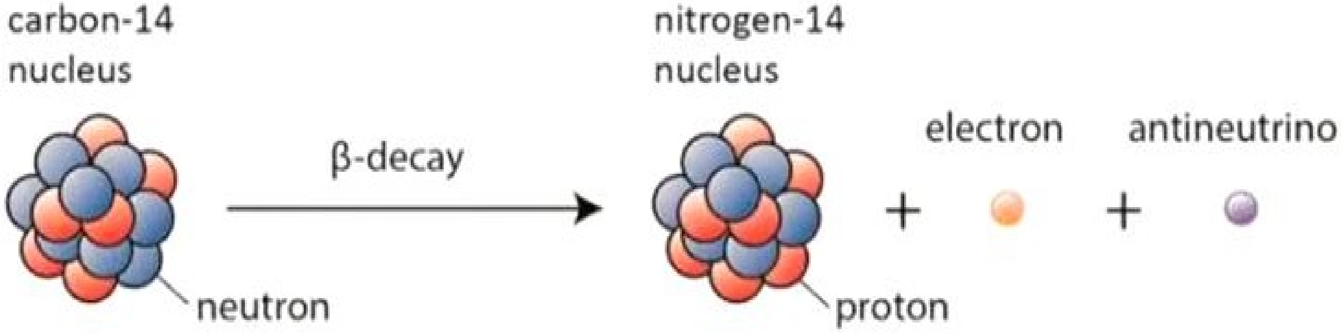
The particles are ^{4}He nuclei. Barely penetrate a piece of paper.





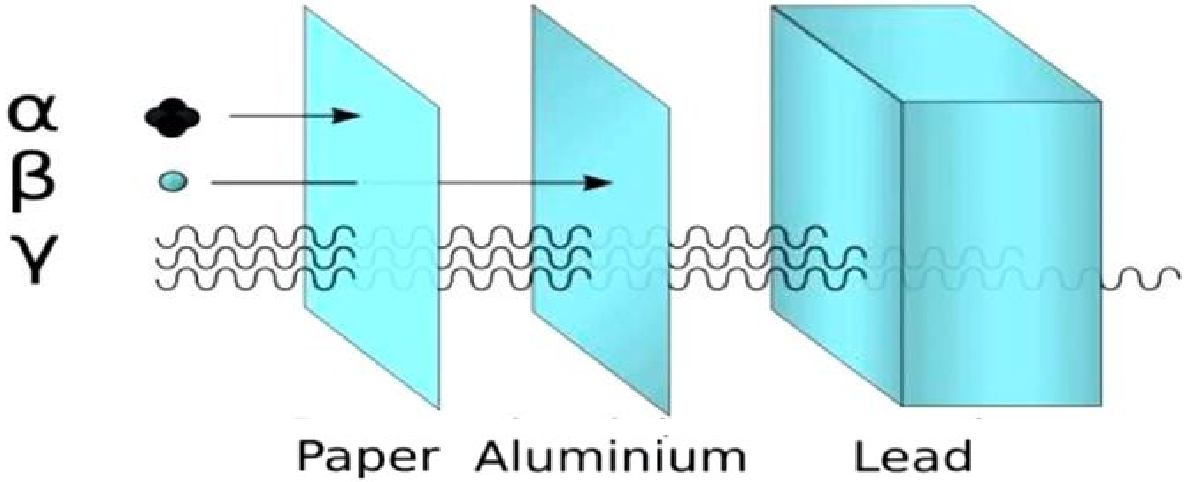
2) Beta particles

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. Can penetrate a few mm of aluminum.



3) Gamma rays

The "rays" are high energy photons. Can penetrate several cm of lead.



The Decay Constant

The number of particles that decay in a given time is proportional to the total number of particles in a radioactive sample.

$$\frac{dN}{dt} = -\lambda N \text{ gives } N = N_o\, e^{-\lambda t}$$

- λ is called the decay constant and determines the probability of decay per nucleus per second.

- N is the number of undecayed radioactive nuclei present.

- N_o is the number of undecayed nuclei at time $t = 0$.

The decay rate R of a sample is defined as the number of decays per second.

Decay Curve and Half-Life

The decay curve follows the equation:

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

The half-life is also a useful parameter. The half-life is defined as the time interval during which half of a given number of radioactive nuclei decay.

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

Radioactive half-life

Radioactive decay constant

$$N_{t_{\frac{1}{2}}} = N_0 e^{-\lambda t_{\frac{1}{2}}}$$

$$\frac{N_0}{2} = N_0 e^{-\lambda t_{\frac{1}{2}}}$$

$$\frac{1}{2} = e^{-\lambda t_{\frac{1}{2}}}$$

$$\ln \frac{1}{2} = -\lambda t_{\frac{1}{2}}$$

$$\ln 2 = \lambda t_{\frac{1}{2}}$$

$$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{.693}{t_{\frac{1}{2}}}$$

$$\Rightarrow t_{\frac{1}{2}} = \frac{.693}{\lambda}$$

The Units

The unit of activity, R, is the **curie** (Ci)

- 1 Ci ≡ 3.7×10^{10} decays/s

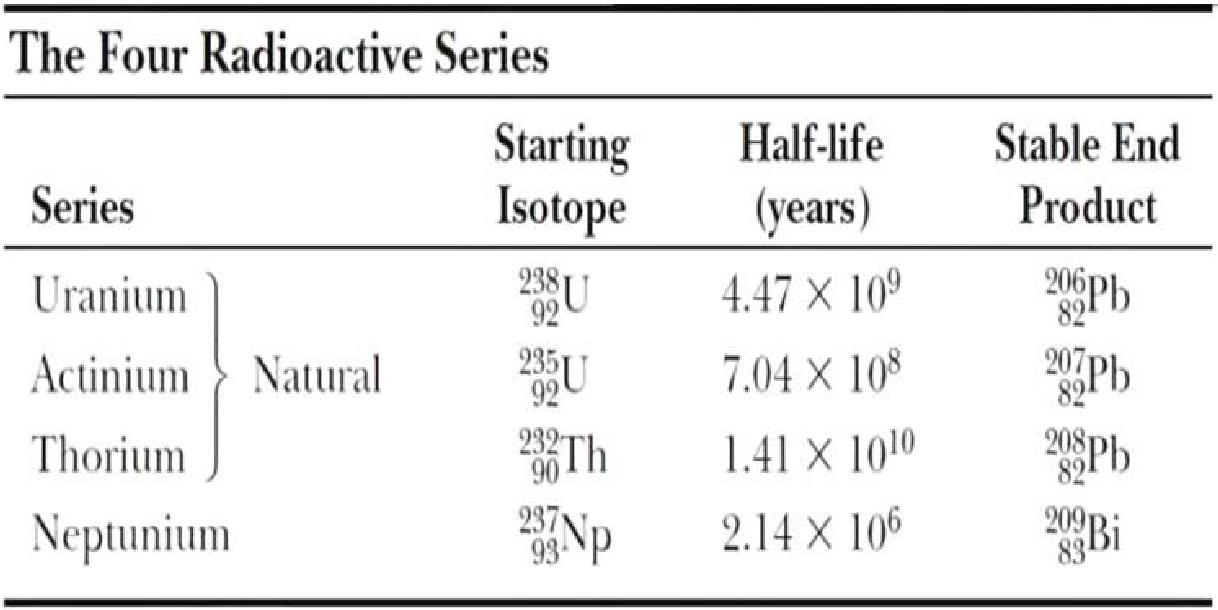
The SI unit of activity is the **Becquerel** (Bq)

- 1 Bq ≡ 1 decay/s
- Therefore, 1 Ci = 3.7×10^{10} Bq

The most commonly used units of activity are the millicurie and the microcurie.

Marie Curie [1867 – 1934] Polish scientist. Shared Nobel Prize in Physics in 1903 for studies in radioactive substances

- Shared with Pierre Curie and Becquerel. Won Nobel Prize in Chemistry in 1911 for discovery of radium and polonium.



The Four Radioactive Series

Series		Starting Isotope	Half-life (years)	Stable End Product
Uranium	Natural	${}^{238}_{92}U$	4.47×10^{9}	${}^{206}_{82}Pb$
Actinium		${}^{235}_{92}U$	7.04×10^{8}	${}^{207}_{82}Pb$
Thorium		${}^{232}_{90}Th$	1.41×10^{10}	${}^{208}_{82}Pb$
Neptunium		${}^{237}_{93}Np$	2.14×10^{6}	${}^{209}_{83}Bi$

Example: The Activity of Carbon. At time t =0, a radioactive sample contains 3.50 mg of pure ${}^{11}_{6}\mathbf{C}$, which has a half-life of 20.4 min.

What is the activity of the sample initially and after 8.00 h?

Natural Radioactivity

Unstable nuclei found in nature. They give rise to natural radioactivity. Three series of natural radioactivity exist. Uranium, Actinium and Thorium.

Nuclei produced in the laboratory through nuclear reactions. They exhibit artificial radioactivity. Some radioactive isotopes are not part of any decay series.

Activity: It's the number of atoms decay per unit time (disintegrations/s), it decreases exponentially with time, and it is defined as the radioactivity of the sample, it's measured by curie (Ci) or Becquerel (Bq).

Curie: Curie is the activity of one gram of pure radium, It's the old unit of activity, and It is a very large amount of activity, thus sub-multiples of curie are commonly used; mCi, μCi,nCi , pCi .

Becquerel: One Becquerel is equal to one disintegration per second (dps), or (d/s). Becquerel is a very small unit of activity, thus multiples of Becquerel are commonly used

Radiation Damage

Radiation absorbed by matter can cause damage. The degree and type of damage depend on many factors.

- Type and energy of the radiation
- Properties of the matter
- Radiation damage in biological organisms is primarily due to ionization effects in cells. Ionization disrupts the normal functioning of the cell.

Ex: What is the half-life of element X if it takes 36 days to decay from 50 grams to 12.5 grams?

50 grams to 25 grams is one half-life.

25 grams to 12.5 grams is another half-life.

So, for 50 grams to decay to 12.5 grams, two half-lives, which would take 36 days total, would need to pass. This means each half-life for element X is 18 days.

Or half-life= $\frac{Total\ time}{Number\ of\ repetitions} = \frac{36}{2} =$ 18 days

Radiation therapy

- Radiation causes the most damage to rapidly dividing cells.
- Therefore, it is useful in cancer treatments.

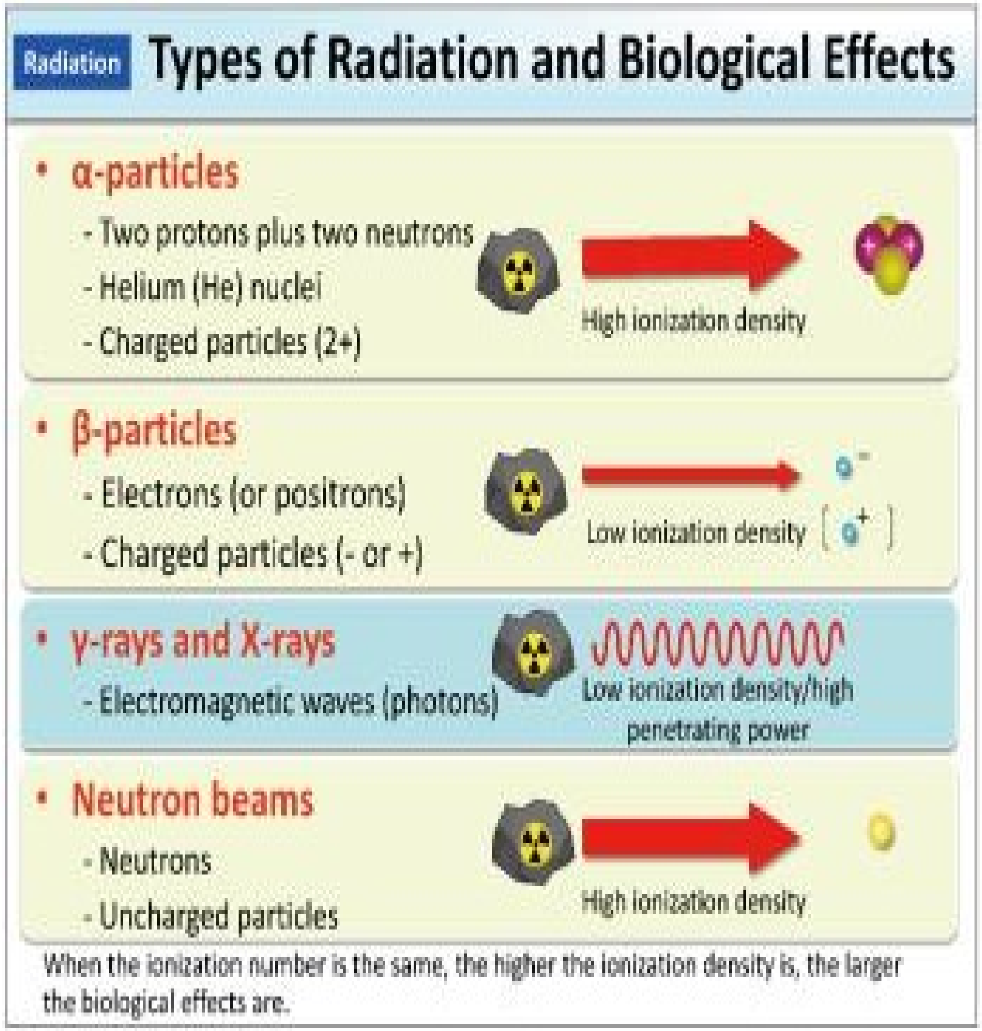
Food preservation

- High levels of radiation can destroy or incapacitate bacteria or mold spores.

Radiation therapy

- Radiation causes the most damage to rapidly dividing cells.
- Therefore, it is useful in cancer treatments.

Types of Radiation and Biological Effects



Radiation

Types of Radiation and Biological Effects

- **α-particles**
  - Two protons plus two neutrons
  - Helium (He) nuclei
  - Charged particles (2+)

High ionization density

- **β-particles**
  - Electrons (or positrons)
  - Charged particles (- or +)

Low ionization density

- **γ-rays and X-rays**
  - Electromagnetic waves (photons)

Low ionization density/high penetrating power

- **Neutron beams**
  - Neutrons
  - Uncharged particles

High ionization density

When the ionization number is the same, the higher the ionization density is, the larger the biological effects are.

- . α-particles does not cause problems because α-particles have weak penetrating power against biological tissues and cannot penetrate the horny layer of the skin (layer of dead cells on the skin surface). However, internal exposure to any radioactive material that emits α-particles causes large amounts of local ionization, i.e., high- density ionization, within tissues, providing concentrated energy. This significantly damages DNA and has strong biological effects.

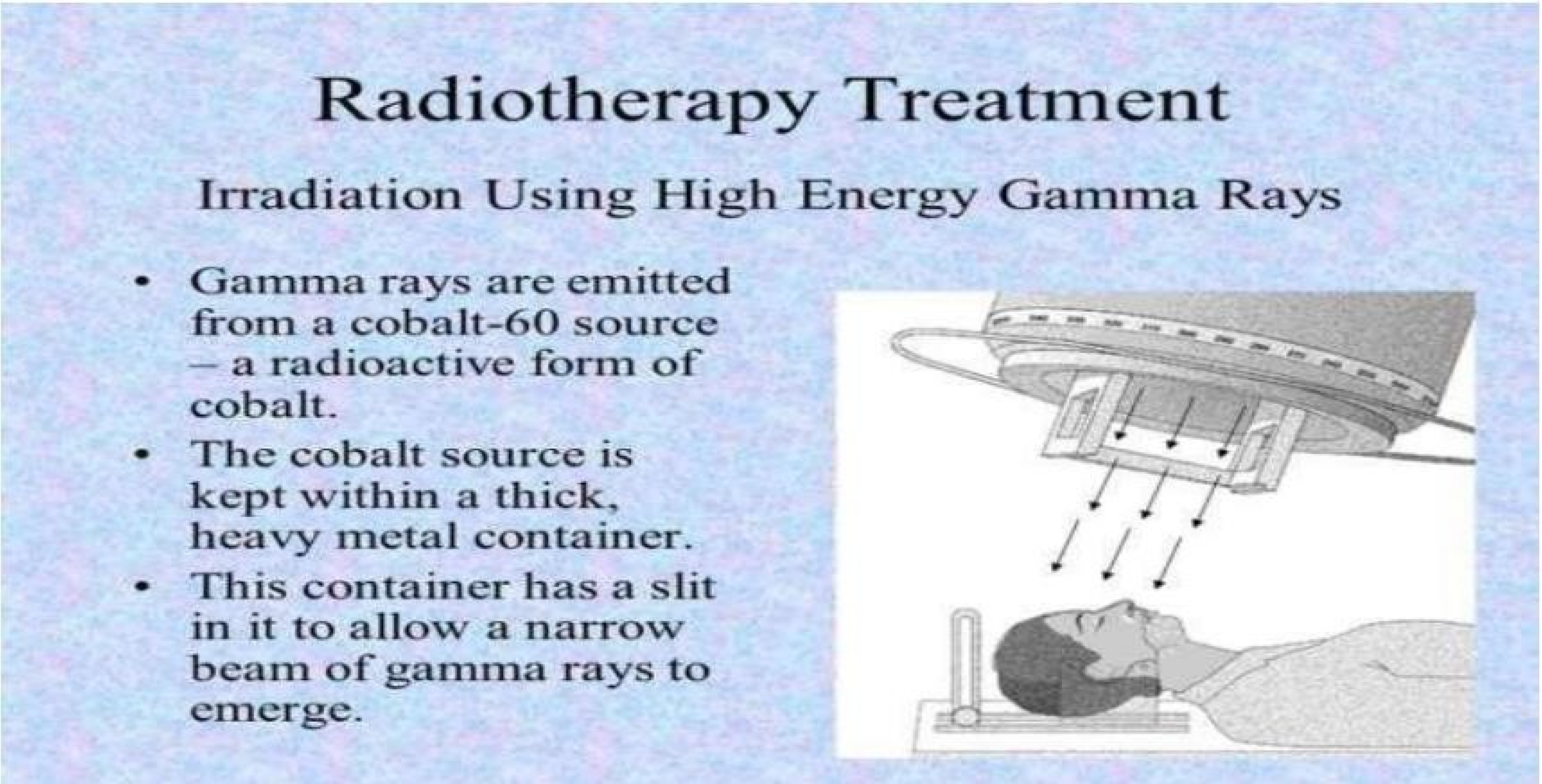
- β-particles cause direct ionization of the substance it passes through, as do α-particles, but because of their low
  ionization density, their biological effects are not as strong as those of α-particles. Penetrating power of β-
  particles is also weak but stronger than that of α-particles, and external exposure to β-particles could affect the
  skin and subcutaneous tissues.

- γ-rays and X-rays reach deep organs and tissues because of their strong penetrating power but do not have high
  ionization density. Their biological effects are similar to those of β-particles.

- Since a neutron has a mass almost equal to that of a proton, a neutron beam stops efficiently when colliding with a proton. Since the human body contains a large amount of water, neutrons lose their energy as they collide with hydrogen nuclei (protons) that make up water molecules.

Radiotherapy

Radiotherapy: The treatment of disease with ionizing radiation. Also called radiation therapy. It is aim to deliver a precise dose of radiation to a defined tumor volume with as minimal damage as possible to surrounding normal tissues.



Radiotherapy Treatment

Irradiation Using High Energy Gamma Rays

- Gamma rays are emitted from a cobalt-60 source – a radioactive form of cobalt.
- The cobalt source is kept within a thick, heavy metal container.
- This container has a slit in it to allow a narrow beam of gamma rays to emerge.

In radiotherapy, high-energy rays are often used to damage cancer cells and stop them from growing and dividing. A specialist in the radiation treatment of cancer is called a radiation oncologist.

In the most basic terms, cancer refers to cells that grow out-of-control and invade other tissues. Cells may become cancerous due to the accumulation of defects, or mutations, in their DNA.

Why Use Radiation Therapy?

- To cure cancer:

–Destroy tumors that have not spread to other body parts.
–Reduce the risk that cancer will return after surgery or chemotherapy.
–Shrink the cancer before surgery.

- For palliation (to reduce symptoms):

–Shrink tumors affecting quality of life, like a lung tumor that is causing shortness of breath.
–Alleviate pain or neurologic symptoms by reducing the size of a tumor.

When is radiation used?

- The best treatment plan for each patient is frequently determined by a team of doctors, including a radiation oncologist, a medical oncologist and a surgeon.
- Sometimes radiation therapy is the only treatment a patient needs.
  Tumor boards meet to discuss comprehensive patient treatment plans
  Other times, it is combined with other treatments, such as surgery and chemotherapy.

Calculation of Radiation Absorbed Dose

Absorbed Dose = Energy Absorbed Dose from Ionizing Radiation / Mass of Organ

- The organ that is the recipient of this radiate energy from the source organs is called a **target organ.**

-The energy deposited in specific organ is called the **self dose.**

-The fraction of the energy emitted by source and deposited in the target is called the **absorbed fraction**. This depends on

1- Type and energy of the radiation.
2- Size, shape and composition of the target.
3- Distance between source and target as well as the type of material separating them.

NOTE: **Equivalent dose** is used to assess how much biological damage is expected from the absorbed dose. (Different types of radiation have different damaging properties).

The difference between absorbed dose in tissue and equivalent dose: 1- Absorbed dose tells us the energy deposit in a small volume of tissue.

2- Equivalent dose addresses the impact that the type of radiation has on that tissue.

Because all radiation used in diagnostic medicine has the same low-harm potential, the absorbed dose and the equivalent dose are numerically the same. Only the units are different.

For diagnostic radiation: The equivalent dose in milliSievert (mSv) = the absorbed dose in mGy.

Effective dose is a calculated value, measured in mSv, that takes three factors into account:

1- the absorbed dose to all organs of the body,
2- the relative harm level of the radiation, and
3- the sensitivities of each organ to radiation.

Effective dose: The quantity of effective dose helps us take into account **sensitivity.** Different body parts have different sensitivities to radiation. For example, the head is less sensitive than the chest.
Effective dose relates to the overall long-term risk to a person from a procedure and is useful for comparing risks from different procedures.
The actual risk to a patient might be higher or lower, **depending on the size of the patient and the type of procedure.**

The First law of Thermodynamic

The First Law of Thermodynamics:

The first law is a statement of the conservation of energy. Energy can be transformed from one kind into another, it cannot be created or destroyed. The relativistic picture of the universe expressed by Einstein's equation

$$Energy = (Mass\ change) \times (Velocity\ of\ light)^2$$

suggests that matter can be considered as another form of energy,

1 g being equivalent to 9×10^{13} joules.

These enormous quantities of energy are involved in nuclear transformations but are not important in ordinary chemical reactions.

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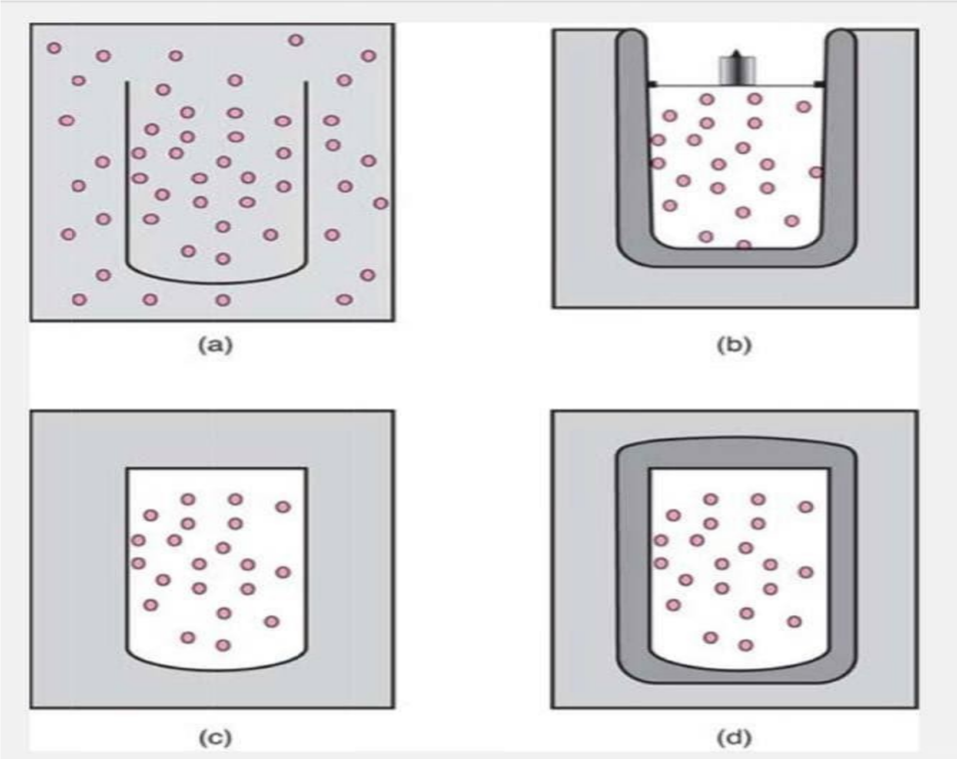

Fig. 3-1: Examples of thermodynamic systems:

(a) An open system exchanging mass with its surroundings; (b) a closed system exchanging work with its surroundings; (c) a closed system exchanging heat with its surroundings; (d) an isolated system, in which neither work nor heat can be exchanged through boundaries.

According to the first law, the effects of Q and W in a given system during a transformation from an initial thermodynamic state to a final thermodynamic state are related to an intrinsic property of the system called the internal energy, defined as

$$\Delta E = E_2 - E_1 = Q + W \quad (3\text{-}1)$$

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$$\Delta E = E_2 - E_1 = Q + W \tag{3-1}$$

Where

E_2 is the internal energy of the system in its final state.

E_1 is the internal energy of the system in its initial state.

Q is the heat.

W is the work.

The change in internal energy ΔE

It is useful to relate the change of internal energy to the measurable properties of the system:

P, V, and T.

For an infinitesimal change in the energy dE, equation (3 – 1) is written as

$$dE = đq + đw \qquad (3-2)$$

Where $đq$ is the heat absorbed and $đw$ is the work done during the infinitesimal change of the system.

The infinitesimal change of any state property like dE can be generally written, for instance,

as a function of T and V as in the following equation for a closed system(i.e., constant mass):

$$dE = \left(\frac{\partial E}{\partial T}\right)_V dT + \left(\frac{\partial E}{\partial T}\right)_T dV \qquad (3-3)$$

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$$dE = \left(\frac{\partial E}{\partial T}\right)_V dT + \left(\frac{\partial E}{\partial T}\right)_T dV \qquad (3-3)$$

By combining equations (3 – 2) and (3 – 3) into

$$dq + dw = \left(\frac{\partial E}{\partial T}\right)_V dT + \left(\frac{\partial E}{\partial V}\right)_T dV \qquad (3-4)$$

This equation will be used later to describe some properties of E as a function of T and V.

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The first law under adiabatic conditions reduces to

$$đw = dE \qquad (3\text{-}5)$$

According to equation (3-5), when work is done by the system, the internal energy decreases and because heat cannot be absorbed in an adiabatic process, the temperature must fall. Here, the work done becomes a thermodynamic property dependent only on the initial and final states of the system.

and because heat cannot be absorbed in an adiabatic process, the temperature must fall.
final states of the system.

Work of Expansion Against a Constant Pressure:

Initial focus is on the work produced by varying the volume of a system against

a constant opposing external pressure, P_{ex}. Imagine a vapor confined in a hypothetical cylinder fitted with a weightless, frictionless piston of area A, as shown in Figure 3-2.

a constant opposing external pressure, P_{ex}. Imagine a vapor confined in a hypothetical
cylinder fitted with a weightless, frictionless piston of area A, as shown in Figure 3-2.

If a constant external pressure P_{ex} is exerted on the piston, the total force is

$P_{ex} \times A$ because $P = Force/Area$. The vapor in the cylinder is now made to expand by increasing the temperature, and the piston moves a distance h. The work done against the opposing pressure in one single stage is

$$W = -P_{ex} \times A \times h \qquad (3-6)$$

Now $A \times h$ is the increase in volume, $\Delta V = V_2 - V_1$, so that, at constant pressure,

$$W = -P_{ex}\Delta V = -P_{ex}(V_2 - V_1) \qquad (3-7)$$

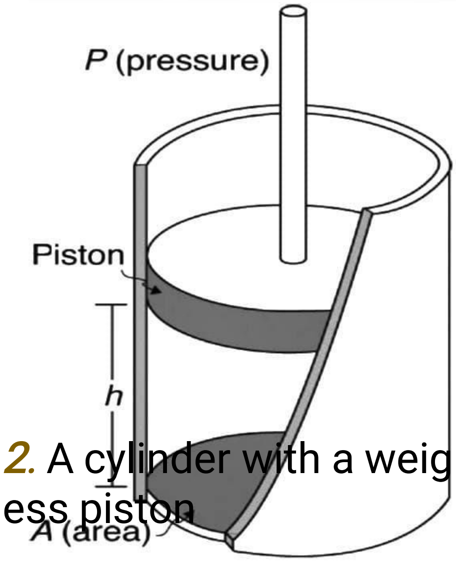


Fig.3 – 2. A cylinder with a weightless and frictionless piston

Reversible Processes

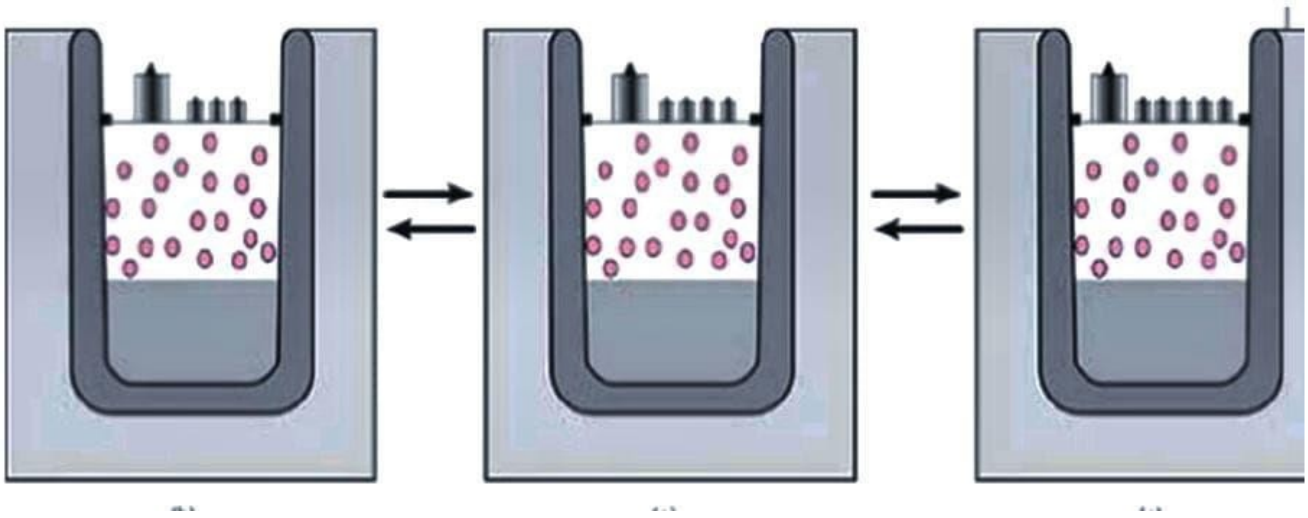


Fig. 3-3. A reversible process: evaporation and water at 1 atm in a closed system. (a) System at equilibrium with $P_{ex} = 1 atm$; (c) compression is infinitesimal.

if the external pressure is decreased slightly by removing one of the infinitesimally small weights (Fig. 3-3b), the volume of the system increases and the vapor pressure falls infinitesimally. Water then evaporates to maintain the vapor pressure constant at its original value, and heat is extracted from the bath to keep the temperature constant and bring about the vaporization. On the other hand, if the external pressure is increased slightly by adding an infinitesimally small weight (Fig. 3-3c), the system is compressed and the vapor pressure

infinitesimally small weight (Fig. 3-3c), the system is compressed and the vapor pressure

also rises infinitesimally. Some of the water condenses to reestablish the equilibrium vapor pressure, and the liberated heat is absorbed by the constant-temperature bath. If the process could be conducted infinitely slowly so that no work is expended in supplying kinetic energy to the piston, and if the piston is considered to be frictionless so that no work is done against the force of friction, all the work is used to expand or compress the vapor. Then, because this process is always in a state of virtual thermodynamic equilibrium, being reversed by an infinitesimal change of pressure, it is said to bereversible.

Maximum Work:

The work done by a system in an isothermal expansion process is at a maximum when it is done reversibly. No work is accomplished if an ideal gas expands freely into a vacuum, where $P = 0$, because any work accomplished depends on the external pressure. As the external pressure becomes greater, more work is done by the system, and it rises to a maximum when the external pressure is infinitesimally less than the pressure of the gas, that is, when the process is reversible. if the external pressure is continually increased, the gas is compressed rather than expanded, and work is done on the system rather than by the system in an isothermal reversible process.

Then the maximum work done for a system that is expanded in reversible fashion is

$$W = \int_1^2 dw = -\int_{V_1}^{V_2} P\,dV \qquad (3-8)$$

where P_{ex} was replaced by P because the external pressure is only infinitesimally smaller than the pressure of the system. In similar fashion, it can be deduced that the minimum work in a reversible infinitesimally larger than P. The right term in equation (3-8) is depicted in the shaded area in Figure 3-4, which represents the maximum expansion work or the minimum compression work in a reversible process.

Example 3-2:

A gas expands by 0.5 liter against a constant pressure of 0.5 atm at 25°C. What is the work in

ergs and in joules done by the system?

Answer//

$$W = P\Delta V$$

$$1\ atm = 1.013 \times 10^6\ dynes/cm^2$$

$$W = (0.507 \times 10^6\ dynes/cm^2) \times 500\ cm^3$$

$$= 2.53 \times 10^8\ ergs = 25.3\ joules$$

The following example demonstrates the kind of problem that can be solved by an application of the first law of thermodynamics.

The external pressure in equation (3-8) can be replaced by the pressure of an ideal gas, $P = nRT/V$, and by ensuring that the temperature of the gas remains constant during the change of state (isothermal process); then one can take nRT outside the integral,

giving the equation:

$$W_{max} = \int P\,dw_{max} = -nRT\int_{V_1}^{V_2}\frac{dV}{V} \quad (3-9)$$

$$W_{max} = -nRT\ln\frac{V_2}{V_1} \quad (3-10)$$

Note that in expansion, $V_2 > V_1$, and In (V_2/V_1) is a positive quantity; therefore, the work is done by the system, so that its energy decreases (negative sign). When the opposite is true, $V_2 < V_1$, and In$(V_2/V_1)$is negative due to gas compression, work is done by the system, so that its energy increases (positive sign).

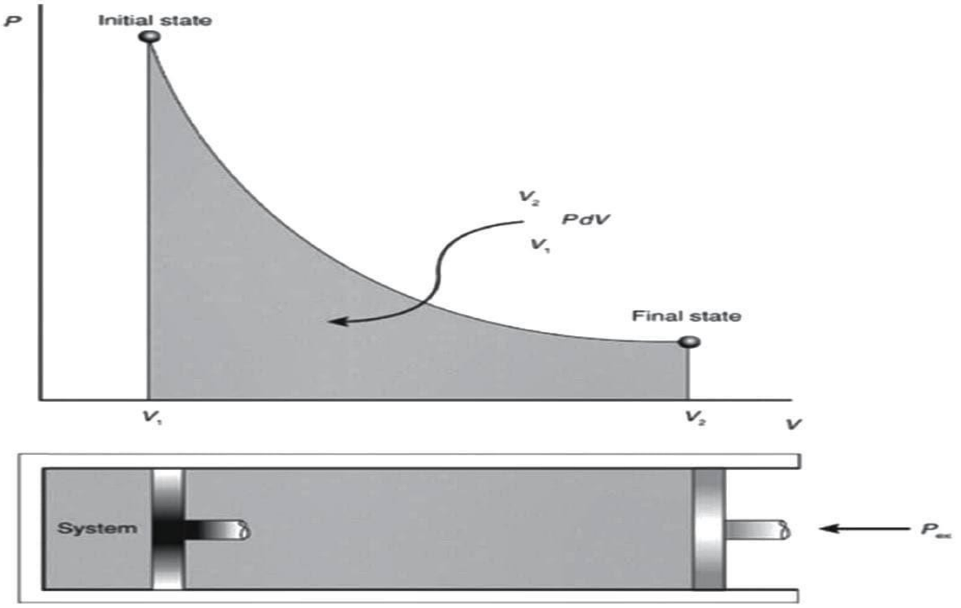


Fig.3 – 4. Reversible expansion of a gas.

Fig.3 – 4. Reversible expansion of a gas.

Equation (3-10) gives the maximum work done in the expansion as well as the heat absorbed, because $Q = \Delta E - W$, and, as ill be shown later, ΔE is equal to zero for an ideal gas in an isothermal process. The maximum work in an isothermal reversible expansion may also be expressed in terms of pressure because, from Boyle's law, $V_2 T V_1 = \frac{P_1 T}{P_2}$ at constant temperature. Therefore, equation (3- 10) can be written as

$$W_{max} = -nRT\ln\frac{P_1}{P_2} \qquad (3-11)$$

$$W_{max} = -nRT\ln\frac{P_1}{P_2}$$

Example 3-3:

One mole of water in equilibrium with its vapor is converted into steam at 100℃ and $1\ atm$.

The heat absorbed in the process (i.e., the heat of vaporization of water at 100°C) is about $9720\ cal/mole$. What are the values of the three first-law terms Q, W and ΔE ?

Answer//

The amount of heat absorbed is the heat of vaporization, given as $9720\ cal/mole$. Therefore, $Q = 9720\ cal/mole$. The work W performed against the constant atmospheric pressure is obtained by using equation (3-10), $W = -nRT \ln(V_2/V_1)$. Now, V_1 is the volume of 1 mole of liquid water at 100°C, or about 0.018 liter. The volume V_2 of 1 mole of steam at 100°C and 1 atm is given by the gas law, assuming that the vapor behaves ideally:

$$V_2 = \frac{RT}{P} = \frac{0.082 \times 373}{1} = 30.6\ liter$$

It is possible to obtain the work,

$$W = -(1\ mole)(1.9872\ cal/K\ mole)(398.15\ K)\ ln\,(30.6/0.018)$$

$$W = -5883\ cal$$

The internal energy change ΔE is obtained from the first – law expression,

$$\Delta E = 9720 - 5883 = 3837\ cal$$

Example 3-4:

What is the maximum work done in the isothermal reversible expansion of 1 mole of an ideal

gas from 1 to 1.5 liters at 25°C?

Answer//

The conditions of this problem are similar to those of Example 3 -2, except that equation (3- 10) can now be used to obtain the (maximum) work involved in expanding reversibly this gas by 0.5 liters; thus,

$$W = (1\,mole)(8.3143\,joule/K\,mole)(297.15\,K)\ln(1.5/1.0)$$

$$W = -1005.3\,joule$$

Changes of State at Constant Volume:

If the volume of the system is kept constant during a change of state $dV = 0$, the first law can be expressed as

$$dE = đQ_v \,, \qquad (3-12)$$

where the subscript V indicates that volume is constant. Similarly, under these conditions the combined equation (3-4) is reduced to

$$dq_v = \frac{\ }{\partial}\Big)_V d \qquad (3-13)$$

This equation relates the heat transferred during the process at constant volume, $đQ_v$, with the change in temperature, dT. The ratio between these quantities defines the molar heat capacity at constant volume:

$$C_v \equiv \frac{đq_v}{dT} = \left(\frac{\partial E}{\partial T}\right)_V \qquad (3-14)$$

Ideal Gases and the First Law:

An ideal gas has no internal pressure, and hence no work needs be performed to separate the molecules from their cohesive forces when the gas expands. Therefore, $đw = 0$, and the first law becomes

$$dE = đq \qquad (3-15)$$

Thus, the work done by the system in the isothermal expansion of an ideal gas is equal to the heat absorbed by the gas. Because the process is done isothermally, there is no temperature change in the surroundings, $dT = 0$ and $q = 0$. Equation (3-5) is reduced to

$$dE = \left(\frac{\partial T}{\partial V}\right)_T dV = 0 \qquad (3-16)$$

In this equation, $dV \neq 0$ because there has been an expansion, so that we can write

$$\left(\frac{\partial E}{\partial}\right)_T = \qquad (3-17)$$

Changes of State at Constant

When the work of expansion is done at constant pressure, $W = -P\,\Delta V = -P\,(V_2 - V_1)$ by equation (3–7), and under these conditions, the first law can be written as

$$\Delta E = Q_P - P\,(V_2 - \qquad (3-18)$$

where Q_P is the heat absorbed at constant pressure. Rearranging the equation results in $Q_P = E_2 - E_1 + P\,(V_2 - V_1)$

$$= (E_2 + P\,V_2) - (E_1 + P\,V_1) \qquad (3-19)$$

The term $E + PV$ is called the enthalpy, H. The increase in enthalpy, ΔH, is equal to the heat absorbed at constant pressure by the system. It is the heat required to increase the internal energy and to perform the work of expansion, as seen by substituting H in equation (3-19),

$$Q_P = H_2 - H_1 = \qquad (3-20)$$

and writing equation (3-18) as

$$\Delta H = \Delta E + P\,\Delta V \qquad (3-21)$$

For an infinitesimal change, one can write as

$$\text{đ}q_p = dH \qquad (3-22)$$

The heat absorbed in a reaction carried out at atmospheric pressure is independent of the number of steps and the mechanism of the reaction. It depends only on the initial and final conditions. It should also be stressed that $\Delta H = Q_P$ only when nonatmospheric work (i.e., work other than that against the atmosphere) is ruled out. When electric work, work against surfaces, or centrifugal forces

are considered, one must write as

$$\Delta H = Q_P - W_{non} \tag{3 – 23}$$

The function H is a composite of state properties.

If T and P are chosen as variables, dH can be written as

$$dH = \left(\frac{\partial H}{\partial}\right)_P dT + \left(\frac{\partial E}{\partial}\right)_T \tag{3 – 24}$$

When the pressure is held constant, as, for example, when a reaction proceeds in an open container in the laboratory at essentially constant atmospheric pressure, equation (3-24) becomes

$$dH = \left(\frac{\partial H}{\partial}\right)_P d$$ (3 –

Because $đq_p = dH$ at constant pressure according to equation (3–22), the molar heat capacity C_P at constant pressure is defined as

$$\overline{C}_P \equiv \frac{dq_p}{d} = \left(\frac{\partial H}{\partial}\right)_P$$ (3 –

and for a change in enthalpy between products and reactants,

$$\Delta H = H_{products} - H$$

Table 3 – 1 Modified First-Law Equations for Processers

Occurring Under Various Conditions:

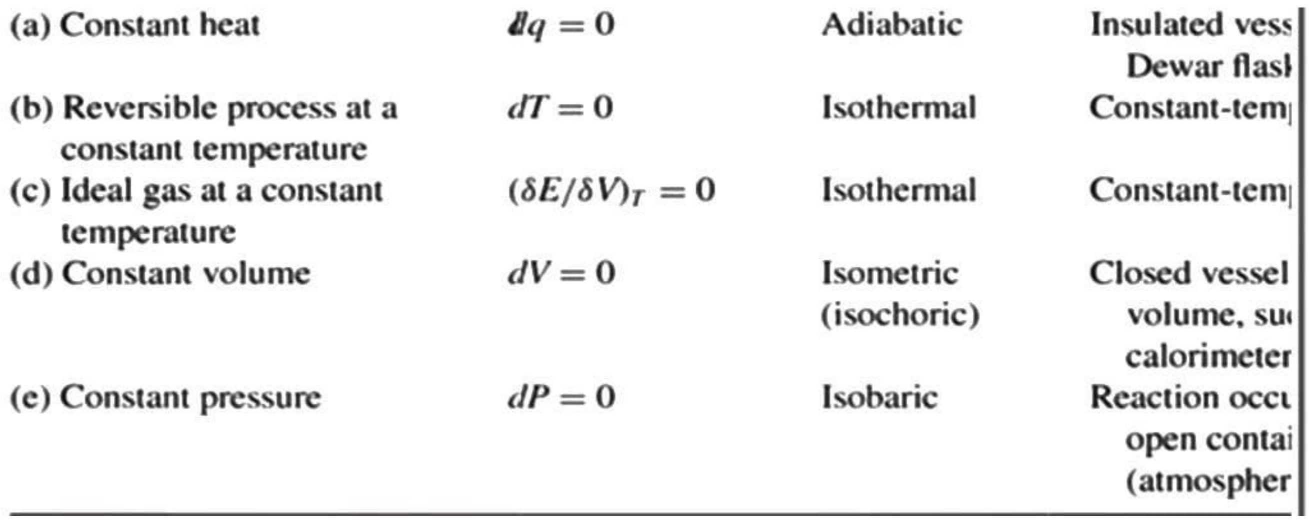
Common

Establishin

Specified

Proces

Condition



(a) Constant heat	$đq = 0$	Adiabatic	Insulated vess Dewar flas
(b) Reversible process at a constant temperature	$dT = 0$	Isothermal	Constant-tem
(c) Ideal gas at a constant temperature	$(\delta E/\delta V)_T = 0$	Isothermal	Constant-tem
(d) Constant volume	$dV = 0$	Isometric (isochoric)	Closed vessel volume, su calorimeter
(e) Constant pressure	$dP = 0$	Isobaric	Reaction occu open contai (atmospher

equation (3 – 26) may be written as

$$\left[\frac{\partial(\Delta H)}{\partial T}\right]_P = \Delta C_P \qquad (3-27)$$

Where $\Delta C_p = (C_P)_{products} - (C_P)_{reactants}$. Equation (3 – 27)is known as the Kirchhoff equation.