Fundamental Quantities and Fundamental Units

What is physics

Physics is one of the branches of the natural sciences, and it is also called "natural science." It is the science that studies basic concepts and everything related to them such as energy, motion, force, time, matter, and mass.

unit of measurement

A unit of measurement is a specific size of a physical quantity, defined and approved by law, and used as a standard for measuring the actual quantity itself. where no subset quantity can be expressed in terms of the others.

SI UNIT IN PHYSICSTS

The answer to what is SI unit is that it is an abbreviation of the French word ***Système International.*** The International System of Units (SI) is the metric system that is used universally as a standard for measurements. SI units play a vital role in scientific and technological research and development. It is made up of 7 base units which are used for defining 22 derived units. The SI units can be expressed either as standard multiple or as fractional quantities. These quantities are defined with the help of prefix multipliers with powers of 10 that range from 10^{-24} to 10^{24}.

The seven fundamental Quantities S.I units are:

	Quantity	Name of unit	SI Unit (symbol)
1	Length	Meter	(m)
2	Mass	Kilogram	(Kg)
3	Time	Second	(s)
4	Temperature	Kelvin	(K)
5	Electric Current	Ampere	(A)
6	Luminous Intensity	Candela	(Cd)
7	Amount of Substance	Mole	(mol)

SI Base Units List

There are ***7 SI base units*.** The seven units along with their SI unit and symbol are given below:

1. Unit of length, meter (m): Meter is the SI unit of length and is defined by taking the fixed value of the speed of light in vacuum. It is expressed as $m.s^{-1}$.
2. Unit of mass, kilogram (kg): Kilogram is the SI unit of mass and is defined by taking the fixed value of the Planck constant. It is expressed as $kg.m^2.s^{-1}$.
3. Unit of time, second (s): Second is the SI unit of time and is defined by taking the fixed value of Cesium frequency. It is expressed as s^1.
4. Unit of electric current, ampere (A): Ampere is the SI unit of electric current and is defined by taking the fixed value of the elementary charge.
5. Unit of thermodynamic temperature, Kelvin (K): Kelvin is the SI unit of thermodynamic temperature and is defined by taking the fixed value of Boltzmann constant k = 1.380649×10^{-23}.
6. Unit of the amount of substance, mole (mol): Mole is the SI unit of the amount of substance and is defined by the fixed value of Avogadro constant N_A. One mole contains 6.02214076×10^{23} elementary entities and is expressed as mol^{-1}.
7. Unit of luminous intensity, candela (cd): Candela is the SI unit of luminous intensity and is defined by the fixed value of the luminous efficacy.

It should be noted that these 7 units are assumed to be mutually independent and hence are called base units.

What are the basic elements of the physical measurement process?

The measurement process has three main elements:

A -the units of measurement used.

B - the physical quantities that can be measured.

C- the measurement tools available

What is SI Units List?

There are several SI units used in physics that are used to express the different quantities. The quantities can be classified into two groups ***base units*** and ***derived units.***

SI Base Units

These are the fundamental units and are considered as the building blocks of the system. All the other units are derived from the SI Base units. One of the examples is that the SI unit of mass is ***kilogram.*** This is often confused with grams.

SI Derived Units

The derived units are unlimited as they are formed by different operations on the base units. For derived units, the dimensions are expressed in terms of the dimensions of the base units. The derived units might also be expressed with the combination of base and derived units.

الأبعاد Dimensions	Unit الوحدة	الكمية
L/T	m/s	velocity السرعة
L/T^2	m/s^2	التسارع acceleration
ML/T^2	(N) or $kg.m/s^2$ (in mks-system) (Dyne) or $g.cm/s^2$ (in cgs-system)	force القوة
L^2	m^2	area المساحة
L^3	m^3	volume الحجم
M/L^3	Kg/m^3	Density الكثافة
1/T	hertz or (cycles/s Hz)	frequency التردد
ML^2/T^2	Joule(J) or $kg.m^2/s^2$ (in mks-system)	energy الطاقة
ML^2/T^3	watt (W) =J/s or $kg.m^2/s^3$	power القدرة

Measurements

Used to describe natural phenomena Each measurement is associated with a physical quantity need defined standards Characteristics of standards for measurements:

- Readily accessible
- Possess some property that can be measured reliably
- Must yield the same results when used by anyone anywhere
- Cannot change with time

Medical physics is the application of the of physics concepts in medicine, healthcare, and medical sciences.

We study physics concept in medical faculties to understanding physical aspect of the body such as ; forces on and in the body, work, energy, power of the body, heat ,blood flow, respiration, electricity, circulation and hearing.

Medical physics has many branches, namely, Ultrasound, Magnetic Resonance, Computed Tomography, Nuclear Medicine, X-rays, Radiation Therapy.

Aims of the Medical physics

Application of the concepts and methods of physics to understanding the function of human body in health and disease

1. Physics of the body

is to understanding physical aspect of the body such as ; forces on and in the body, work, energy, power of the body, heat ,blood flow, respiration, electricity, circulation and hearing.

2. Application of physics in medicine

Medical physics Techniques are used for

A)) Diagnostic:

1- Stethoscope
2- Manometer (blood pressure)
3- Sphygmomanometer
4- Electrocardiograph(ECG),
5- X- Ray,
6- Electroencephalograph(EEG), Electromyography (EMG),
7- Computer tomography (CT scan),
8- Ultrasound, tuning Fork,
9- Magnetic Resonance Imaging (MRI),
10- Flow meter, Spirometer to study the function lungs,
11- Audiometer,
12- Optics, Laser, Gamma camera to study the function of kidney, liver, and lungs.

B)) Therapy

1- Radiotherapy
2- Cobalt sixty(Co sixty)
3- High voltage
4- Ultrasound
5- infrared
6- Radio frequency
7- Heating
8- Laser

C)) Patient monitoring

ECG, spirometer, blood pressure, and thermometer.

What are the types of measurement fields in medical physics?

Areas of measurement in medical physics include:

1- Nuclear medicine: Radioactive materials are used to diagnose and treat diseases

2- X-rays: They are used to diagnose diseases and determine the sizes and locations of tumors before surgery

3- Ultrasound: used to image the internal organs of the body

4- Magnetic resonance imaging: It relies on the use of magnetic fields and electromagnetic rays to diagnose diseases

5- Biomedicine: includes the study of the body's effect on cells, tissues and organs.

6- Biophysics: includes studies on the exchange of energy and matter between biological systems and their environment and how they interact.

Muscles and bones act together to form levers

Biomechanics: Lever Systems in the Body

How do bones and muscles act as levers?

Levers work to create movement in the human body

Human Kinetics

Bones, ligaments, and muscles are the structures that form levers in the body to create human movement. In simple terms, a joint (where two or more bones join together) forms the axis (or fulcrum), and the muscles crossing the joint apply the force to move a weight or resistance.

Levers in our body are formed from bones, joints and muscles.

A lever consists of:

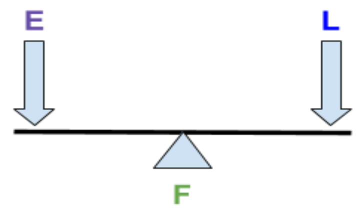
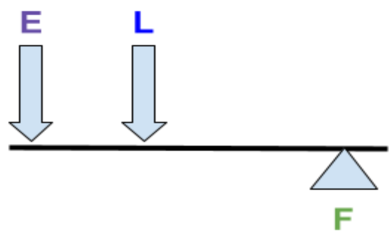
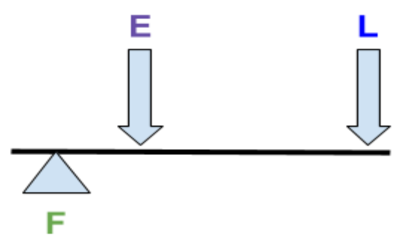
- bones act as lever arms
- joints act as pivots
- muscles provide the effort forces to move loads
- load forces are often the weights of the body parts that are moved or forces needed to lift, push or pull things outside our bodies.

Levers can also be used to magnify movement, for example, when kicking a ball, small contractions of leg muscles produce a much larger movement at the end of the leg.

Levers are able to give us a strength advantage or a movement advantage but not both together.

There are three types of lever.

- First class lever – the fulcrum is in the middle of the effort and the load.
- Second class lever – the load is in the middle between the fulcrum and the effort.
- Third class lever – the effort is in the middle between the fulcrum and the load

Lever class	Effort (E), load (L), & fulcrum (F)
1st Class	
2nd Class	
3rd Class	

1. **First class lever** – the fulcrum is in the middle of the effort and the load.

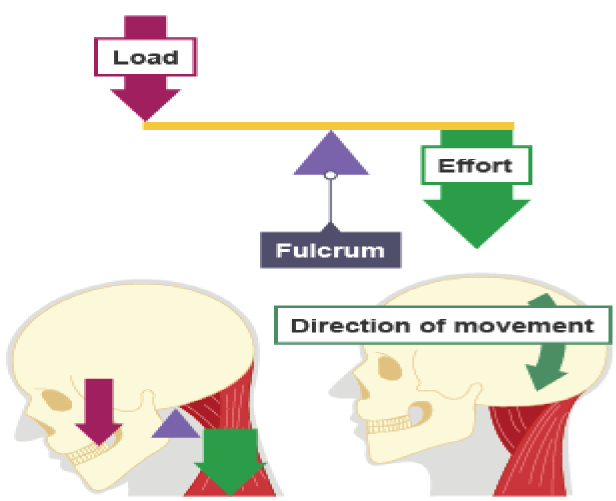
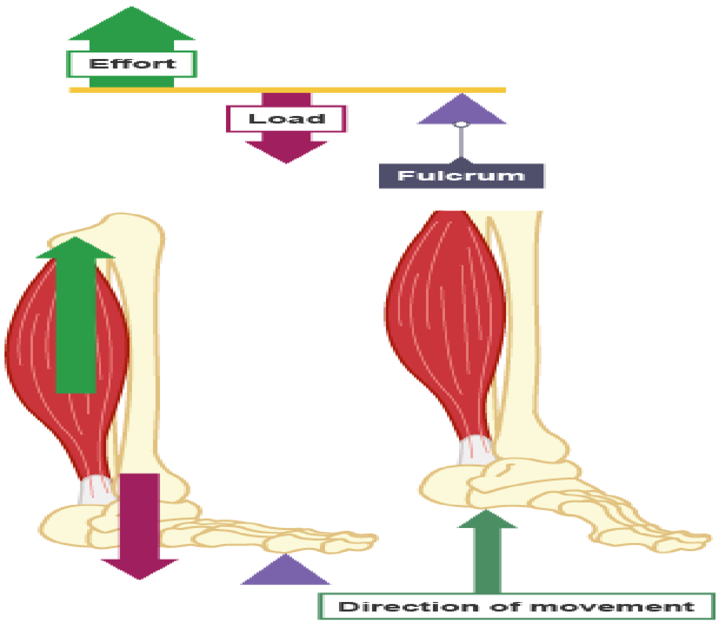


Figure caption,
First class lever

This type of lever is found in the neck when raising your head to head a football. The neck muscles provide the effort, the neck is the fulcrum, and the weight of the head is the load.

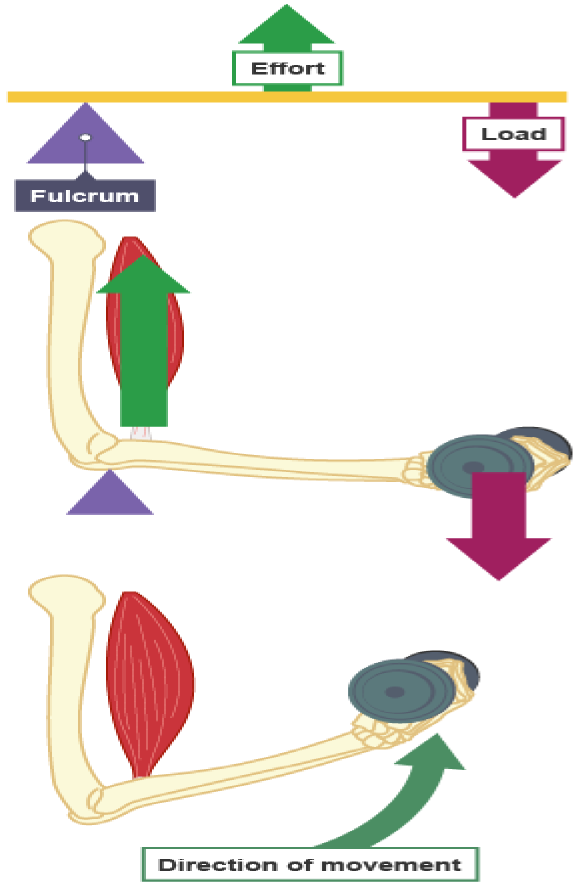
2. **Second class lever** – the load is in the middle between the fulcrum and the effort.



Second class lever

This type of lever is found in the ankle area. When standing on tiptoe, the ball of the foot acts as the fulcrum, the weight of the body acts as the load and the effort comes from the contraction of the gastrocnemius muscle. This second class lever is used when taking off for a jump or pushing against the blocks in a sprint start.

3. **Third class lever** – the effort is in the middle between the fulcrum and the load.



Third class lever

During a biceps curl, the fulcrum is the elbow joint, the effort comes from the biceps contracting and the resistance is the weight of the forearm and any weight that it may be holding.

Mechanical advantages of levers

When a lever's effort arm is longer than its load arm, it is said to have high mechanical advantage. Levers with high mechanical advantage can move large loads with a relatively small amount of effort. Second class levers always have high mechanical advantage. First class levers can have high mechanical advantage, if the fulcrum is close to the load.

To recall the order of the levers, use the term '**FLE**' - this will help you to remember which part of the lever is in the **middle**.

First class lever - **F**ulcrum is in the middle.

Second class lever - **L**oad is in the middle.

Third class lever - **E**ffort is in the middle.

Heat and Cold in Medicine

Heat and low temperature

Heat and cold have been used for medical purposes for several thousand years .If we want to describe temperature as a physical phenomenon , however, we should try to understand it on a molecular scale .

Matter is composed of molecules that are in motion.
molecules motion. Means that they have kinetic energy.
kinetic energy (K.E.) is related with temperature (T) .
the energy transferred to molecules due to temperature causes the following :

Solid + heat →liquid

Liquid + heat → gas

Gas + heat → ions

As molecules of all materials are moving so they have kinetic energy. The average kinetic energy of an ideal gas can be shown to be directly proportional with temperature. The same thing is for liquids and solids .The movement of gas molecules are more free than liquid and liquid molecules are more free than solid , an increase of temp. of any material means an increase in the energy of molecules of that material.

temperature scales

Thermometry and temperature scales Temperature is difficult to measure directly, so we usually measure it indirectly by measuring one of many physical properties that change with temp.

1- **Fahrenheit scale(°F)**:in this scale the freezing temp. is 32°F and boiling point of water is 212°F ,and normal body temp. is about 98.6°F .
2- **The Celsius(°C):**the freezing point is 0°C and the boiling point is 100°C ,in between is divided into 100 division.
3- **The Kalvin scale(°K):**or the absolute scale this scale has the same divisions as the Celsius but takes the 0° K at the absolute zero which is=-273.15°C.

To change °C to °F

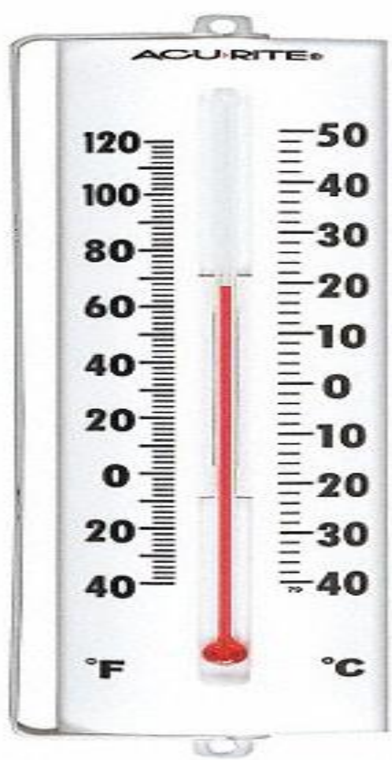
[°C= (°F-32) 5/9] or [°F=°C (9/5)+32]

Also °C=°K-273 or °K=°C+273

Types of thermometers

1-Glass-liquid thermometer

This thermometer composed of glass capillary tube ends with a bulb a store for liquid, the liquid can be mercury or alcohol for low temp. When the thermometer is heated the liquid inside will expand more than the glass causing the liquid to rise in the capillary tube , for mercury it expand 1.8%from (0- 100°C).



2- Thermistor

It's composed from a bridge of four resistances with a source of electricity. These resistors are in balance and is used for temp.,therefore are used quite often in medicine because of their sensitivity. Thermistores are placed in the nose to monitor the breathing rate of patients by showing the temp. change between inspired cool air and expired warm air).

also Patient temperature is measured using thermistors that are packaged in variety of probes such as skin(surface) rectal, esophageal and catheter probes for subcutaneous applications.

3-Thermocouple

A thermocouple is simply a sensor used to measure temperature. The design of this sensor consists of two different metal wires connected together at one end, connected to a device capable of accepting the thermocouple input and measuring the reading. As for its medical applications, the thermocouple needle is one of the important parts of cryosurgery, a procedure used to treat external tumors. The needle measures the temperature of the tissue at its tip and helps the doctor determine the depth of freezing

Heat capacity

Heat capacity or thermal capacity is a physical property of matter, defined as the amount of heat to be supplied to an object to produce a unit change in its temperature. The SI unit of heat capacity is joule per kelvin (J/K). Heat capacity is an extensive property

specific heat

specific heat, the quantity of heat required to raise the temperature of one gram of a substance by one Celsius degree. The units of specific heat are usually calories or joules per gram per Celsius degree. For example, the specific heat of water is 1 calorie (or 4.186 joules) per gram per Celsius degree.

Heat therapy

Heat was recognized as therapeutic agent several thousand years ago. It has two primary therapeutic effects:

1- An increase in metabolism resulting in relaxation of the blood capillaries (vasodilation).

2- An increase in blood supply to cool down the heated area.

Heat production for therapy

1- The conductive method

Heat can transfer by conduction, the quantity of heat transfer depends on the temp. difference, the time of contact, the area of contact, and the thermal conductivity of the materials and using in the treatment of arthritis, neuritis, strains, sinusitis and back pain.

2- Radiant heat (IR)

Heat radiation can be achieved by using infrared radiation (IR), it penetrates about 3mm in the skin. The wavelengths used are between (800-40000nm) an excessive exposure can cause reddening and sometimes swelling longer exposure can cause skin browning or hardening. It is considered to be more effective than conductive heating because it can penetrate deeper.

3- Diathermy

Diathermy uses shortwave electromagnetic waves that penetrate deeply into tissue. The heat generated by diathermy penetrates the body deeper than radiant and conductive heat, and is therefore useful for internal heating and has been used in the treatment of skeletal inflammation, shinitis, and neuralgia.

4- Ultrasonic waves

Ultrasound produces mechanical vibrations within tissues. It is the same as sound waves but has much higher frequencies. Ultrasound can be produced by special transducers that are placed in direct contact with the skin. It is used to relieve tightness and scarring that occurs in joint diseases. It can get rid of more heat in the bones, as bones absorb ultrasound energy better than soft tissue.

Heat radiation power can be measured by:

$W = e\,\sigma\,T^4$

Where **W**: power radiated

T: is the absolute temp. of the body

e: is the emissivity depends upon the emitter material and its temp.

for radiation from body e is almost 1.

σ: is the Stefan –Boltzmann constant$=5.7\times10^{-12}$ W/cm^2 °K^4

Example:

A) what is the power radiated per square centimeters from skin at a temp. of 306°K.?

$W = e\,\sigma T^4 = (5.7\times10^{-12})\,(306)^4 = 0.05$ W/cm^2

B) what is the power radiated from a nude body 1.75m^2 (1.75×10^4 cm^2) in area?

$W = (0.05)\,(1.75\times10^4$ cm$^2) = 875$ W

Cryogenics

Cryogenics is the science of very low temp., it is used in biology and called cryobiology.

Low temp. can be produced by liquefying gases. It was succeeded to produce liquid air

(-196 °C) in 1877 and liquid helium (-269°C) in 1908.For solid carbon dioxide it is (-79°C) and liquid nitrogen(-196°C). These cold liquids have many medical and biological advantages. The storages of liquefied gases is rather difficult because it can take heat rapidly from the environment by conduction, convection, and radiation.

Cryosurgery

The cryogenic methods are used to destroy cells called cryosurgery. It has several advantages:

1- Cause a little bleeding
2- The volume of the tissue destroyed can be controlled
3- Little pain because low temp. desensitizes the nerves.
4- Very short recovery.

Cryosurgery is used in several types of eye surgery:

1- In retinal detachment, a cooled tip is applied to the outside of the eyeball in the vicinity of the detachment a reaction occurs that acts in weld the retina to the wall of the eyeball
2- Extraction of the lens, remove the darkened lens, in this procedure the cold probe is touched to the front of the lens, the probe sticks to the lens making the lens easy to remove.

Heat of Vaporization

What is Heat of Vaporization?

The Heat of Vaporization is the quantity of heat that needs to be absorbed to vaporize a particular quantity of liquid at a constant temperature. If the solutions of vapour and liquid states are compared, the kinetic energy of the steam is proved to be higher than the kinetic energy of the fluid.

PHYSICS OF VAPORIZATION

At operating room temperatures, volatile anesthetics exist in both liquid phase and gas phase in vaporizers. The *latent heat of vaporization* is the number of calories required at a specific temperature to convert 1 g of a liquid into a vapor. As the temperature of the liquid decreases, the heat of vaporization necessary for molecules to leave the liquid phase increases. When equilibrium between the liquid phase and vapor phase is reached, vaporization ceases as an equal number of molecules enter and leave the liquid phase.

Specific heat is the calories required for 1 g of a substance to increase by 1°C. Knowledge of the specific heat of an anesthetic agent allows for vaporizers to be designed such that the correct amount of heat can be added to maintain the temperature of the liquid as vaporization occurs. In addition, vaporizer components are designed with a high specific heat to minimize temperature change.

what is vaporization therapy?

Water Vapor Therapy is a revolutionary in-office treatment that uses the natural energy stored in water vapor to remove excess tissue that is pressing on the urethra. For most men, the procedure eliminates the need for medications or surgery and eliminates the side effect

Hyperthermia to Treat Cancer

What is hyperthermia treatment?

Hyperthermia is a type of treatment in which body tissue is heated to as high as 113 °F to help damage and kill cancer cells with little or no harm to normal tissue. Hyperthermia to treat cancer is also called thermal therapy, thermal ablation, or thermotherapy.

Different types of techniques may be used to create heat for hyperthermia treatment. These techniques include:

- probes that make energy from microwaves
- radio waves (also called radiofrequency)

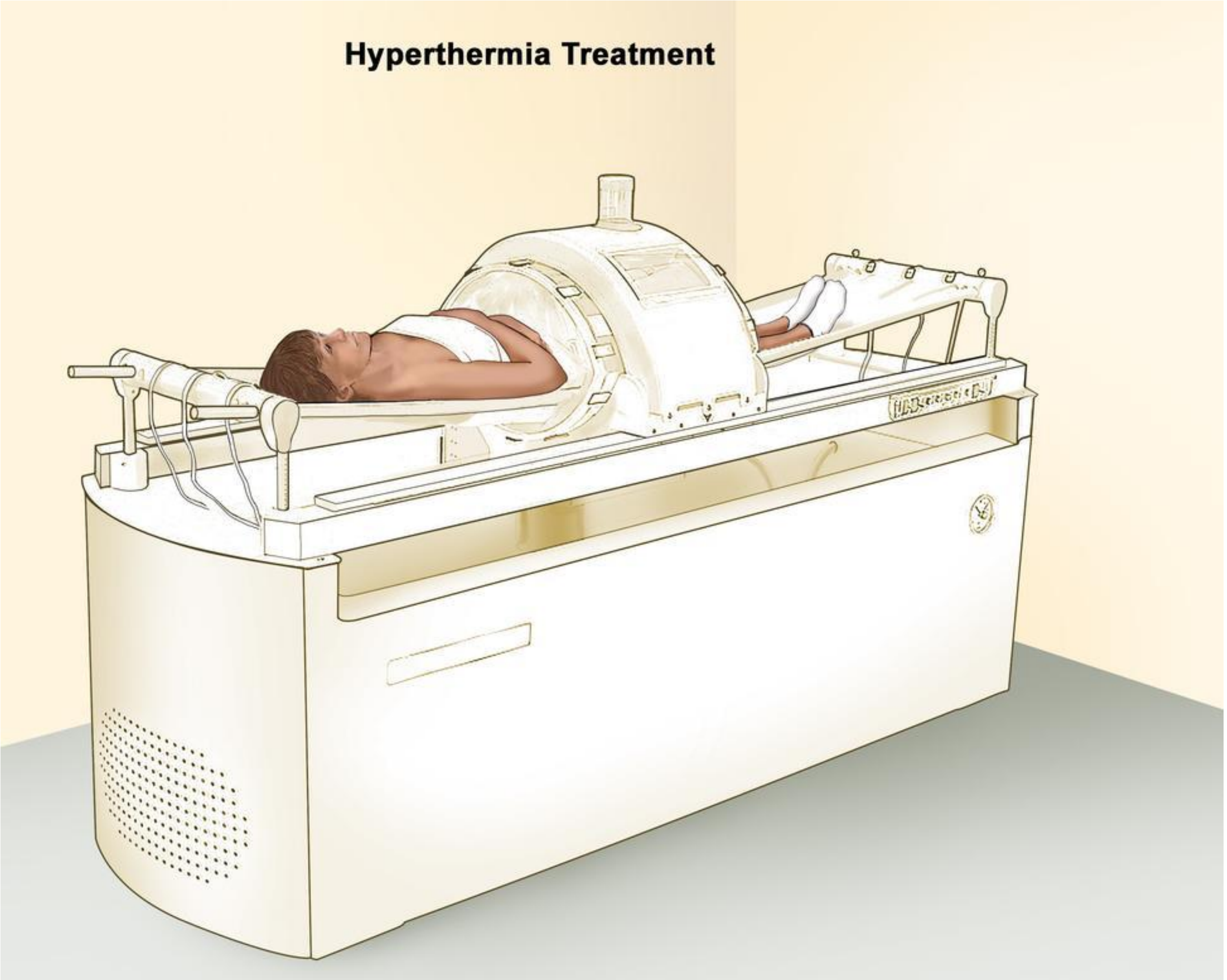
- lasers
- ultrasound
- heating fluids such as blood or chemotherapy drugs and putting them into the body (called perfusion)
- placing the entire body in a heated chamber or hot water bath or wrapping with heated blankets

Cancers treated with hyperthermia

Hyperthermia to treat cancer is not widely available. But at some centers it is used, along with other treatments such as radiation therapy and chemotherapy, for advanced cancers. It has been used to treat these types of advanced cancers:

- appendix cancer
- bladder
- brain cancer
- breast
- cervical cancer
- esophageal cancer
- head and neck cancer
- liver
- lung cancer
- melanoma
- mesothelioma
- sarcoma
- rectal cancer

How hyperthermia treats cancer



In hyperthermia, heat is used to help damage and kill cancer cells.

Hyperthermia is almost always used with other forms of cancer treatment. Many clinical trials have shown that hyperthermia, when used with treatments such as radiation therapy and chemotherapy, helps shrink tumors and may make it easier for them to kill cancer cells.

How hyperthermia is given

During treatment, the doctor numbs the treatment area and inserts small probes with tiny thermometers into the tumor. Thermometers help the doctor closely watch the temperature of the tumor and nearby tissue during treatment. Imaging techniques, such as CT scans, may be used to make sure the probes are in the proper place.

Types of hyperthermia treatment

Hyperthermia can be used to treat small areas of the body, large areas, or the entire body.

In **local hyperthermia**, doctors apply heat to a small area. The type of local hyperthermia used depends on where the tumor is located.

- **External hyperthermia** is used to treat tumors that are on or just below the skin. For this type of hyperthermia, doctors place devices that create heat around or near the treatment area.
- **Intraluminal** or **endocavitary hyperthermia** is used to treat tumors within or near body cavities, such as the esophagus or rectum. In this type of hyperthermia, doctors place probes that create heat inside the cavity and insert them into the tumor.
- **Interstitial hyperthermia** is used to treat tumors deep within the body, such as in the brain. This type of hyperthermia allows the tumor to be heated to higher temperatures than external techniques. The doctor will insert probes or needles into your tumor while you are under anesthesia. Imaging techniques, such as ultrasound, may be used to help make sure the probe is in the right place. The heat source is then inserted into the probe.

  Radiofrequency ablation is a type of interstitial hyperthermia that uses radio waves to heat and kill cancer cells.

In **regional hyperthermia**, doctors apply heat to large areas of the body, such as a cavity, organ, or limb. Techniques used in regional hyperthermia include deep tissue techniques, regional perfusion, and continuous hyperthermic peritoneal perfusion.

- **Deep tissue** techniques treat cancers within the body, such as cervical or bladder cancer. During this procedure, devices that deliver heat are placed around the cavity or organ to be treated and energy is focused on the area to raise its temperature.
- **Regional perfusion** techniques treat cancers in the arms and legs, such as melanoma, or in some organs, such as the liver or lung. During this procedure, some of your blood is removed, heated, and then pumped back into the limb or organ. Chemotherapy is often given during this treatment.
- **Continuous hyperthermic peritoneal perfusion** treats cancer within the peritoneal cavity, which is the space within the abdomen that contains the intestines, stomach, and liver.

  This treatment is given during surgery. While you are under anesthesia, heated chemotherapy drugs flow from a warming device through your peritoneal cavity, causing the temperature in the area to reach 106 to 108°F.

Whole-body hyperthermia treats cancer that has spread throughout the body. In this type of hyperthermia, you are placed in a thermal chamber or wrapped in hot water blankets that raise your body temperature to 107 or 108 °F for short periods of time.

Benefits of hyperthermia

Hyperthermia can help other cancer treatments, such as chemotherapy and radiation therapy, work better.

Drawbacks of hyperthermia to treat cancer

Treatment with hyperthermia requires special equipment and expertise and is not widely available. It is also not clear if it helps people live longer.

Hyperthermia side effects

Most healthy tissue is not damaged during hyperthermia if the temperature stays under 111°F. But different features of different tissues may cause higher temperatures to occur in certain spots. This can cause burns, blisters, discomfort, or pain.

Perfusion techniques can cause swelling, blood clots, bleeding, and other damage to the normal tissues in the treated area. But most of these side effects improve after treatment.

Diarrhea, nausea, and vomiting are common after whole-body hyperthermia. It can also cause more serious side effects that are not common, including heart and blood vessel problems.

Gases

Boyle's Law

What is Boyle's Law?

Boyle's law: states that the pressure and volume of a gas are inversely proportional to each other as long as the temperature and the quantity of gas are kept constant.

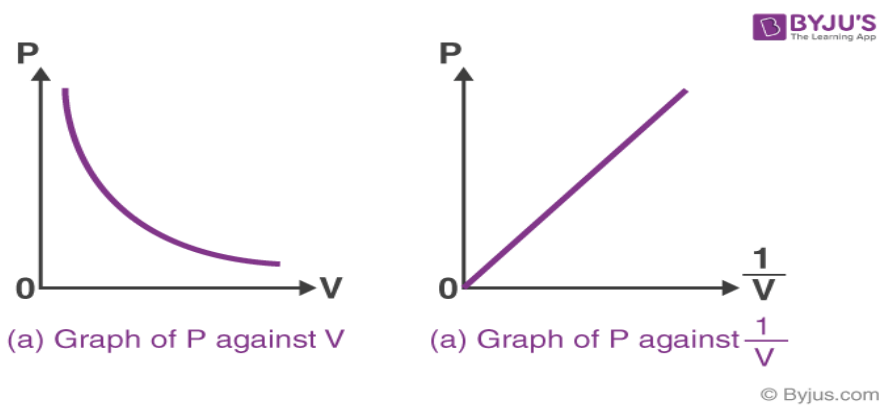
For a gas, the relationship between volume and pressure (at constant mass and temperature) can be expressed mathematically as follows.

$P \propto (1/V)$

Where P is the pressure exerted by the gas and V is the volume occupied by it. This proportionality can be converted into an equation by adding a constant, k.

$P = k*(1/V) \Rightarrow PV = k$

The pressure v/s volume curve for a fixed amount of gas kept at constant temperature is illustrated below.



Formula and Derivation

As per Boyle's law, any change in the volume occupied by a gas (at constant quantity and temperature) will result in a change in the pressure exerted by it. In other words, the product of the initial pressure and the initial volume of a gas is equal to the product of its final pressure and final volume (at constant temperature and number of moles). This law can be expressed mathematically as follows:

$P_1V_1 = P_2V_2$

Where,

- P_1 is the initial pressure exerted by the gas
- V_1 is the initial volume occupied by the gas
- P_2 is the final pressure exerted by the gas
- V_2 is the final volume occupied by the gas

Example 1

A fixed amount of a gas occupies a volume of 1L and exerts a pressure of 400 kPa on the walls of its container. What would be the pressure exerted by the gas if it is completely transferred into a new container having a volume of 3 liters (assuming the temperature and quantity of gas remains constant)?

Given,

Initial volume (V_1) = 1L

Initial pressure (P_1) = 400 kPa

Final volume (V_2) = 3L

As per Boyle's law, $P_1V_1 = P_2V_2 \Rightarrow P_2 = (P_1V_1)/V_2$

$P_2 = (1L * 400\ kPa)/3L = 133.33\ kPa$

Therefore, the gas exerts a pressure of 133.33 kPa on the walls of the 3-liter container.

Example 2

A gas exerts a pressure of 3 kPa on the walls of container 1. When container 1 is emptied into a 10-liter container, the pressure exerted by the gas increases to 6 kPa. Find the volume of container 1. Assume that the temperature and quantity of the gas remain constant.

Given,

Initial pressure, P_1 = 3kPa

Final pressure, P_2 = 6kPa

Final volume, V_2 = 10L

According to Boyle's law, $V_1 = (P_2V_2)/P_1$

V_1 = (6 kPa * 10 L)/3 kPa = 20 L

Therefore, the volume of container 1 is 20 L.

Why Boyle's law is not applicable at high pressure?

Boyle's law applies to low pressure and not at high pressure because gases behave like ideal gas at high pressure

Charlee's Law

What is Charlee's Law?

Charlee's law is a special case of the ideal gas law. The law is applicable to the ideal gases that are held at constant pressure, but the temperature and volume keep changing. In other words Charles' law, also sometimes referred to as the law of volumes, gives a detailed account of how gas expands when the temperature is increased. Conversely, when there is a decrease in temperature, it will lead to a decrease in volume.

When we compare a substance under two different conditions, from the above statement, we can write this in the following manner:

V_2/V_1=T2/T1

OR

V1T2=V2T1

This above equation depicts that as absolute temperature increases, the volume of the gas also goes up in proportion.

where is Charles Law applied?

An application of Charles Law in our daily life is a floating hot air balloon in air. A torch heats the air inside the balloon because of which the air particles move faster and disperse, making the air in the balloon less dense than the surrounding air so that the balloon floats.

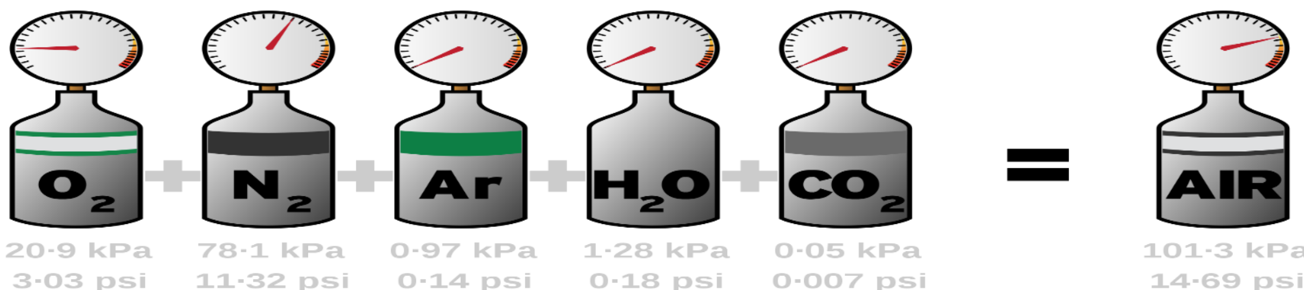
what are the limitations of the Charles law?

Charles's law is applicable to only ideal gases and on real gases only at high temperatures and low pressures.

Dalton’s Law

What is Dalton’s Law?

Dalton’s Law Formula explains the behavior of gases and more precisely, for mixtures of gases. the law state that when there is a blend of inactive gases (there is no reaction between them), the total pressure that it applies is equal to the amount of the partial pressure of each gas. We know this law by another name that is Dalton’s law of partial pressures.



In other words, it is a mixture of non-reacting gases, the total pressure exercised is equal to the sum of the partial pressures of the individual gases.

Dalton’s Law Formula

For a mixture of n number of gases the total pressure is:

$$p_{total}=\sum_{i=1}^{n} p_i$$

Or we can simply write it as:

$$p_{total}=p_1+p_2+p_3+p_4+p_5 \dots +p_n$$

In this equation or formula, $p_1+p_2+p_3+p_4+p_5 \dots +p_n$ characterize the partial pressure of each gas in the mixture. Furthermore, we can relate the Dalton’s law to the ideal gas law through the next equation:

$$p=\frac{nRT}{V} \rightarrow n_{total}\frac{RT}{v}=n_1\frac{RT}{v}+n_2\frac{RT}{v}+n_3\frac{RT}{v}+n_4\frac{RT}{v}+n_5\frac{RT}{v}+\cdots+n_n\frac{RT}{v}$$

In this the term $\frac{RT}{v}$ is common and the same for all the gases then we can reduce the expression to:

$$n_{Total}=n_1+n_2+n_3+n_4+n_5+\dots+n_n$$

In this way, the number of moles in a mixture of gases is equal to the sum of the moles of each gas.

Dalton's law of partial pressures

Dalton's law of partial pressures states that the total pressure of a mixture of gases is the sum of the partial pressures of its components:

$P_{total} = P_{gas\ 1} + P_{gas\ 2} + P_{gas\ 3}$

where the partial pressure of each gas is the pressure that the gas would exert if it was the only gas in the container. That is because we assume there are no attractive forces between the gases.

Uses of Dalton’s law

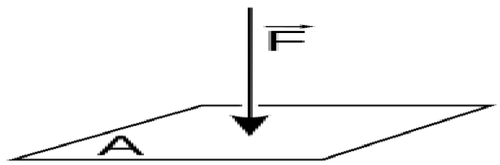
We can use it to calculate the mixtures of gases and the pressure and volume of each gas.

Pressure

Pressure is defined as the physical force exerted on an object. the force applied is perpendicular to the surface of objects.

The basic formula for pressure is F/A (Force per unit area).

Types of Pressures are Absolute, Atmospheric, Differential, and Gauge Pressure.



Mathematically:

$$P = F/ A$$

where:

P …..is the pressure,
F …..is the magnitude of the normal force,
A ….is the area of the surface on contact.

Units of pressure

Pressure can be measured in physics in different units of measurement, and the following are the units of pressure:

1- **<u>Unit of Pascal</u> :** Pressure is measured in the Pascal unit, its symbol is **(Pa)**, which is equivalent to a newton/m2. Named after the French mathematician and physicist Blaise Pascal, a pascal is a pressure of one newton per square meter in the International System of Units. The pascal is a small unit, so it is the most common Using kilopascals (kPa), which is equal to 1000 newtons per square meter.

2- **Bar unit:** Pressure is also measured in the bar unit, which is one of the widely used metric units. It was created in 1909 AD by the British meteorologist William Napier Shaw. It is a pressure of 10,000 newtons per square meter in the international system of units, and the bar is greater than the pascal, as 1 bar = 10,000 Pa.

3- **unit of atm**: the unit of atmosphere, whose symbol is atm, it came to refer to what is called atmospheric pressure, which is the amount of air force acting on a certain area when standing at sea level, considering the force here is the weight of the air column, the pressure at sea level is 1 atm, which is equivalent to:

1 atmosphere = 1.013*105 Pascal.

1atm = 1.013 bar

These are famous and different units of measurement for pressure, all of which express the amount of force acting on a unit area.

blood pressure measurement

Blood pressure is measured in millimeters of mercury (mm Hg). A blood pressure measurement has two numbers: The top number (systolic) is the pressure of the blood flow when the heart muscle squeezes (contracts), pumping blood. The bottom number (diastolic) is the pressure measured between heartbeats.

What is the difference between systolic and diastolic blood pressure?

Systolic blood pressure : the top number, measures the force the heart exerts on the walls of the arteries each time it beats.

Diastolic blood pressure : the lowest number, measures the force the heart exerts on the walls of the arteries between beats or pulses.

What are the types of blood pressure?

We may know that “high blood pressure” is one of the common diseases in our modern era, as pressure measurements rise above these ideal values for low and high pressure.

Depending on the amount of this increase, high blood pressure can be classified into:

1- Ideal blood pressure is when the high pressure is at 120 mm Hg and the low pressure is at 80 mm Hg.

2- A Simple case if the low pressure rises to 85 mm Hg or the high pressure rises to 140 mm Hg.

3- An average condition if the low pressure reaches 90 mm Hg or the high pressure reaches 160 mm Hg.

4- A severe case. Numbers higher than that are considered a severe case!

JNC7 Blood Pressure Classification[2]	SBP (mm Hg)	DBP (mm Hg)
Normal	<120	and <80
Prehypertension	120-139	and <80
Stage 1 hypertension	140-159	or 80-89
Stage 2 hypertension*	≥160	≥90

Basic techniques of blood pressure measurement

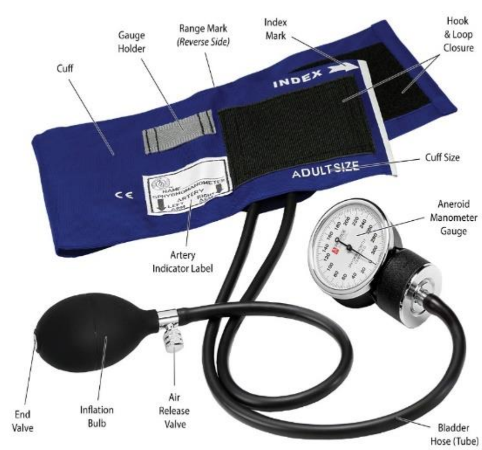
- Location of measurement. The standard location for blood pressure measurement is the brachial artery. ...
- The auscultatory method. ...
- The oscillometric technique. ...
- Ultrasound techniques. ...

What are the 3 types of sphygmomanometer?

- They are three major types of sphygmomanometers–

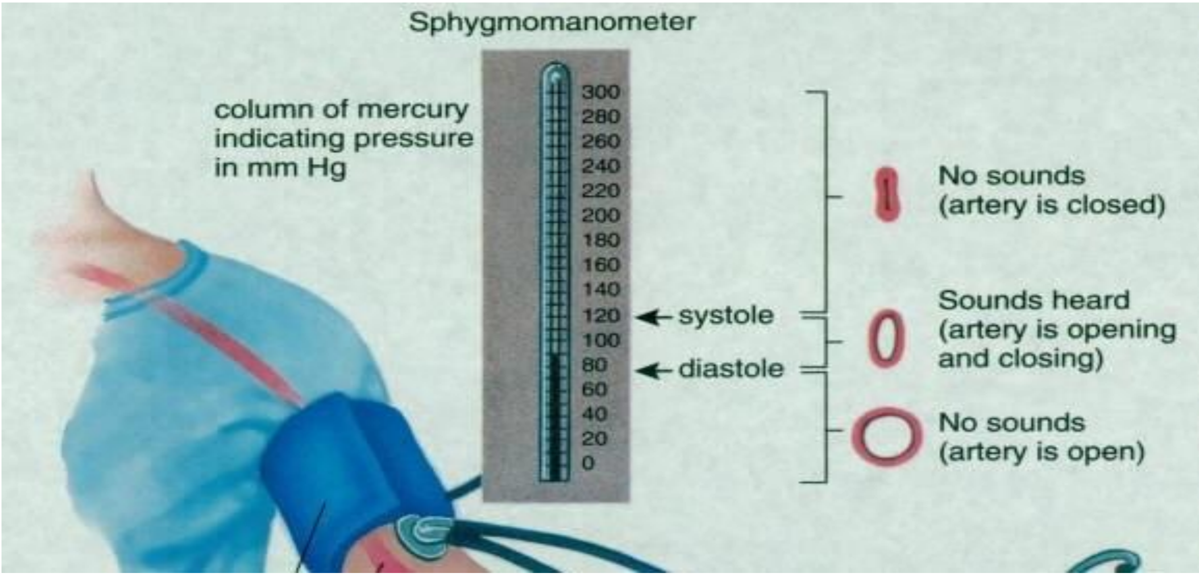
  1-mercury. 2- aneroid. 3-digital.

- The mercury sphygmomanometer is the most conventional form of blood pressure apparatus, and it can be considered the golden standard in the health industry



High blood pressure between medicine and physics

In the world of medicine, and inside our bodies, there is a blood pump (the heart), which consists of a strong muscle with chambers inside it (the ventricles and atria), and it works by contraction (muscle contraction), leading to pumping blood to the body, and relaxation (muscle relaxation) when blood returns from the body to the heart,,, Based on this, there is systolic (high) blood pressure, which is normal at 120 mm Hg or a little more, and there is diastolic (low) blood pressure, which is normal at 80 mm Hg or a little less!



What causes high blood pressure??

Let's turn to physics to zoom in on the picture. Imagine that we replaced the heart with a water pump (running on electricity) and connected to it rubber tubes that are connected to devices that operate with pressurized water... Let us metaphorically say that the rubber tubes represent (arteries and veins)... while the devices represent (the organs of the body, including muscles, brain, eyes, kidneys, liver, etc.) That...and to complete the simile, just as rubber tubes need clamps, these clamps can be likened to valves in the heart.

Water pump .... the heart

Rubber tubes .... arteries and veins

Clamps .... valves

Devices .... body organs

This physical system (pump, tubes, devices) works in a harmonious manner, so that the force of pumping blood from the pump is proportional to the diameter and flexibility of these tubes and is proportional to the force required for the operation of the devices connected to these tubes.

Reasons that could cause the pressure in this system to rise above the ideal standard values:

1- Increased pump activity (heart), thus increasing the amount of blood flowing through the rubber tubes.
2- Reducing the diameter of the pipes and narrowing them due to deposits and calcifications on their internal walls.
3- Decrease in pipe flexibility and stiffness for any reason.
4- A malfunction in the devices connected to the tubes, such that they attract a larger amount of compressed blood coming from the heart through these tubes.

Possible consequences of high blood pressure in this system:

1- Damage to the pump (heart) itself when it works beyond its capacity.
2- Valve failure due to increased pressure on them.
3- Problems in the arteries and veins themselves due to clots and obstructions.
4- Damage to the devices connected to these pipes.

The physics of the lungs and breathing

The human machine really consists of billions of very small engines (the living cells of the body)

The function of the lungs

1. Exchange O_2 and CO_2: make oxygen available to your body and remove other gases, such as carbon dioxide, from your body. This process takes place 12 to 20 times per minute.

2. Maintaining a stable pH (acidity) of the blood.

3. Heat exchange between the body and atmosphere.

4. Maintaining the balance of body fluids by warming and moisturizing them the air we breathe.

5. Control airflow while speaking, coughing, sneezing, sighing, laughs, and sniffling.

6. voice production

Breathing

1- We are breath about (6) liters of air per minute.

2- Men breath about (12) times per minute at rest.

3- Women breath about (20) times per minute at rest.

4- Infants breath about (60) times per minute at rest.

5- We breath about (10 kg)of air each day .

6- Of this lungs absorbs (400)liters of O_2 (0.5 kg) and release a slightly smaller amount of CO_2 .

7- Each time we breath about (10^{22}) molecules air inter our lungs .

8- Each liter of air contain about (6×10^{23}) molecules (Avogadro᾽s number).

Gases we Breathe In We all are aware that our atmosphere is a mixture of gases and it contains 78% nitrogen, 21% oxygen, 1% argon, 0.04% carbon dioxide, 0.5% water vapor. When we breathe in, we inhale the same mixture of gases contained in the atmosphere as our nose cannot filter out the oxygen from other gases.

Exhaled air contains : (78%) N_2 , (17%) O_2 carbon dioxide , (4%) CO_2 (1%) other gases.

Air ways

The principal air passage in to the lungs, air normally enters the body through the :

1- **Nose:** where it is warmed, filtered and moisturized.
   The air then passes through
2- **Trachea:** where the tracheadivides in to two to furnish air to each lung through the bronchi.
3- **Bronchus:** each bronchus divides and re divides about (15) time ,the resulting terminal.
4- **Bronchioles:** supply air to millions of small sacs called.
5- **Alveoli:** the Alveoli is small interconnected bubbles are about (0.2 mm) in diameter and have walls only (0.4 µm) thick. They expand and contract during breathing , they are in the exchanging of (O_2) and (CO_2) .Each alveolus is surrounded by blood so that (O_2) can diffuse from the blood into the air in the alveolus.

Some examples of lung function tests include :

- **Spirometry:** This test measures how much and how quickly people can move air in and out of their lungs.
- **Plethysmography:** Also known as a lung volume test, this measures the amount of air individuals can hold in the lungs and how much air remains after breathing out.
- **Gas diffusion test:** This test can measure gases, such as oxygen, moving from the lungs to the bloodstream.

Exercise stress test: This test typically involves a bike or treadmill to investigate how exercise affects lung function

What is a spirometer device?

A spirometer is a diagnostic device that measures the amount of air you can inhale and exhale. It also tracks the time it takes you to fully exhale after you take a deep breath. A spirometry test requires that you breathe into a tube attached to a device called a spirometer

What is the abbreviation for FEV1?

Forced expiratory volume in one second

Both expiratory volume per second (FEV1) and vital capacity (VC) (which is the extent of the amount of air that the patient exhales after inhaling the largest amount of air into the lung) are obtained, then the results are compared with the expected values according to age, sex, height, and group. Ethnicity.

How do doctors perform a lung function test?

Doctors can use many different devices. The most common types are:

1- Spirometers
2- Peak flow meters

Spirometers

A spirometer is a device through which a patient breathes to measure the amount of air his lungs can hold, and the speed of exhaled air.

Doctors use a spirometer to:

a- Find out if something is blocking your airways
b- Find out how much air the lungs can hold
c- Check the strength of the breathing muscles

Peak flow meter

The portable device that detects subtle and unnoticed decreases in air flow to the lungs and is used by people suffering from asthma, thus helping the supervising physician monitor small changes in respiratory capacity.

Lung Diseases:

1. Disorder of low compliance:

-Fibrosis: scarring of connective tissue framework cause by many disease occupational hazards (welders miners) and ionizing radiation

a- Lung stiffens→ reduced compliance

b- Alveolar membrane thickens→O2 cannot diffuse

-RDS (respiratory distress syndrome): absence of surfactant→ reduced compliance.

2. Obstructive diseases:

-Emphysema:

a- Alveolar walls destroyed (due to smoking)

b- Lung flabby (i.e., increased compliance) →chest expands (barrelchested) →hard to blow out, airway collapses when exhale

-Asthma: airway narrowing

a- Incidence on the rise: leading cause of hospitalization in children

b- Due to sensitive airway (allergic reaction)

c- Excess mucus secretion, bronchospasm (constriction of smooth lining airways)

The Physics of Exchanging of Gas between the Lungs and the Blood

The transfer of O_2 and CO_2 into and out of the blood is controlled by the physical law of diffusion. All molecules are continually in motion. In gases and liquids, and to certain extent even in solids, the molecules do not remain in one direction. Molecules of a particular type diffuse from region of higher concentration to a region of lower concentration until the concentration is uniform In the lungs we are concerned with diffusion in both gas and liquids. In the O_2 and CO_2 exchange in the tissues we are concerned only with diffusion in liquids. The molecules in a gas at room temperature move at about the speed of sound. Each molecule collides about 10^{10} times each second with neighboring molecules.

The distance D of molecule will travel from its origin after N collisions is

$$D = \lambda \sqrt{N}$$

Where λ is the mean free path.

λ is defined as the average distance between collision.

in air $\lambda = 10^{-7}$ m

in tissue $\lambda = 10^{-11}$ m

Ex.: What is the typical value of D in air and in tissue for an O_2 molecule after 1 sec if $N = 10^{10}$ in air and in tissue $N = 10^{12}$?

Sol. //

In air $D = 10^{-7} (10^{10})^{1/2} = 10^{-2}$ m

In tissue $D = 10^{-11} (10^{12})^{1/2} = 10^{-5}$m

Diffusion depends on the speed of the molecules; the speed of molecules increases with temperature. Since N is proportional to the diffusion time Δt .

$$N \propto \Delta t$$

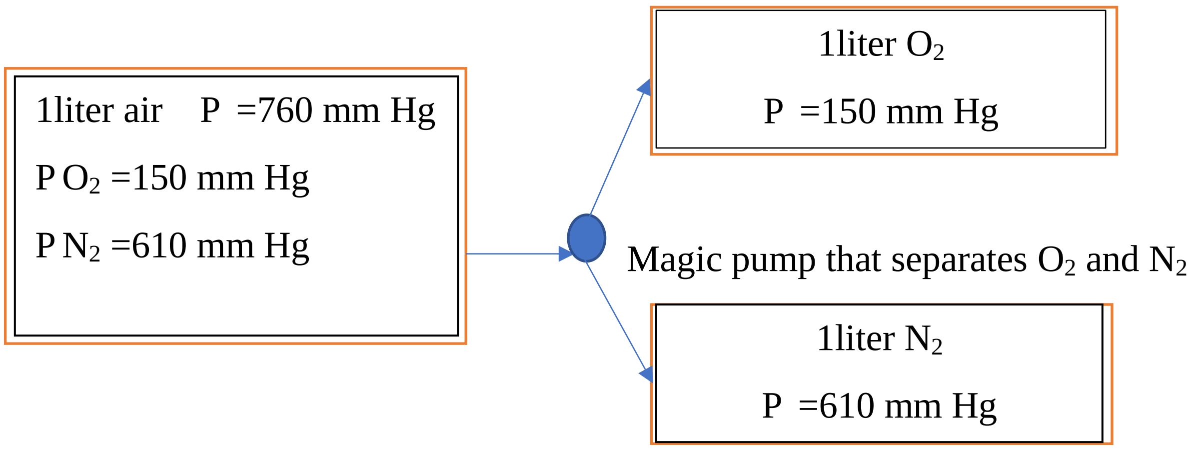
$$D \propto \sqrt{\Delta t}$$

$$\Delta t \propto D^2$$

In the lungs the distance to be traveled in air usually a small fraction of a millimeter, and diffusion takes place in a fraction of a second. The diffusion of O_2 and CO_2 in tissue is about

10,000 times slower than it is in air , but the tissue thickness of the molecules must diffuse through in the lungs is very small (0.4μm) and diffusion through the alveolar wall takes place in much less than 1 sec .

To understand the behavior of gases in lungs it is necessary to know Dalton' s law of partial pressures. **Dalton's law** state that if you have a mixture of several gases, each gas makes its own contribution to the total pressure as though it were all alone.



The pressure exerted by any one of the gases is known as the partial pressure of that gas, and the total pressure of these gases is the sum of the partial pressures of the mixture gases.

p = p + p + p ----- total= t 1 t2 t3

where p is a partial pressure.

Henry's Law of Solubility of Gases:

Henry 's law states that the quantity of a gas going into simple solution at constant temperature is proportional to the pressure .If we have a closed container of blood and CO2 ,It found that some of O2 molecules collide with blood and are dissolved .After a while the number of O2 molecules that are escaping from the blood each second is the same as the number that are entering it .The blood then has a PO2 equal to that of the O2 in contact with it .If PO2 in the gas phase is doubled

, the amount of O_2 dissolved in the blood will also double . This proportionality is Henry's law of solubility of gases. The amount of gas dissolved in blood varies greatly from one gas to another. Oxygen is not very soluble in blood or water. The different solubility of O_2 and CO_2 in tissue affect the transport of these gases across the alveolar wall. A molecule of O_2 diffuse faster than a molecule of CO_2 because of its smaller mass.

However, because of greater number of CO_2 molecules in solution, the transport of CO_2 is more efficient than the transport of O_2. The mixture of gases in the alveoli is not the same as the mixture of gases in ordinary air. The lungs are not emptied during expiration. During normal breathing the lungs retain about 30 % of their volume at the end of each expiration. This is called the functional residual volume (FRC). At each breath 500 cm^3 of fresh air (PO_2 of 150 mm Hg) mixes with 2000 cm^3 of stale air in the lungs to result in alveolar air with a PO_2 100 mm Hg. The PCO_2 in the alveoli is about 40 mm Hg .Expired air includes about 150 cm of relatively fresh air from the trachea that are not in contact with alveolar surface , so expired air has a slightly higher PO_2 and lower PCO_2 than alveolar air .

The percentages and partial pressures of O_2 and CO_2 in inspired, alveolar and Expired.

	% O_2	PO_2 (mmHg)	% CO_2	PCO_2 (mmHg)
Inspired	20.9	150	0.04	0.3
Alveolar air	14.0	100	5.6	40
Expired air	16.3	116	4.5	32

Measurement of Lungs Volume:

The spirometer is an instrument used to measure airflow into and out the lungs and rerecord it on a graph off volume versus time.

This instrument consists off a counter balanced bell free to move in the vertical plane, as shown in figure ((3)). It has a water –seal so that it forms an airtight chamber off variable volume. The changes in volume off this chamber are rerecorded on a chart.

When breathing through the mouth piece into the spirometer with a nose clip applied, the air in the lungs, air passage and the spirometer is a closed system.

Thus, when the lungs volume increases in the inspiration the volume off gas in the spirometer is reduced, and when the lung volume decreases in expiration, the spirometer volume increases.

-Tidal volume: is defined as the amount off air in or out per breath.

-Inspiratory reserve volume: is the additional amount off air which can be inspired at the end off a normal inspiration.

-Expiratory Reserve volume: is the additional amount off air which can be expired at the end off a normal expiration.

-Residual volume.is the amount off air remaining in the lungs at the end of a forced expiration

Capacity

By adding all four types off volume together, we get the total lung capacity. If we add only Inspiratory reserve volume, tidal volume, and expiratory reserve volume we get the vital capacity If we add only the expiratory reserve volume and residual volume, we get functional residual capacity (FRC).

Elasticity of lungs

The lungs and chest wall are elastic structures. The combined elasticity may be measured by relaxing the respiratory muscles, and then by how much the volume increases, when the pressure in the lungs increased

E ti ity = $\Delta P/\Delta v$

ΔP = is the change in pressure

ΔV = is the change in volume

In respiratory mechanics it is usually to consider elasticity, but its reciprocal.

Compliance: is the change in the volume produced by a small change in pressure.

Comp i n =$\Delta v/\Delta p$ (Liters/cm of water)

……Compliance in normal range is 0.18- 0.26 Liter/cm H_2O

The Breathing Mechanism

Breathing is normally under unconscious control. The physiological control of breathing depends on many factors, but the respiratory center of the brain exerts primary control.

If a lung were removed from the chest all the air would be squeezed from it and it would collapse to about one third of its size much as a balloon collapses when air is let out of it. The lungs can be thought of as millions of small balloons, all trying to collapse. The lungs do not normally collapse because they are in an airtight container – the chest. As the diaphragm and rib cage move the lungs stay in contact with them.

Two forces keep the lungs from collapsing:

1. Surface tension between the lungs and the chest wall.
2. Air pressure inside the lungs.

If the lungs overcame the surface tension forces and pulled away from the chest walls a vacuum would be created since air cannot reach the intrathoraic space. Since the air inside the lungs is at atmospheric pressure (105 N/m^2), it would push the lungs back in contact with the chest wall. There is normally a negative pressure of 5 to 10 mm Hg in the intrapleural space. Various muscles are involved in breathing. Normally most breathing is done by contracting the diaphragm muscles. These pull the diaphragm down expanding the lungs.

Laminar Flow and Turbulent Flow

A fluid flowing through a closed channel such as pipe or between two flat plates is either laminar flow or turbulent flow, depending on the velocity, pipe size (or on the Reynolds number), and fluid viscosity.

Laminar Flow

Laminar flow is the movement of fluid particles along well-defined paths or streamlines, where all the streamlines are straight and parallel. Hence, the particles move in laminar or layers gliding smoothly over the adjacent layer.

Laminar flow occurs in small diameter pipes in which fluid flows at lower velocities and high viscosity. This type of flow is also called streamline flow or viscous Flow.

Laminar flow is subdivided into:

1. Unidirectional laminar flow.
2. Pulsatile laminar flow :it is flow with continuous and constant periodic flow variations, the best example of which is the heartbeat.
3. Oscillatory laminar flow: is a type of fluid flow characterized by repetitive periodic motion, such as the flow of water in a sluice gate.

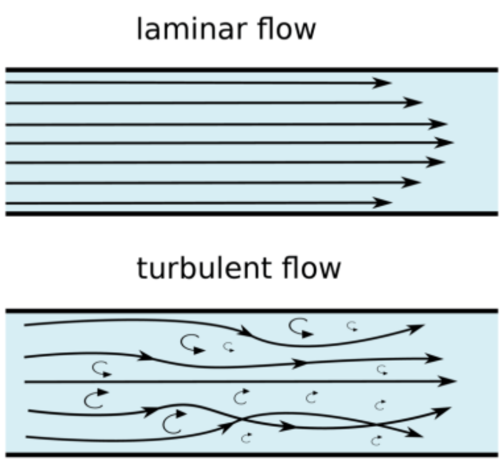
The typical examples of laminar flow are oil flow through a thin tube, blood flow through capillaries, and smoke rising in a straight path from the incense stick. However, the smoke changes into the turbulent flow after rising to a small height as it eddies from its regular path.

Turbulent Flow

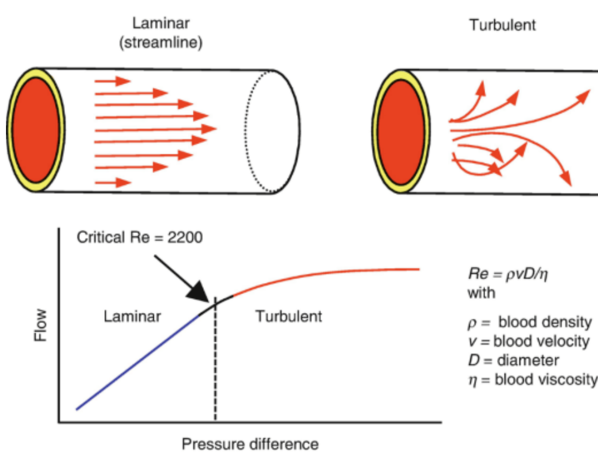
Turbulent flow is defined as the flow in which the fluid particles move in a zigzag way. Due to the movement of fluid particles in a zigzag way, the formation of eddies takes place, which is responsible for high energy loss.

In turbulent flow, the speed of the fluid at a point continuously changes in both magnitude and direction. Turbulent flow tends to occur in large diameter pipes in which fluid flows with high velocity.

The main tool available for the analysis of turbulent flow is **Computational fluid dynamics** CFD analysis. CFD is a branch of fluid mechanics that uses algorithms and numerical analysis to analyze and solve problems that involve turbulent fluid flows.



Graph representing flow vs pressure difference for laminar and turbulent flow



Reynolds Number

Reynolds Number (Reynolds Number) for short is Re an important non-dimensional number in fluid mechanics applications. It is defined as the ratio of the inertial forces in a studied system to the viscosity forces, and thus it determines the relative importance of these forces in relation to the given flow conditions.

This number is attributed to an Irish physicist named Osborne Reynolds (1842 - 1912), who proposed the use of Reynolds numbers in 1883.

The Reynolds number, represented by the letter "Re", is a dimensionless measurement used in fluid dynamics to describe the type of fluid flow, whether it is a liquid or a gas. This volume is necessary to determine whether the flow is laminar or turbulent, and is widely used in fields such as engineering, physics, and fluid mechanics.

The Reynolds number is also used to predict the behavior of fluids in different types of channels, such as tubes, conduits, or closed conduits. In addition, it is necessary for the design of fluid conveying systems, such as water pipes, air conditioning ducts, ventilation ducts, and others.

Reynolds number values: what are they and how are they calculated?

In engineering and physics, the Reynolds number is a dimensionless quantity used to describe the flow of a fluid in a channel. It was proposed by British engineer and physicist Osborne Reynolds in the 19th century, and has since become an essential tool in the study of fluid mechanics.

The Reynolds number is calculated from three variables: flow velocity (V), channel diameter (D) and kinematic viscosity of the fluid (ν). The formula for calculating the Reynolds number (Re) is:

$$\mathbf{Re = (V * D) / \nu}$$

where:

V…. is the flow velocity, measured in meters per second (m/s).

D…. is the diameter of the channel also in meters (m).

ν…. is the kinematic viscosity of the fluid, expressed in square meters per second (m^2/s).

Result:

1. If the Reynolds number is less than 2000, then the flow is called laminar flow.
2. If the Reynolds number is more than 4000, then the flow is called turbulent flow.
3. If the Reynolds number is between 2000 and 4000, the flow may be laminar or turbulent flow.

The common examples of turbulent flow are blood flow in arteries, oil transport in pipelines, lava flow, atmosphere and ocean currents, the flow through pumps and turbines, the flow in boat wakes and around aircraft wingtips.

What is a laminar flow in medicine?

Laminar flow is the normal condition for blood flow throughout most of the circulatory system. It is characterized by concentric layers of blood moving in parallel down the length of a blood vessel. The highest velocity (V_{max}) is found in the center of the vessel.

Why laminar flow is important in pharmaceutical industry?

Laminar Air Flow Profiles are important in the pharmaceutical industry because proper airflow provides protection to both personnel and product (or specimen).

What is laminar flow in surgery?

Laminar flow theatres aim to reduce the number of infective organisms in the theatre air by generating a continuous flow of bacteria free air. In laminar flow theatres air may be 'changed' in theatre more than 300 times per hour compared to standard positive pressure theatre rates of 15-25 air changes per hour.

What is the type of flow?

There are three fluid flow regimes: laminar, turbulent, and a transition region. The conditions that lead to each type of flow behavior are system-specific. Fluid flow simulations for various Reynolds numbers can be used to clearly identify and quantify when flow will transition from laminar to turbulent.

Bernoulli's equation

Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.

The principle is named after Daniel Bernoulli, a swiss mathemetician, who published it in 1738 in his book

Bernoulli's principle is a key concept in fluid dynamics that relates pressure, speed and height. Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in static pressure or the fluid's potential energy.

A common form of Bernoulli's equation is:

The Bernoulli's Equation

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

The previous equation shows the mathematical formula of Bernoulli's equation, where:

P is static pressure (fluid pressure)

ρ is the density

V is the speed

g is the acceleration due to gravity

h is the height of the liquid

To apply Bernoulli's equation

• The streamlined flow must be constant. (Velocity, density and pressure must not change at any time during flow.)

• The flow must be incompressible, so that when the pressure changes, the density must remain constant along the streamline.

• Friction due to viscous forces should be minimal.

In echocardiography, Bernoulli's principle can be applied when interpreting blood flow to describe a localized pressure decrease produced by high flow rate near blockages. For clinical medicine, the equation is used for an easy estimation of pressure gradients from velocity

What is the clinical application (Importance in clinical medicine) of Bernoulli's principle?

** In echocardiography, the Bernoulli's principle can be applied when interpreting blood flow, which can describe a decrease in localized pressure produced by high flow rate near blockages as mentioned above with an illustration.

** This principle is applied in more than one such as transporting liquid medications and oxygen, blood pressure measurement is also performed where a medical instrument called a sphygmomanometer is inflated around an arm to temporarily stop blood flow in an artery and then pressure is released from the cuff slowly to measure the blood pressure.

We cannot apply Bernoulli's principle to a turbulent fluid

Indeed, we cannot apply Bernoulli's principle to a turbulent fluid because it does not agree with the conditions for applying this principle, which are:

1- The fluid must move in a steady line
2- The liquid must be in a constant state

Here we can say that the main reason for not applying Bernoulli's principle to a turbulent fluid is its random and unpredictable nature, as it does not follow a fixed line, nor does it remain constant over time due to turbulence.

Bernoulli's equation requires things to remain stable and perfect, which is never the case for a turbulent fluid, which is inherently viscous, as viscosity is required for the eddies that form and take kinetic energy away from the normal flow.

Requirements for applying Bernoulli's equation to a fluid

There are many assumptions that must be made before using Bernoulli's equation to study the flow of a particular fluid. If there is no agreement with these assumptions, this principle cannot be applied. The following are the requirements for using Bernoulli's formula:

1- The fluid must move in a steady line
2- The liquid should be non-sticky
3- The fluid must be in a constant state
4- The fluid must be incompressible

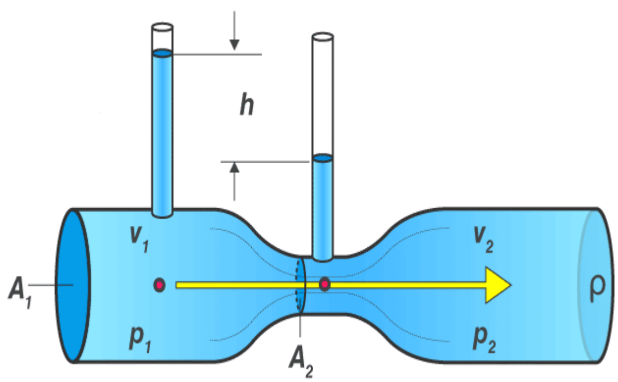
Venturi Tube

What is a Venturi Tube?

A Venturi tube is a tubular setup for calculating the flow of fluids. The fluid moves through a pipe of inconsistent diameter. To reduce excessive drag, Venturi tubes usually have one entry cone of thirty degrees and five degrees exit cone.

Typically, Venturi tubes are used in conditions where the permanent loss of pressure is not tolerable and where the highest accuracy is required in the case of heavily viscous liquids.

A pressure reduction, accompanied by a rise in the flow velocity, is the basis of the laws of fluid dynamics. In 1738, Daniel Bernoulli derived the relationship between velocity, pressure and other properties of a fluid. Fundamentally, his theorem is applied in the development of aircraft wings to generate lift from the airflow over the wing surface.



Applications of Venturi Tubes

Mainly, there are two implementations of Venturi tubes. By connecting manometers to three parts of the tube, the pressure reduction can be calculated, and the rate of flow through the tube's throat can be calculated. A Venturi tube can utilise this negative pressure to attract a second fluid into the central flow. Even though the fundamental mechanism has stayed the same for the last two centuries, this phenomenon is applied in various industries.

It is also extensively used in waste treatment processes. It enables solid materials to move through because of its gradually inclined smooth structure. Thus, it is ideal for the estimation of dirty fluid.

types of Venturi Meters

There are normally three types of venturi meters:

- **Horizontal Venturi Meter:** In this venturimeter, the kinetic energy is the highest and the potential energy is the lowest
- **Vertical Venturi Meter:** In this, the **potential energy** is maximum and the kinetic energy is minimum
- **Inclined Venturi Meter:** It is a venturi meter that is inserted in an inclined pipeline in a vertical plane. It helps in measuring the flow rate through the pipe.

Applications of a Venturi Meter

A Venturi Meter has a number of applications in the practical world such as:

- It is used to determine the flow of chemicals in pipelines.
- Venturimeter can determine the flow rate of the fluid discharged through the pipe of the device.
- It is used a lot in the waste treatment process in which large diameter pipes are used.
- It is used in the industrial sector to determine the pressure and the quantity of gas and liquid that flows inside the pipe.
- Venturimeter is also used in the medical sector to measure the rate of flow of blood in arteries.
- Recovery of high pressure is carried out by venturi meters.

THE BLOOD FLOW

What is flow rate of blood?

It is volume of blood passing through a vessel per unit time. Flow rate is directly proportional to the pressure gradient and inversely proportional to vascular resistance.

$$\mathbf{F=\Delta PR}$$

Where **F:** is flow rate of blood through vessel,

$\boldsymbol{\Delta P}$**:** is pressure gradient. (Which is difference in pressure between the beginning and end of vessel, and blood flow from area of high pressure to an area of low pressure), In practice, this means blood will flow from the arterial end of a vessel to the venous end. This pressure gradient is primarily created by the pumping action of the heart.

$\boldsymbol{R}$**:** is resistance of blood vessel (caused by friction between the blood in the vessel wall).

If resistance to flow increase, it is difficult for blood to pass through a vessel, therefore, flow rate decrease. When resistance increase, the pressure gradient must increase to maintain the same flow rate.

What is Blood flow through a vessel depends on?

- Directly proportional to Pressure differences.
- Inversely proportional to Vascular resistance

What is the resistance to blood flow depends on?

1- **Viscosity of blood (η)**: referred to the fluid's resistance to flow, which is caused by a shearing stress within a flowing fluid and between a flowing fluid and its container. For example, syrup has a higher viscosity than water.

Blood viscosity determined by number of circulating (RBC), and it increased in Polycythemia and decreased in Anemia.

2- **Viscosity** decrease with increasing temperature.

3-**vessel length:** greater the length of vessel, more will be resistance.

4-**redius of the vessel**: it is the most important factor to determine the resistance to flow. The resistance is inversely proportional to the fourth power of the radius.

Flow of blood is faster in the main artery than in the blood capillaries? Why ?

Because the sum of cross-sectional areas of blood capillaries is greater than the cross-sectional area of the main artery so , speed of blood decreases in the blood capillaries to allow exchange of oxygen and carbon dioxide gases in the tissues to supply it with food .

3

Blood Flow and Heart Attack:

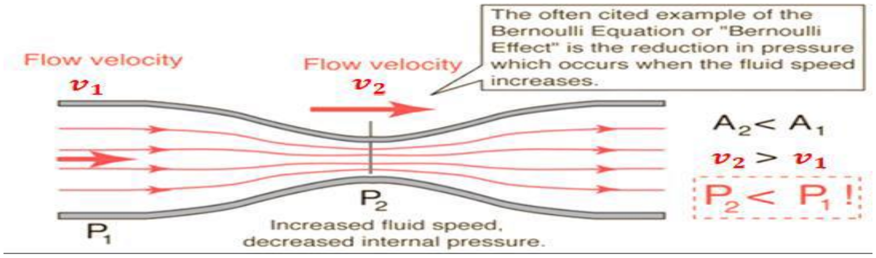
*Bernoulli's principle says that the sum of potential, kinetic and pressure energy per unit mass of incompressible, non-viscous fluid remains constant.

*Bernoulli's principle states that an increase in velocity must be accompanied by a corresponding decrease in pressure.

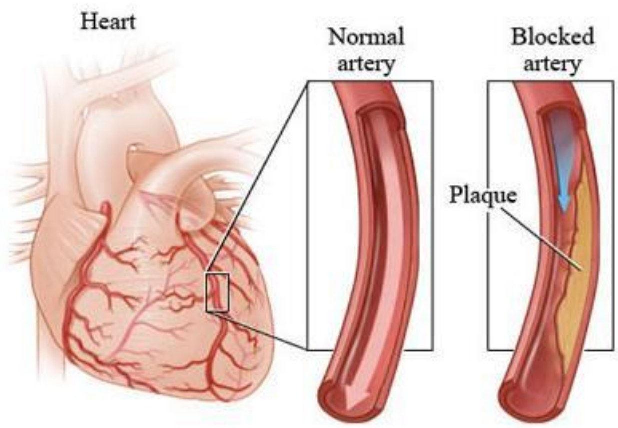
$$v \, \alpha 1 p$$

* We know if the cross sectional area decreases, the velocity of the blood will increase.

$$v \, \alpha 1 A$$



Bernoulli's principle helps in explaining blood flow in artery. The artery may get constricted due to the accumulation of plaque on its inner walls. This happens because of high cholesterol intake. In order to drive the blood through this constriction a greater demand is placed on the activity of the heart.

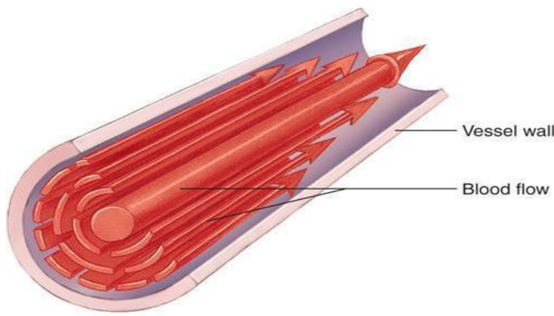


The speed of the flow of the blood in this region is raised which lowers the pressure inside and the artery may collapse due to the external pressure. The heart exerts further pressure to open this artery and forces the blood through. As the blood rushes through the opening, the internal pressure once again drops due to same reasons leading to a repeat collapse. This may result in heart attack.

Types of blood flow:

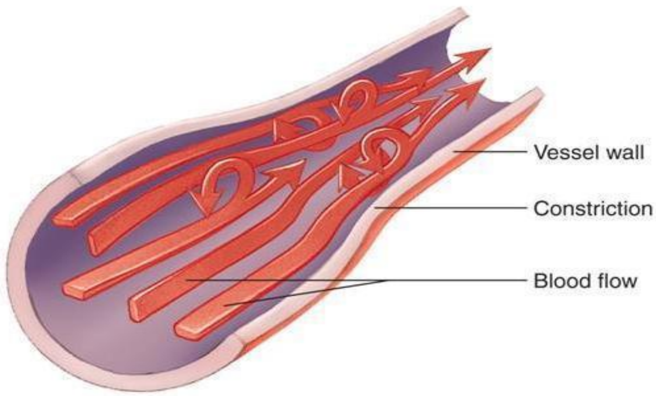
1) Laminar flow: Also known as streamline flow,

- Which is present in blood flow through capillaries,
- Occurs when the flow is slowest near the vessel wall (where there is more friction) and fastest in the center of the blood vessel (where there is less friction).
- Laminar flow occurs in small diameter pipes in which fluid flows at lower velocities and high viscosity. This type of flow is also called viscous Flow.



2) Turbulent flow:

- The flow is disorderly rather than laminar, with blood flowing crosswise as well as along the vessel.
- Eddy currents form.
- Turbulence is occurs in situations of vessel obstruction.
- Turbulent flow tends to occur in large diameter pipes in which fluid flows with high velocity.



To determine whether flow is laminar or turbulent, calculate the Reynold's number (N_R)

Injector: simple injector

an injection is the process of administering a liquid, especially a medication, into a person's body using a needle (usually a hypodermic needle) and a syringe. An injection is a form of parenteral drug administration that does not involve absorption into the gastrointestinal tract, allowing the medication to be absorbed more quickly and avoiding the first-pass effect. There are many types of injections, generally named after the body tissue into which the injection is given, including subcutaneous, intramuscular, and intravenous injections, as well as less common injections such as intraperitoneal, intraosseous, intracardiac, intraarticular, and extracavernous injections.

Types of injection

Needle insertion angles are divided into 4 types of drug injections: intradermal, intravenous, subcutaneous, and intramuscular.

Injections are classified in several ways, including the type of tissue into which they are injected, the location in the body where the injection is designed to produce effects, and the duration of effects. Regardless of classification, injections require a puncture procedure, and therefore require sterile environments and procedures to minimize the risk of introducing pathogens into the body. All injections are parenteral forms of administration, which avoid first-pass metabolism and thus prevent potential changes in drug absorption through the gastrointestinal tract.

1- Systemic injections

Many injections are designed to deliver a medication that has an effect throughout the body. Systemic injections may be used when a person cannot take a medication by mouth, or when the medication itself is not absorbed into the bloodstream from the digestive tract. Drugs given by systemic injection enter the bloodstream, either directly or indirectly, causing them to affect the entire body

2- Intravenous injections

Intravenous injections involve inserting a needle into a vein, allowing the drug to be delivered directly into the bloodstream.

3- Intramuscular injections

Intramuscular injections deliver the drug deep into the muscle, where it is rapidly absorbed into the systemic circulation. Common injection sites include the deltoid, vastus lateralis, and gluteus maximus.

4- Subcutaneous injection

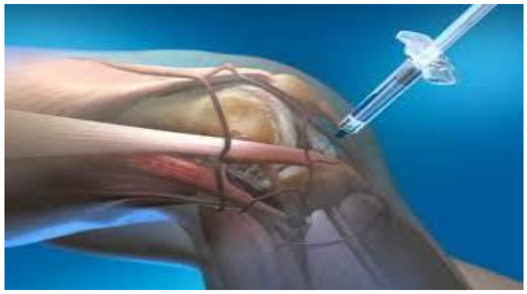
A subcutaneous injection involves injecting the drug under the skin using a needle. The drug is absorbed from this tissue at a slower rate than with an intramuscular injection. Since the needle does not need to penetrate the muscle, a thinner, shorter needle can be used. Subcutaneous injections can be given into the fatty tissue behind the upper arm, in the abdomen, or in the thigh. Some medications, including epinephrine, can be given either intramuscularly or subcutaneously. Others, such as insulin, are injected almost exclusively under the skin. Live or attenuated vaccines, including measles, mumps, rubella, chickenpox, and shingles, are also injected subcutaneously.

5- Intradermal injection

Intradermal injection involves injecting the drug into the dermis, the layer of skin above the subcutaneous fat layer and below the epidermis, or upper layer. Intradermal injections are given with a needle held almost flat against the skin at a 5 to 15 degree angle. Absorption from intradermal injections takes longer than when the injection is given intravenously, intramuscularly, or subcutaneously. For this reason, few drugs are given intradermally. Intradermal injections are commonly used for allergy testing, such as tuberculin skin tests and allergy tests, as well as for allergy testing for drugs that a person has not taken before. Reactions to tests using intradermal injections are more easily seen because of the injection site, and when a positive result is usually seen as redness or swelling. Common sites for intradermal injections include the forearm and lower back

6- Intraosseous injection

Intraosseous injection is the injection of a drug through a needle inserted into the bone marrow of a large bone. This method is only used when a less invasive route such as an intravenous line is difficult to use, either because of repeated loss of access due to collapsed blood vessels, or because it is difficult to find a suitable vein in the first place. A needle is usually inserted into the bone marrow in the humerus or tibia, and this method is usually only used when several attempts at intravenous injection have failed. Except for occasional differences in the accuracy of blood tests when drawn from an intraosseous line, it is considered to be equally effective as intravenous injection. This method is also commonly used in emergency situations when there is not enough time to access a vein frequently, or in younger people for whom intravenous access is more difficult.

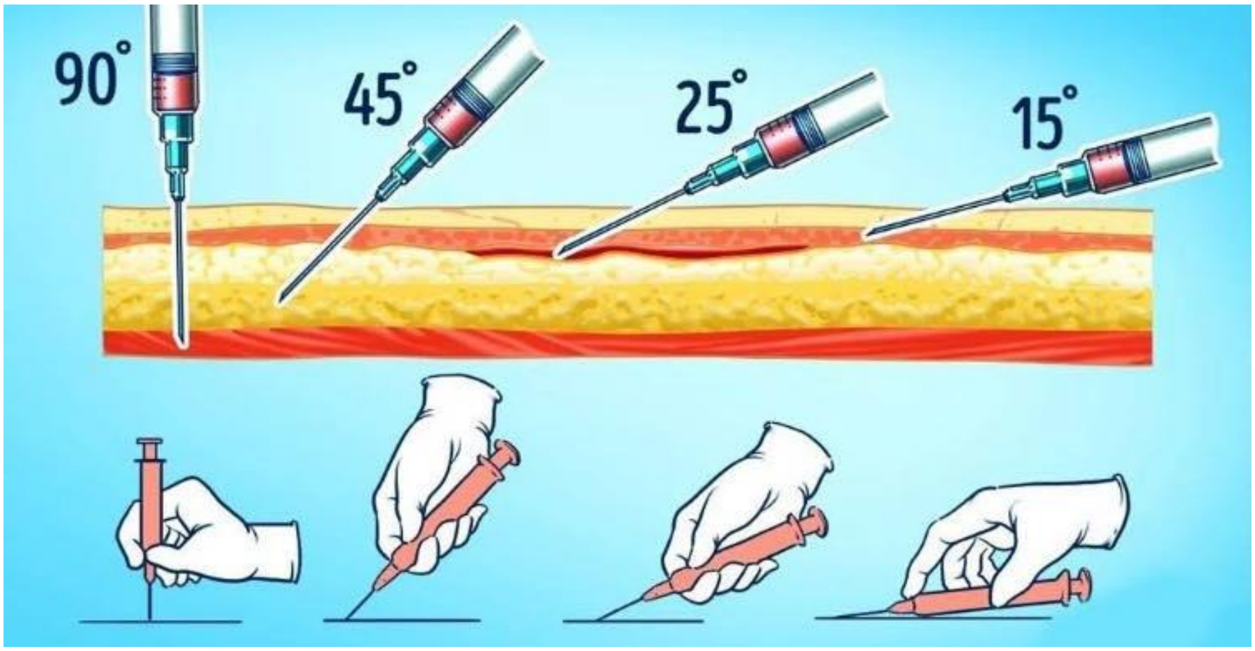
types of injection angles!

10-15 degrees intradermal injection

45 degrees subcutaneous tissue

25 degrees dermis

90 degrees intramuscular injection



Electrical safety

electrical shock, macro– shock, micro – shock, damage of macro –Shock.

Definition of electric shock

Electric shock occurs when an electric current passes through the body, affecting the functions of internal organs and sometimes causing skin burns.

Electrical shock injuries

- Often the main symptom is a skin burn, but other serious damage may not be visible.

- The doctor checks for any irregular heart rhythm, bone fractures, joint dislocations, spinal injuries, or other injuries.

- The patient's heart rhythm is monitored, skin burns are treated, and fluids are given intravenously if the skin burns have caused extensive internal damage, among other treatments.

- Electric shocks can result from using faulty electrical appliances or accidentally touching electrical wires or extension cords. Electrical shocks from contact with household electrical outlets or wiring are rarely serious, but statistics indicate that about 300 deaths occur each year in the United States from high-voltage electrical shocks.

How Electricity Affects the Body

The passage of electric current through the body generates heat, causing burns and damaging tissue. Burns can affect internal organs as well as the skin. An electric shock can cause a short circuit in the body's electrical system, causing nerves to stop transmitting nerve signals, or transmit abnormal nerve signals. ***Abnormal nerve signals can affect:***

- Muscles, causing them to contract violently
- Heart, causing it to stop beating (heart attack)
- Brain, causing seizures, loss of consciousness, or other problems

The severity of the injury ranges from mild to fatal, and is determined by the following factors:

1- The intensity of the electric current
2- The type of electric current
3- The path of the electric current through the body
4- The duration of the electric current's passage through the body
5- Resistance to the electric current

Type of Current

There are two types of electrical current: direct current (DC) and alternating current (AC). Direct current flows continuously in one direction, such as the current from batteries. Alternating current changes direction 50 or 60 times per second, such as household electricity connected to the public electricity grid.

Alternating current is more dangerous than direct current. Direct current tends to cause a single muscle spasm, often strong enough to push a person away from the source of electricity. Alternating current causes continuous muscle contractions, often preventing a person from moving away from the source of electricity or freeing their hand from the place where it is in contact with the current. As a result, exposure to the electric current is longer. A simple exposure to alternating current can cause a fist to freeze, even if it feels like a mild shock. Slightly stronger alternating current can cause chest muscles to contract, making it difficult to breathe. Stronger alternating current can cause a fatal heart rhythm disorder (arrhythmias).

Symptoms of Electrical Shock Injuries

The main symptom of electrical shock is often a skin burn, although not all electrical shocks cause external organ injuries. High-voltage electrical current injuries can cause extensive internal burns. If muscle damage is extensive, the limb may swell so much that it compresses the arteries (compartment syndrome), cutting off the limb's blood supply. If the electric current passes near the eye, it can cause cataracts. Cataracts can develop within days of the injury or years later. If a large amount of muscle is damaged (a condition called rhabdomyolysis), a chemical called myoglobin is released into the blood. Myoglobin can damage the kidneys.

If a young child bites or sucks on electrical wires, it can cause burns to the mouth and lips. These burns can cause facial disfigurement, and problems with the development of teeth, jaws, and faces. The risk is increased if there is bleeding from an artery in the lip when the scabs fall off, which usually happens within 5-10 days of the injury.

A mild electrical shock can cause muscle pain, and may cause minor muscle spasms, or the victim to jerk and fall to the ground. Severe electrical shocks can cause cardiac arrhythmias that range from mild to fatal. Severe electrical shocks can cause muscle contractions severe enough to knock the victim to the ground, and cause joint dislocations, bone fractures, or other traumatic injuries.

Nerves and bones can be damaged in several ways, causing seizures, brain hemorrhages, brief episodes of memory loss, personality changes, agitation, or insomnia. Physical or spinal damage can cause weakness, paralysis, numbness, tingling, chronic pain, and erectile dysfunction (impotence).

Diagnosing Electrical Shock Injuries

A doctor's evaluation

A doctor will look for skin burns, bone fractures, joint dislocations, spinal injuries, and other injuries.

Most people who have no symptoms, no known heart problems, have been exposed to only low levels of electrical current, and are not pregnant, if they are women, do not need testing or monitoring. An electrocardiogram (ECG) is done to monitor the heart rhythm in some people. Blood and urine tests may be needed for some people. If the person is unconscious, imaging tests of the brain, such as a computed tomography (CT) scan or magnetic resonance imaging (MRI), may be done.

treating Electrical Shock Injuries

- **Cardiopulmonary Resuscitation**
- **Treatment of Burns**

The first step is to remove the victim from the electrical source. The safest way to do this is to turn off the electrical current (by turning off the electrical circuit or by disconnecting the shock device from the electrical source). The victim should not be touched unless the electrical current has been turned off.

As soon as the victim can be safely touched, the rescuer should check the victim's vital signs (breathing and pulse). If the victim is not breathing and has no heartbeat, CPR should be started immediately.

Emergency care should be sought for any victim with an injury that is not considered minor. Since the severity of electrical burns can be deceptive, medical care should be sought if there is any doubt about the severity of the injury.

People with rhabdomyolysis are usually given large amounts of fluids intravenously.

A tetanus shot may be given if needed.

If the injury is severe, the injured person should be given painkillers.

Skin burns are treated with burn ointments and sterile dressings. Minor burns can be treated at home without hospitalization. If the injury is more severe, the person should be admitted to the hospital, or to a burn center if available. The person should stay in the hospital for 6-12 hours ***if any of the following occurs:***

1- If the heart rate or ECG results are abnormal
2- If the person has symptoms of heart problems (such as chest pain or sometimes shortness of breath)
3- If there are other severe injuries
4- If the person is pregnant (in most, but not necessarily all, cases)
5- If the person has a known heart problem (in most, but not necessarily all, cases)
6- Children who have bitten or sucked on electrical cords should be referred to an orthodontist, maxillofacial surgeon, or surgeon who specializes in such injuries.

Preventing injuries caused by electrical shock

It is very important to raise awareness about the dangers of electricity and the rules for its use. Ensure that all electrical appliances in the home are in good condition, properly installed, and subject to regular maintenance, which helps prevent electrical shocks. Electrical wires should be extended and maintained by specialized technicians. Electrical socket protectors can reduce the risk of electrical shock to infants and young children.

Any electrical device that can be touched by the body should be grounded. Three-pronged electrical sockets are the safest. It is dangerous to remove the grounding prong from the three-pronged electrical plug to make it easier to insert into two-pronged sockets, as this increases the risk of electrical shock. It is useful to use circuit breakers that disconnect the electrical circuit when a weak current leaks from it (even if the leaking current reaches 5 milliamps), in damp places, such as kitchens, bathrooms, and areas exposed to rain.

To avoid injury from airborne electrical current, ladders and metal bars should not be used near high-voltage power lines.

Electromagnetic spectrum

What is electromagnetic radiation?

It is a type of energy created by oscillating magnetic and electrical disturbances or by the motion of electrically charged particles travelling through a vacuum or substance. These combined magnetic and electrical waves go perpendicular to each other since the electric and magnetic fields are at right angles, causing the disturbances. Photons, bunches of light energy that move at the velocity of light as quantum harmonic waves, are the byproducts of electron radiation. The electromagnetic spectrum is then used to categorise this energy depending on its wavelength. These magnetic and electric waves have certain properties, such as amplitude, wavelength, and frequency, and they move perpendicularly.

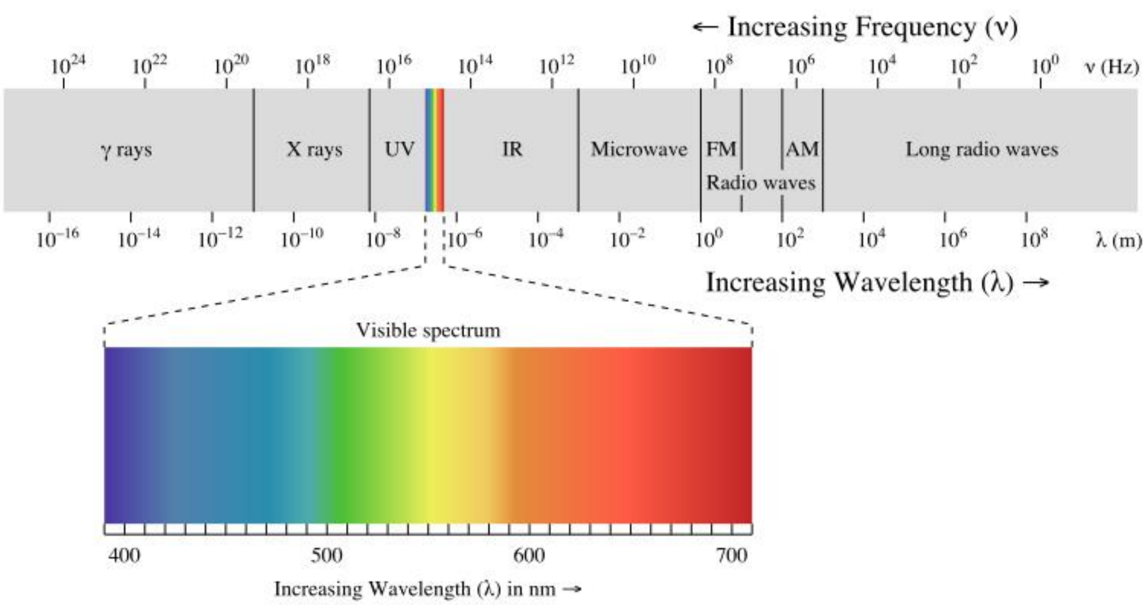
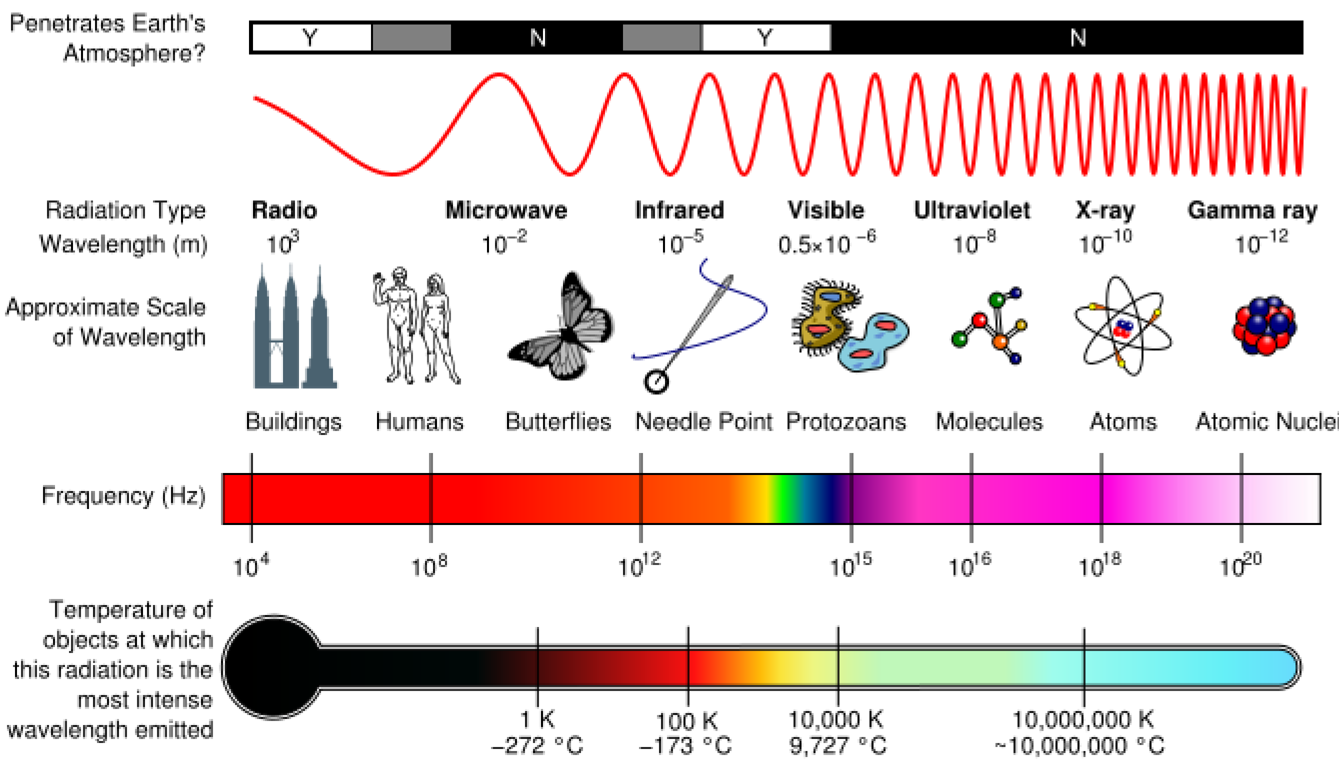


Figure: *Electromagnetic spectrum with light highlighted. from Wikipedia.*

As a wave's wavelength increases, the frequency decreases, and as wave's wavelength decreases, the frequency increases. When electromagnetic energy is released as the energy level increases, the wavelength decreases and frequency decreases. Thus, electromagnetic radiation is then grouped into categories based on its wavelength or frequency into the electromagnetic spectrum. The different types of electromagnetic radiation shown in the electromagnetic spectrum consists of radio waves, microwaves, infrared waves, visible light, ultraviolet radiation, X-rays, and gamma rays. The part of the electromagnetic spectrum that we are able to see is the visible light spectrum.



Electromagnetic Radiation Characteristics

Electromagnetic Radiation Characteristics

- Wavelength. Wavelength (λ) represents the distance between successive crests or troughs of a wave. ...
- Amplitude. Amplitude refers to the maximum displacement of a wave from its equilibrium position. ...
- Frequency. ...
- Velocity.
- Period

Understanding the characteristics of electromagnetic waves is crucial to comprehending the behaviour and applications of electromagnetic waves. Let's explore these characteristics in more detail:

Wavelength

Wavelength (λ) represents the distance between successive crests or troughs of a wave. It is the length of one complete cycle of oscillation. Wavelength and frequency (ν) are related by the equation $c = \lambda\nu$, where 'c' is the speed of light. Shorter wavelengths correspond to higher frequencies and higher energy levels.

Amplitude

Amplitude refers to the maximum displacement of a wave from its equilibrium position. It represents the distance from the middle of the wave to the crest or trough. Amplitude provides information about the brightness or intensity of a wave relative to other waves. Larger amplitudes indicate higher energy levels, while smaller amplitudes correspond to lower energy levels.

Frequency

Frequency is the number of wave cycles that occur per second, measured in Hertz (Hz) or cycles per second. It determines how many times a wave oscillates within a given time frame. Frequency (ν) and energy (E) is directly proportional, as indicated by the equation $E = h\nu$, where 'h' is Planck's constant (6.62607×10^{-34}). Higher frequencies correspond to higher energy levels.

Period

Period (T) represents a wave's total time to complete one full cycle or travel one wavelength. It is the reciprocal of frequency, given by $T = 1/\nu$. The period provides information about the time characteristics of a wave.

Velocity

In electromagnetic radiation, velocity is expressed as the product of wavelength and frequency, given by Velocity = $\lambda\nu$. For electromagnetic waves propagating in a vacuum, the velocity is equal to the speed of light, which is approximately 186,282 miles per second or 2.99 x 10^8 metres per second (m/s).

Understanding these characteristics of electromagnetic waves allows us to interpret and utilise their behaviour across a wide range of scientific, technological, and everyday applications.

Why are electromagnetic waves used in medicine?

1- Some electromagnetic waves can be used in medicine for imaging purposes, which allows doctors to explore what is happening inside a person's body without having to perform surgery

2- The uses of electromagnets are also seen in the medical field. MRI scan which is short for Magnetic Resonance Imaging is a device that uses electromagnets. The device can scan all the tiny details in the human body with the help of electromagnetism

3- There are several new areas of EMF application, including bone repair, wound healing, nerve stimulation, tissue regeneration, osteoarthritis therapy, and electroacupuncture. The healing of non-union bone fractures using various types of electromagnetic energy including low-level electric currents (micro-currents) have become popular. Ultrasonic (radio waves) also have been used for bone healing with similar results. Finally, PEMFs have become popular in Canada, Europe, and Asia, less so in the United States, but their use is growing as well.

Magnetic Resonance Imaging (MRI)

is a non-invasive imaging technology that produces three dimensional detailed anatomical images. It is often used for disease detection, diagnosis, and treatment monitoring. It is based on sophisticated technology that excites and detects the change in the direction of the rotational axis of protons found in the water that makes up living tissues.

Media Image

How does MRI work?

MRIs employ powerful magnets which produce a strong magnetic field that forces protons in the body to align with that field. When a radiofrequency current is then pulsed through the patient, the protons are stimulated, and spin out of equilibrium, straining against the pull of the magnetic field. When the radiofrequency field is turned off, the MRI **sensors** are able to detect the energy released as the protons realign with the magnetic field. The time it takes for the protons to realign with the magnetic field, as well as the amount of energy released, changes depending on the environment and the chemical nature of the molecules. Physicians are able to tell the difference between various types of tissues based on these magnetic properties.

To obtain an MRI image, a patient is placed inside a large magnet and must remain very still during the imaging process in order not to blur the image. Contrast agents (often containing the element Gadolinium) may be given to a patient intravenously before or during the MRI to increase the speed at which protons realign with the magnetic field. The faster the protons realign, the brighter the image.

What is MRI used for?

MRI scanners are particularly well suited to image the non-bony parts or soft tissues of the body. They differ from **computed tomography** (CT), in that they do not use the damaging **ionizing radiation** of **x-rays**. The brain, spinal cord and nerves, as well as muscles, ligaments, and tendons are seen much more clearly with MRI than with regular x-rays and CT; for this reason MRI is often used to image knee and shoulder injuries.

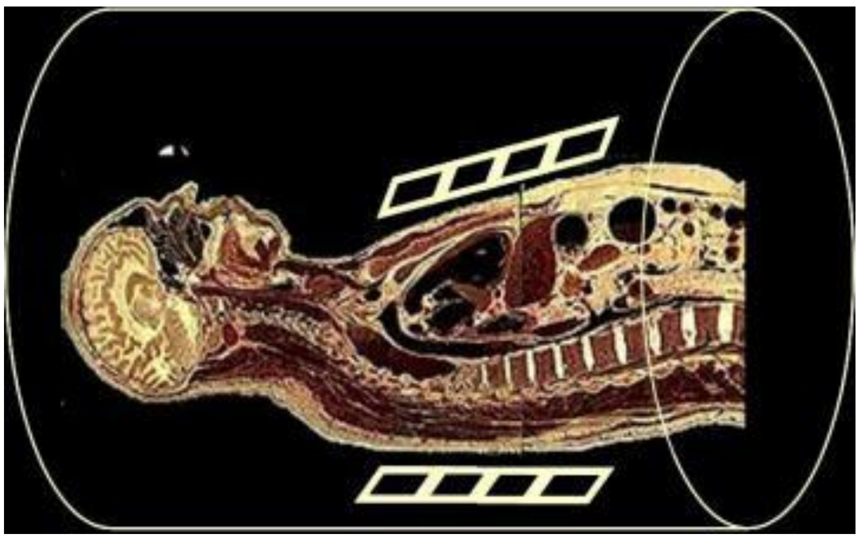
In the brain, MRI can differentiate between white matter and grey matter and can also be used to diagnose aneurysms and tumors. Because MRI does not use x-rays or other **radiation**, it is the imaging modality of choice when frequent imaging is required for diagnosis or therapy, especially in the brain. However, MRI is more expensive than x-ray imaging or CT scanning.

One kind of specialized MRI is functional Magnetic Resonance Imaging (fMRI.) This is used to observe brain structures and determine which areas of the brain "activate" (consume more oxygen) during various cognitive tasks. It is used to advance the understanding of brain organization and offers a potential new standard for assessing neurological status and neurosurgical risk.

Are there risks?

Although MRI does not emit the **ionizing radiation** that is found in x-ray and CT imaging, it does employ a strong magnetic field. The magnetic field extends beyond the machine and exerts very powerful forces on objects of iron, some steels, and other magnetizable objects; it is strong enough to fling a wheelchair across the room. Patients should notify their physicians of any form of medical or implant prior to an MR scan.

When having an MRI scan, the following should be taken into consideration:



- **People with implants, particularly those containing iron,** — pacemakers, vagus nerve stimulators, implantable cardioverter- defibrillators, loop recorders, insulin pumps, cochlear implants, deep brain stimulators, and capsules from capsule endoscopy should not enter an MRI machine.
- **Noise**—loud noise commonly referred to as clicking and beeping, as well as sound intensity up to 120 decibels in certain MR scanners, may require special ear protection.
- **Nerve Stimulation**—a twitching sensation sometimes results from the rapidly switched fields in the MRI.
- **Contrast agents**—patients with severe renal failure who require dialysis may risk a rare but serious illness called nephrogenic systemic fibrosis that may be linked to the use of certain gadolinium-containing agents, such as gadodiamide and others. Although a causal

link has not been established, current guidelines in the United States recommend that dialysis patients should only receive gadolinium agents when essential, and that dialysis should be performed as soon as possible after the scan to remove the agent from the body promptly.

- **Pregnancy**—while no effects have been demonstrated on the fetus, it is recommended that MRI scans be avoided as a precaution especially in the first trimester of pregnancy when the fetus' organs are being formed and contrast agents, if used, could enter the fetal bloodstream.

New open MRI machine

- **Claustrophobia**—people with even mild claustrophobia may find it difficult to tolerate long scan times inside the machine. Familiarization with the machine and process, as well as visualization techniques, sedation, and anesthesia provide patients with mechanisms to overcome their discomfort. Additional coping mechanisms include listening to music or watching a video or movie, closing or covering the eyes, and holding a panic button. The open MRI is a machine that is open on the sides rather than a tube closed at one end, so it does not fully surround the patient. It was developed to accommodate the needs of patients who are uncomfortable with the narrow tunnel and noises of the traditional MRI and for patients whose size or weight make the traditional MRI impractical. Newer open MRI technology provides high quality images for many but not all types of examinations.

What are examples of NIBIB-funded projects in MRI?

Replacing Biopsies with Sound

Chronic liver disease and cirrhosis affect more than 5.5 million people in the United States. NIBIB-funded researchers have developed a method to turn sound waves into images of the liver, which provides a new non-invasive, pain-free approach to find tumors or tissue damaged by liver disease. The Magnetic Resonance **Elastography** (MRE) device is placed over the liver of the patient before he enters the MRI machine. It then pulses sound waves through the liver, which the MRI is able to detect and use to determine the density and health of the liver tissue. This technique is safer and more comfortable for the patient as well as being less expensive than a traditional biopsy. Since MRE is able to recognize very slight differences in tissue density, there is the potential that it could also be used to detect cancer.

New MRI just for Kids

MRI is potentially one of the best imaging modalities for children since unlike CT, it does not have any **ionizing radiation** that could potentially be harmful. However, one of the most difficult challenges that MRI technicians face is obtaining a clear image, especially when the patient is a child or has some kind of ailment that prevents them from staying still for extended periods of time. As a result, many young children require anesthesia, which increases the health risk for the patient. NIBIB is funding research that is attempting to develop a robust pediatric body MRI. By creating a pediatric coil made specifically for smaller bodies, the image can be rendered more clearly and quickly and will demand less MR operator skill. This will make MRIs cheaper, safer, and more available to children. The faster imaging and motion compensation could also potentially benefit adult patients as well.

Another NIBIB-funded researcher is trying to solve this problem from a different angle. He is developing a motion correction system that could greatly improve image quality for MR exams. Researchers are developing an optical tracking system that would be able to match and adapt the MRI pulses to changes in the patient’s pose in real time. This improvement could reduce cost (since less repeat MR exams will have to take place due to poor quality) as well as make MRI a viable option for many patients who are unable to remain still for the exam and reduce the amount of anesthesia used for MR exams.

Determining the aggressiveness of a tumor

Traditional MRI, unlike PET or SPECT, cannot measure metabolic rates. However, researchers funded by NIBIB have discovered a way to inject specialized compounds (hyperpolarized carbon 13) into prostate cancer patients to measure the metabolic rate of a tumor. This information can provide a fast and accurate picture of the tumor's aggressiveness. Monitoring disease progression can improve risk prediction, which is critical for prostate cancer patients who often adopt a wait and watch approach.

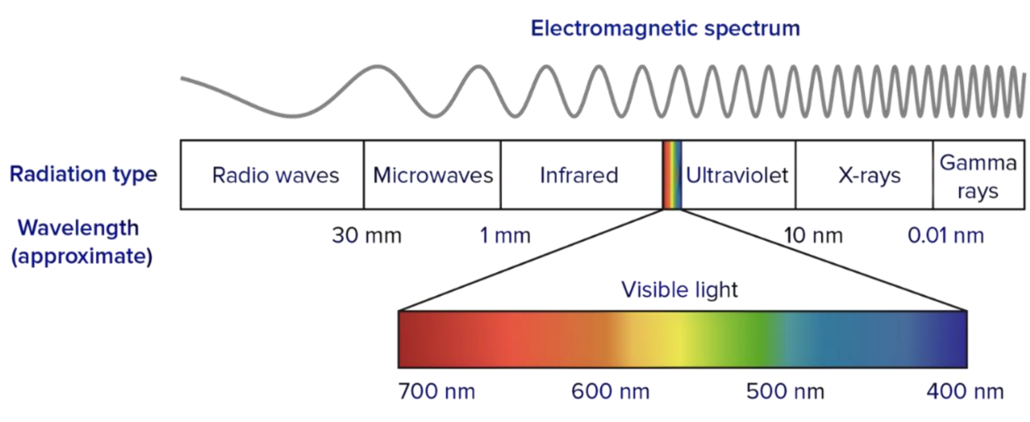
Applications of Light Wavelengths in Medical

The use of light in medicine dates back to ancient civilizations, when sunlight was employed to treat various ailments. Today, with advancements in technology, the medical community has harnessed specific wavelengths of light to develop targeted treatments for a wide range of conditions.

From ultraviolet (UV) to visible (VL) and infrared (IR) light, each wavelength interacts uniquely with human tissues, offering therapeutic benefits and presenting potential risks. Understanding these interactions is important for optimizing the use of light in medical applications while ensuring patient safety.

How Different Wavelengths Penetrate Skin and Body

Understanding how various wavelengths penetrate different layers of skin and tissue is key to maximizing therapeutic benefits while minimizing risks. Each wavelength interacts uniquely with human tissue, providing specific advantages and challenges in medical applications.



Source: *Wavelengths of light and photosynthetic pigments*

Ultraviolet (UV) Light

UV light, ranging from 100–400 nanometers (nm), is divided into three categories[1]:

- **UV-A (320–400 nm):** Penetrates the dermis; used in phototherapy for conditions like psoriasis and vitiligo. Prolonged exposure can cause skin aging and increase cancer risk.
- **UV-B (290–320 nm):** Penetrates the epidermis; effective in treating skin conditions by slowing cell growth. Also administered in controlled doses to prevent sunburn and lower cancer risk.
- **UV-C (100–290 nm):** Primarily used for sterilization due to its germicidal properties. Science has shown 208-210 nm range has strong germicidal effects, able to inactivate bacteria and viruses on skin without harming human tissue.[2]

Visible Light (VL)

Visible light takes up the 400–700 nm spectrum and is perceived as different colors, each offering unique therapeutic benefits[1]:

- **Blue light (440–500 nm):** Penetrates the upper dermis; effective for neonatal jaundice and acne. Antibacterial properties also help eliminate bacteria on the skin's surface.
- **Green light (500–570 nm):** Penetrates the upper dermis and is used to treat pigmentation issues by targeting melanocytes.
- **Yellow light (570–590 nm):** Penetrates the dermis and is known for its ability to stimulate collagen production, improve skin texture and also has a calming effect on the nervous system.
- **Red light (620–750 nm):** Penetrates the dermis and subcutaneous tissue, known for anti-inflammatory and wound-healing properties.

Infrared (IR) Light

Infrared light ranges from 700 nm to 1 mm and is categorized into three types[1]:

- **Near-Infrared (NIR) light (700–1.400 nm):** Penetrates muscles, nerves, and bones, and can be effective for pain management and deep tissue repair.
- **Mid-Infrared (MIR) light (1,400–3,000 nm):** Provides thermal benefits; used in therapies requiring moderate heat.

- **Far-Infrared (FIR) light (3,000 nm–1 mm):** Penetrates surface layers of the skin, providing gentle heating beneficial for circulation and reducing stiffness.

Medical Applications of Different Wavelengths

Various wavelengths of light are harnessed in different medical applications that leverage their unique properties to treat numerous conditions.

Optical Biosensors

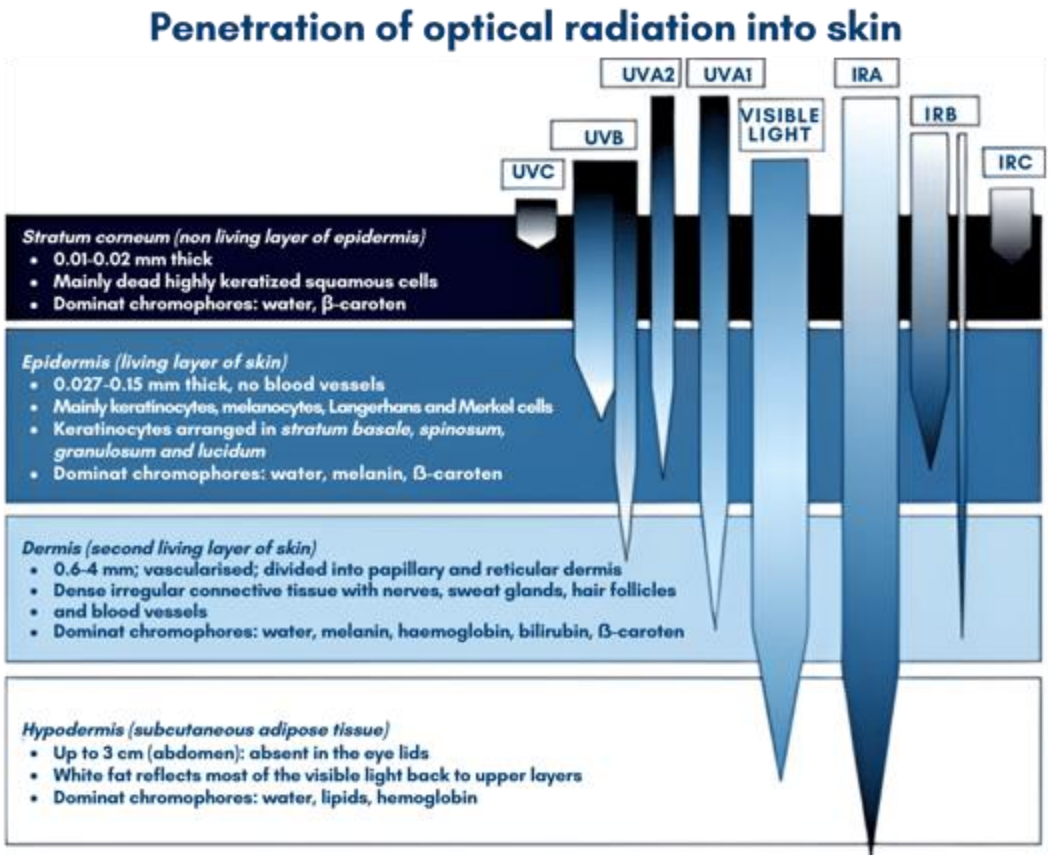
Optical biosensors are advanced analytical devices that use light to detect and analyze biological molecules and/or chemical substances. These sensors measure changes in light properties, such as absorbance, fluorescence, luminescence, or reflectance, caused by the interaction between a target analyte and a biorecognition element on the sensor surface.

Optical biosensors are highly valued in healthcare, environmental monitoring, and biotech for their high sensitivity, specificity, and real-time analysis capabilities. Factors such as color temperature, which affects fluorescence excitation and signal stability, can influence their performance, making them crucial tools for noninvasive, multifaceted, and continuous health monitoring[4].

Photo biomodulation (PBM) for Wound Care

Light therapy is emerging as a promising technique for accelerating wound healing, particularly for severe and chronic wounds that are challenging to treat with conventional methods. Light therapy uses specific wavelengths of light to interact with tissues and cells, promoting natural healing processes by accelerating mitochondrial production of ATP and thereby reducing inflammation, minimizing scarring, and accelerating tissue repair.

Unlike traditional methods, light therapy is minimally invasive and often provides faster healing times. Wound care light therapy applications include treating burns, surgical wounds, and even non-healing wounds, making it a valuable tool in modern wound care.[5]



Source: *Optical radiation in modern medicine (National Library of Medicine; 2013)*

Photobiomodulation in Neurological Applications

PBM therapy is emerging as a catalytic, non-invasive treatment for various neurological disorders, including Alzheimer's, Parkinson's, and different traumatic brain injuries.

This innovative therapy involves the use of low-intensity red or near-infrared (NIR) light to stimulate neural activity and enhance brain function. By targeting cytochrome c oxidase in mitochondria, PBM therapy promotes cellular survival, reduces apoptosis, alleviates oxidative stress, and suppresses inflammation, potentially leading to significant improvements in cognitive and motor functions.

Bioluminescence in Medicine

Bioluminescence, the natural phenomenon by which living organisms emit light, has recently gained traction in medical research due to its potential in diagnostics, imaging, and therapeutic techniques.

Most types of bioluminescence involve a chemical reaction between luciferin, a light-emitting molecule, and luciferase, an enzyme, which produces light efficiently without significant heat generation.[9]

Observed by figures of antiquity like Aristotle and Pliny the Elder, bioluminescence has transitioned from a curiosity of the natural world to a tool with powerful potential in modern medicine. Bioluminescent markers enable researchers to visualize and track diseases by incorporating luciferase genes into cells, which emit light when a substrate like luciferin is present. This non-invasive imaging technique allows for real-time monitoring of disease progression and treatment efficacy in live animal models, providing critical insights into cancer growth, metastasis, and infectious disease dynamics.

Additionally, bioluminescence facilitates drug discovery and development, enabling rapid and sensitive screening of potential therapeutic agents. As advancements continue, bioluminescence could potentially transform non-invasive diagnostics.

Potential Risks of Light Therapy

UV Radiation Risks

UV radiation can cause acute skin damage, manifesting as erythema similar to sunburn. Chronic exposure may lead to photo-aging and a higher risk of skin cancers like melanoma.

The eyes are particularly sensitive to UV radiation. Too much UV light could lead to conditions like photokeratitis and conjunctivitis, which can also contribute to cataract formation.[7]

Visible Light Risks

Blue light, though beneficial for specific medical treatments, can cause retinal damage with prolonged exposure, requiring regulated exposure to prevent eye strain and potential macular degeneration. Additonally, some people have a nausea reaction to blue light.[7]

Infrared Radiation Risks

The primary concern with infrared radiation is thermal damage, including skin burns and heat-induced rashes. Chronic exposure might lead to conditions like erythema ab igne (EAI), increasing the risk of skin cancer. However, these risks are generally associated with improper use or excessive exposure.[7]

The Transformative Potential of Light in Medicine

The powerful potential of light in medicine is to offer non-invasive diagnostics, real-time disease monitoring, and targeted treatments.

While understanding and mitigating associated risks is crucial for patient safety, the integration of light-based technologies promises improved patient outcomes, reduced treatment times, and lower healthcare costs, promising a brighter future for medical advancements.

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Doctors use UV to help with some skin conditions including some skin cancers. When using UVA, they need to combine it with a drug called psoralen as UVA would not work on its own. This treatment is called Psoralen ultraviolet light treatment (PUVA). You might also hear ultraviolet light treatment called phototherapy.

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hat is the application of UV spectroscopy in medicine?

Dissolution testing: UV-Vis spectroscopy has long been a method for analyzing the results of dissolution testing of solid oral dosage forms like tablets. Chemical identification and quantification: UV-Vis spectroscopy can confirm chemical identity and quantify the purity of drugs/drug ingredients.

How is infrared used in medicine?

Infrared therapy has been used in a wide range of applications for many years. It is one of several innovative therapies used to help patients suffering from pain and/or injury. Infrared therapy utilizes numerous light wavelengths between 780 nm to 1000 μm, which are directed at injured or inflamed sites in the body