Medical Physics, Lectures in General Physics for Medical Sciences Students

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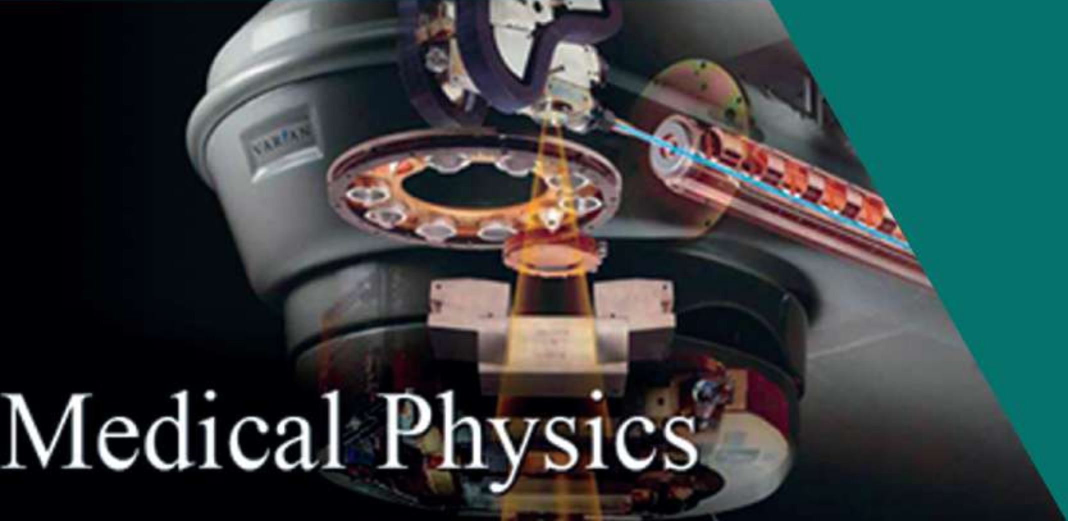

Medical Physics

Principles and Applications

Lectures in General Physics for Medical Sciences Students

By

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Preface

In general, study the physics concepts provide the student with a clear and logical presentation of the basic concepts and principles of physics and to

strengthen an understanding of the concepts and principles through a broad range of interesting applications to the real world.

Medical physics is the application of the concept 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. These branches where continued research is being conducted by a very large group of dedicated researchers consisting of highly qualified physicists, engineers and radiologists.

Preface

The field of medical physics as we know it today started with the discovery of x-rays and radioactivity in the 1890's. The first radiograph was taken by the physicist Wilhelm Conrad Roentgen (1845-1923) in his Wurzburg University laboratory in Germany. It was a radiograph of his wife's hand. For his thorough scientific investigations of x-rays he received the first Nobel prize in Physics in 1901.

I hope to present a good course for our students in medical sciences faculties. It is essential that the students understand the basic concepts and principles before attempting to solve assigned problems. You can best accomplish this goal by carefully reading the textbook before you attend your lecture on the covered material. When reading the text, you should jot down those points that are not clear to you.

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Chapter 1 – Physics and Measurements

Physics

Fundamental Science

- Concerned with the fundamental principles of the Universe
- Foundation of other physical sciences
- Has simplicity of fundamental concepts

Divided into six major areas:

- Classical Mechanics
- Relativity
- Thermodynamics
- Electromagnetism
- Optics
- Quantum Mechanics

Objectives of Physics

To find the limited number of fundamental laws that govern natural phenomena

To use these laws to develop theories that can predict the results of future experiments

Express the laws in the language of mathematics

- Mathematics provides the bridge between theory and experiment.

Theory and Experiments

Should complement each other

When a discrepancy occurs, theory may be modified or new theories formulated.

- A theory may apply to limited conditions.
  - Example: Newtonian Mechanics is confined to objects traveling slowly with respect to the speed of light.
- Try to develop a more general theory

Medical Physics

Medical Physics is defined as the application of physics to the needs of medicine

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

i. Diagnostic:

- ✓ Stethoscope
- ✓ Manometer (blood pressure)
- ✓ Sphygmomanometer
- ✓ Electrocardiograph(ECG),
- ✓ X- Ray,
- ✓ Electroencephalograph(EEG), Electromyography (EMG),
- ✓ thyroid function using I^{131}
- ✓ Computer tomography (CT scan),
- ✓ Ultrasound, tuning Fork,
- ✓ Magnetic Resonance Imaging (MRI),
- ✓ Flow meter, Spirometer to study the function lungs,
- ✓ Audiometer,
- ✓ Optics, Laser, Gamma camera to study the function of kidney, liver, and lungs.

ii. Therapy

- ✓ Radiotherapy
- ✓ Cobalt sixty(Co sixty)
- ✓ High voltage
- ✓ Ultrasound
- ✓ infrared
- ✓ Radio frequency
- ✓ Heating
- ✓ Laser

iii. Patient monitoring

ECG, spirometer, blood pressure, and thermometer.

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

Standards of Fundamental Quantities

Standardized systems

- Agreed upon by some authority, usually a governmental body

SI – Systém International (Main system used in this text)

- Agreed to in 1960 by an international committee

Fundamental Quantities and Their Units

Quantity	SI Unit (symbol)
Length	Meter (m)
Mass	Kilogram (Kg)
Time	Second (s)
Temperature	Kelvin (K)
Electric Current	Ampere (A)
Luminous Intensity	Candela (Cd)
Amount of Substance	Mole (mol)

- In mechanics, three fundamental quantities are used: Length, Mass, Time
- All other quantities in mechanics can be expressed in terms of the three fundamental quantities.

Derived quantities can be expressed as a mathematical combination of fundamental quantities.

Examples:

- Area
  - A product of two lengths
- Speed
  - A ratio of a length to a time interval
- Density
  - A ratio of mass to volume

Prefixes

Prefixes correspond to powers of 10.

Each prefix has a specific name and has a specific abbreviation.

The prefixes can be used with any basic units.

They are multipliers of the basic unit.

Examples: 1 mm = 10^{-3} m 1 mg = 10^{-3} g

TABLE 1.4 *Prefixes for Powers of Ten*

Power	Prefix	Abbreviation	Power	Prefix	Abbreviation
10^{-24}	yocto	y	10^{3}	kilo	k
10^{-21}	zepto	z	10^{6}	mega	M
10^{-18}	atto	a	10^{9}	giga	G
10^{-15}	femto	f	10^{12}	tera	T
10^{-12}	pico	p	10^{15}	peta	P
10^{-9}	nano	n	10^{18}	exa	E
10^{-6}	micro	μ	10^{21}	zetta	Z
10^{-3}	milli	m	10^{24}	yotta	Y
10^{-2}	centi	c			
10^{-1}	deci	d			

Models of Matter

Some Greeks thought matter is made of atoms. No additional structure

JJ Thomson (1897) found electrons and showed atoms had structure.

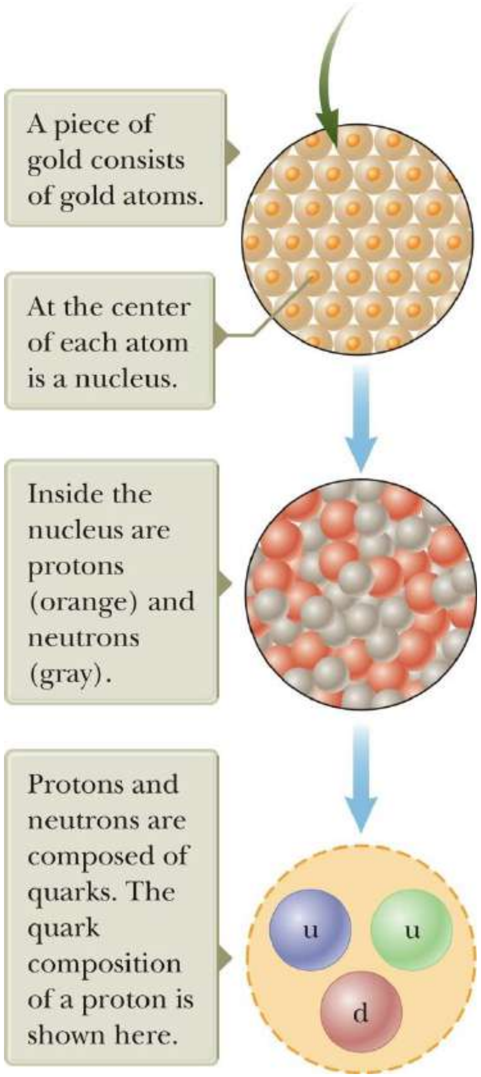
Rutherford (1911) determined a central nucleus surrounded by electrons.

Nucleus has structure, containing protons and neutrons

- Number of protons gives atomic number
- Number of protons and neutrons gives mass number

Protons and neutrons are made up of quarks.
Six Quarks: Up, down, strange, charmed, bottom, top

- Fractional electric charges
  - +⅔ of Up, charmed, top
  - ⅓ of Down, strange, bottom



Basic Quantities and Their Dimension

Dimension has a specific meaning – it denotes the physical nature of a quantity.

Dimensions are often denoted with square brackets.

- Length [L]
- Mass [M]
- Time [T]

Dimensions and Units

Each dimension can have many actual units.

Table 1.5 for the dimensions and units of some derived quantities

TABLE 1.5 *Dimensions and Units of Four Derived Quantities*

Quantity	Area (A)	Volume (V)	Speed (v)	Acceleration (a)
Dimensions	L^2	L^3	L/T	L/T^2
SI units	m^2	m^3	m/s	m/s^2
U.S. customary units	ft^2	ft^3	ft/s	ft/s^2

Dimensions and Units

Quantity	SI Unit		Dimension
velocity	m/s	ms^{-1}	LT^{-1}
acceleration	m/s^2	ms^{-2}	LT^{-2}
force	N $kg\ m/s^2$	$kg\ ms^{-2}$	$M\ LT^{-2}$
energy (or work)	Joule J N m, $kg\ m^2/s^2$	$kg\ m^2s^{-2}$	ML^2T^{-2}
power	Watt W N m/s $kg\ m^2/s^3$	Nms^{-1} $kg\ m^2s^{-3}$	ML^2T^{-3}
pressure (or stress)	Pascal P, N/m^2, $kg/m/s^2$	Nm^{-2} $kg\ m^{-1}s^{-2}$	$ML^{-1}T^{-2}$
density	kg/m^3	$kg\ m^{-3}$	ML^{-3}

Dimensional Analysis

Technique to check the correctness of an equation or to assist in deriving an equation

Dimensions (length, mass, time, combinations) can be treated as algebraic quantities.

- Add, subtract, multiply, divide

Both sides of equation must have the same dimensions.

Any relationship can be correct only if the dimensions on both sides of the equation are the same.

Cannot give numerical factors: this is its limitation

Example: Given the equation: $x = \frac{1}{2} a t^2$ Check dimensions on each side:

$$L = \frac{L}{\cancel{T^2}} \cdot \cancel{T^2} = L$$

The T^2's cancel, leaving L for the dimensions of each side.

- The equation is dimensionally correct.
- There are no dimensions for the constant.

Dimensional Analysis to Determine a Power Law

Determine powers in a proportionality

- Example: find the exponents in the expression

$$x \propto a^m t^n$$

  - You must have lengths on both sides.
  - Acceleration has dimensions of L/T^2
  - Time has dimensions of T.
  - Analysis gives $x \propto at^2$

Example

Suppose that the acceleration of a particle moving in circle of radius *r* with uniform velocity *v* is proportional to the r^n and v^m. Use the dimensional analysis to determine the power n and m.

Solution

Let us assume *a* is represented in this expression *a* = $k\, r^n\, v^m$

Where *k* is the proportionality constant of dimensionless unit.

The right hand side $[a] = \; = \frac{L}{T^2}$

The left hand side

$$[k\, r^n\, v^m] = L^n \left(\frac{L}{T}\right)^m = \frac{L^{n+m}}{T^m}$$

Therefore

$$\frac{L}{T^2} = \frac{L^{n+m}}{T^m}$$

hence

n+m=1 and m=2

Therefore. n =-1 and the acceleration a is $a = k\, r^{-1}\, v^2$

k=1 $$a = \frac{v^2}{r}$$

Conversion of Units

When units are not consistent, you may need to convert to appropriate ones.

See Appendix A for an extensive list of conversion factors.

Units can be treated like algebraic quantities that can cancel each other out.

Always include units for every quantity, you can carry the units through the entire calculation.

Multiply original value by a ratio equal to one.

Example:

$$15.0\,in = ?\,cm$$

$$15.0\,\cancel{in}\left(\frac{2.54\,cm}{1\,\cancel{in}}\right) = 38.1\,cm$$

- Note the value inside the parentheses is equal to 1, since 1 inch is defined as 2.54 cm.

conversions

Length

$1 \text{ in.} = 2.54 \text{ cm (exact)}$

$1 \text{ m} = 39.37 \text{ in.} = 3.281 \text{ ft}$

$1 \text{ ft} = 0.304\,8 \text{ m}$

$12 \text{ in.} = 1 \text{ ft}$

$3 \text{ ft} = 1 \text{ yd}$

$1 \text{ yd} = 0.914\,4 \text{ m}$

$1 \text{ km} = 0.621 \text{ mi}$

$1 \text{ mi} = 1.609 \text{ km}$

$1 \text{ mi} = 5\,280 \text{ ft}$

$1\ \mu\text{m} = 10^{-6} \text{ m} = 10^{3} \text{ nm}$

$1 \text{ lightyear} = 9.461 \times 10^{15} \text{ m}$

Area

$1 \text{ m}^2 = 10^4 \text{ cm}^2 = 10.76 \text{ ft}^2$

$1 \text{ ft}^2 = 0.092\,9 \text{ m}^2 = 144 \text{ in.}^2$

$1 \text{ in.}^2 = 6.452 \text{ cm}^2$

Volume

$1 \text{ m}^3 = 10^6 \text{ cm}^3 = 6.102 \times 10^4 \text{ in.}^3$

$1 \text{ ft}^3 = 1\,728 \text{ in.}^3 = 2.83 \times 10^{-2} \text{ m}^3$

$1 \text{ L} = 1\,000 \text{ cm}^3 = 1.057\,6 \text{ qt} = 0.035\,3 \text{ ft}^3$

$1 \text{ ft}^3 = 7.481 \text{ gal} = 28.32 \text{ L} = 2.832 \times 10^{-2} \text{ m}^3$

$1 \text{ gal} = 3.786 \text{ L} = 231 \text{ in.}^3$

Mass

$1\,000 \text{ kg} = 1 \text{ t (metric ton)}$

$1 \text{ slug} = 14.59 \text{ kg}$

$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931.5 \text{ MeV}/c^2$

conversions

Force

$1\ \text{N} = 0.224\,8\ \text{lb}$

$1\ \text{lb} = 4.448\ \text{N}$

Velocity

$1\ \text{mi/h} = 1.47\ \text{ft/s} = 0.447\ \text{m/s} = 1.61\ \text{km/h}$

$1\ \text{m/s} = 100\ \text{cm/s} = 3.281\ \text{ft/s}$

$1\ \text{mi/min} = 60\ \text{mi/h} = 88\ \text{ft/s}$

Acceleration

$1\ \text{m/s}^2 = 3.28\ \text{ft/s}^2 = 100\ \text{cm/s}^2$

$1\ \text{ft/s}^2 = 0.304\,8\ \text{m/s}^2 = 30.48\ \text{cm/s}^2$

Pressure

$1\ \text{bar} = 10^5\ \text{N/m}^2 = 14.50\ \text{lb/in.}^2$

$1\ \text{atm} = 760\ \text{mm Hg} = 76.0\ \text{cm Hg}$

$1\ \text{atm} = 14.7\ \text{lb/in.}^2 = 1.013 \times 10^5\ \text{N/m}^2$

$1\ \text{Pa} = 1\ \text{N/m}^2 = 1.45 \times 10^{-4}\ \text{lb/in.}^2$

Time

$1\ \text{yr} = 365\ \text{days} = 3.16 \times 10^7\ \text{s}$

$1\ \text{day} = 24\ \text{h} = 1.44 \times 10^3\ \text{min} = 8.64 \times 10^4\ \text{s}$

Energy

$1\ \text{J} = 0.738\ \text{ft} \cdot \text{lb}$

$1\ \text{cal} = 4.186\ \text{J}$

$1\ \text{Btu} = 252\ \text{cal} = 1.054 \times 10^3\ \text{J}$

$1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}$

$1\ \text{kWh} = 3.60 \times 10^6\ \text{J}$

Power

$1\ \text{hp} = 550\ \text{ft} \cdot \text{lb/s} = 0.746\ \text{kW}$

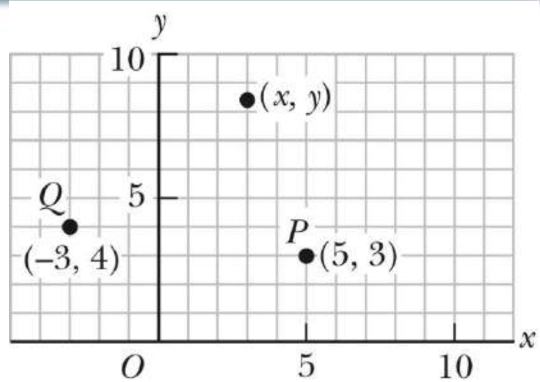
$1\ \text{W} = 1\ \text{J/s} = 0.738\ \text{ft} \cdot \text{lb/s}$

$1\ \text{Btu/h} = 0.293\ \text{W}$

Coordinate Systems

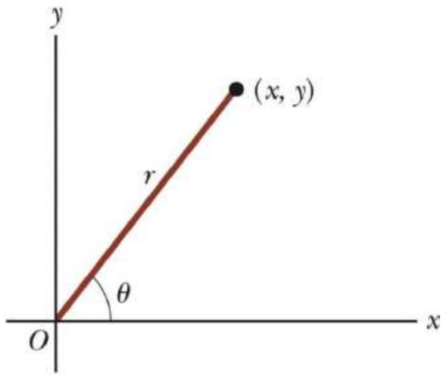
Used to describe the position of a point in space

Common coordinate systems are:



Cartesian Coordinate System

In Cartesian (Also called rectangular) coordinate system: x- and y- axes intersect at the origin Points are labeled (x,y)



Polar Coordinate System

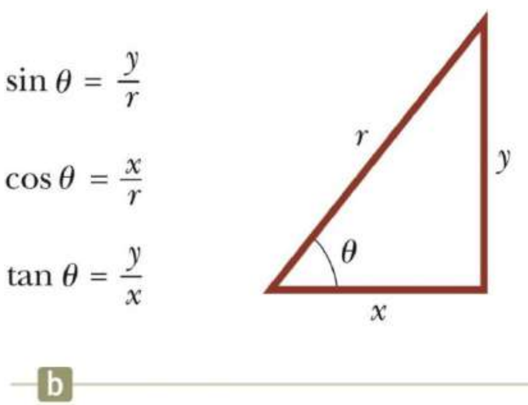
Origin and reference line are noted

Point is distance *r* from the origin in the direction of angle θ, from reference line. The reference line is often the x-axis. Points are labeled (r,θ). Based on forming a right triangle from *r* and θ

$x = r\cos\theta$ *and* $y = r\sin\theta$

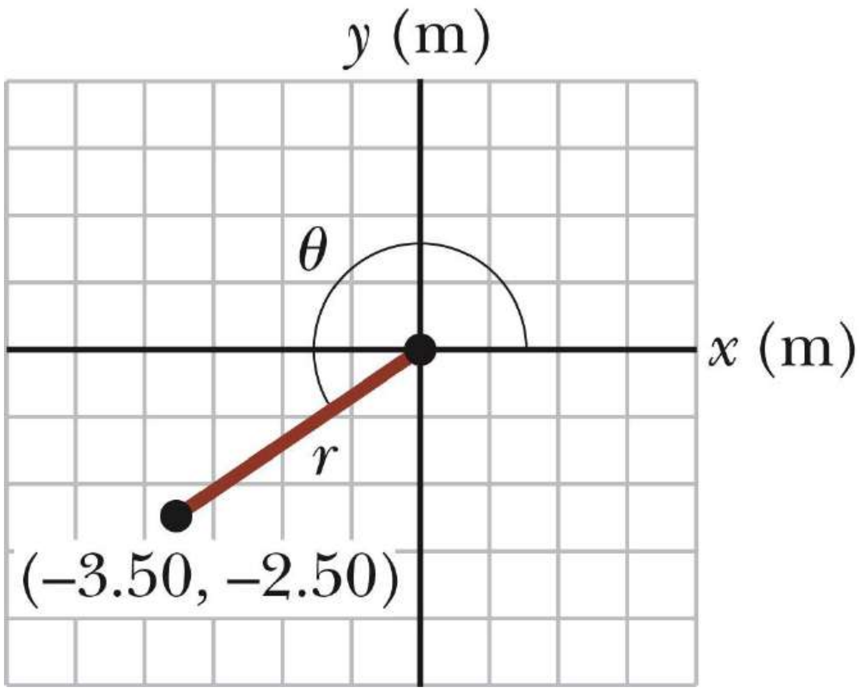
If the Cartesian coordinates are known: $\tan\theta = \frac{y}{x}$

$$r = \sqrt{x^2 + y^2}$$



Example

The Cartesian coordinates of a point in the *xy* plane are (*x*,*y*) = (-3.50, -2.50) m, as shown in the figure. Find the polar coordinates of this point.



Solution: From Equation 3.4,

$$r = \sqrt{x^2 + y^2}$$
$$= \sqrt{(-3.50\ \text{m})^2 + (-2.50\ \text{m})^2}$$
$$= 4.30\ \text{m}$$

and from Equation 3.3,

$$\tan\theta = \frac{y}{x} = \frac{-2.50\ \text{m}}{-3.50\ \text{m}} = 0.714$$
$$\theta = 216^\circ \quad \text{(signs give quadrant)}$$

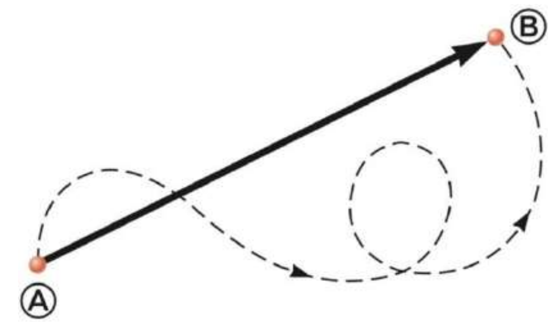
Vectors and Scalars

A ***scalar quantity*** is completely specified by a single value with an appropriate unit and has no direction. It may be positive or negative.

A ***vector quantity*** is completely described by a number and appropriate units plus a direction.

Example: A particle travels from A to B along

the path shown by the broken line.



- This is the ***distance*** traveled and is a scalar.

The ***displacement*** is the solid line from A to B

- The ***displacement*** is the solid line from A to B and it is a vector
- The displacement is independent of the path taken between the two points.

Vector Notation

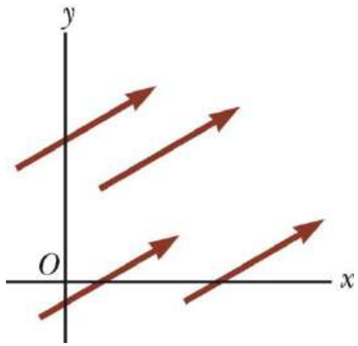
Text uses bold with arrow to denote a vector: $\vec{\mathbf{A}}$ or for printing is simple bold print: **A**. When dealing with just the magnitude of a vector in print, an italic letter will be used: *A* or $|\vec{\mathbf{A}}|$

- The magnitude of the vector has physical units.
- The magnitude of a vector is always a positive number.

Equality of Two Vectors

Two vectors are ***equal*** if they have the same magnitude and the same direction.

$\vec{\mathbf{A}} = \vec{\mathbf{B}}$ if $A = B$ and they point along parallel lines



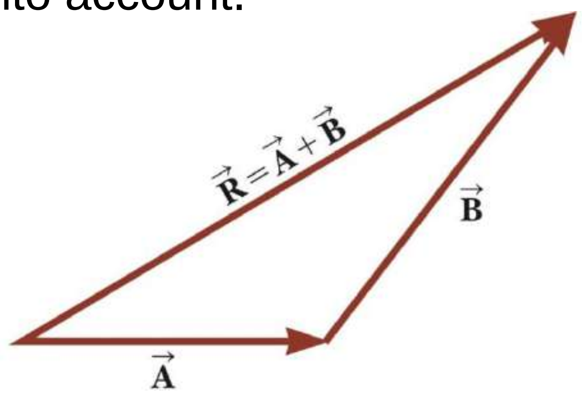
Adding Vectors

Vector addition is very different from adding scalar quantities.

When adding vectors, their directions must be taken into account.

The resultant is drawn from the origin of the first vector to the end of the last vector.

Measure the length of the resultant and its angle.



The negative of the vector will have the same magnitude, but point in the opposite direction.

- Represented as $-\vec{\mathbf{A}}$
-

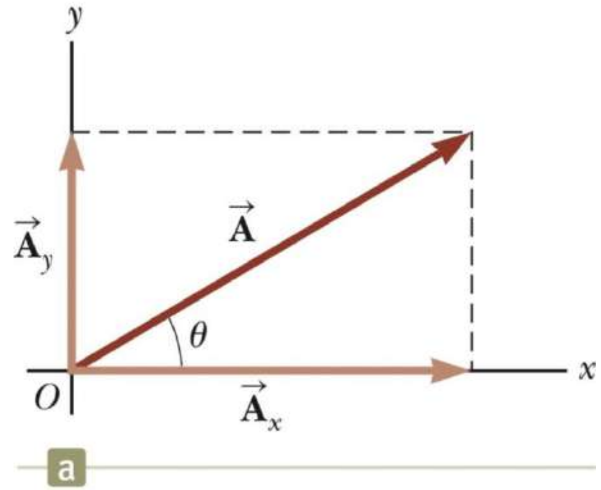
To subtract two vectors use $\vec{\mathbf{A}} - \vec{\mathbf{B}}$ as $\vec{\mathbf{A}} + (-\vec{\mathbf{B}})$

Components of a Vector

A **component** is a projection of a vector along an axis. Any vector can be completely described by its components.

It is useful to use **rectangular components.**

- A_x and A_y are the projections of the vector along the x- and y-axes.



The **x-component** of a vector is the projection along the x-axis. [illegible]

The **y-component** of a vector is the projection along the y-axis. [illegible]

This assumes the angle θ is measured with respect to the x-axis.

If not, do not use these equations, use the sides of the triangle directly.

The components are the legs of the right triangle whose hypotenuse is the length of *A.*

- [illegible]
- May still have to find θ with respect to the positive x-axis

In a problem, a vector may be specified by its components or its magnitude and direction.

Unit Vectors

A ***unit vector*** is a dimensionless vector with a magnitude of exactly 1.

Unit vectors are used to specify a direction and have no other physical significance.

The symbols $\hat{i}, \hat{j}$, and $\hat{k}$ represent unit vectors

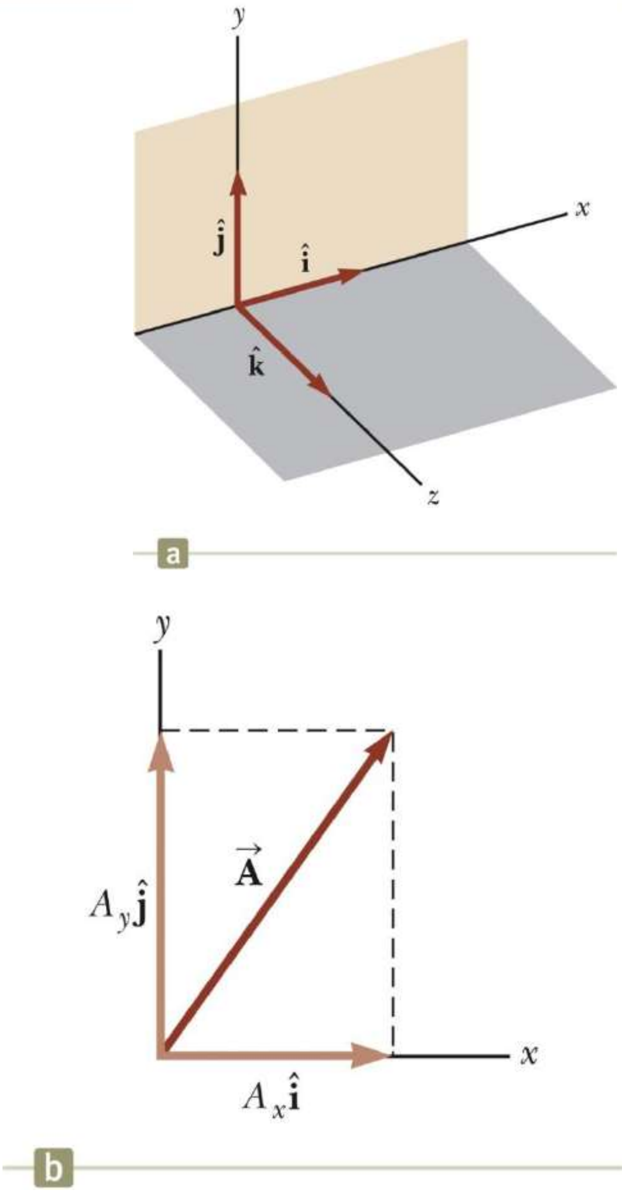
They form a set of mutually perpendicular vectors in a right-handed coordinate system

The magnitude of each unit vector is 1

$$|\hat{\mathbf{i}}| = |\hat{\mathbf{j}}| = |\hat{\mathbf{k}}| = 1$$

$\mathbf{A_x}$ is the same as $A_x\,\hat{\mathbf{i}}$ and $\mathbf{A_y}$ is the same as $A_y\,\hat{\mathbf{j}}$ etc.
The complete vector can be expressed as:

$$\vec{\mathbf{A}} = A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}$$



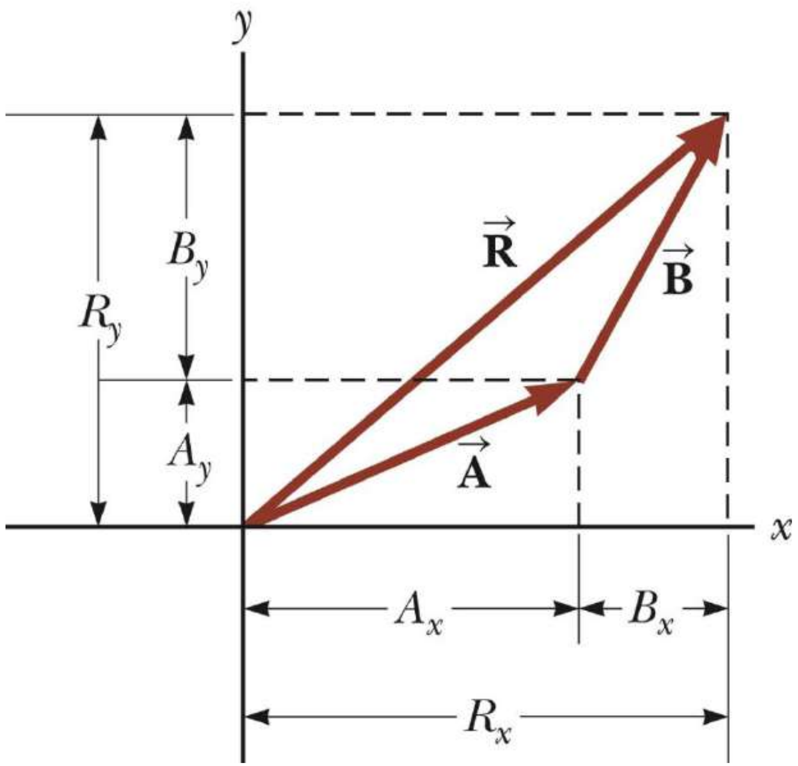
Adding Vectors Using Unit Vectors

Using $\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$

Then $\vec{\mathbf{R}} = \left(A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}\right) + \left(B_x\hat{\mathbf{i}} + B_y\hat{\mathbf{j}}\right)$

$$\vec{\mathbf{R}} = \left(A_x + B_x\right)\hat{\mathbf{i}} + \left(A_y + B_y\right)\hat{\mathbf{j}}$$

$$\vec{\mathbf{R}} = R_x\hat{\mathbf{i}} + R_y\hat{\mathbf{j}}$$



So $R_x = A_x + B_x$ and $R_y = A_y + B_y$

$$R = \sqrt{R_x^2 + R_y^2} \qquad \theta = \tan^{-1}\frac{R_y}{R_x}$$

Three-Dimensional Extension

$$\vec{R} = \left(A_x\hat{i} + A_y\hat{j} + A_z\hat{k}\right) + \left(B_x\hat{i} + B_y\hat{j} + B_z\hat{k}\right)$$

$$\vec{R} = \left(A_x + B_x\right)\hat{i} + \left(A_y + B_y\right)\hat{j} + \left(A_z + B_z\right)\hat{k}$$

$$\vec{R} = R_x\hat{i} + R_y\hat{j} + R_z\hat{k}$$

$$R = \sqrt{R_x^2 + R_y^2 + R_z^2} \qquad \theta = \cos^{-1}\frac{R_x}{R}$$

The result of the multiplication or division of a vector by a scalar is a vector.

The magnitude of the vector is multiplied or divided by the scalar

Example

Two vectors are given by $A = 3i - 2j$ and $B = -i - 4j$. Calculate (a) $\vec{A} + \vec{B}$, (b) $\vec{A} - \vec{B}$, (c) $|\vec{A} + \vec{B}|$, (d) $|\vec{A} - \vec{B}|$, and (e) the direction of $\vec{A} + \vec{B}$ and $|\vec{A} - \vec{B}|$.

(a) $\vec{A} + \vec{B} = (3i - 2j) + (-i - 4j) = 2i - 6j$

(b) $\vec{A} - \vec{B} = (3i - 2j) - (-i - 4j) = 4i + 2j$

(c) $|\vec{A} + \vec{B}| = \sqrt{2^2 + (-6)^2} = 6.32$

(d) $|\vec{A} - \vec{B}| = \sqrt{4^2 + 2^2} = 4.47$

(e) For $\vec{A} + \vec{B}$, $\theta = \tan^{-1}(-6/2) = -71.6^\circ = 288^\circ$

For $\vec{A} - \vec{B}$, $\theta = \tan^{-1}(2/4) = 26.6^\circ$

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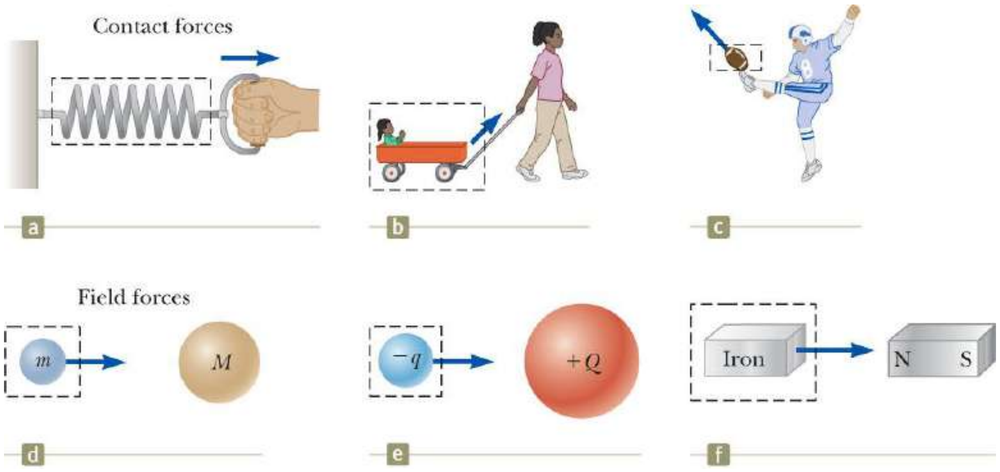
Chapter 2 - Force and Laws of Motion

Forces

- A force is that which causes an acceleration. Formulated by Sir Isaac Newton (1642 – 1727)



Classes of Forces

Contact forces involve physical contact between two objects. Examples a, b, c

Field forces act through empty space. Examples d, e, f

Fundamental Forces

Gravitational force: Between objects

Electromagnetic forces: Between electric charges

Nuclear force: Between subatomic particles

Weak forces: Arise in certain radioactive decay processes

Note: These are all field forces.

Newton's First Law

states that an object at rest will remain at rest and an object in motion will remain in motion with a constant velocity unless acted on by a net external force.

- Can conclude that any isolated object is either at rest or moving at a constant velocity

The First Law also allows the definition of ***force*** as ***that which causes a change in the motion of an object.***

The tendency of an object to resist any attempt to change its velocity is called ***inertia.***

Mass is that property of an object that specifies how much resistance an object exhibits to changes in its velocity.

Mass is a scalar quantity. The SI unit of mass is kg.

Mass and **weight** are two different quantities.

Weight is equal to the magnitude of the gravitational force exerted on the object.

- Weight will vary with location.
- m_{earth} = 3 kg; m_{moon} = 3 kg
- w_{earth} = 30 N; w_{moon} ~ 6 N

Newton's Second Law

states that the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. Force is the cause of *changes* in motion, as measured by the acceleration.

- Remember, an object can have motion in the absence of forces.

$$\vec{\mathbf{a}} \propto \frac{\sum \vec{\mathbf{F}}}{m} \rightarrow \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

$\sum \vec{\mathbf{F}}$ is the net force. May also be called the total force, resultant force

- This is the vector sum of all the forces acting on the object.

Newton's Second Law can be expressed in terms of components:

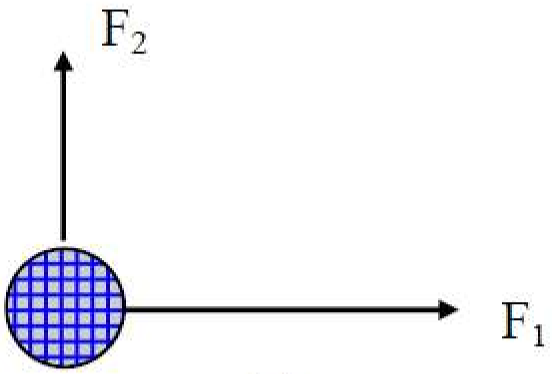
- $\Sigma F_x = m\ a_x$
- $\Sigma F_y = m\ a_y$
- $\Sigma F_z = m\ a_z$

The SI unit of force is the **newton** (N).

- $1\ \text{N} = 1\ \text{kg}\cdot\text{m} / \text{s}^2$

Example

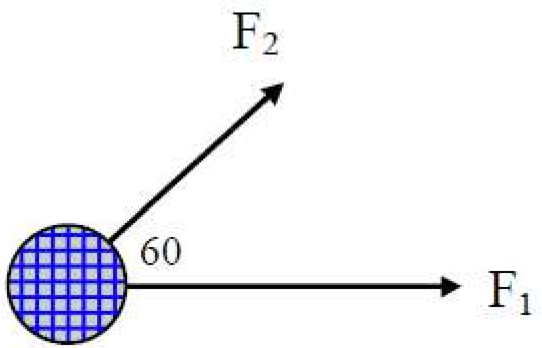
Two forces, $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$, act on a 5-kg mass. If F_1 =20 N and F_2 =15 N,
find the acceleration in (a) and (b) of the Figure



(a)

Solution

(a) $\sum F = F_1 + F_2 = (20i + 15j)$ N
$\sum F = ma \therefore 20i + 15j = 5\ a$
$a = (4i + 3j)$ m/s2 or a = 5m/s2
(b) $F2$x = 15 cos 60 = 7.5 N
$F2$y = 15 sin 60 = 13 N
$F2 = (7.5i + 13j)$ N
$\sum F = F1 + F2 = (27.5i + 13j) = ma = 5\ a$
$a = (5.5i + 2.6j)$ m/s2 or a = 6.08m/s2



(b)

Gravitational Force

The gravitational force, $\vec{\mathbf{F}}_g$, is the force that the earth exerts on an object.

This force is directed toward the center of the earth.

From Newton's Second Law:

- $\vec{\mathbf{F}}_g = m\vec{\mathbf{g}}$

Its magnitude is called the weight of the object.

- Weight = $F_g = mg$
- *g*, and therefore the weight, is less at higher altitudes.
- This can be extended to other planets, but the value of g varies from planet to planet, so the object's weight will vary from planet to planet.
- The weight is a property of a *system* of items: the object and the Earth.

Note about units:

- Kilogram is **not** a unit of weight.
- 1 kg = 2.2 lb is an equivalence valid only on the Earth's surface.

Newton's Third Law

If two objects interact, the force $\vec{F}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{F}_{21}$ exerted by object 2 on object 1.

- $\vec{F}_{12} = -\vec{F}_{21}$
- Note on notation: $\vec{F}_{AB}$ is the force exerted *by* A *on* B.

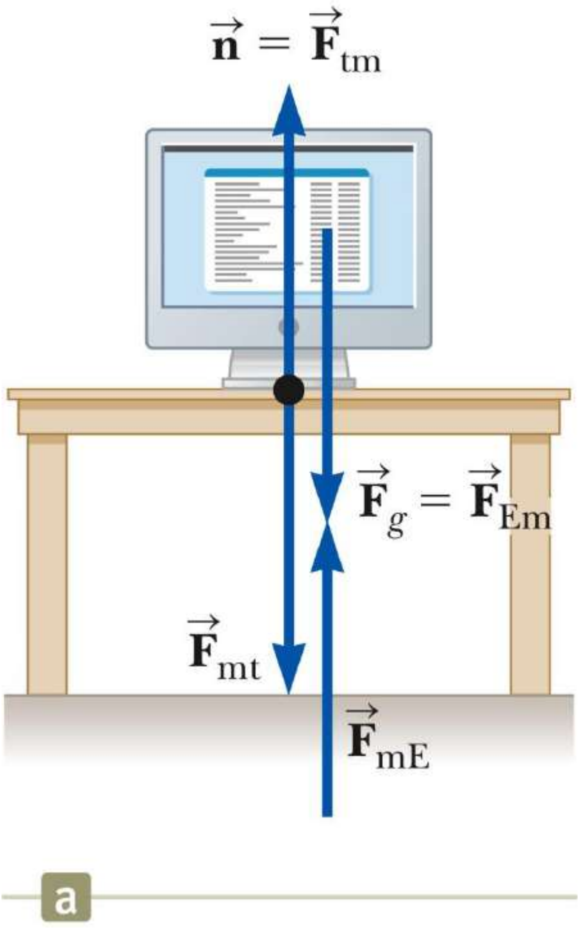
The action force is equal in magnitude to the reaction force and opposite in direction.

- One of the forces is the action force, the other is the reaction force.

The normal force (table on monitor) is the reaction of the force the monitor exerts on the table. (Figure a)

- Normal means perpendicular, in this case

The action (Earth on monitor) force is equal in magnitude and opposite in direction to the reaction force, the force the monitor exerts on the Earth.



Free Body Diagram

In a free body diagram, you want the forces acting on a particular object. (Figure b)

- Model the object as a particle

The normal force and the force of gravity are the forces that act on the monitor.

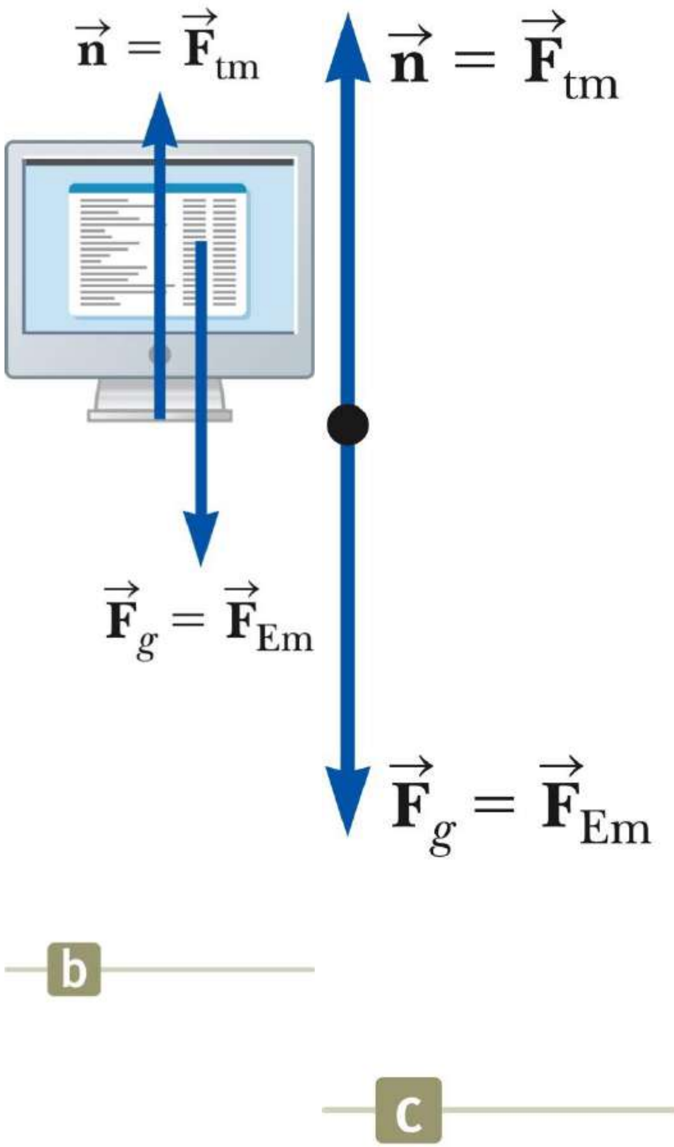
The most important step in solving problems involving Newton's Laws is to draw the free body diagram.

Be sure to include only the forces acting on the object of interest.

Include any field forces acting on the object.

Do not assume the normal force equals the weight.

The forces that act on the object are shown as being applied to the dot. The free body helps isolate only those forces acting on the object and eliminate the other forces from the analysis.



The object in Equilibrium

If the acceleration of an object is zero, the object is said to be in **equilibrium.**

- The model is the *particle in equilibrium.*

Mathematically, the net force acting on the object is zero.

$\Sigma F = 0$

Equilibrium, Example

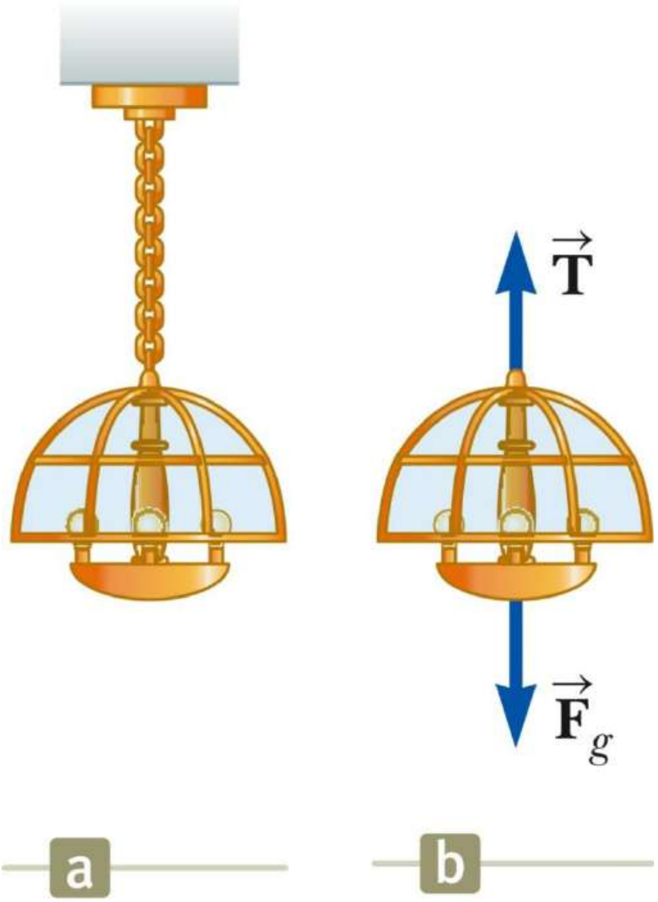
A lamp is suspended from a chain of negligible mass.

The forces acting on the lamp are:

- the downward force of gravity
- the upward tension in the chain

Applying equilibrium gives

$$\sum F_y = 0 \rightarrow T - F_g = 0 \rightarrow T = F_g$$



Forces in and on the body

1- Muscular forces that cause the blood to circulate and the lungs to take in air.

2- Molecular forces (in bone , calcium atom).

3- Electric forces.

4- Gravitational forces.

Medical effects of gravitation forces

Medical effects of gravitation forces is the formation of varicose veins in the legs as the venous blood travels against the force of gravity on its way to the heart, and the second effects is on the bone.

If a person becomes weightless such as in orbiting satellite, he may lose bone mineral.

Long term bed rest removes much of the force of the body weight from bones.

Frictional Force

Friction and energy loss due to friction appear every day in our life.

The maximum force of friction F is

F = μ N

Where **N** is a normal force

μ Is the coefficient betwee the two surfaces.

The value of μ depends upon the two materials contact , and it is essentially independen of the surface area , as shown in Table 1.

Table 2.1. Example Values of Coefficient of Friction

Material	μ (Static Friction)
Steel on steel	0.15
Rubber tire on dry concrete road	1.00
Rubber tire on wet concrete road	0.7
Steel on ice	0.03
Between tendon and sheath	0.013
Lubricated bone joint	0.003

When a person is walking , as the heel of the foot touches the ground a force is transmitted from the foot to the ground.

we can resolve this force into horizontal and vertical components. The vertical reaction force is applied by the surface and is labeled N (normal force).

The horizontal reaction component must be applied by frictional forces, as shown in figure.

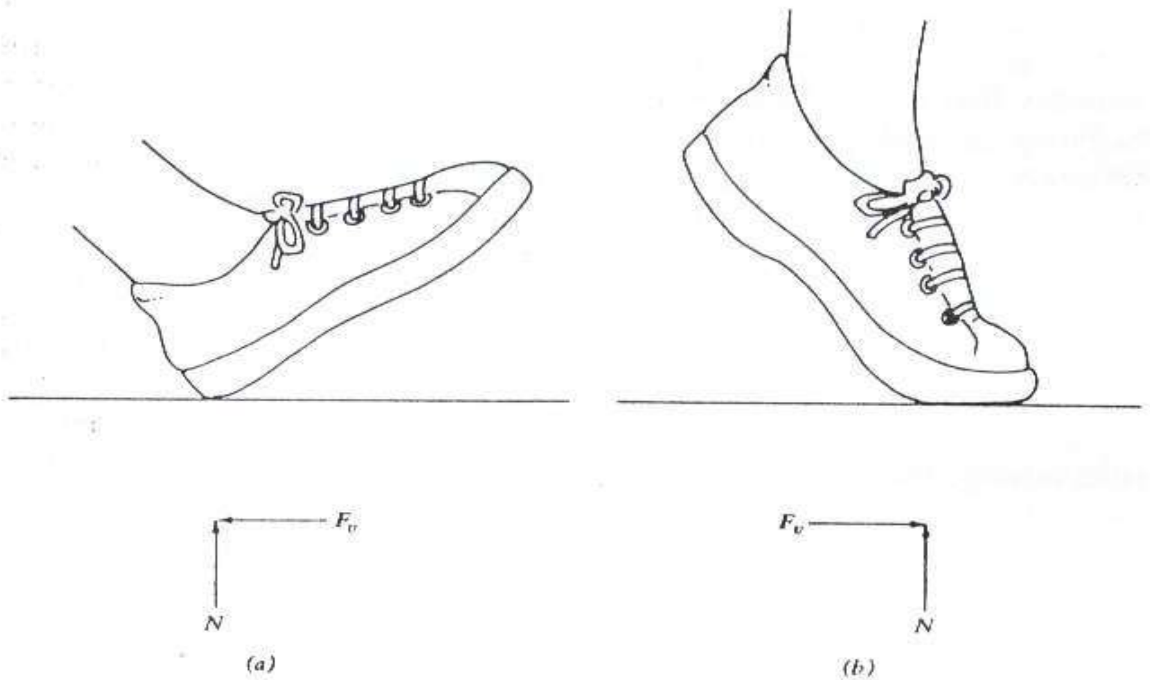


Figure 2.9. Normal walking. (a) Both a horizontal frictional component of force F_v and a vertical (normal) component of force N exist on the heel as it strikes the ground. Friction between the heel and surface prevents the foot from slipping forward. (b) When the foot leaves the ground the frictional component of force F_v prevents the toe from slipping backward. (Adapted from Williams, M., and Lissner, H.R., *Biomechanics of Human Motion*, Philadelphia, W.B. Saunders Company, 1962, p. 122, by permission.)

Measurements have been made of the horizontal force component of the heel as it strikes the ground when a person is walking, and it has been to be = 0.15 W,

where W is the person’s weight.

The frictional force is large enough both when the heel touches down and when the toe leaves the surface to prevent a person from slipping.

this how large the frictional force must be in order to prevent the heel from slipping.

The coefficient of friction in bone joints is very small (Table 1).

If a disease of the joint exists, the friction may become large.

The synovial fluid in the joint is involved in the lubrication.

The saliva we add when we chew food acts as a lubricant (to reduce the friction force).

For example, if you swallow a piece of dry toast you become painfully aware of this lack of lubricant.

The Object Under a Net Force, the dynamical force

According to second law of Newton, the force is equal

F = ma = Δ(mv) / Δt

where mv is the momentum

Example: Forces acting on the crate:

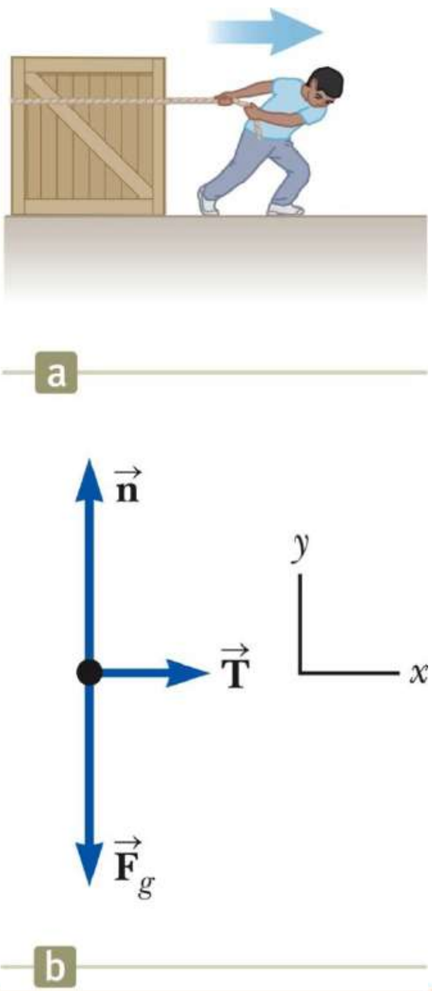
- A tension, acting through the rope, is the magnitude of force $\vec{\mathbf{T}}$
- The gravitational force, $\vec{\mathbf{F}}_g$
- The normal force, $\vec{\mathbf{n}}$, exerted by the floor

Apply Newton's Second Law in component form:

$$\sum F_x = T = ma_x$$

$$\sum F_y = n - F_g = 0 \rightarrow n = F_g$$

Solve for the unknown(s)



Example 1: A 60 Kg person walking at 1 m/sec bumps into a wall and stops in a distance of 2.5 cm in about 0.05 sec . what is the force developed on impact ?

$\Delta(mv) = (60\ Kg)\ (1 m/sec) - (60\ Kg)\ (0\ m/sec) = 60\ Kg\ m/sec$

the force developed on impact is

$F = \Delta(mv)/\Delta t = 60 Kg\ m/sec / 0.05 = 1200\ Kg\ m/sec^2$

$F = 1200$ Newton

Example 2: A 50kg person jumping from a height of 1 m is travelling at 4.5 m/sec just prior to landing. Suppose she lands on a pad and stops in 0.2 sec . What maximum force will she experience ?

$F = \Delta (mv)/\Delta t = 50 x\ 4.5/0.2 = 1125\ N$

Example 3: Estimate the force on the forehead if the mass of the head is 4 kg, its velocity is 15 m/sec, and the padded dash stops it in 0.002 sec.

$F = \Delta (mv)/\Delta t = 4 \times 15 / 0.002 = 3 \times 10^4\ N$

Medical Physics

Lectures in General Physics for Medical Sciences Students

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Chapter 3 - Static Equilibrium and Elasticity

Static Equilibrium

Equilibrium implies that the object moves with both constant velocity and constant angular velocity relative to an observer in an inertial reference frame.

Will deal now with the special case in which both of these velocities are equal to zero

- This is called ***static equilibrium***.

Static equilibrium is a common situation in engineering.

The principles involved are of particular interest to civil engineers, architects, and mechanical engineers.

Rigid Object in Equilibrium

In *the particle in equilibrium model* a particle moves with constant velocity because the net force acting on it is zero.

- The objects often cannot be modeled as particles.

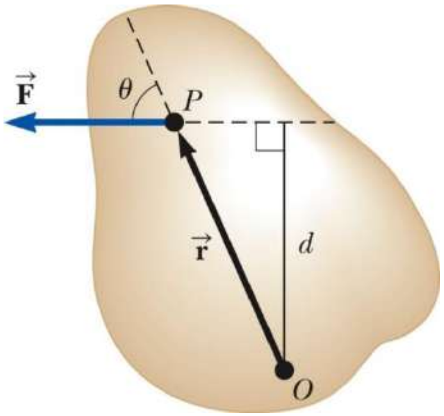
For an extended object to be in equilibrium, a second condition of equilibrium must be satisfied.

- This second condition involves the rotational motion of the extended object.

Torque

$$\vec{\tau} = \vec{\mathbf{F}} \times \vec{\mathbf{r}}$$

- The tendency of the force to cause a rotation about O depends on F and the moment arm *d.* The net torque on a rigid object causes it to undergo an angular acceleration.



The net external force on the object must equal zero.

- $\sum \vec{\mathbf{F}}_{ext} = 0$
- If the object is modeled as a particle, then this is the only condition that must be satisfied.

The net external torque on the object about any axis must be zero.

- $\sum \vec{\tau}_{ext} = 0$
- This is needed if the object cannot be modeled as a particle.

These conditions describe the **rigid object in equilibrium analysis model.**

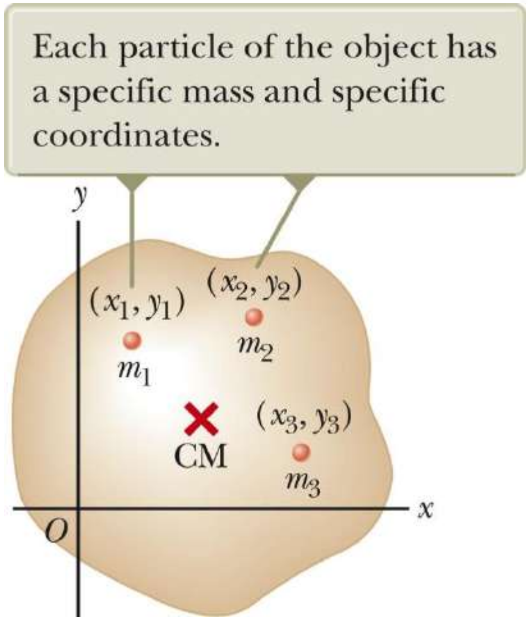
We will restrict the applications to situations in which all the forces lie in the xy plane. There are three resulting equations:

- $\Sigma F_x = 0$, $\Sigma F_y = 0$
- $\Sigma \tau_z = 0$

Center of Mass

An object can be divided into many small particles.

- Each particle will have a specific mass and specific coordinates.



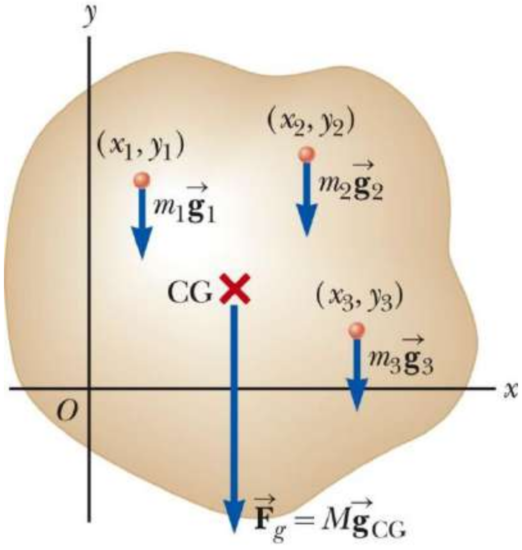
The x coordinate of the center of mass will be

$$x_{CM} = \frac{\sum_i m_i x_i}{\sum_i m_i}$$

Similar expressions can be found for the y and z coordinates.

Center of Gravity

All the various gravitational forces acting on all the various mass elements are equivalent to a single gravitational force acting through a single point called the center of gravity (CG).



Each particle contributes a torque about an axis through the origin equal in magnitude to the particle’s weight multiplied by its moment arm.

The center of gravity of the object coincides with its center of mass.

Center of Gravity of Humans

Another technique used to determine the center of gravity of humans is described in the figure below.

A board of length l is supported at its ends resting on scales adjusted to read zero with the board alone.

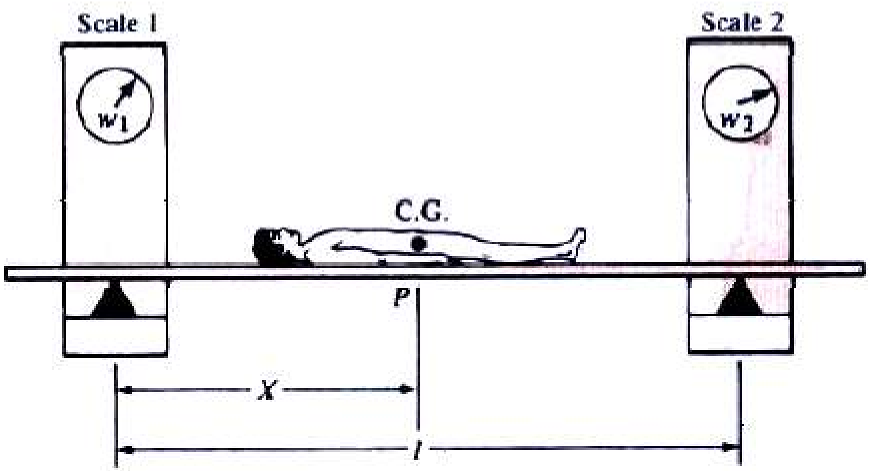
When a person lies on the board the scales read w_1 and w_2.

The condition for the torque $\Sigma\tau = 0$ can be used to Find X.

- The torque about point P is

$$Xw_1 - (l - X)w_2 = 0$$

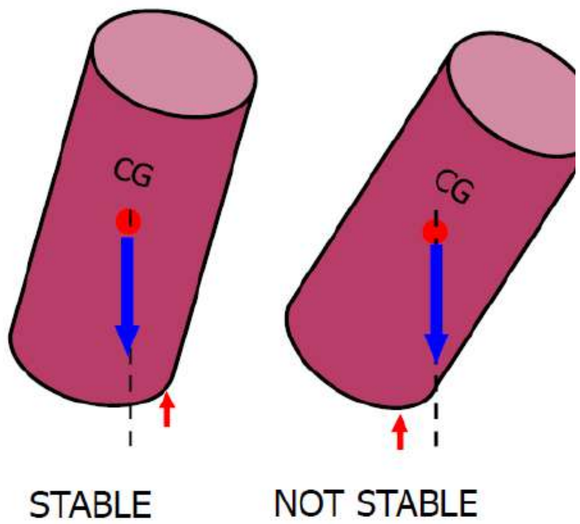
$$X = \frac{lw_2}{w_1 + w_2}$$



Stability

Why things fall over

- if the center of gravity is **supported**, the object will not fall over.
- You generally want a running back with a low CG, then it's harder to knock him down.
- The lower the CG the more **stable** an object is. Stable, not easy to knock over!



Condition for stability

If the CG is above the edge, the object

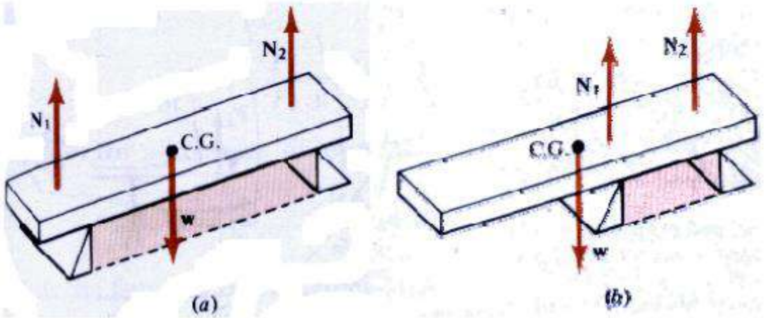
will not fall.

If the vertical line extending down from

the CG is inside the edge the object will

return to its upright position,

the torque due to gravity brings it back.

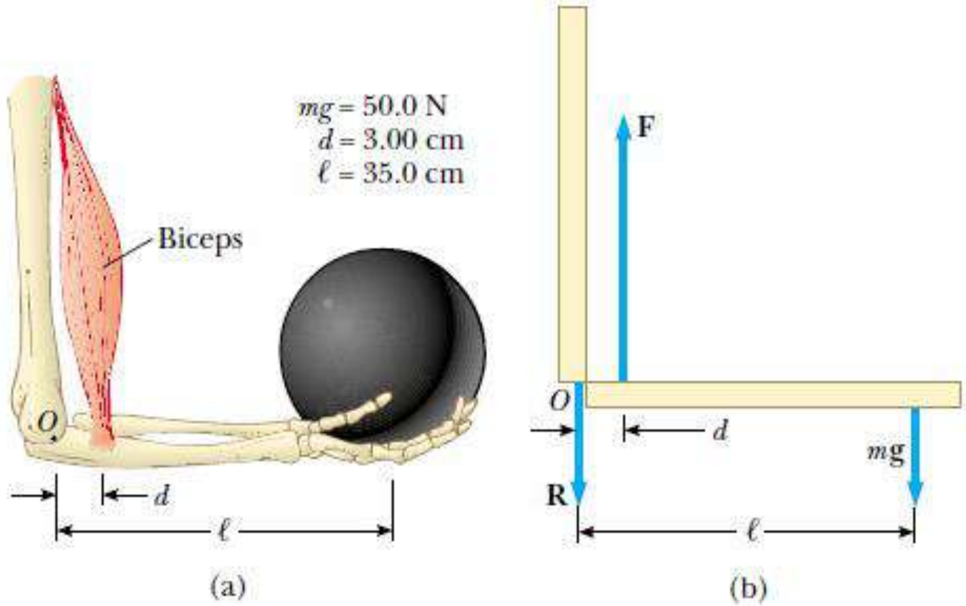


The beam is in equilibrium

The beam is not in equilibrium

Example A Weighted Hand

F is the upward force exerted by the biceps and R is the downward forc exerted by the upper arm at the joint.



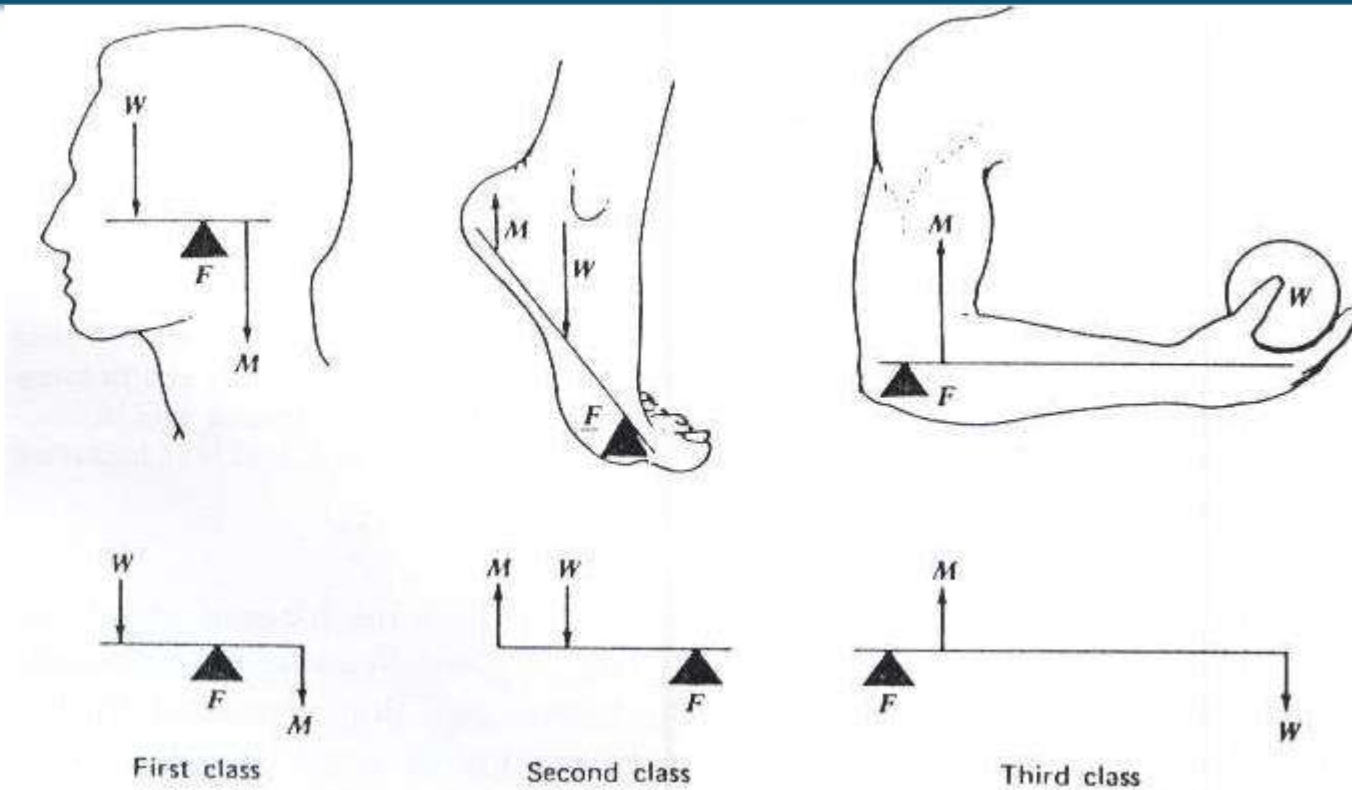
$$\sum F_y = F - R - 50.0\text{ N} = 0$$

$$\sum \tau = Fd - mg\ell = 0$$

$$F(3.00\text{ cm}) - (50.0\text{ N})(35.0\text{ cm}) = 0$$

$$F = 583\text{ N}$$

This value for *F* can be substituted into to give *R* =533 N. As this example shows, the forces at joints and in muscles can be extremely large.



Torque = force x length

The sum of the torque's about any axis is equals to zero.

In the body, many of the muscles and bones systems acts as levers.

Levers are classified as first, second, and third - class systems as shown in figure.

Example of a levers system in the body

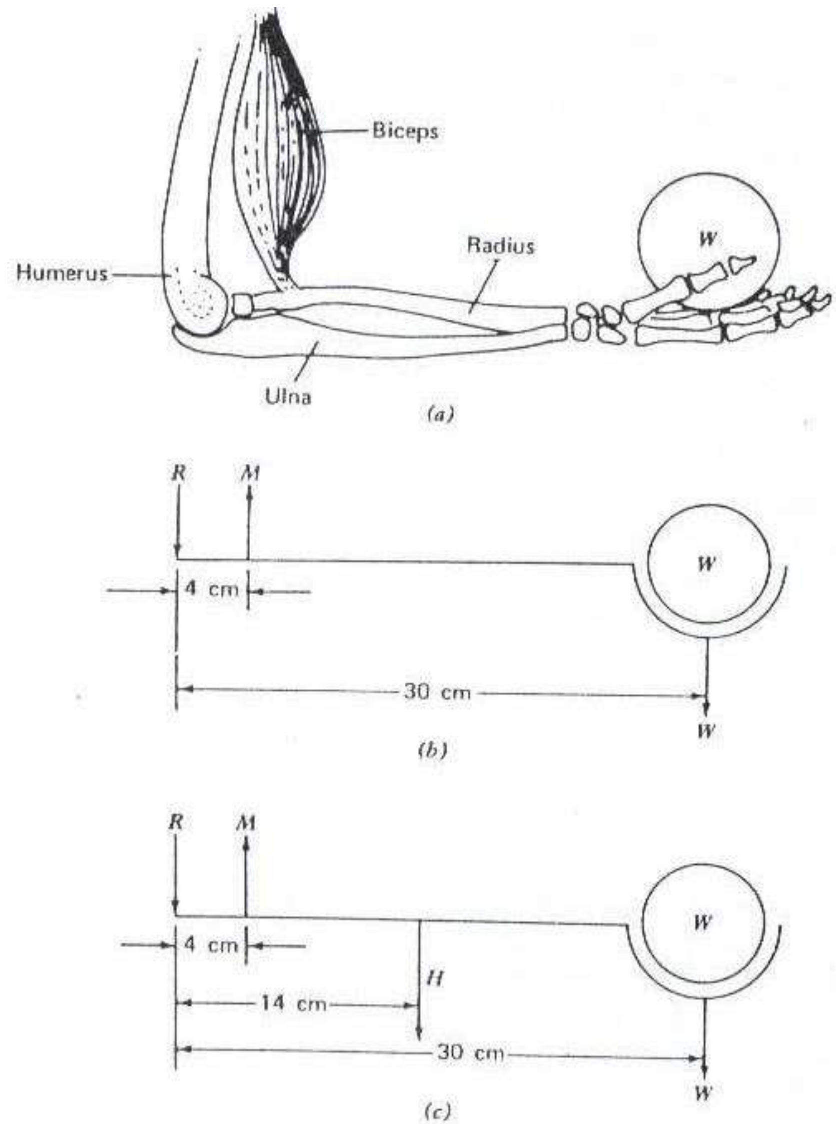
A simple class of a levers in the body is the case of the biceps muscle and the radius bone acting to support a weight **W** in the hand, as shown in fig.

For example, we can find the force supplied by the biceps, if we sum the torque's about the pivot point at the joint (fig b).

There are only two torque's;

1.due the weight W acting clock wise, for example: torque =30 W

2. produced by the muscle force M, which is counterclockwise, for example = 4M



when the arm is in equilibrium, we find that

4M = 30W

where **M is the muscular force**, **W is weight of the object**

M = 7.5 W

If W = 20 Newton then 4 M – 30 x 20 = 0

M = 30 x 20 /4= 15 Newton

In case of finding the center of gravity for the weight of the forearm and hand H, we consider all the weight at point as shown in figure c.

For example a typical value of hand is H = 15 N

By assuming torque's about the joint we obtain

4 M = 30 W + 14 H

M =7.5 W + 3.5 H

W = weight = 20 N

H = hand weight = 15 N

M =7.5 W + 3.5 H

M =7.5 x 30 + 3.5 x 15 = 15 + 52.5 = 67.5 Newton

Example

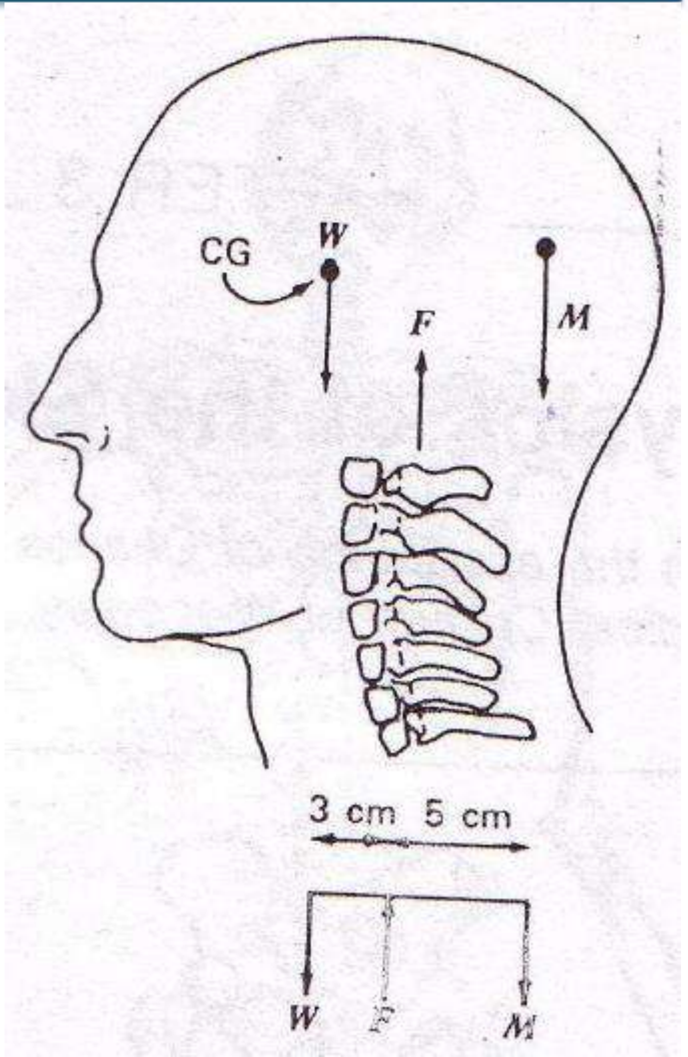
One first class lever system involves the extensor muscle , which exerts a force M to hold the head erect:

the force W of the weight of the head, located at its center of gravity, lies forward of the force F exerted by the first cervical vertebra . the head has a mass of about 4 kg or is about 40N.

a. Find F and M .

b. If the area of the first cervical vertebra, which the head rests on ,is 5 cm² , find the stress on it .

c . What is this stress for a 70 Kg person standing on his head ? how does this stress compare with the maximum compression strength for bones (1.7 x10^8 N/m²).



Answer

(a)The distance between F and W =3 cm

The distance between F and M =5 cm

3W = 5M

M = 0.6 W

W= 4 kg Or W= 40 N

M= 0.6 x 40 = 24 N

F = W + M = 64 N

(b)The stress is 64/5 x 10^{-4}

stress = 1.28 x 10^{5} N/m²

The mass of body is 70 kg

The mass of head is 4 kg

In standing position = 70 – 4 = 66 kg

The stress = 66 x 9.8 / 5x 10^{-4} = 1.3 x 10^{6} N/m²

Which is less 1 % of the maximum compression strength .

Elasticity

So far we have assumed that objects remain rigid when external forces act on them.

- Except springs

Actually, all objects are deformable to some extent.

- It is possible to change the size and/or shape of the object by applying external forces.

Internal forces resist the deformation.

Stress

- Is proportional to the force causing the deformation
- It is the external force acting on the object per unit cross-sectional area.

Strain

- Is the result of a stress
- Is a measure of the degree of deformation

Elastic Modulus

The elastic modulus is the constant of proportionality between the stress and the strain.

- For sufficiently small stresses, the stress is directly proportional to the stress.
- It depends on the material being deformed.
- It also depends on the nature of the deformation.

The elastic modulus, in general, relates what is done to a solid object to how that object responds.

$$\textit{elastic}\ \text{modulus} \equiv \frac{\textit{stress}}{\textit{strain}}$$

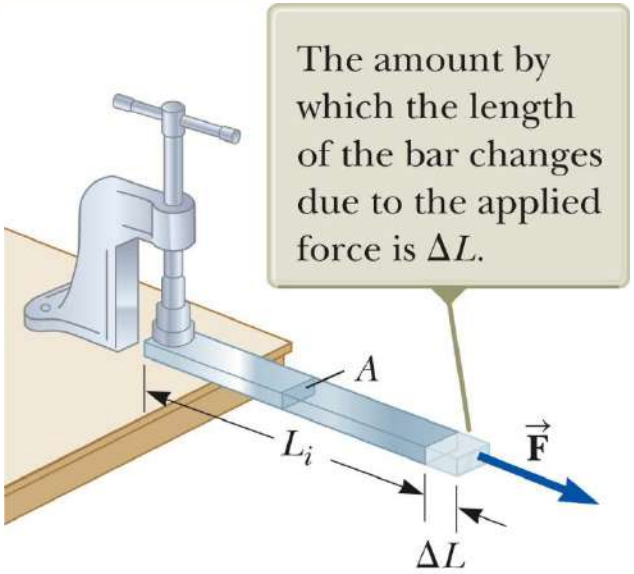
Various types of deformation have unique elastic moduli.

Young's Modulus: Measures the resistance of a solid to a change in its length

Shear Modulus: Measures the resistance of motion of the planes within a solid parallel to each other

Bulk Modulus: Measures the resistance of solids or liquids to changes in their volume

Young's Modulus



The bar is stretched by an amount ΔL under the action of the force F.

The **tensile stress** is the ratio of the magnitude of the external force to the cross-sectional area A.

The **tension strain** is the ratio of the change in length to the original length.

Young's modulus, Y, is the ratio of those two ratios:

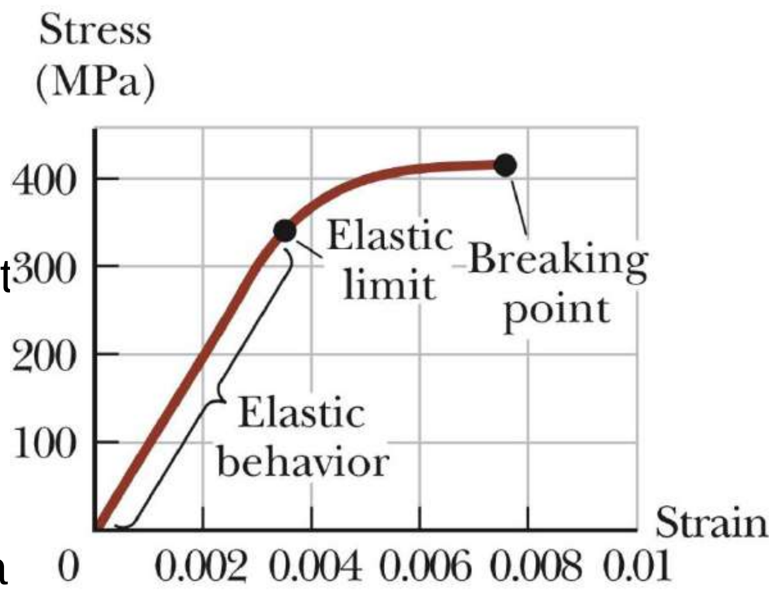
$$Y \equiv \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{F/A}{\Delta L/L_i}$$

Units are N / m^2

Experiments show that for certain stresses, the stress is directly proportional to the strain. This is t
elastic behavior part of the curve.

When the stress exceeds **the elastic limit**, the substance will be permanently deformed.

With additional stress, the material ultimately brea



Shear Modulus

Another type of deformation occurs when a force acts parallel to one of its faces while the opposite face is held fixed by another force.

This is called a ***shear stress.***

For small deformations, no change in volume occurs with this deformation.

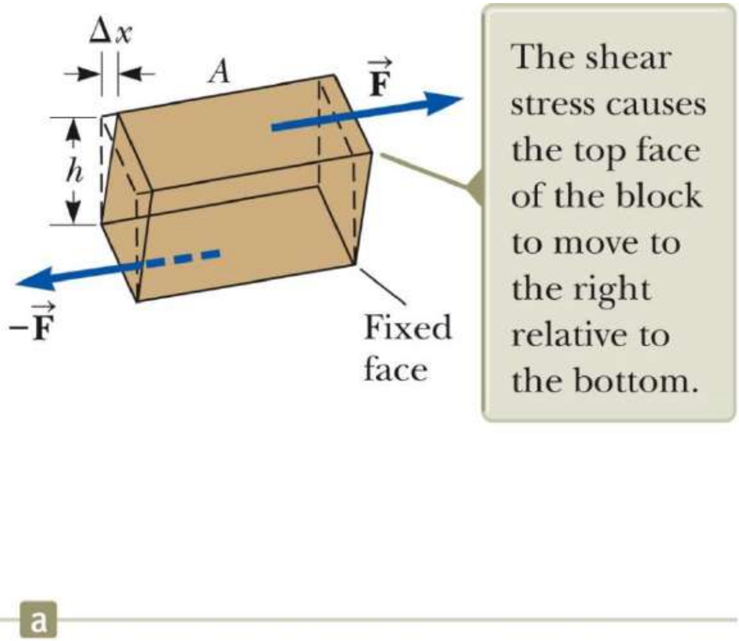
- A good first approximation

The shear strain is Δx / h.

- Δx is the horizontal distance the sheared face moves.
- h is the height of the object.

The shear stress is F / A.

- F is the tangential force.
- A is the area of the face being sheared.



The shear modulus is the ratio of the shear stress to the shear strain.

$$S = \frac{\text{shear stress}}{\text{shear strain}} = \frac{F/A}{\Delta x / h}$$

Units are N / m^2

Example

A 200-kg load is hung on a wire having a length of 4.00 m, cross-sectional area 0.200 $x10^{-4} m^2$, and Young's modulus 8.00 x $10^{10} N/m^2$. What is its increase in length?

Example

Assume that Young's modulus for bone is 1.5x10^10 N/m2 and that a bone will fracture if more than 1.5x10^8 N/m2 is exerted. (a) What is the maximum force that can be exerted on the femur bone in the leg if it has a minimum effective diameter of 2.50 cm? (b) If a force of this magnitude is applied compressively, by how much does the 25.0-cm-long bone shorten?

Example

A man leg can be thought of as a shaft of bone 1.2 m long. If the strain is $1.3x10^{-4}$ when the leg supports his weight, by how much is his leg shortened?

Example

What is the spring constant of human femur under compression of average cross-sectional area 10-3 m2 and length 0.4 m?

Young's modulus for the bone is 1.5 × 1010 N/m2

$$k = \frac{YA}{l_o}$$

$$k = \frac{YA}{l_o} = 3.75 \times 10^6 N/m$$

Example

The average cross-sectional area of a woman femur is $10^{-3} m^2$ and it is 0.4m long.

The woman weights 750 N (a) what is the length change of this bone when it supports half of the weight of the woman? (b) Assuming the stress-strain relationship is linear until fracture, what is the change in length just prior to fracture?

Example: Shear stress on the spine

Between each pair of vertebrae of the spine is a disc of cartilage of thickness 0.5 cm. Assume the disc has a radius of 0.04 m. The shear modulus of cartilage is 1 10^7 N=m^2. A shear force of 10 N is applied to one end of the disc while the other end is held fixed. (a) What is the resulting shear strain? (b) How far has one end of the disc moved with respect to the other end?

Solution: (a) The shear strain is caused by the shear force,

$$\begin{aligned} \text{strain} &= \frac{F}{AS} \\ \text{strain} &= \frac{10\ \text{N}}{\pi(0.04\ \text{m})^2(1 \times 10^7\ \text{N/m}^2)} \\ \text{strain} &= 1.99 \times 10^{-4}. \end{aligned}$$

(b) A shear strain is dened as the displacement over the height,

$$\begin{aligned} \text{strain} &= \frac{\Delta x}{h} \\ \Delta x &= h \times \text{strain} \\ \Delta x &= (0.5\ \text{cm})(1.99 \times 10^{-4}) \\ \Delta x &= 0.99\ \mu\text{m}. \end{aligned}$$

Bulk Modulus

Another type of deformation occurs when a force of uniform magnitude is applied perpendicularly over the entire surface of the object.

The object will undergo a change in volume, but not in shape.

The volume stress is defined as the ratio of the magnitude of the total force, F, exerted on the surface to the area, A, of the surface.

- This is also called the ***pressure.***

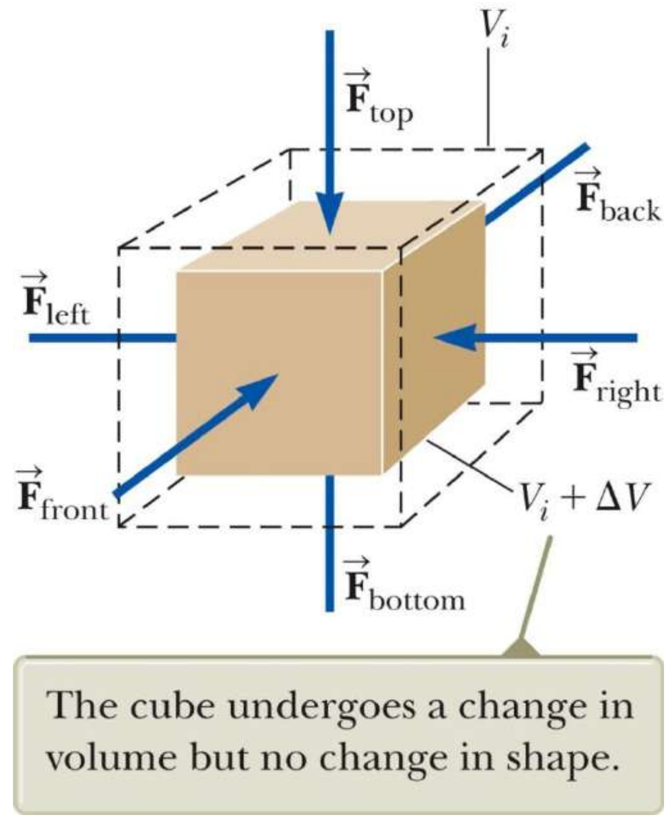
The volume strain is the ratio of the change in volume to the original volume.

The bulk modulus is the ratio of the volume stress to the volume strain.

$$B = \frac{\text{volume stress}}{\text{volume strain}} = -\frac{\Delta F / A}{\Delta V / V_i} = -\frac{\Delta P}{\Delta V / V_i}$$

The negative indicates that an increase in pressure will result in a decrease in volume.

The compressibility is the inverse of the bulk modulus.



Moduli and Types of Materials

Both solids and liquids have a bulk modulus.

Liquids cannot sustain a shearing stress or a tensile stress.

- If a shearing force or a tensile force is applied to a liquid, the liquid will flow in response.

Typical Values for Elastic Moduli

Substance	Young's Modulus (N/m^2)	Shear Modulus (N/m^2)	Bulk Modulus (N/m^2)
Tungsten	35×10^{10}	14×10^{10}	20×10^{10}
Steel	20×10^{10}	8.4×10^{10}	6×10^{10}
Copper	11×10^{10}	4.2×10^{10}	14×10^{10}
Brass	9.1×10^{10}	3.5×10^{10}	6.1×10^{10}
Aluminum	7.0×10^{10}	2.5×10^{10}	7.0×10^{10}
Glass	$6.5–7.8 \times 10^{10}$	$2.6–3.2 \times 10^{10}$	$5.0–5.5 \times 10^{10}$
Quartz	5.6×10^{10}	2.6×10^{10}	2.7×10^{10}
Water	—	—	0.21×10^{10}
Mercury	—	—	2.8×10^{10}

Medical Physics

Lectures in General Physics for Medical Sciences Students

By

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Chapter 4 – Energy, Work, and Power

Introduction to Energy

The concept of energy is one of the most important topics in science and engineering.

Every physical process that occurs in the Universe involves energy and energy transfers or transformations.

Energy is not easily defined.

Systems

A *system* is a small portion of the Universe.

A valid system:

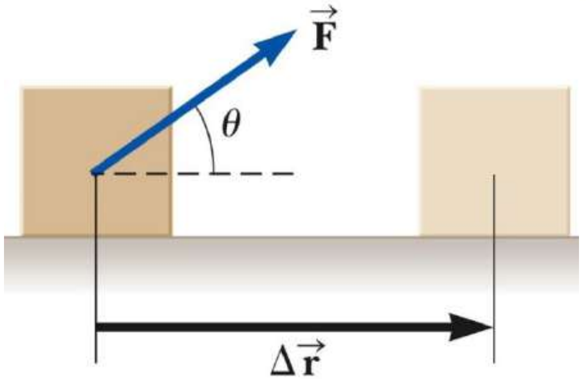
- May be a single object or particle
- May be a collection of objects or particles
- May be a region of space
- May vary with time in size and shape

System Example

A force applied to an object in empty space

Work

The **work**, *W*, done on a system by an agent exerting a constant force on the system is the product of the magnitude *F* of the force, the magnitude Δr of the displacement of the point of application of the force, and cos θ, where θ is the angle between the force and the displacement vectors.



A force does no work on the object if the force does not move through a displacement.

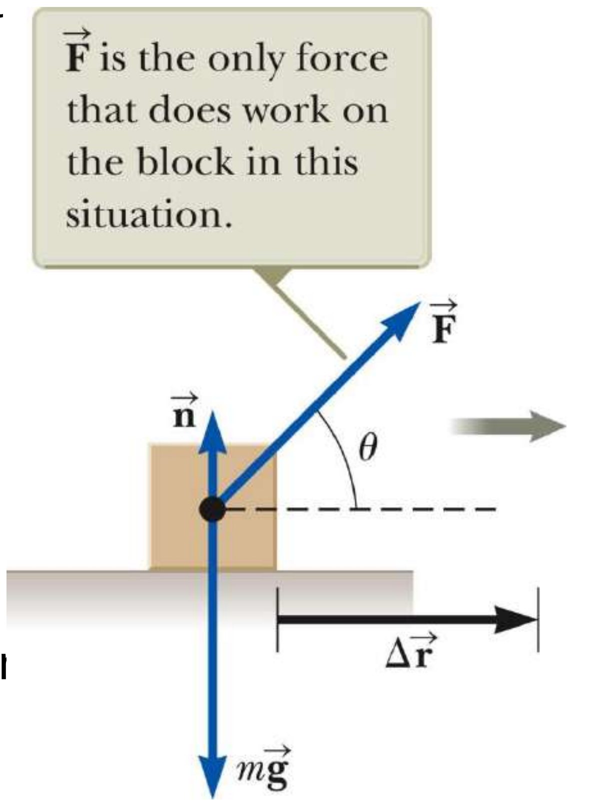
- The work done by a force on a moving object is zero when the force applied is perpendicular to the displacement of its point of application.
- Work can be given as $W = F\Delta r\cos\theta = \vec{F}\cdot\Delta\vec{r}$

Work is a scalar quantity.

The unit of work is a joule (J = N · m)

- 1 joule = 1 newton · 1 meter = kg · m² / s²

The normal force and the gravitational force do no work on the object. cos θ = cos 90° = 0



Kinetic Energy

One possible result of work acting as an influence on a system is that the system changes its speed. The system could possess *kinetic energy.*

Kinetic Energy is the energy of a particle due to its motion.

- ***K* = ½ *mv*²**
  - *K* is the kinetic energy
  - *m* is the mass of the particle
  - *v* is the speed of the particle

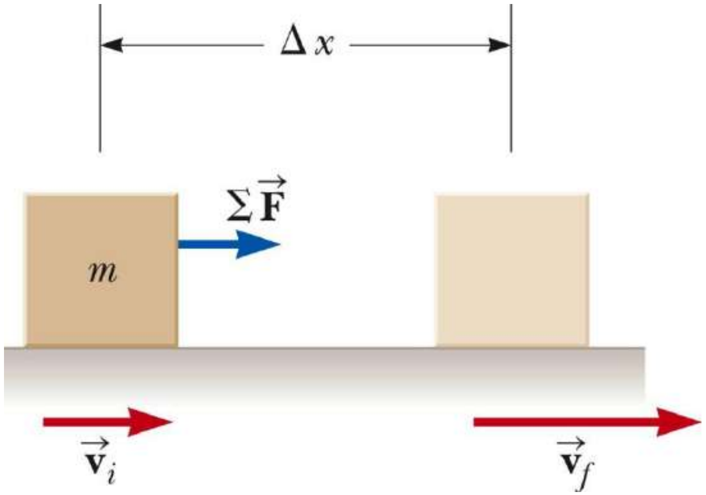
A change in kinetic energy is one possible result of doing work to transfer energy into a system. Calculating the work:

$$W_{ext} = \int_{x_i}^{x_f} \sum F\, dx = \int_{x_i}^{x_f} ma\, dx$$

$$W_{ext} = \int_{v_i}^{v_f} mv\, dv$$

$$W_{ext} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$W_{ext} = K_f - K_i = \Delta K$$



This is the **Work-Kinetic Energy Theorem**.

Potential Energy

The system is the Earth and the book. Do work on the book by lifting it slowly through a vertical displacement. $\Delta\vec{\mathbf{r}} = (y_f - y_i)\,\hat{\mathbf{j}}$

The work done on the system must appear as an increase in the energy of the system. The energy storage mechanism is called *potential energy.*

Gravitational potential energy is the energy associated with an object at a given location above the surface of the Earth.

$$W_{ext} = (\vec{\mathbf{F}}_{\text{app}}) \cdot \Delta\vec{\mathbf{r}}$$

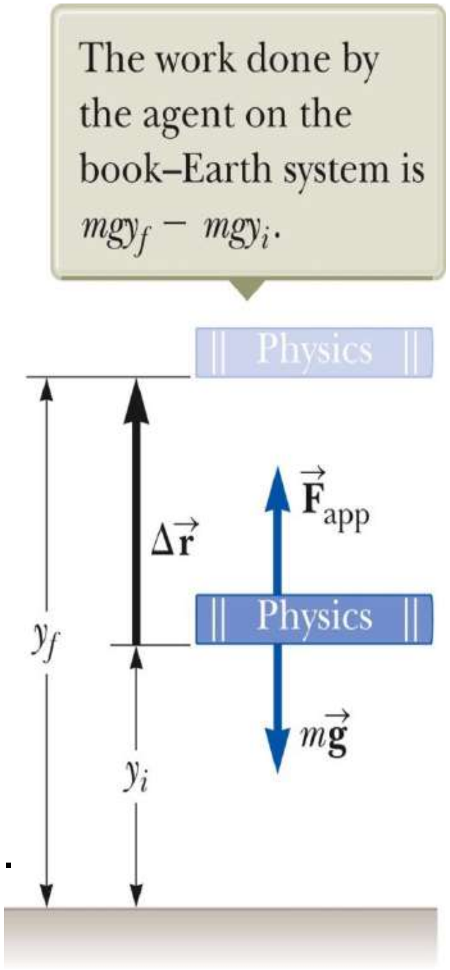
$$W_{ext} = (mg\hat{\mathbf{j}}) \cdot \left[(y_f - y_i)\,\hat{\mathbf{j}}\right]$$

$$W_{ext} = mgy_f - mgy_i$$

The quantity *mgy* is identified as the **gravitational potential energy**,

$\boldsymbol{U_g = mgy}$, U_g is a scalar. Units are joules (J)

Work may change the gravitational potential energy of the system.
$W_{\text{ext}} = \Delta u_{\text{g}}$



Energy Review

Kinetic Energy: Associated with movement of members of a system

Potential Energy: Determined by the configuration of the system such as Gravitational and Elastic Potential Energies

Internal Energy: Related to the temperature of the system

Types of Systems

Non-isolated systems: Energy can cross the system boundary in a variety of ways.

- Total energy of the system changes

Isolated systems: Energy does not cross the boundary of the system

- Total energy of the system is constant

Conservation of energy

- Can be used if no non-conservative forces act within the isolated system
- Applies to biological organisms, technological systems, engineering situations, etc

Ways to Transfer Energy Into or Out of A System

In non-isolated systems, energy crosses the boundary of the system during some time interval due to an interaction with the environment.

Work – transfers energy by applying a force and causing a displacement of the point of application of the force.

Mechanical Wave – transfers energy by allowing a disturbance to propagate through a medium.

Heat – the mechanism of energy transfer that is driven by a temperature difference between two regions in space.

Matter Transfer – matter physically crosses the boundary of the system, carrying energy with it.

Electrical Transmission – energy transfer into or out of a system by electric current.

Electromagnetic Radiation – energy is transferred by electromagnetic waves.

Examples of Ways to Transfer Energy

Energy is transferred to the block by *work*.

a

Energy leaves the radio from the speaker by *mechanical waves*.

b

Energy transfers to the handle of the spoon by *heat*.

c

Energy enters the automobile gas tank by *matter transfer*.

d

Energy enters the hair dryer by *electrical transmission*.

e

Energy leaves the light-bulb by *electromagnetic radiation*.

f

Conservation of Energy

Energy is conserved

- This means that energy cannot be created nor destroyed.
- If the total amount of energy in a system changes, it can only be due to the fact that energy has crossed the boundary of the system by some method of energy transfer.

Mathematically, $\Delta E_{\text{system}} = \Sigma T$

- E_{system} is the total energy of the system
- T is the energy transferred across the system boundary by some mechanism
  - Established symbols: $T_{\text{work}} = W$ and $T_{\text{heat}} = Q$

The primarily mathematical representation of the energy version of the analysis model of the non-isolated system is given by the full expansion of the above equation.

- $\Delta K + \Delta U + \Delta E_{int} = W + Q + T_{MW} + T_{MT} + T_{ET} + T_{ER}$
  - T_{MW} – transfer by mechanical waves
  - T_{MT} – by matter transfer
  - T_{ET} – by electrical transmission
  - T_{ER} – by electromagnetic transmission

Isolated System

For an isolated system, $\Delta E_{mech} = 0$

- Remember $\mathbf{E_{mech} = K + U}$
- This is ***conservation of energy*** for an isolated system with no non-conservative forces acting.

If non-conservative forces are acting, some energy is transformed into internal energy.

Conservation of Energy becomes $\Delta E_{system} = 0$

- E_{system} is all kinetic, potential, and internal energies
- This is the most general statement of the isolated system model.

The changes in energy can be written out and rearranged.

$\mathbf{K_f + U_f = K_i + U_i}$

- Remember, this applies only to a system in which conservative forces act.

Example – Ball in Free Fall

Determine the speed of the ball at a height *y* above the ground.

Conceptualize: Use energy instead of motion

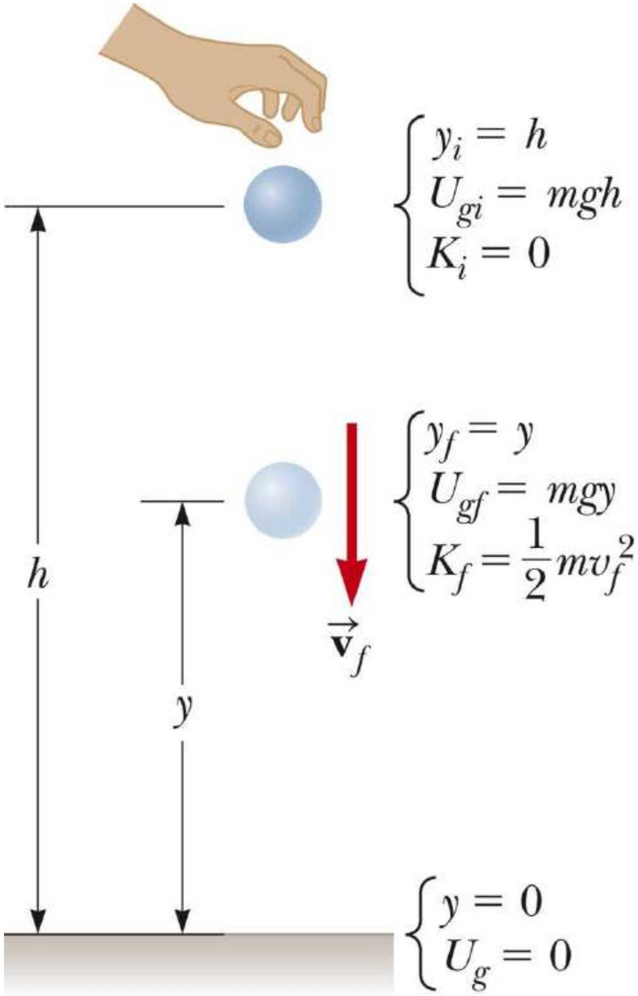
Categorize:

- System is the ball and the Earth
- System is isolated. Use the isolated system model
- Only force is gravitational which is conservative

Analyze

- Apply the Conservation of Mechanical Energy
- $K_f + U_{gf} = K_i + U_{gi}$
  - $K_i = 0$, the ball is dropped
  - Solve for v_f $\quad v_f = \sqrt{2g(h-y)}$

Finalize: The equation for v_f is consistent with the results obtained from the particle under constant acceleration model for a falling object.



Power

Power is the time rate of energy transfer.

The ***instantaneous power*** is defined as $P \equiv \frac{dE}{dt}$

Using work as the energy transfer method, this can also be written as

$$P_{avg} = \frac{W}{\Delta t}$$

The instantaneous power is the limiting value of the average power as Δt approaches zero.

$$P = \lim_{\Delta t \to 0} \frac{W}{\Delta t} = \frac{dW}{dt} = \vec{\mathbf{F}} \cdot \frac{d\vec{\mathbf{r}}}{dt} = \vec{\mathbf{F}} \cdot \vec{\mathbf{v}}$$

The SI unit of power is called the watt.

- 1 watt = 1 joule / second = 1 kg · m^2 / s^3

Units of power can also be used to express units of work or energy.

- 1 kWh = (1000 W)(3600 s) = 3.6 x10^6 J

Energy, Work, and Power of the Body

Under resting conditions about 25% of the body's energy is being used by the skeletal muscles and the heart, 19 % is being used by the brain, 10 % is used by the kidneys, and 27 % is being used by the liver and spleen.

The body's basic energy (fuel) source is food .

The food is converted into molecules chemically .

The body uses the food energy to operate its various organs :

Maintain constant temperature

Do external force for example ,lifting.

A small percentage (5 %) of the food energy is excreted in the feces and urine ; any energy that is left over is stored as body fat .

The energy used to operate the organs eventually appears as body heat. Some of this heat is useful in maintaining the body at its normal temperature, but the rest must be disposed of.

Energy of food

The human needs about 2400 Cal per day (for female about 2000 Cal/day)

where

1 (food) Calories = 1000 cal where 1 cal = 4.18 J

1 gram of fat gives **9** Calories,

1 gram of carbohydrates and sugars gives **4** Calories

1 gram of proteins gives **4.3** Calories

1 gram of Alcohol gives **7** Calories

Example

One chocolate piece weights **100 g** {**5 g** of fat, **5 g** of protein, **75 g** of carbohydrates, **15 g** of vitamins and water and others } how much calories in this piece

Conservation of Energy in the Body

Conservation of energy in the body can be written as a simple equation.

[Change in stored energy] = Heat lost from the

[in the body (food energy,] body + Work done

[fat, and body heat

There are a continuous energy changes in the body both when is doing work and when it is not.

The first law of thermodynamic equation is :

$\Delta U = \Delta Q + \Delta W$

Where ΔU is the change in stored energy

ΔQ is the heat lost or gain

ΔW is the work done by the body in some interval of time.

A body doing no work ($\Delta W = 0$)

and at a constant temperature to lose heat to its surroundings , and ΔQ is negative.

ΔU is also negative, indicating a decrease in stored energy.

Conservation of Energy in the Body

The change of ΔU , ΔQ and ΔW in a short interval of time Δt,

$$\frac{\Delta U}{\Delta t} = \frac{\Delta Q}{\Delta t} + \frac{\Delta W}{\Delta t}$$

where $\Delta U/\Delta t$ is the rate of change of stored energy

$\Delta Q/\Delta t$ is rate of change of heat loss or gain,

$\Delta W/\Delta t$ is the rate of doing work, that is mechanical work.

The unit of energy in SI unit is Joule.

The physiological unit of food energy is Kilocalories .

The unit of heat production = Kcal/minute

1 Kcal =4184 J

Power = Joule / second = Watts

Met: is the rate of energy consumption of the body.

1 Met = 50 Kcal /hour per m^2 of the body surface area

Metabolic rate (MR)

A typical man has surface area 1.85 m^2 of the surface area A typical women has about 1.4 m^2 of the surface area

1met =50 Kcal /hour per m^2 = 58 watts/m^2

1 met =92 kcal /hr   1**met** =107 watts

Metabolic rate: is define as the rate of oxidation

In oxidation process within the body heat is released as energy of metabolism

. **Basal Metabolic Rate** (BMR): is the lowest rate of energy consumption, or is defined as the amount of energy needed to perform minimal body functions (Such as breathing and pumping the blood through the arteries) under resting conditions.

The energy used for basal metabolism becomes heat which is primarily dissipated from the skin, so that the basal rate is not related to the surface area but on the mass of the body. The metabolic rate depends on the temperature of the body, if the body temperature changes by 1 C^{o} ,there is a change of about 10 % in the metabolic rate.

Example

In oxidation of the glucose, heat energy is released

$C_6H_{12}O_6 + 6O_2 \longrightarrow 6\,H_2O + 6CO_2 + 686$ Kcal

1 (mole) + 6 (mole) $\longrightarrow$ 6(mole) +6 (mole)+heat energy

180 gm + 192 gm $\longrightarrow$ 108 gm +64 gm + 686 Kcal

Energy released per gm of glucose = 686/180 = 3.8Kcal /gm

Energy released per liter of O2 used = 686 /6 x22.4 =5.1 Kcal /liters

Liters of O2 used per of fuel = 22.4 x 6/ 180 =0.75liters/gm

Liters of CO2 produced per gm of fuel = 6 x22.4/180 = 0.75liters /gm

Example (metabolic)

Suppose you wish to lose 4.54 kg either through physical activity or by dieting.

a . How long would you have to work at an activity of 15 kcal/ min to lose 4.54 of fat ?

from table energy release for 1 gm of fat is 9.3 kcal/g

If you work for T minutes ,then

$(T\ min)(15\ kcal/min) = (4.54 \times 10^3\ g)(9.3\ kcal/g)$

$(T\ min)(15\ kcal/min) = 4.2 \times 10^5\ kcal$

T = 28810 min T = 47 hour the time taken to lose 4.54 kg of fat

b. It is usually much easier to lose weight by reducing your food intake . If you normally use 2500 kcal/day , how long must you diet at 2000 kcal/day to lose 4.54 kg of fat

Energy of 4.54 kg of fat = 42 000 kcal

From table energy deficit per day = 5×10^2 kcal/day

T= energy of 4.54 kg of fat /energy deficit per day= 42000 kcal/5×10^2 kcal/day

T = 84 days

Efficiency of the human Body

We can consider the human body as a machine in doing external work.

The efficiency of the human body as a machine can be obtain from the usual definition of the efficiency (ε):

Efficiency (ε) = Work done / Energy consumed

Efficiency (ε) is lowest at low power, but can increase to 20 % for trained individuals in activities such as cycling and rowing.

Table 1 shows the efficiency of man for several activities along with the efficiency of several mechanical engines.

The maximum work capacity of the body is variable.

For short periods of time the body can perform at very high power levels, but for long – term efforts it is more limited. Experimentally it has been found that long -term power is proportional to the maximum rate of oxygen consumption in the working muscles.

Task or Machine	Efficiency %
Cycling	~20
Swimming(on surface) (under water)	<2 ~4
Shoveling	~3
Steam engine	17

The maximum work capacity of the body is variable

The body supplies instantaneous energy for short-term power needs by splitting energy - rich phosphates and glycogen, leaving an oxygen deficit in the body .This process can only last about a minute and is called the anaerobic (without oxygen) phase of work; long –term activity requires oxygen (aerobic work) as shown in figure 1 .

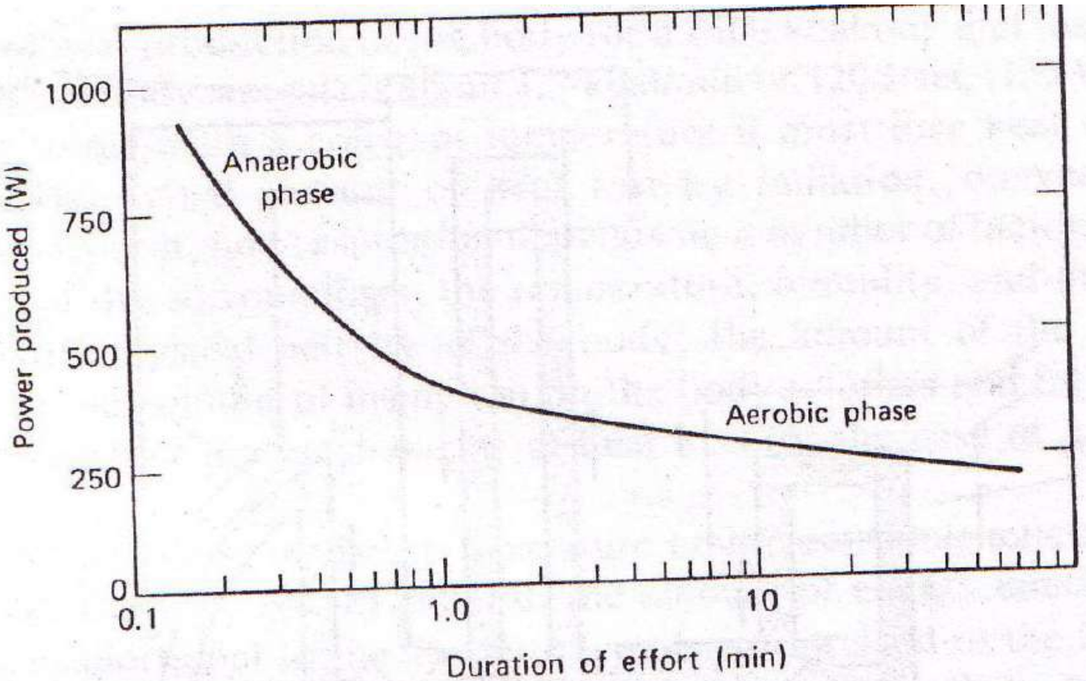


Figure 5.3. Typical power output on a bicycle versus duration of effort for an average healthy adult. Anaerobic work can only be maintained about 1 min.

Solved problems

Q1. For a hypothetical animal that has a mass of 700 kg (the basal metabolic rate = 10000 kcal/ day).Assuming 5 kcal/g of food , estimate the minimum amount of food needed each day ?

The basal metabolic rate of mass 700kg

= 10000 kcal/day

$$\frac{10000}{5} = 2 \times 10^3 \text{ g/day}$$

amount of food needed each day = 2 kg/day

Q2 (a) What is the energy required to walk 20 km at 5 km/hr ?

From the table , the energy rate of walking activity at 5km/hr is 3.8 kcal /min.

Energy=Power x time=power x distance/velocity

The energy required to walk 20 km

$$= 3.8 \text{ kcal/min} \times \frac{20\text{km}}{5\text{km/hr}} \times 60 \text{ min/hr}$$

Energy = 912 kcal

Q2 (b) Assuming 5 kcal /g of food ,calculate the grams of food needed for walk .

The amount of food needed for walk =[Energy] / [Energy /gm]

= 912 kcal/5 kcal/gm = 182 gram

Q 3. Suppose that the elevator is broken in the building in which you work and you have to climb 9 stories – a height of 45 m above ground level .How many extra calories will this external work cost you if your mass is 70 kg and your body at 15% efficiency ?

External work = m g h = 70 x9.8x 45

since 1 kcal = 4.2×10^3 J

$$\text{External work} = \frac{70 \times 9.8 \times 45}{4.2 \times 10^3}$$

= 7.3 kcal

$$\text{calories needed} = \frac{7.3\ \text{kcal}}{\text{efficiency}} = \frac{7.3}{0.15}$$

= 49 kcal

Q4. A 70 Kg hiker climbed a mountain 1000 m high . He reached the peak in 3 hr.

a . calculate the external work done by the climber.

External work = m g h = $70 \times 9.8 \times 10^3 = 6.9 \times 10^4$ J

b. Assuming the work was done at a steady rate during the 3 hr period, calculate the power generated during climb.

Power = Work/Time = 6.9×10^4 J/ 3x 3600 sec = 64 watts

c. Assuming the average O2 consumption during the climb was 2 liter /min (corresponding to 9.6 Kcal /min), find the efficiency of the hiker's body.

Energy consumed =(9.6 Kcal /min)(180 min)(4.2×10^3J/kcal)= 7.3×10^6 J

Efficiency = work done /Energy consumed

€ = $6.9 \times 10^4 / 7.3 \times 10^6 = 0.094$

€ = 9.4 %

d . How much energy appeared as heat in the body ?

$\Delta U = \Delta Q + \Delta W$

7.3×10^6 J = $\Delta Q + 6.9 \times 10^4$ then $\Delta Q = 6.6 \times 10^6$ J

Example

A student eats a dinner rated at 2000 (food) Calories. He whishes to do an equivalent amount of work in the gymnasium by lifting 50Kg mass. How many times must he raise the weight to expend this much energy? Assume that he raises the weight a distance of 2m each time and no work is done when the weight is dropped to the floor.

Solution

1 (food) Calories = 1000 cal

then the work required is $2x10^6$cal.

Converting this to joule, then the work required is

$W = 2x10^6 cal \times 4.186 J/cal = 8.37x106 J$

Medical Physics

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Chapter 5 - Fluid Mechanics

States of Matter

Solid

- Has a definite volume and shape

Liquid

- Has a definite volume but not a definite shape

Gas – unconfined

- Has neither a definite volume nor shape

Fluids

A fluid is a collection of molecules that are randomly arranged and held together by weak cohesive forces and by forces exerted by the walls of a container.

Both liquids and gases are fluids.

Fluids do not sustain shearing stresses or tensile stresses.

The only stress that can be exerted on an object submerged in a static fluid is one that tends to compress the object from all sides.

The force exerted by a static fluid on an object is always perpendicular to the surfaces of the object.

Density Notes

Density is defined as the mass per unit volume of the substance.

$$\rho = \frac{m}{V}$$

where r is the density, m is the mass of the substance and V is the Volume. The unit of density in SI unit system is kg/m^3.

The values of density for a substance vary slightly with temperature since volume is temperature dependent.

The various densities indicate the average molecular spacing in a gas is much greater than that in a solid or liquid.

Substance	ρ (kg/m^3)	Substance	ρ (kg/m^3)
Ice	0.917×10^3	Water	1×10^3
Aluminum	2.7×10^3	Glycerine	1.26×10^3
Iron	7.86×10^3	Ethyl alcohol	0.8×10^3
Copper	8.92×10^3	Benzene	0.88×10^3
Silver	10.5×10^3	Mercury	13.6×10^3
Lead	11.3×10^3	Air	1.29
Gold	19.3×10^3	Oxygen	1.43
Platinum	21.4×10^3	Hydrogen	910^3
		Helium	1.8×10^3

Viscosity

Real fluids (especially liquids) exhibit a kind of internal friction called *viscosity*. Fluids that flow easily (like water and gasoline) have a fairly low viscosity; liquids like molasses that are "thick" and flow with difficulty have a high viscosity.

There are two different types of viscosity defined. The more common is *dynamic viscosity*; the other is *kinematic viscosity*.

Dynamic Viscosity

When a body is placed under transverse (shear) stress σ = Ft/A, the resulting strain ε is the tangential displacement x divided by the transverse distance l:

$$\sigma = E\varepsilon$$

$$\frac{F_t}{A} = S\frac{x}{l}$$

where S is the shear modulus. Fluid flow undergoes a similar kind of shear stress; however, with fluids, we find that the stress is not proportional to the strain, but to the *rate of change* of strain:

$$\frac{F_t}{A} = \mu\frac{d}{dt}\frac{x}{l} = \mu\frac{v}{l}$$

Dynamic Viscosity

where v is the fluid velocity. The proportionality constant , which takes the place of the shear modulus, is the *dynamic viscosity*. The SI units of dynamic viscosity are Pascal-seconds (Pa s). Other common units are the *poise* (1 P = 0.1 Pa s) and the *centipoise* (1 cP = 0.001 Pa s).

Viscosity, especially liquid viscosity, is temperature dependent. You've probably noticed this from everyday experience: refrigerated maple syrup is fairly thick (high viscosity), but if you warm it on the stove it becomes much thinner (low viscosity).

Kinematic Viscosity.

The kinematic viscosity is defined as the dynamic viscosity divided by the density:

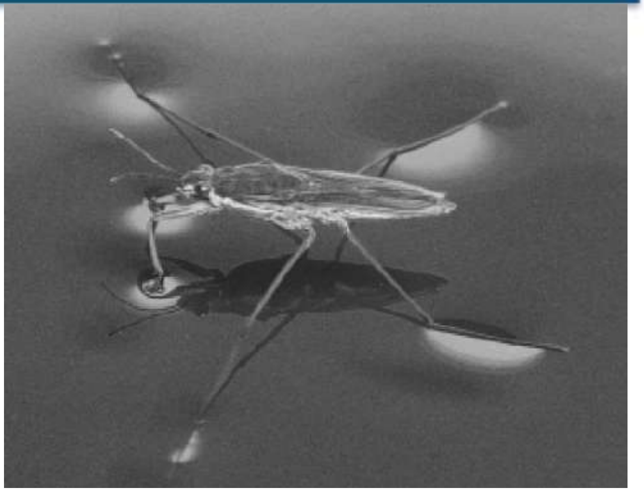
$$\nu = \frac{\mu}{\rho}$$

SI units for kinematic viscosity are m^2/s. Other common units are *stokes* (1 St = 10^{-4} m^2/s) and *centistokes* (1 cSt = 10^{-6} m^2/s).

Viscosities of common liquids (room temperature).

Liquid	Dynamic viscosity μ (Pa s)	(cP)
gasoline	5×10^{-4}	0.5
water	8.9×10^{-4}	0.89
mercury	0.0016	1.6
olive oil	0.09	90
ketchup	1.3	1300
honey	5	5000
molasses	7	7000
peanut butter	250	250,000

Surface tension

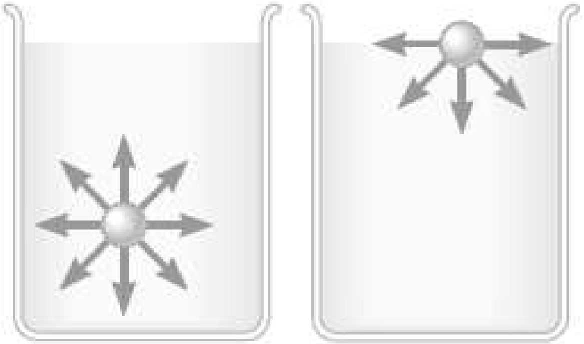


A fluid is matter that has no definite shape and adjusts to the container that it is placed in.

Gases and liquids are both fluids. All fluids are made of molecules. Every molecules attracts other molecules around it.

Liquids exhibit surface tension. A liquid has the property that its free surface tends to contract to minimum possible area and is therefore in a state of tension.

The surface tension of the water allows the insect to walk on the water without sinking.



The molecules of the liquid exerts attractive forces on each other, which is called **cohesive forces**. Deep inside a liquid, a molecule is surrounded by other molecules in all directions. Therefore there is no net force on it. At the surface, a molecule is surrounded by only half as many molecules of the liquid, because there are no molecules above the surface.

Surface tension, definition

The force of contraction is at right angles to an imaginary line of unit length, tangential to the surface of a liquid, is called its **surface tension *T* or *γ***:

$$\gamma = \frac{F}{L}$$

. Here *F* is the force exerted by the "skin" of the Liquid. The SI unit of the surface tension is N/m.

Liquid	Surface Tension γ (N/m)
Benzene (20 °C)	0.029
Blood (37 °C)	0.058
Glycerin (20 °C)	0.063
Mercury (20 °C)	0.47
Water (20 °C)	0.073
Water (100 °C)	0.059

Why are soap bubbles spherical?

Generally, a system under the influence of forces moves towards an equilibrium configuration that corresponds to minimum potential energy. The sphere contains the most volume for the least area ⇒ minimum surface potential energy. There are no cubic raindrops.

Capillary Action

The molecules of the liquid exerts attractive forces on each other, which is called **cohesive forces**.

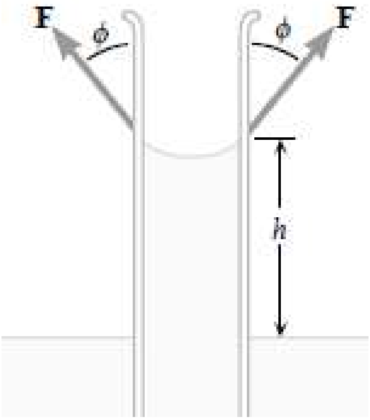
When liquids come into contact with a solid surface, the liquid's molecules are attracted by the solid's molecules (called **adhesive forces**).

If these adhesive forces are stronger than the cohesive forces, the liquid's molecules are pulled towards the solid surface and liquid surface becomes curved inward (e.g. water in a narrow tube).

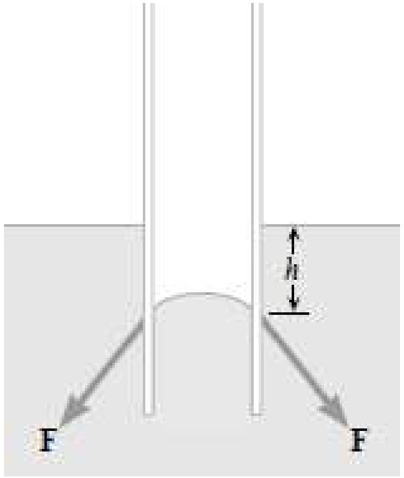
If cohesive forces are stronger the surface becomes curved outwards (e.g. with mercury instead).

This also explains why certain liquids spread when placed on the solid surface and wet it (e.g., water on glass) while others do not spread but form globules (e.g., mercury on glass).

The behavior of the liquids in both Figures is called ***capillary action***.



$$h = \frac{2T\cos\theta}{R\rho g}$$



Pressure

The **pressure** *P* of the fluid at the level to which the device has been submerged is the ratio of the force to the area.

P=F/A

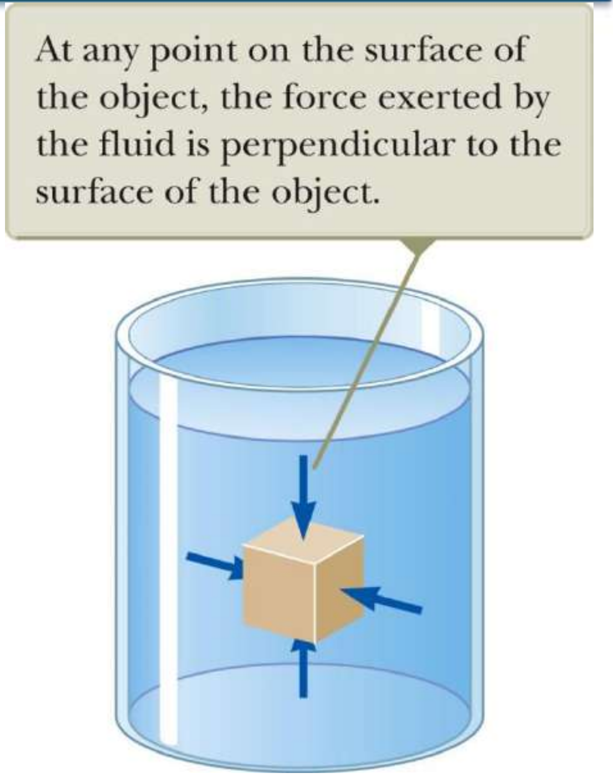
Pressure is a scalar quantity.

- Because it is proportional to the magnitude of the force.

If the pressure varies over an area, evaluate *dF* on a surface of area *dA* as *dF = P dA.*

Unit of pressure is **pascal** (Pa)

$1\,\text{Pa} = 1\,\text{N/m}^2$



Variation of Pressure with Depth

If a fluid is at rest in a container, all portions of the fluid must be in static equilibrium.

All points at the same depth must be at the same pressure.

Examine the darker region, a sample of liquid within a cylinder. It has a cross-sectional area A. The liquid has a density of ρ.

The three forces are:

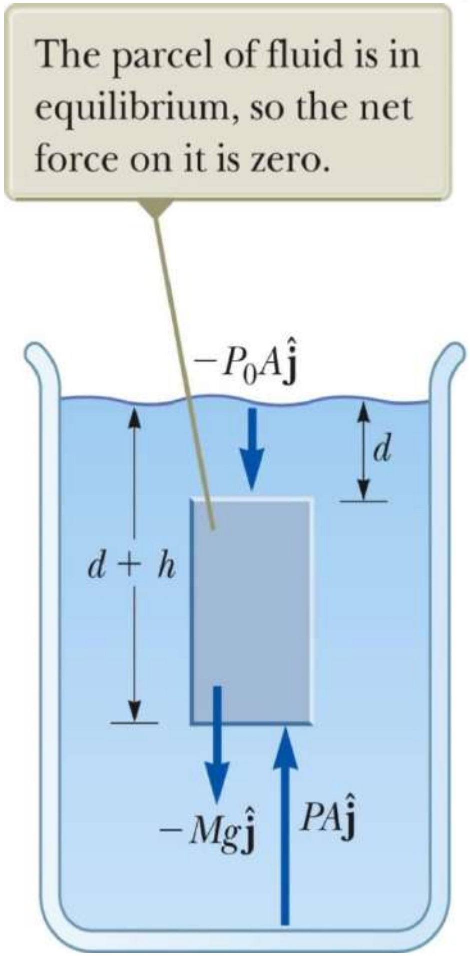
- Downward force on the top, P_0A
- Upward on the bottom, PA
- Gravity acting downward, Mg
  - The mass can be found from the density: $M = \rho V = \rho A h$.

Since the net force must be zero: Solving for the pressure gives

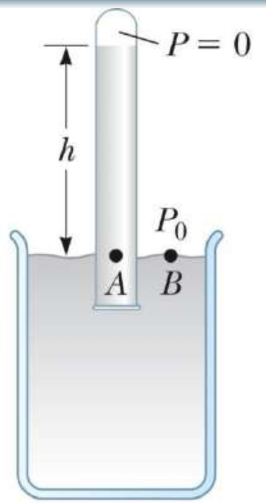
- $P = P_0 + \rho g h$

If the liquid is open to the atmosphere, and P_0 is the pressure at the surface of the liquid, then P_0 is ***atmospheric pressure***.

$\mathbf{P_0 = 1.00\ atm = 1.013 \times 10^5\ Pa}$



Pressure Measurements



a

Barometer Invented by Torricelli

A long closed tube is filled with mercury and inverted in a dish of mercury. The closed end is nearly a vacuum.

Measures atmospheric pressure as $P_o = \rho_{Hg}\, g\, h$

One 1 atm = 0.760 m (of Hg)

Manometer

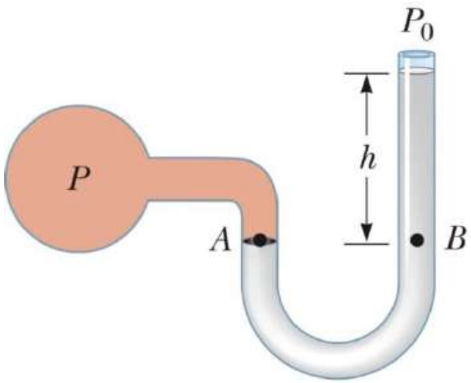
A device for measuring the pressure of a gas contained in a vessel. One end of the U-shaped tube is open to the atmosphere.

The other end is connected to the pressure to be measured.

Pressure at B is $P = P_o + \rho g h$

The height can be calibrated to measure the pressure.

The difference in height, "h," which is the sum of the readings above and below zero, indicates the gauge pressure ($p = \rho\, g h$).



b

□ The difference in height, "h," which is the sum of the readings above and below zero, indicates the amount of vacuum.

sphygmomanometer

The manometer is a part of medical device that measures the blood pressure, which is called a **sphygmomanometer**

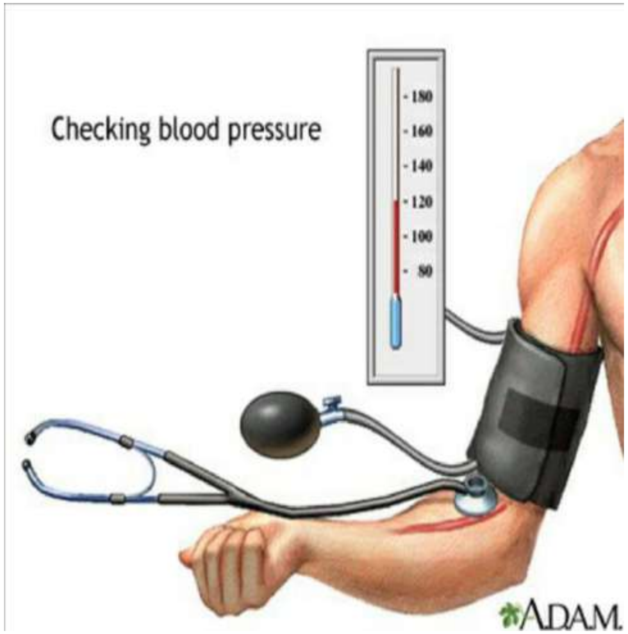
There are many types of blood pressure measuring instruments

Blood pressure

Blood pressure (BP) is the pressure of circulating blood on the walls of blood vessels. It usually refers to the pressure in large arteries of the systemic circulation. Blood pressure is usually expressed in terms of the systolic pressure (maximum during one heart beat) over diastolic pressure (minimum in between two heart beats) and is measured in millimeters of mercury (mmHg) above the surrounding atmospheric pressure (considered to be zero for convenience).

Measuring of blood pressure

Normal resting blood pressure in an adult is approximately 120 millimetres of systolic, and 80 millimetres of diastolic, abbreviated "120/80 mmHg".



Hypertension **(high blood pressure)**

Blood pressure increases when the heart pumps blood more vigorously or when arteries narrow, causing increased resistance to blood. In order to understand how narrowness of arteries can affect blood pressure, imagine pressing a tube of toothpaste. If the tube is normal

Absolute vs. Gauge Pressure

$P = P_0 + \rho g h$

P is the **absolute pressure.**

The **gauge pressure** is $P - P_0 = \rho g h$. This is what you measure in your tires.

Example: Calculate the pressure at an ocean depth of 500m. Assume the density of water is $10^3 kg/m^3$ and the atmospheric pressure is $1.01 \times 10^5 Pa$.

Solution $\because P = P_a + \rho g h$

$$\therefore P = 1.01 \times 10^5 + (10^3 \times 9.8 \times 500)$$

$$= 5 \times 10^6 \, Pa$$

Example: What is the pressure on a swimmer 5 m below the surface of a lake?

Solution: Using the depth of the swimmer is $h = 5\ mm$,

the density for water is $\rho = 1000\ kgm^{-3}$, and

the atmospheric pressure is $1.013 \times 10^5\ Pa$.

So using equation $p = pa + \rho\ g\ h$ to calculate the pressure on the swimmer to be:

$$p = p_a + \rho\, g\, h = 1.013\times10^5 + (1000)\,(10)\,5 = 1.5\times10^5\ Pa$$

Buoyant Force and Archimedes' Principle

The **buoyant force** is the upward force exerted by a fluid on any immersed object.

The magnitude of the buoyant force always equals the weight of the fluid displaced by the object.

- This is called **Archimedes' Principle.**

The pressure at the bottom of the cube is greater than the pressure at the top of the cube.

The pressure at the top of the cube causes a downward force of P_{top} A.

The pressure at the bottom of the cube causes an upward force of P_{bot} A.

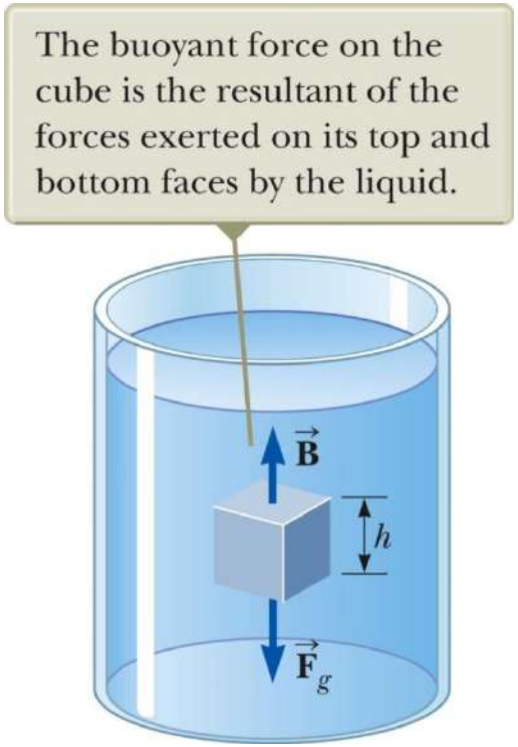
$B = (P_{bot} – P_{top})\ A = (\rho_{fluid}\ g\ h)\ A$

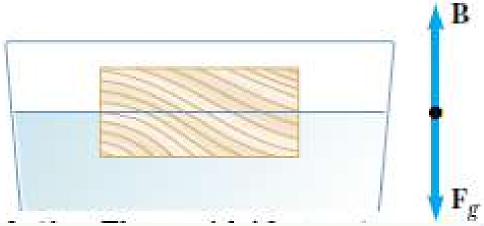
$B = \rho_{fluid}\ g\ V_{disp}$

- V_{disp} = A h is the volume of the fluid displaced by the cube.

$B = M g$

- *Mg* is the weight of the fluid displaced by the cube.





Archimedes' Principle: Totally Submerged Object

An object is totally submerged in a fluid of density $\rho_{fluid.}$

The volume V_{disp} of the fluid is equal to the volume of the object, $V_{obj.}$

The upward buoyant force is $B = \rho_{fluid}\, g\, V_{object}$

The downward gravitational force is $F_g = Mg = = \rho_{obj}\, g\, V_{obj}$

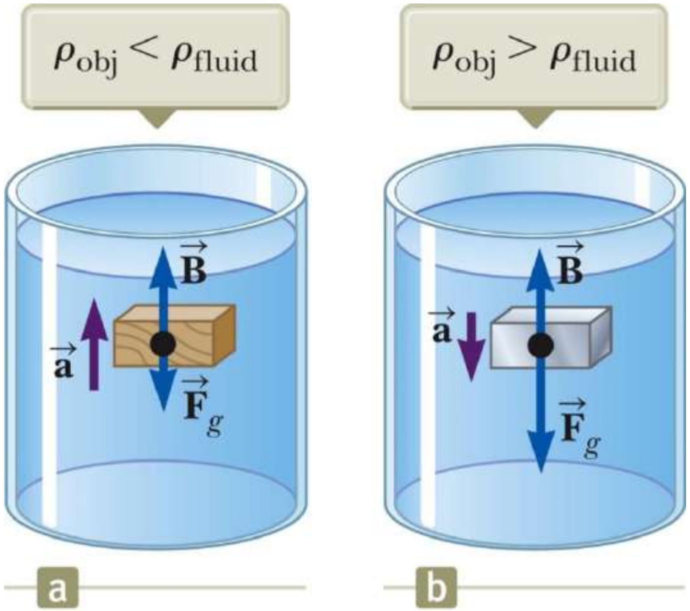
The net force is $B - F_g = (\rho_{fluid} - \rho_{obj})\, g\, V_{obj}$

If the density of the object is less than the density of the fluid, the unsupported object accelerates upward.

If the density of the object is more than the density of the fluid, the unsupported object sinks.

If the density of the submerged object equals the density of the fluid, the object remains in equilibrium.

The direction of the motion of an object in a fluid is determined only by the densities of the fluid and the object.



Archimedes's Principle: Floating Object

The density of the object is less than the density of the fluid.

The object is in static equilibrium.

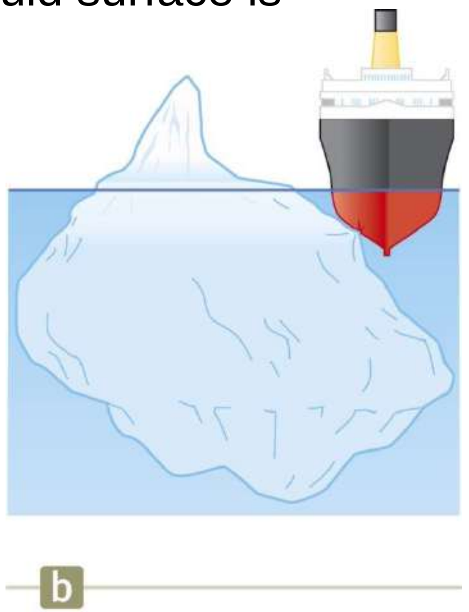
The object is only partially submerged.

The upward buoyant force is balanced by the downward force of gravity.

Volume of the fluid displaced corresponds to the volume of the object beneath the fluid level.

The fraction of the volume of a floating object that is below the fluid surface is equal to the ratio of the density of the object to that of the fluid.

Archimedes's Principle, Iceberg Example



What fraction of the iceberg is below water where

ρ_{ice}= 917 Kg/m^3 and $\rho_{seawater}$ = 1030 Kg/m^3 ?

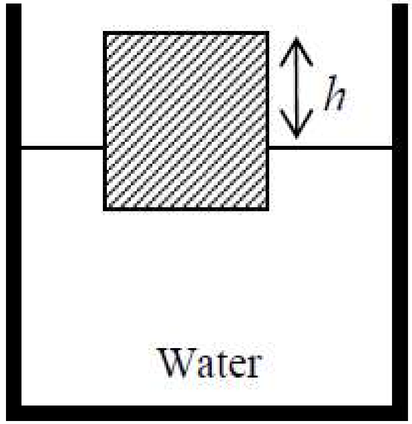
The iceberg is only partially submerged and so $V_{disp} / V_{ice} = \rho_{ice} / \rho_{seawater}$ applies

About 89% of the ice is below the water's surface.

Example

A cube of wood 20cm on a side and having a density of $0.65 \times 10^3 kg/m^3$ floats on water. What is the distance from the top of the cube to the water level?

Solution



(a) According to Archimedes principle

$B = \rho_w V g = (1g/cm^3) \times [20 \times 20 \times (20\text{-}h)]g$

but

B = weight of the wood = $mg = \rho_{wood} V_{wood}\ g = (0.65g/cm^3)(20)^3$ h

$(1g/cm^3) \times [20 \times 20 \times (20\text{-}h)]g = (0.65g/cm^3)(20)^3$

$20 - h = 20 \times 0.65$ then $h = 20(1\text{-}0.65) = 7cm$

(b) $B = W + Mg$ where M is the mass of lead

$1(20)^3 g = (0.65)(20)^3 g + Mg$

$M = 20^3(1\text{- }0.65) = 2800\ g = 2.8kg$

Types of Fluid Flow

Laminar flow

- Steady flow
- Each particle of the fluid follows a smooth path.
- The paths of the different particles never cross each other.
- Every given fluid particle arriving at a given point has the same velocity.

Turbulent flow

- An irregular flow characterized by small whirlpool-like regions.
- Turbulent flow occurs when the particles go above some critical speed.

Ideal Fluid Flow

- ***The fluid is non-viscous*** – internal friction is neglected
- ***The flow is steady***: all particles passing through a point have the same velocity.
- ***The fluid is incompressible***: the density of the incompressible fluid remains constant.
- ***The flow is irrotational***: the fluid has no angular momentum about any point.

Equation of Continuity

Consider a fluid moving through a pipe of non-uniform size

Consider the small blue-colored portion of the fluid.

At t = 0, the blue portion is flowing through a cross section of area A_1 at speed v_1.

At the end of Δt , the blue portion is flowing through a cross section of area A_2 at speed v_2.

The mass that crosses A_1 in some time interval is the same as the mass that crosses A_2 in that same time interval.

$m_1 = m_2$ or $\rho A_1 v_1 \Delta t = \rho A_2 v_2 \Delta t$

The fluid is incompressible, so ρ is a constant.

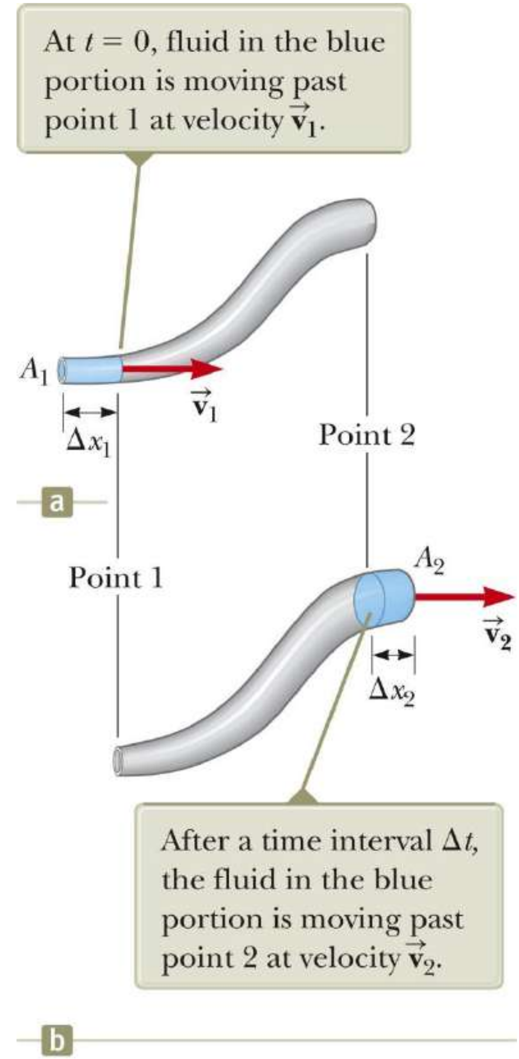
$A_1 v_1 = A_2 v_2 = \text{constant}$

- This is called the **equation of continuity for fluids.**

The speed is high where the tube is constricted (small *A*).

The speed is low where the tube is wide (large *A*).

***Q=Av*, is called the *volume flux* or the *flow rate*.**



Example: A water pipe of radius 3cm is used to fill a 40liter bucket. If it takes 5min to fill the bucket, what is the speed *v* at which the water leave the pipe?

Solution:

The cross sectional area of the pipe *A* is

$$A = \pi r^2 = \pi \times 3^2 = 9\pi\, cm^2$$

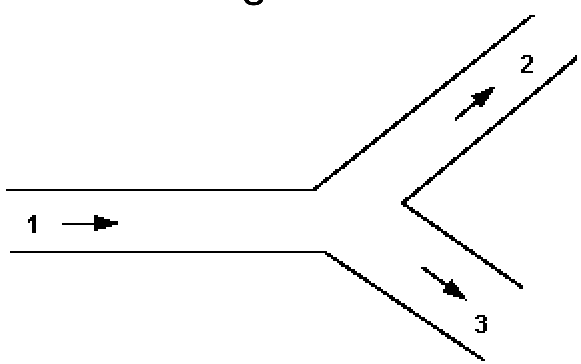
$$Av = 40\frac{liter}{\min} = \frac{40\times 10^3 cm^3}{60s} = 666.6 cm^3/s$$

therefore,

$$v = \frac{666.6}{9\pi} = 23.5 cm/s$$

Example: If pipe 1 diameter = 50mm, mean velocity 2m/s, pipe 2 diameter 40mm takes 30% of total discharge and pipe 3 diameter 60mm. What are the values of discharge and mean velocity in each pipe?

$$Q_1 = A_1 u_1 = \left(\frac{\pi d^2}{4}\right) u$$
$$= 0.00392\, m^3/s$$



$$Q_2 = 0.3 Q_1 = 0.001178 m^3/s$$
$$Q_1 = Q_2 + Q_3$$
$$Q_3 = Q_1 - 0.3 Q_1 = 0.7 Q_1$$
$$= 0.00275 m^3/s$$

$$Q_3 = A_3 u_3$$
$$u_3 = 0\ 972 m \quad s$$

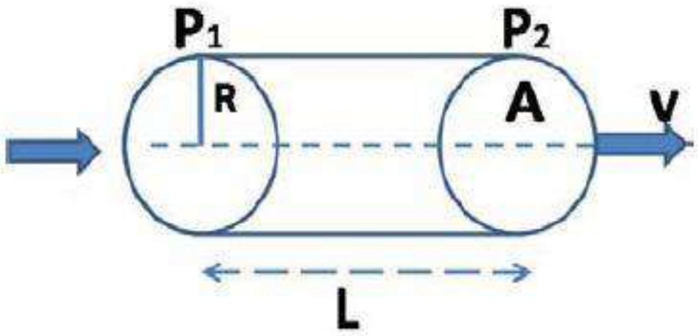
$$Q_2 = A_2 u_2$$
$$u_2 = 0\ 936 m \quad s$$

Laminar Flow in a Tube

Consider a fluid moving through a tube of length **L** and cross sectional area, $A = \pi R^2$.

The pressure difference across the segment of the tube is $\Delta p = p_2 - p_1$ as shown in the figure. The average velocity and the flow rate of laminar flow of a fluid through a tube is given by:

$$\bar{v} = \frac{\Delta p\, R^2}{8\, \eta\, L}$$



Then, ***the flow rate*** is given by ***Poiseuille law***

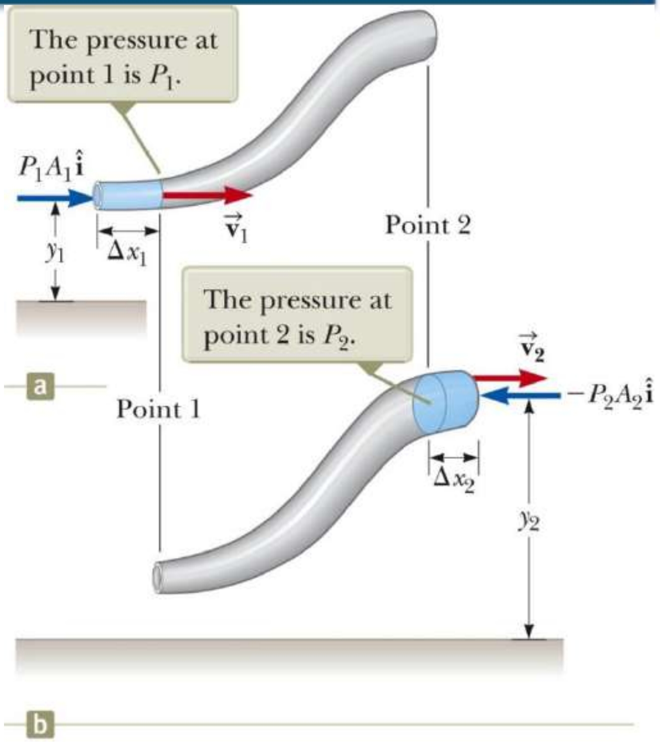
$$Q = A\bar{v} = \pi R^2 \bar{v} = \frac{\pi\, \Delta p\, R^4}{8\, \eta\, L}$$

It indicates that **high viscosity** leads to **low flow rate** and **low speed of flow**, It also shows that the flow rate is proportional to the 4th power of **R**.

This indicates that for blood vessel, any small change in the radius of the vessel results in a considerable change of the flow rate.

The viscosity of blood about 3-4 x 10^{-3} Pa.s

Bernoulli's Equation



Consider the two shaded segments.The volumes of both segments are equal.

The net work done on the segment is $W = (P_1 - P_2)\, V$.

Part of the work goes into changing the kinetic energy and some to changing the gravitational potential energy.The change in kinetic energy is:

- $\Delta K = \frac{1}{2} mv_2^2 - \frac{1}{2} mv_1^2$

The change in gravitational potential energy:

- $\Delta U = mgy_2 - mgy_1$

Combining: $(P_1 - P_2)V = \frac{1}{2} mv_2^2 - \frac{1}{2} mv_1^2 + mgy_2 - mgy_1$

Rearranging and expressing in terms of density:

$$\boldsymbol{P_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho g y_2}$$

Or $\quad P + \frac{1}{2} \rho v^2 + \rho g y = constant$

This is **Bernoulli's Equation** for an ideal fluid.

As the speed increases, the pressure decreases.

Example

The diameter of a horizontal blood vessel is reduced from 12 to 4 mm. What is the flow rate of blood in the vessel, if the pressure at the wide part is 8 kPa and 4 kPa at the narrow one. (Take the density of blood to be 1060 kgm-3.)

Solution

□ By applying Bernoulli's equation for horizontal flow and by taking one point in the wider section and the other at the narrower one, we get:

$$p_{wid} - p_{narr} = \frac{1}{2}\rho\left(\overline{v}^2_{narr} - \overline{v}^2_{wid}\right)$$

Using the **continuity equation**,

$$v_{wid} = \frac{r^2_{narr}}{r^2_{wid}} v_{narr} = \left(\frac{4}{12}\right)^2 v_{narr} = \frac{1}{9} v_{narr}$$

Then substitute and solve for v_narr to get

$$4 \times 10^3 = \frac{1}{2}(1060)\ \overline{v^2_{narr}}\left(1 - \frac{1}{81}\right),\ \text{so then } v^2_{narr} = \frac{81 \times 2 \times 4 \times 10^3}{80 \times 1060} = 7.64$$

□ The flow rate is constant everywhere and can be calculated from the relation

$$Q = \pi r^2_{narr} v_{narr} = 3.14 \times (4 \times 10^{-3})^2\ 2.76$$

$$Q = 1.387 \times 10^{-4}\ m^3 s^{-1} = 138.7\ mL/s$$

The Role of Gravity on blood circulation

The blood pressure in human organs is affected by its location from earth.

If we have a person in the reclining (laying down) position, the measurement of blood pressure in the large arteries are almost the same everywhere.

In the **standing position**, the situation is different, where only the term $\frac{1}{2}\rho\bar{v}^2$ can be ignored and the term $\rho\, gh$ has a significant effect.

Hence the gauge pressures at the brain p_B, at the heart p_H and at the foot

P_F are related by: $p_F = p_H + \rho g h_H = p_B + \rho g h_B$

Note that h_F = 0 in the standing position.

Typical values for adults standing upward h_H=1.3 m and h_B = 1.7 m.

Typical value of the blood pressure at the heart is pH =13.3 kPa, and take

the blood density to be 1060 kgm^{-3}, we find:

$$p_F = p_H + \rho g h_H = 13.3 \times 10^3 + (1060)(10)(1.3) \sim 27.1\, kPa$$

In a similar way, we find that:

$$p_B = p_H + \rho g(h_H - h_B) = 13.3 \times 10^3 + (1060)(10)(-0.4) = 9.06\, kPa$$

Applications of Fluid Dynamics – Airplane Wing

Streamline flow around a moving airplane wing.

Lift is the upward force on the wing from the air.

Drag is the resistance.

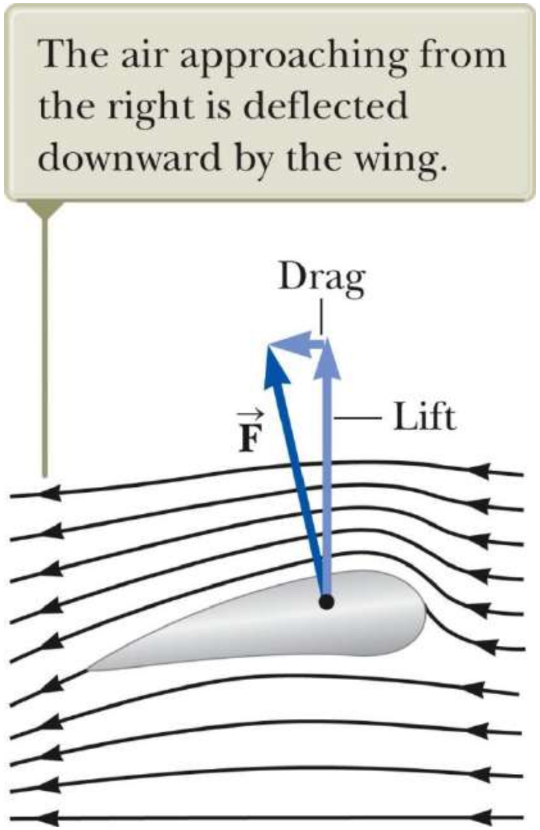
The curvature of the wing surfaces causes the pressure above the wing to be lower than that below the wing due to the Bernoulli effect.

The lift depends on the speed of the airplane, the area of the wing, its curvature, and the angle between the wing and the horizontal.

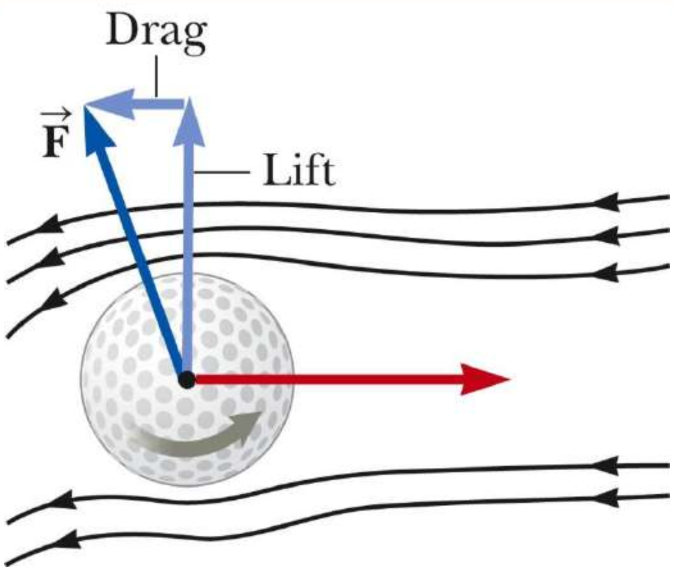
In general, an object moving through a fluid experiences lift as a result of any effect that causes the fluid to change its direction as it flows past the object.

Some factors that influence lift are:

- The shape of the object
- The object's orientation with respect to the fluid flow
- Any spinning of the object
- The texture of the object's surface



Golf Ball Example



The ball is given a rapid backspin.

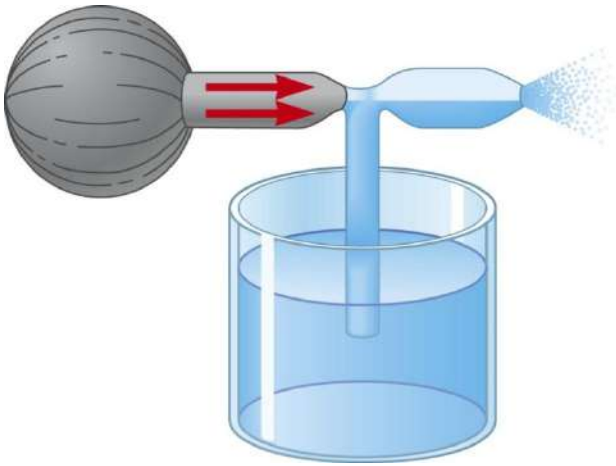
The dimples increase friction.

- Increases lift

It travels farther than if it was not spinning.

The lift gained by spinning the ball more than compensates for the loss of range due to the effect of friction on the translational motion of the ball.

Atomizer Example



A stream of air passes over one end of an open tube.

The other end is immersed in a liquid.

The moving air reduces the pressure above the tube.

The fluid rises into the air stream.

The liquid is dispersed into a fine spray of droplets.

Medical Physics

Lectures in General Physics for Medical Sciences Students

By

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Chapter 6 – Temperature and Heat

Thermodynamics

Thermodynamics involves situations in which the temperature or state of a system changes due to energy transfers.

Thermodynamics is very successful in explaining the bulk properties of matter.

Also successful in explaining the correlation between these properties and the mechanics of atoms and molecules.

Historically, the development of thermodynamics paralleled the development of atomic theory.

To describe thermal phenomena, careful definitions are needed:

- Temperature
- Heat
- Internal energy

Thermal Contact and Thermal Equilibrium

Two objects are in **thermal contact** with each other if energy can be exchanged between them.

- The exchanges we will focus on will be in the form of heat or electromagnetic radiation.

The energy is exchanged due to a temperature difference.

Thermal equilibrium is a situation in which two objects would not exchange energy by heat or electromagnetic radiation if they were placed in thermal contact.

- The thermal contact does not have to also be physical contact.

Zeroth Law of Thermodynamics

If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.

- Let object C be the thermometer
- Since they are in thermal equilibrium with each other, there is no energy exchanged among them.

Temperature – Definition

We associate the concept of temperature with how hot or cold an object feels.

Our senses provide us with a qualitative indication of temperature.

We need a reliable and reproducible method for measuring the relative hotness or coldness of objects.

- We need a technical definition of temperature.

Temperature can be thought of as the property that determines whether an object is in thermal equilibrium with other objects.

Two objects in thermal equilibrium with each other are at the same temperature.

- If two objects have different temperatures, they are not in thermal equilibrium with each other.

A **thermometer** is a device that is used to measure the temperature of a system.

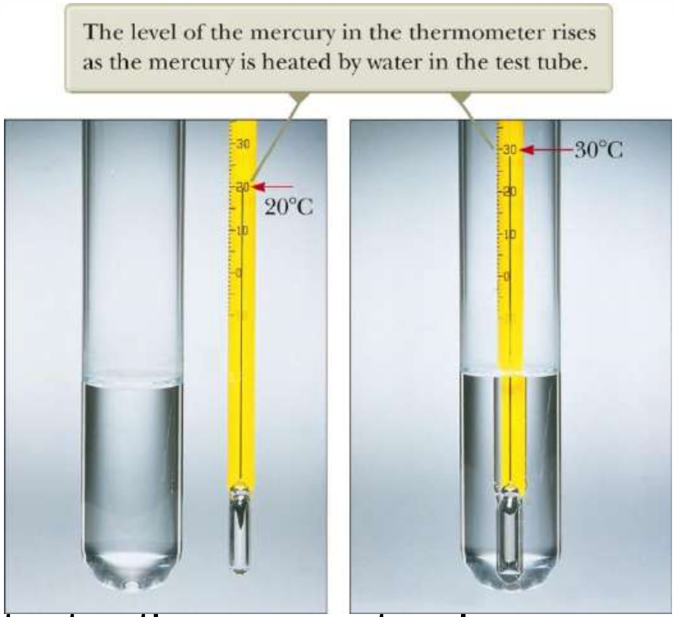
Thermometers are based on the principle that some physical property of a system changes as the system's temperature changes.

Thermometer, Liquid in Glass

A common type of thermometer is a liquid-in-glass.

The material in the capillary tube expands as it is heated.

The liquid is usually mercury or alcohol.



Calibrating a Thermometer

A thermometer can be calibrated by placing it in contact with some natural systems that remain at constant temperature.

Common systems involve water

- A mixture of ice and water at atmospheric pressure
  - Called the *ice point* of water
- A mixture of water and steam in equilibrium
  - Called the *steam point* of water

Once these points are established, the length between them can be divided into a number of segments.

Celsius Scale

The ice point of water is defined to be 0º C.

The steam point of water is defined to be 100º C.

The length of the column between these two points is divided into 100 increments, called degrees.

Problems with Liquid-in-Glass Thermometers

An alcohol thermometer and a mercury thermometer may agree only at the calibration points.

The discrepancies between thermometers are especially large when the temperatures being measured are far from the calibration points.

The thermometers also have a limited range of values that can be measured.

- **Mercury cannot be used under –39º C**
- **Alcohol cannot be used above 85º C**

Absolute Zero

The thermometer readings are virtually independent of the gas used.

If the lines for various gases are extended, the pressure is always zero when the temperature is –273.15° C.

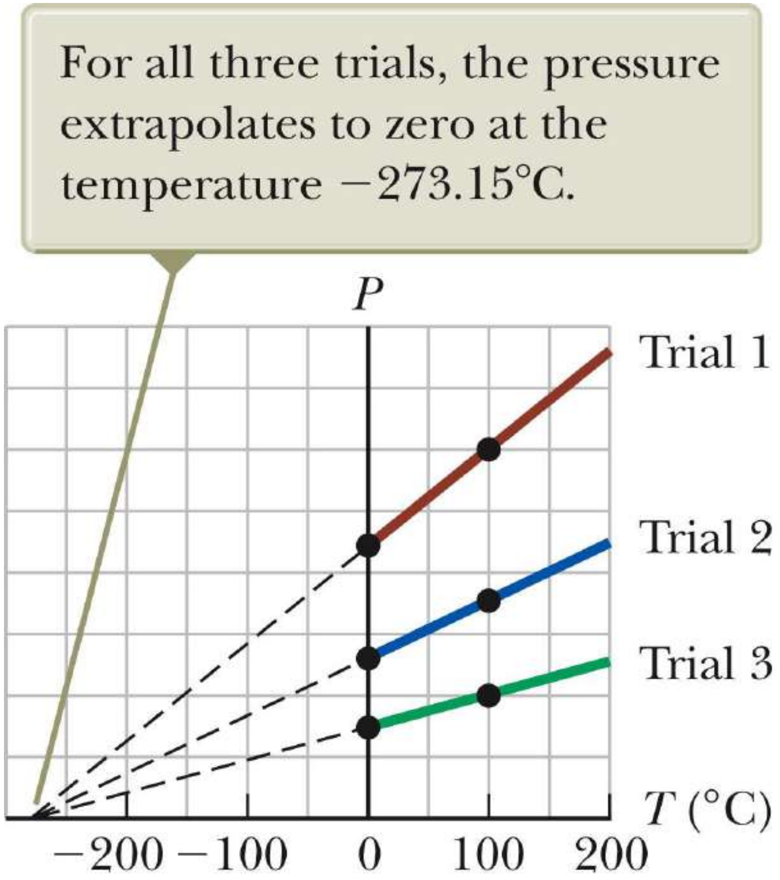
This temperature is called **absolute zero.**

Absolute zero is used as the basis of the **absolute temperature scale.**

The size of the degree on the absolute scale is the same as the size of the degree on the Celsius scale.

To convert: $\mathbf{T_C = T - 273.15}$

The units of the absolute scale are **kelvins.** The absolute scale is also called the Kelvin scale. Named for William Thomson, Lord Kelvin



Fahrenheit Scale

A common scale in everyday use in the US. Named for Daniel Fahrenheit

Temperature of the ice point is 32°F.

Temperature of the steam point is 212°.

There are 180 divisions (degrees) between the two reference points.

$$\Delta T_C = \Delta T = \frac{5}{9}\Delta T_F$$

Comparison of Scales

Celsius and Kelvin have the same size degrees, but different starting points.

- $T_C = T - 273.15$

Celsius and Fahrenheit have different sized degrees and different starting points.

$$T_F = \frac{9}{5}T_C + 32^\circ F$$

To compare changes in temperature

Ice point temperatures 0°C = 273.15 K = 32° F

Steam point temperatures 100°C = 373.15 K = 212° F

An Ideal Gas

For gases, the interatomic forces within the gas are very weak.

State variables describe the state of a system.

Variables may include:

- Pressure, temperature, volume, internal energy

The state of an isolated system can be specified only if the system is in thermal equilibrium internally.

- For a gas in a container, this means every part of the gas must be at the same pressure and temperature.

It is useful to know how the volume, pressure, and temperature of the gas of mass *m* are related.

The equation that interrelates these quantities is called the **equation of state.**

The **ideal gas model** can be used to make predictions about the behavior of gases.

The Mole

The amount of gas in a given volume is conveniently expressed in terms of the number of moles, *n.*

One **mole** of any substance is that amount of the substance that contains **Avogadro's number** of constituent particles.

- Avogadro's number is $N_A = 6.022 \times 10^{23}$
- The constituent particles can be atoms or molecules.

The number of moles can be determined from the mass of the substance:

$$n = \frac{m}{M}$$

- *M* is the molar mass of the substance.
  - Can be obtained from the periodic table
  - Is the atomic mass expressed in grams/mole
    - Example: He has mass of 4.00 u so M = 4.00 g/mol
- *m* is the mass of the sample.
- *n* is the number of moles.

Gas Laws

When a gas is kept at a constant temperature, its pressure is inversely proportional to its volume (Boyle's law).

When a gas is kept at a constant pressure, its volume is directly proportional to its temperature (Charles and Gay-Lussac's law).

When the volume of the gas is kept constant, the pressure is directly proportional to the temperature (Guy-Lussac's law).

Ideal Gas Law

The equation of state for an ideal gas combines and summarizes the other gas laws:

$$PV = nRT$$

This is known as the **ideal gas law.**

R is a constant, called the Universal Gas Constant.

- $R = 8.314$ J/mol · K = 0.08214 L · atm/mol · K

From this, you can determine that 1 mole of any gas at atmospheric pressure and at 0^o C is 22.4 L.

It is common to call *P*, *V*, and *T* the **thermodynamic variables** of an ideal gas.

Example

Pure helium gas is admitted into a tank containing a movable piston. The initial volume, pressure and temperature of the gas are $15x10^{-3}m^3$, 200kPa and 300K respectively. If the volume is decreased to $12x10^{-3}m^3$ and the pressure is increased to 350KPa, find the final temperature of the gas.

Solution

Since the gas can not escape from the tank then the number of moles is constant,

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$T_2 = (\frac{p_2V_2}{p_1V_1})T_1 = \frac{3.5\,atm\,.12\,liters}{2\,atm\,.15\,liters}(300K) = 420\,K$$

Internal Energy

Internal energy is all the energy of a system that is associated with its microscopic components.

- These components are its atoms and molecules.
- The system is viewed from a reference frame at rest with respect to the center of mass of the system.

The kinetic energy due to its motion through space is not included.

Internal energy does include kinetic energies due to:

- Random translational motion
- Rotational motion
- Vibrational motion

Internal energy also includes potential energy between molecules

Heat

Heat is defined as the transfer of energy across the boundary of a system due to a temperature difference between the system and its surroundings.

The term heat will also be used to represent the amount of energy transferred by this method.

There are many common phrases that use the word “heat” incorrectly.

Heat, internal energy, and temperature are all different quantities.

- Be sure to use the correct definition of heat.
- **One calorie** is the amount of energy transfer necessary to raise the temperature of 1 g of water from 14.5^{o}C to 15.5^{o}C.
  - The “Calorie” used for food is actually 1 kilocalorie.
  - The standard in the text is to use Joules.

more precise, measurements determined the amount of mechanical energy needed to raise the temperature of water from 14.5^{o}C to 15.5^{o}C.

1 cal = 4.186 J

- This is known as the **mechanical equivalent of heat.**

Heat Capacity

The **heat capacity**, C, of a particular sample is defined as the amount of energy needed to raise the temperature of that sample by 1^{o}C.

If energy *Q* produces a change of temperature of ΔT, then $Q = C\,\Delta T$.

Specific Heat

Specific heat, c, is the heat capacity per unit mass.

If energy *Q* transfers to a sample of a substance of mass *m* and the temperature changes by ΔT, then the specific heat is

$$c \equiv \frac{Q}{m\,\Delta T}$$

The specific heat is essentially a measure of how thermally insensitive a substance is to the addition of energy.

- The greater the substance's specific heat, the more energy that must be added to a given mass to cause a particular temperature change.

The equation is often written in terms of Q : $\boldsymbol{Q = m\,c\,\Delta T}$

Water has the highest specific heat of common materials.

Some Specific Heat Values

Specific Heats of Some Substances at 25°C and Atmospheric Pressure

Substance	Specific Heat c J/kg · °C	Specific Heat c cal/g · °C	Substance	Specific Heat c J/kg · °C	Specific Heat c cal/g · °C
Elemental solids			*Other solids*		
Aluminum	900	0.215	Brass	380	0.092
Beryllium	1 830	0.436	Glass	837	0.200
Cadmium	230	0.055	Ice (−5°C)	2 090	0.50
Copper	387	0.092 4	Marble	860	0.21
Germanium	322	0.077	Wood	1 700	0.41
Gold	129	0.030 8	*Liquids*		
Iron	448	0.107	Alcohol (ethyl)	2 400	0.58
Lead	128	0.030 5	Mercury	140	0.033
Silicon	703	0.168	Water (15°C)	4 186	1.00
Silver	234	0.056	*Gas*		
			Steam (100°C)	2 010	0.48

Example

A quantity of hot water at 91° C and another cold one at 12° C. How much kilogram of each one is needed to make an 800 liter of water bath at temperature of 35° C.

Solution

Assume the mass of hot water m_H and cold one is m_C,

800 liter of water is equivalent to 800 kg, *So* $m_H + m_C = 800$,

From the conservation of energy $m_H C_w (T_H - T_f) = m_C C_w (T_f - T_C)$

$$T_H = 92°C,\ \ T_C = 12°C,\ \ T_f = 35°C$$

$$56\, m_H = 23\, m_C,$$

- So

$$m_C = 2.43\, m_H$$

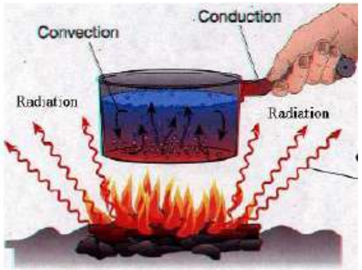
- So by substitution

$$3.43\, m_H = 800,$$

$$m_H = 233\, kg,\ \text{and}\ m_C = 567\, kg$$

Mechanisms of Energy Transfer In Thermal Processes

- The heat is a transfer of the energy from a high temperature object to a lower temperature one. There are various mechanisms responsible for the transfer: Conduction, Convection, Radiation



Conduction

It is an exchange of kinetic energy between microscopic particles by collisions.

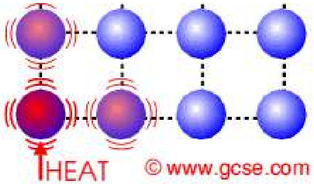
- The microscopic particles can be atoms, molecules or free electrons.

- Less energetic particles gain energy during collisions with more energetic particles.

Rate of conduction depends upon the characteristics of the substance.

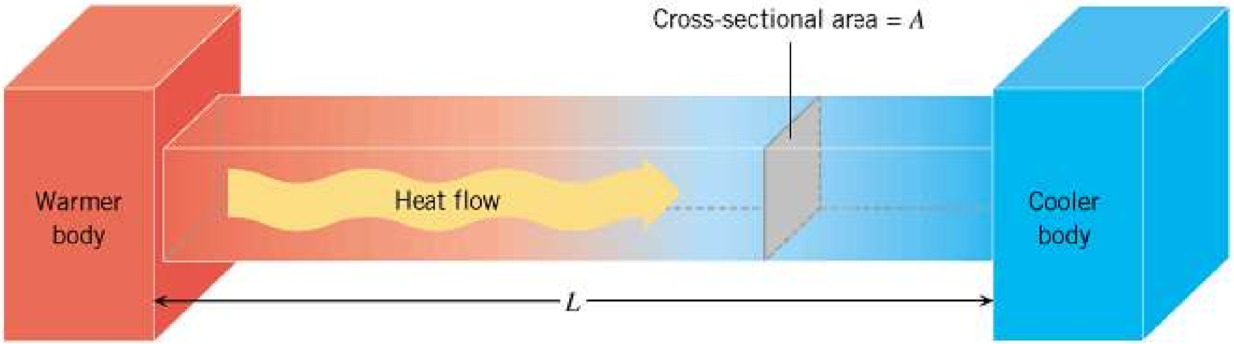
In general, metals are good thermal conductors.

- They contain large numbers of electrons that are relatively free to move through the metal.
- They can transport energy from one region to another.



Poor conductors include asbestos, paper, and gases.Conduction can occur only if there is a difference in temperature between two conducting medium.

Conduction, equation



The slab at right allows energy to transfer from the region of higher temperature to the region of lower temperature.

The rate of transfer is given by:

$$H = \frac{Q}{t} = kA\left(\frac{\Delta T}{L}\right)$$

A is the cross-sectional area. L is the length of a rod

H (or P) = rate of conduction heat transfer (Watt)

k is the thermal conductivity of the material.

- Good conductors have high k values and good insulators have low k values

TABLE 20.3

Thermal Conductivities

Substance	Thermal Conductivity (W/m · °C)
Metals (at 25°C)	
Aluminum	238
Copper	397
Gold	314
Iron	79.5
Lead	34.7
Silver	427
Nonmetals (approximate values)	
Asbestos	0.08
Concrete	0.8
Diamond	2 300
Glass	0.8
Ice	2
Rubber	0.2
Water	0.6
Wood	0.08
Gases (at 20°C)	
Air	0.023 4
Helium	0.138
Hydrogen	0.172
Nitrogen	0.023 4
Oxygen	0.023 8

Example

- An aluminum pot contains water that is kept steadily boiling (100 ºC). The bottom surface of the pot, which is 12 mm thick and 1.5×10^4 mm^2 in area, is maintained at a temperature of 102° C by an electric heating unit. Find the rate at which heat is transferred through the bottom surface. Compare this with a copper based pot.

Solution

$$H = kA\left(\frac{\Delta T}{L}\right)$$

- For the aluminum base: $T_H = 102\ ^\circ C, T_C = 100\ ^\circ C,\ L = 12\ mm = 0.012\ m,\ K_{Al} = 238\, Wm^{-1}K^{-1}$, Base area $A = 1.5 \times 10^4\ mm^2 = 0.015\ m^2$.

$$H_{Al} = 238\,(0.015)\,\frac{(102-100)}{0.012} = 588\,W$$

- For the copper base $K_{Cu} = 397\, Wm^{-1}K^{-1}$.

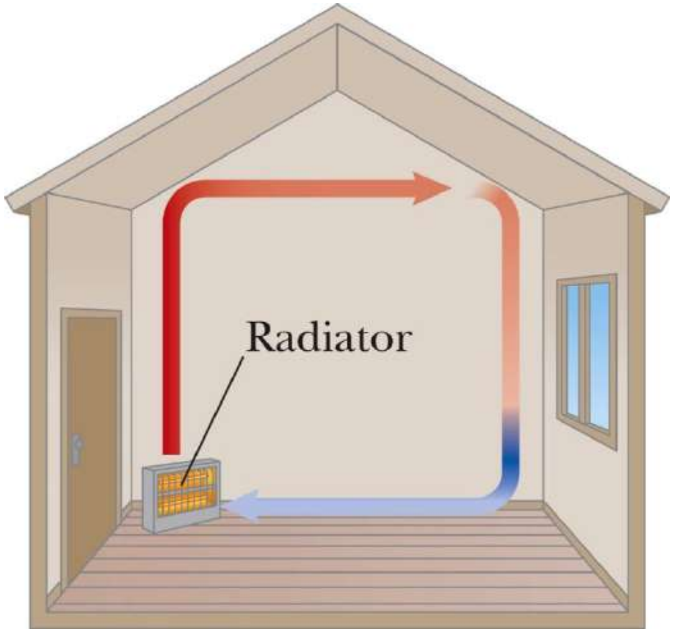
$$H_{Cu} = 397\,(0.015)\,\frac{(102-100)}{0.012} = 1003\,W$$

Convection

Energy transferred by the movement of a substance.

It is a form of matter transfer:

- When the movement results from differences in density, it is called *natural convection.*
- When the movement is forced by a fan or a pump, it is called *forced convection.*



Example

Air directly above the radiator is warmed and expands.

The density of the air decreases, and it rises.

A continuous air current is established

Radiation

Radiation does not require physical contact.

All objects radiate energy continuously in the form of electromagnetic waves due to thermal vibrations of their molecules.

Rate of radiation is given by **Stefan's law.**

$P = \sigma A e T^4$

- P is the rate of energy transfer, in Watts.
- $\sigma = 5.6696 \times 10^{-8}\ W/m^2 \cdot K^4$
- A is the surface area of the object.
- e is a constant called the emissivity.
  - e varies from 0 to 1
  - The emissivity is also equal to the absorptivity.
- T is the temperature in Kelvins.

An ***ideal absorber*** is defined as an object that absorbs all of the energy incident on it. $e = 1$

This type of object is called a **black body.**

Energy Absorption and Emission by Radiation

With its surroundings, the rate at which the object at temperature T with surroundings at T_o radiates is

- $P_{net} = \sigma A e\,(T^4 - T_o^4)$
- When an object is in equilibrium with its surroundings, it radiates and absorbs at the same rate.
  - Its temperature will not change

Example: A student tries to decide what to wear is staying in a room that is at 20° C. If the skin temperature is 37° C, how much heat is lost from the body in 10 minutes? Assume that the emissivity of the body is 0.9 and the surface area of the student is 1.5 m2.

Solution

Using the Stefan-Boltzmann's law

$$P_{net} = e\,\sigma\,A\,(T^4 - T_s^4) = (5.67\times10^{-8})(0.9)(1.5)(310^4 - 293^4) = 143\,watt\,.$$

The total energy lost during 10 min is

$$Q = P_{net}\,\Delta t = 143\times600 = 85.8\,kJ$$

The Dewar Flask

A Dewar flask is a container designed to minimize the energy losses by conduction, convection, and radiation.

- Invented by Sir James Dewar (1842 – 1923)

It is used to store either cold or hot liquids for long periods of time.

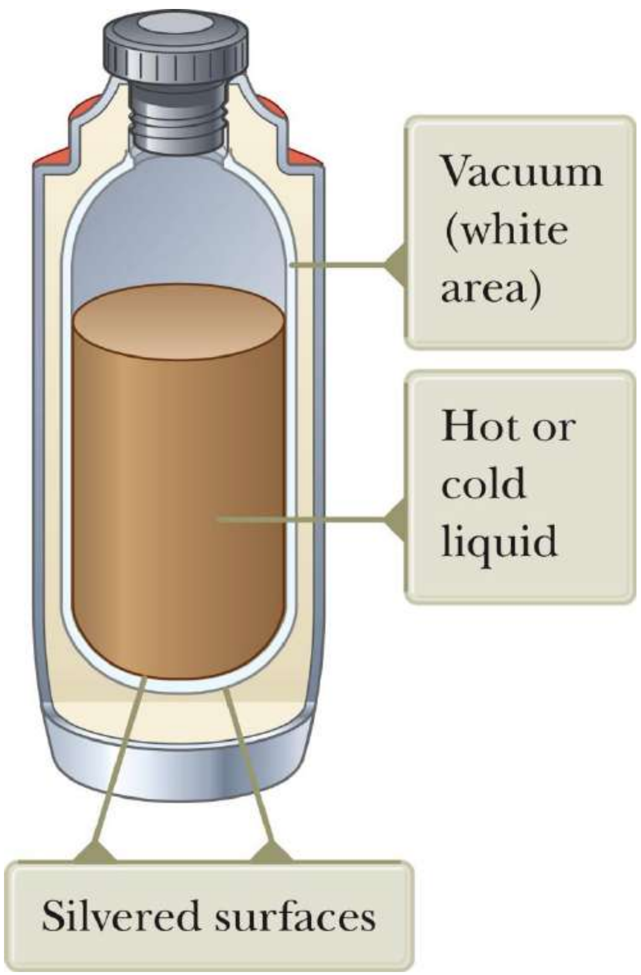
- A Thermos bottle is a common household equivalent of a Dewar flask.

The space between the walls is a vacuum to minimize energy transfer by conduction and convection.

The silvered surface minimizes energy transfers by radiation.

- Silver is a good reflector.

The size of the neck is reduced to further minimize energy losses.



Heat losses from the Body

Constant body temperatures permit metabolic processes to proceed at constant rates .

Because the body at a constant temperature it contains stored heat energy that is essentially constant as long as we are alive .

The normal body (core) temperature is often given as 37 ° C, only small percentage of people have exactly that temperature .If we measured the temperature of a large number of healthy people ,we would find a distribution of temperature with 0.5± ° C of normal temperature

The temperature depends upon the time of the day (lower in the morning);the temperature of the environment ; and the amount of recent physical activity, the amount of clothing ,and the health of individual

The heat is generated in the organs and tissues of the body; most of it is removed by several processes that take place on the skins surface.

Heat losses from the Body

The main heat loss mechanisms are :

1 . Radiation

2 .Convection

3 . Evaporation

some cooling of the body takes place in the lungs where the inspired air heated and vaporized water is added to expired air. Eating hot or cold food may also heat or cool the body.

For the body to hold its temperature close to its normal value it must have a thermostat analogous to a home thermostat that maintains the temperature of the rooms nearly constant. The hypothalamus of the brain contains the body's thermostat.

If the core temperature rises, the hypothalamus initiates sweating vasodilatation which increases the skin temperature. Both of these reactions increase the heat loss to the environment.

The rate of heat production of the body for a 2400 Kcal / hr diet is about 1.7 Kcal /min or 120 J / sec (120 W).

If the body is to maintain a constant temperature it must lose heat at the same rate.

The actual heat lost by radiation , convection , evaporation of sweat and respiration dependents on a number of factors:

1.The temperature of the surrounding.

2 . Temperature .

3 . Humidity .

4 . Motion of the air .

5 . The physical activity of the body .

6 . The amount of the body exposed .

7 . The amount of insulation on the body (cloth and fat).

All subjects regardless of their temperature emits electromagnetic radiation.

The amount of energy emitted by the body is proportional to absolute temperature raised to the fourth power.

The body also receives radiant energy from the surrounding objects.

The approximate difference between the energy radiated by the body and the energy absorbed from the equation:

$H_r = K_r \; A_r \, e \, (T_s - T_w)$

where H_r is the rate of energy loss (or gain) due to radiation.

A_r is the effective body surface area emitting radiation .

e is the emissivity of the surface

T_s is the skin temperature (c °)

T_w is the temperature of the surrounding walls .

K_r is the constant that depends upon various physical parameters and is about

5 Kcal / m^2. Hr . C° .

e in the infrared region is independent of the color of the skin and is very nearly equal to one, indicating that the skin at this wavelength is almost a perfect absorber and emitter of radiation.

The heat loss due to convection (Hc) is

$Hc = Kc \ Ac \ (Ts - T\alpha)$

Where Kc is constant that depend upon the movement of the air .

Ac is the effective surface area.

Ts is the temperature of the skin.

T α is the temperature of the air.

When the body is resting and there is no apparent wind, K is about 2.3 Kcal $/m^2 \ hr \ c^\circ$.

When the air is moving, the constant K increases according to equation

$Kc = 10.45 - v + 10 \sqrt{v}$

Where the wind speed v is in meter per second.

This equation is valid for speeds between 2.23 m/sec and 20 m /sec .

The equivalent temperature due to moving air is called wind chill factor and is determined by the actual temperature and wind speed.

3. Evaporation

The method of heat loss that of us familiar with is the evaporation of sweat.

Under exterme conditions of heat and exercise ,a man may sweat more than 1 liter of liquid per hour .

Since each gram of water that evaporates carries with it the heat of vaporization 580 calories , the evaporation of 1 liter carries with it 580 Kcal.

The sweat must evaporate from the skin in order to give the cooling effect.

The amount evaporated depends upon the air movement and the relative humidity.

Insulation of clothing

The unit of clothing is clo

This unit corresponds to the insulating value of clothing needed to maintain a subjects sitting at rest in comfort in a room at 21 c with air movement of 0.1 m/sec and air humidity of less than 50 % .

One clo of insulation is equal to a light weight business suit .

2 clo of clothing would enable a man to withstand a colder temperature than 1 clo.

Example

Consider a man on a beach in Florida. It is a sunny day so he is receiving radiation from the sun at the rate of 30 Kcal/hr. He has an effective body surface of 0.9 m^2, $T_s = 32\ ^\circ C$, and the temperature of his surrounding is $30^\circ C$.

a. Find the net energy gained by radiation per hour .

b. If there is a breeze at 4m/sec ,find the energy lost by convection per hour

c. If he loses 10 Kcal/hr , and his metabolic rate is 80 kcal /hr, how much is heat is lost by evaporation?

$H_r = K_r A_r e (T_s - T_w)$ Since $K_r = 5 Kcal/ m^2 . hr .^\circ C$ and $e=1$

$H_r = 5 \times 0.9 (32 - 30) = 9$ Kcal/hr

b . $H_c = K_c A_c (T_s - T\alpha)$

$K_c = 10.45 - v + 10 \sqrt{v} = 10.45 - 4 + 10 \sqrt{4} = 6.45 + 20 = 26.5$ Kcal /hr.$m^2 .^\circ C$

$H_c = 26.5 \times 0.9 (32 - 30) = 48$ Kcal /hr

c. Heat lost = Heat gain

Heat lost by radiation +evaporation +convection +respiration

Heat lost = 9 +evaporation +48 +10 =67 + evaporation

Heat gain = 80 +30 = 110 =67 + evaporation

Heat lost by evaporation =110 -67 = 43 Kcal /hr

Medical Physics

Lectures in General Physics for Medical Sciences Students

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Chapter 7 - Sound Waves

Types of Waves

Example of a wave

- A pebble hits the water's surface.
- The resulting circular wave moves outward from the creation point.
- An object floating on the disturbed water will move vertically and horizontally about its original position, but does not undergo any net displacement.

In wave motion, energy is transferred over a distance.

Matter is not transferred over a distance.

There are two main types of waves.

- Mechanical waves
  - Some physical medium is being disturbed.
  - The wave is the propagation of a disturbance through a medium.
- Electromagnetic waves
  - No medium required.
  - Examples are light, radio waves, x-rays

Pulse on a String

The wave is generated by a flick on one end of the string.

The string is under tension.

A single bump is formed and travels along the string.

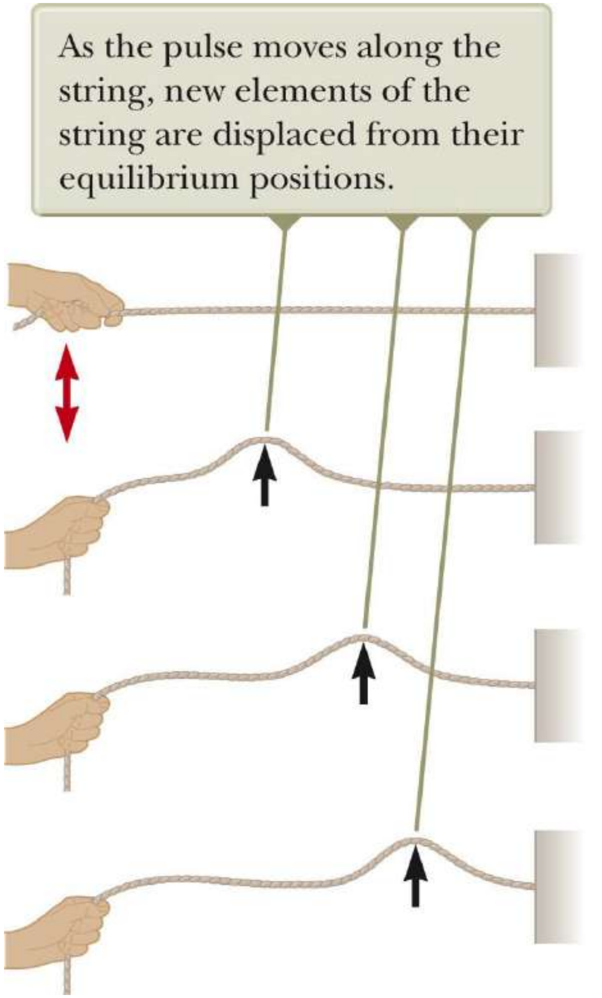
- The bump is called a **pulse.**
- The speed of the pulse is *v.*

The string is the medium through which the pulse travels.

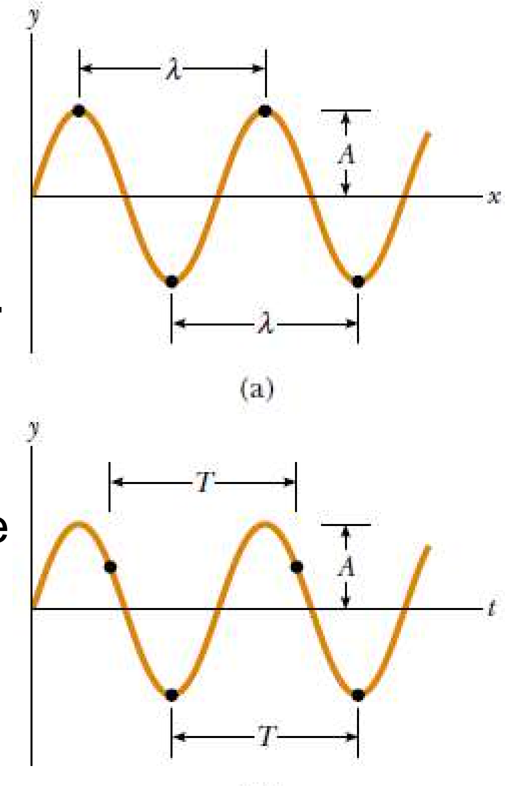
- Individual elements of the string are disturbed from their equilibrium position.

The pulse has a definite height. It has a definite speed of propagation along the medium.

The shape of the pulse changes very little as it travels along the string.



Terminology: Amplitude and Wavelength



The **crest** of the wave is the location of the maximum displacement of the element from its normal position.

- This distance is called the **amplitude**, *A.*

The **wavelength**, λ, is the distance from one crest to the next.

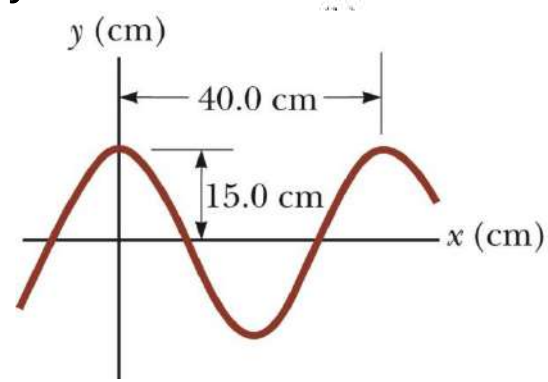
The **period**, T , is the time interval required for two identical points of adjacent waves to pass by a point.

The **frequency**, f, is the number of crests (or any point on the wave) that pass a given point in a unit time interval.

$$f = \frac{1}{T}$$

When the time interval is the second, the units of frequency are s^{-1} = Hz. Hz is a hertz

Example



The wavelength, λ, is 40.0 cm

The amplitude, *A*, is 15.0 cm

The wave function can be written as $y = A \cos(kx - \omega t)$.

Speed of a Wave on a String

The speed of the wave depends on the physical characteristics of the string and the tension to which the string is subjected.

$$v = \sqrt{\frac{\text{tension}}{\text{mass/length}}} = \sqrt{\frac{T}{\mu}}$$

This assumes that the tension is not affected by the pulse.

Energy in Waves in a String

Waves transport energy when they propagate through a medium. Every element has the same total energy.

the total kinetic energy in one wavelength is $K_\lambda = \frac{1}{4}\mu\,\omega^2 A^2\lambda$.

The total potential energy in one wavelength is $U_\lambda = \frac{1}{4}\mu\,\omega^2 A^2\lambda$.

This gives a total energy of $E_\lambda = K_\lambda + U_\lambda = \frac{1}{2}\mu\,\omega^2 A^2\lambda$

Power Associated with a Wave

- The power is the rate at which the energy is being transferred:

$$P = \frac{E_\lambda}{T} = \frac{\frac{1}{2}\mu\omega^2 A^2\lambda}{T} = \frac{1}{2}\mu\omega^2 A^2 v$$

Sound Waves

Waves can move through three-dimensional bulk media.

Sound waves are longitudinal waves.

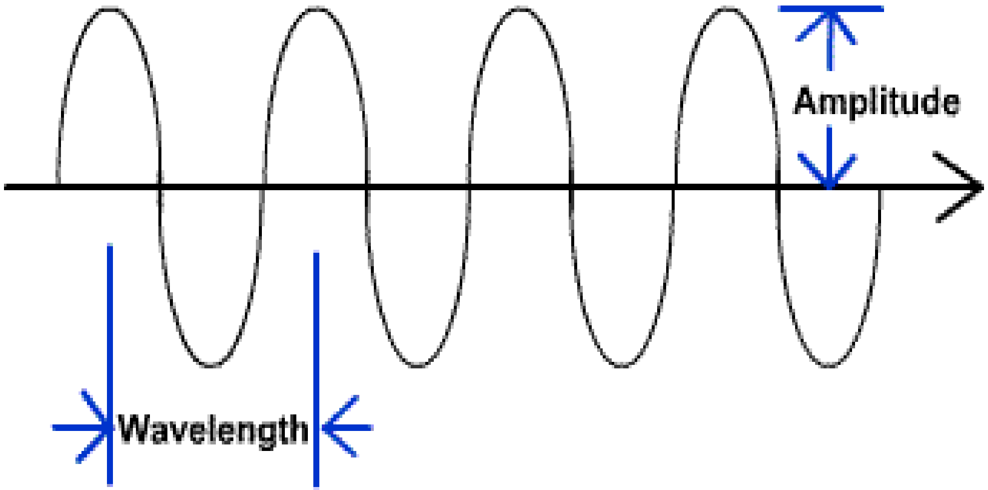
Sound waves cannot be transmitted through vacuum. The transmission of sound requires at least a medium, which can be solid, liquid, or gas.

- Commonly experienced as the mechanical waves traveling through air that result in the human perception of hearing
- As the sound wave travels through the air, elements of air are disturbed from their equilibrium positions.
- Accompanying these movements are changes in density and pressure of the air.

The mathematical description of sinusoidal sound waves is very similar to sinusoidal waves on a string.

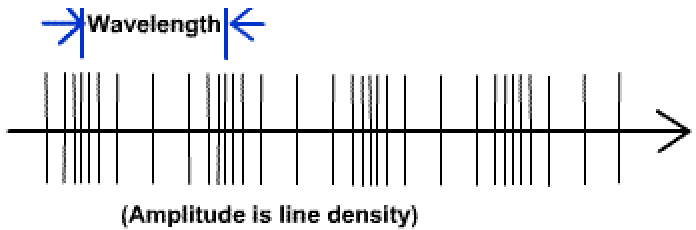
The categories cover different frequency ranges.

Audible waves [20Hz - 20kHz] are within the sensitivity of the human ear.
Infrasonic waves [less than 20kHz] have frequencies below the audible range.
Ultrasonic waves [larger than 20kHz] have frequencies above the audible range.



Transverse Wave
(water wave)

compression
(increase in pressure)



Compression Wave
(sound)

rarefaction
(Decrease in pressure)

The illustration above shows a comparison of a transverse wave such as a water wave and the compression wave sound wave.

Characteristics of sound

A sound wave has characteristics just like any other type of wave, including:

Amplitude

Since sound is a compression wave, its loudness or amplitude would correspond to how much the wave is compressed. It is sometimes called pressure amplitude

Wavelength (λ)

Wavelength is the distance from one crest to another of a wave. Since sound is a compression wave, the wavelength is the distance between maximum compressions

Frequency (f)

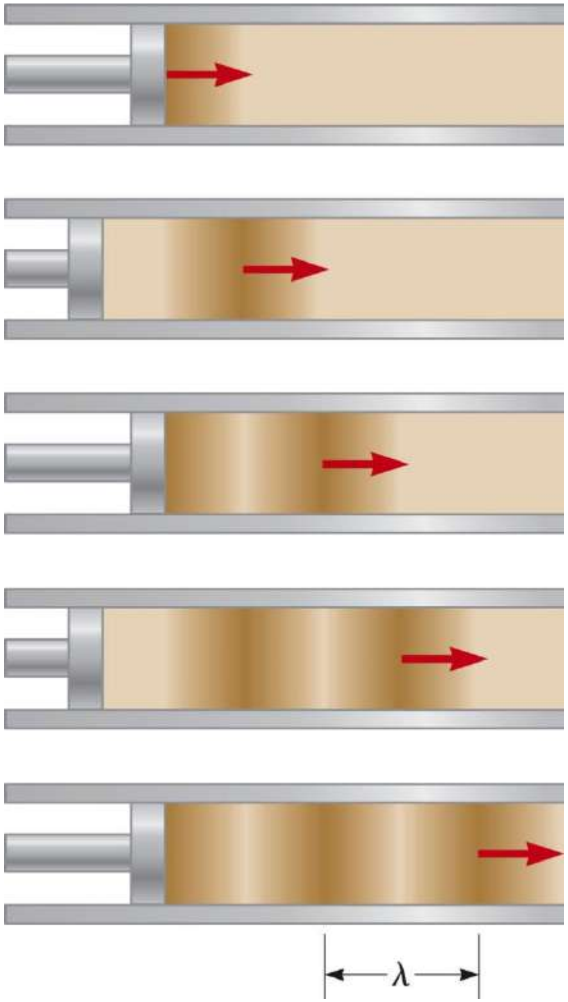
The frequency of sound is the rate at which the waves pass a given point. It is also the rate at which a guitar string or a loud speaker vibrates.

Period (T) :is the time taken by a crest to move forward one wave length. $T = 1 / f$

velocity (v) : velocity $(v) = \lambda / T = \lambda f$ m/sec

Resonance : The ability of an object to vibrate by absorbing energy of its own natural frequency is called *resonance*

Producing a Periodic Sound Wave



A one-dimensional periodic sound wave can be produced by causing the piston to move in simple harmonic motion.

The darker parts of the areas in the figures represent areas where the gas is compressed. The compressed region is called a **compression.**

When the piston is pulled back, the gas in front of it expands. The low-pressure regions are called **rarefactions.**

Both regions move at the speed of sound in the medium.

The distance between two successive compressions (or rarefactions) is the wavelength.

Speed of Sound Waves, General

The speed of sound waves in a medium depends on the compressibility and the density of the medium. The speed of *all mechanical waves* follows a general form:

$$v = \sqrt{\frac{\text{elastic property}}{\text{inertial property}}}$$

For a solid rod, the speed of sound depends on Young's modulus and the density of the material.

Speed of Sound in a Gas

The speed of sound in a gas is

$$v = \sqrt{\frac{B}{\rho}}$$

- The bulk modulus of the material is B.
- The density of the material is ρ.

Example Find the speed of sound in water, which has a bulk modulus of 2.1 & 10_9 N/m_2 at a temperature of 0° C and a density of 1.00 & 10^3kg/m_3.

Solution

$$v_{\text{water}} = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{2.1 \times 10^9\ \text{N/m}^2}{1.00 \times 10^3\ \text{kg/m}^3}} = 1.4\ \text{km/s}$$

Speed of Sound in Air

The speed of sound also depends on the temperature of the medium.

For air, the relationship between the speed and temperature is

$$v = (331\text{ m/s})\sqrt{1 + \frac{T_C}{273}}$$

- The 331 m/s is the speed at 0º C. T_C is the air temperature in Celsius.

Speed of Sound in Various Media

Medium	v (m/s)	Medium	v (m/s)	Medium	v (m/s)
Gases		**Liquids at 25°C**		**Solids**[a]	
Hydrogen (0°C)	1 286	Glycerol	1 904	Pyrex glass	5 640
Helium (0°C)	972	Seawater	1 533	Iron	5 950
Air (20°C)	343	Water	1 493	Aluminum	6 420
Air (0°C)	331	Mercury	1 450	Brass	4 700
Oxygen (0°C)	317	Kerosene	1 324	Copper	5 010
		Methyl alcohol	1 143	Gold	3 240
		Carbon tetrachloride	926	Lucite	2 680
				Lead	1 960
				Rubber	1 600

A Point Source

A **point source** will emit sound waves equally in all directions. This can result in a **spherical wave.**

This can be represented as a series of circular arcs concentric with the source.

Each surface of constant phase is a **wave front.**

The radial distance between adjacent wave fronts that have the same phase is the wavelength λ of the wave.

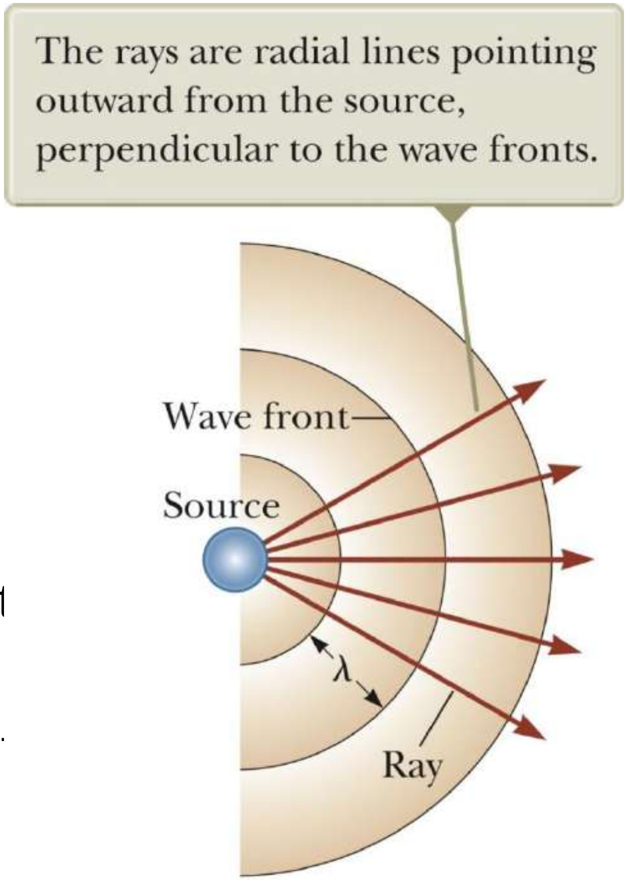
Radial lines pointing outward from the source, represent the direction of propagation, are called **rays.**

The power will be distributed equally through the area of the sphere.

The wave intensity at a distance *r* from the source is

$$I = \frac{(Power)_{avg}}{A} = \frac{(Power)_{avg}}{4\pi r^2}$$

This is an inverse-square law. The intensity decreases in proportion to the square of the distance from the source.



Example: Intensity Variations of a Point Source

A point source emits sound waves with an average power output of 80.0 W.

(A) Find the intensity 3.00 m from the source.

SOLUTION

Because a point source emits energy in the form of spherical waves

$$I = \frac{\mathcal{P}_{\text{avg}}}{4\pi r^2} = \frac{80.0 \text{ W}}{4\pi (3.00 \text{ m})^2} = 0.707 \text{ W/m}^2$$

(B) Find the distance at which the intensity of the sound is 1.00 108 W/m2.

$$r = \sqrt{\frac{\mathcal{P}_{\text{avg}}}{4\pi I}} = \sqrt{\frac{80.0 \text{ W}}{4\pi (1.00 \times 10^{-8} \text{ W/m}^2)}}$$

$$= 2.52 \times 10^4 \text{ m}$$

Sound Level

The range of intensities detectible by the human ear is very large.

It is convenient to use a logarithmic scale to determine the intensity level, β.

$$\beta = 10\log\left(\frac{I}{I_o}\right)$$

I_0 is called the **reference intensity.**

- It is taken to be the threshold of hearing. $I_0 = 1.00 \times 10^{-12}$ W/ m^2
- I is the intensity of the sound whose level is to be determined.

β is in decibels (dB)

Threshold of pain: I = 1.00 W/m^2; β = 120 dB

Threshold of hearing: $I_0 = 1.00 \times 10^{-12}$ W/ m^2 corresponds to β = 0 dB

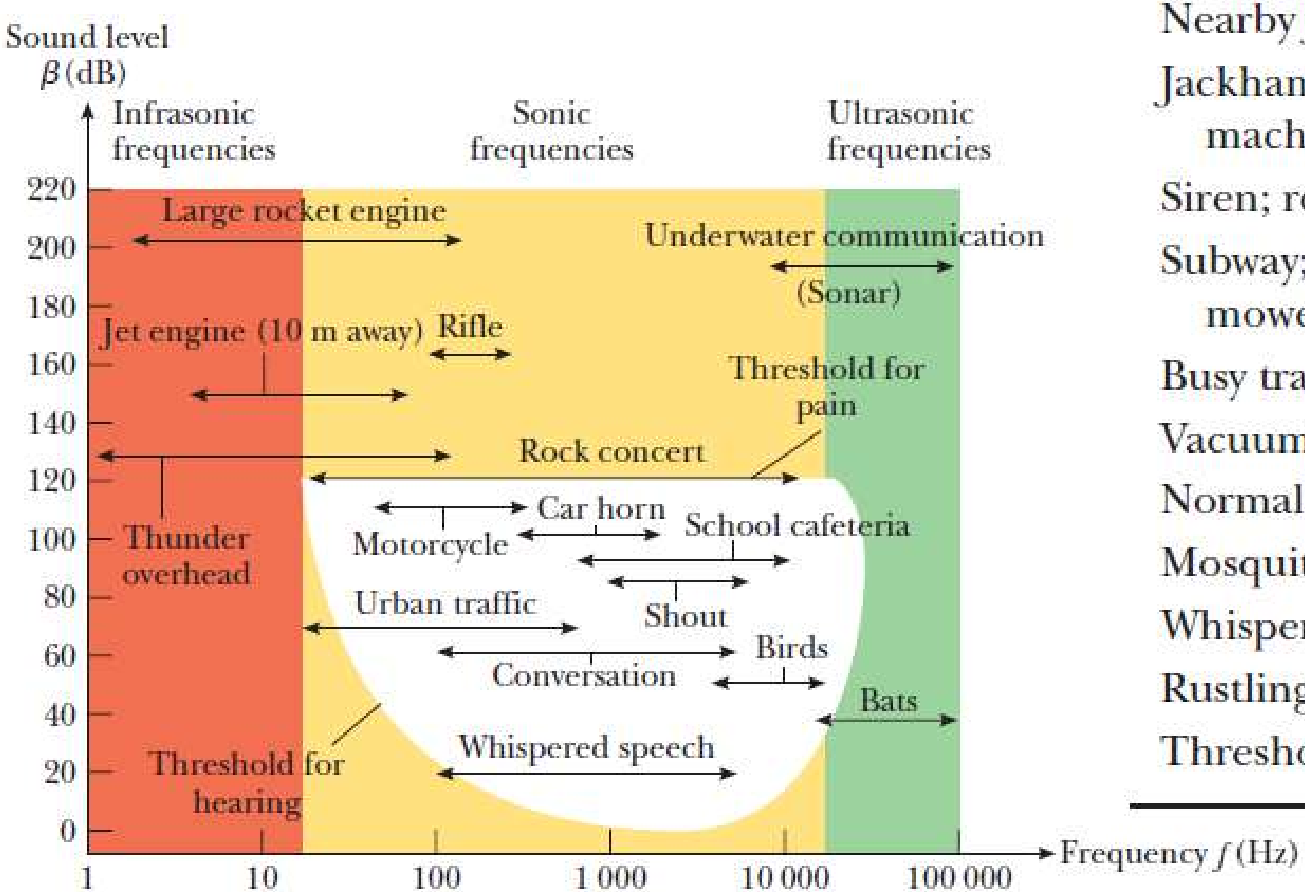
What is the sound level that corresponds to an intensity of 2.0×10^{-7} W/m^2 ?

$$\beta = 10 \log (2.0 \times 10^{-7} \text{ W/m}^2 / 1.0 \times 10^{-12} \text{ W/m}^2)$$

$$= 10 \log 2.0 \times 10^{5} = 53 \text{ dB}$$

Rule of thumb: A doubling in the loudness is approximately equivalent to an increase of 10 dB.

Sound Levels



Sound Levels

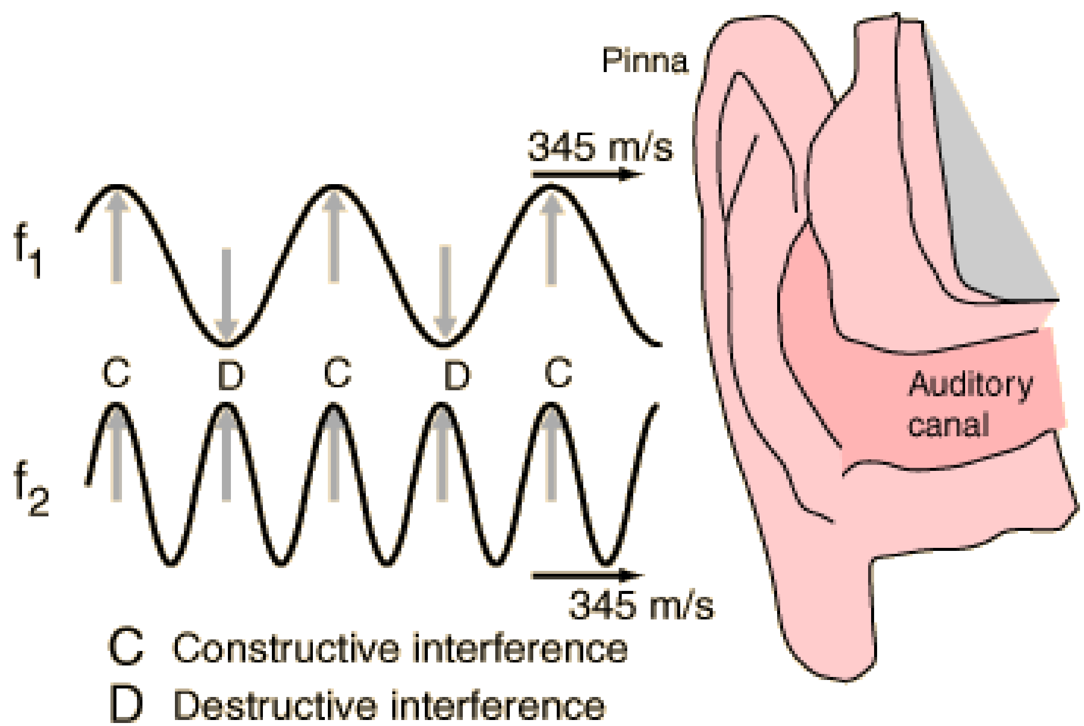
Source of Sound	β (dB)
Nearby jet airplane	150
Jackhammer; machine gun	130
Siren; rock concert	120
Subway; power lawn mower	100
Busy traffic	80
Vacuum cleaner	70
Normal conversation	50
Mosquito buzzing	40
Whisper	30
Rustling leaves	10
Threshold of hearing	0

Beats

When two sound waves of different frequency approach your ear, the alternating constructive and destructive **interference** causes the sound to be alternatively soft and loud - a phenomenon which is called "**beating**" or producing beats. The beat frequency is equal to the absolute value of the difference in frequency of the two waves.

.

$$f_{beat} = |f_2 - f_1|$$



The Doppler Effect

The **Doppler effect** is the apparent change in frequency (or wavelength) that occurs because of motion of the source or observer of a wave.

- When the relative speed of the source and observer is higher than the speed of the wave, the frequency appears to increase.
- When the relative speed of the source and observer is lower than the speed of the wave, the frequency appears to decrease.

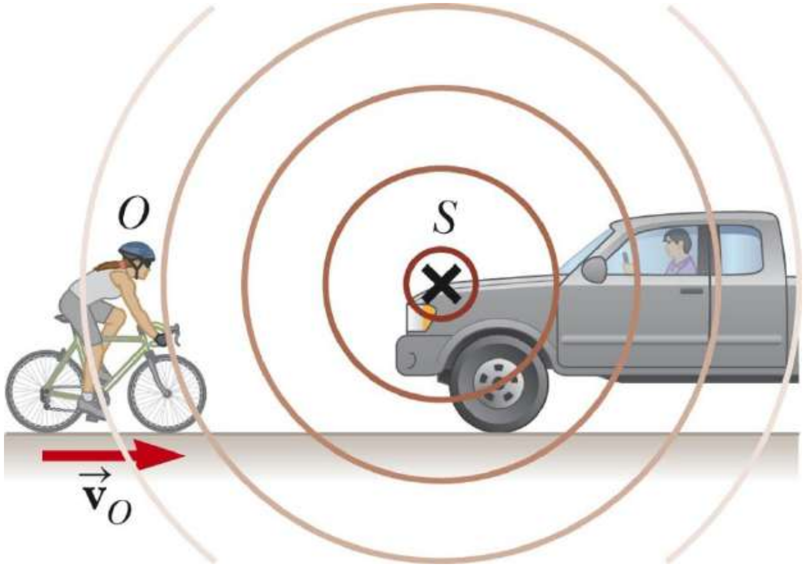
Doppler Effect, Observer Moving

The observer moves with a speed of v_o.

Assume a point source that remains stationary relative to the air.

It is convenient to represent the waves as wave fronts.

- These surfaces are called wave fronts.
- The distance between adjacent wave fronts is the wavelength.



Doppler Effect, Observer Moving, cont

The speed of the sound is v, the frequency is f, and the wavelength is λ.

When the observer moves toward the source, the speed of the waves relative to the observer is $v' = v + v_o$.

- The wavelength is unchanged.

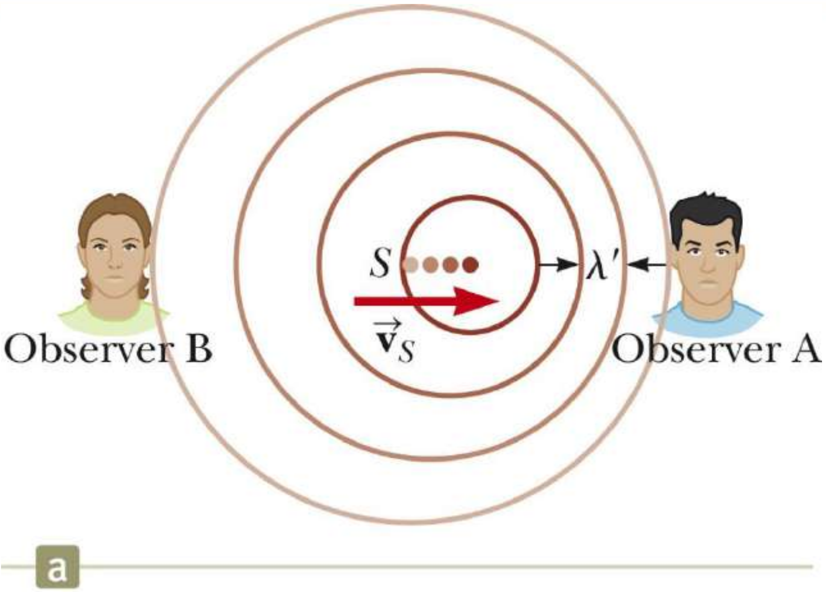
The frequency heard by the observer, f', appears higher when the observer approaches the source.

$$f' = \left(\frac{v + v_o}{v}\right) f$$

The frequency heard by the observer, f', appears lower when the observer moves away from the source.

$$f' = \left(\frac{v - v_o}{v}\right) f$$

Doppler Effect, Source Moving



Consider the source being in motion while the observer is at rest.

As the source moves toward the observer, the wavelength appears shorter.

As the source moves away, the wavelength appears longer.

When the source is moving toward the observer, the apparent frequency is higher.

$$f' = \left(\frac{v}{v - v_s} \right) f$$

When the source is moving away from the observer, the apparent frequency is lower.

$$f' = \left(\frac{v}{v + v_s} \right) f$$

Doppler Effect, General

Combining the motions of the observer and the source

$$f' = \left(\frac{v + v_o}{v - v_s} \right) f$$

The signs depend on the direction of the velocity.

- A positive value is used for motion of the observer or the source *toward* the other.
- A negative sign is used for motion of one *away from* the other.

Convenient rule for signs.

- The word "toward" is associated with an increase in the observed frequency.
- The words "away from" are associated with a decrease in the observed frequency.

The Doppler effect is common to all waves.

Doppler Effect, Submarine Example

Sub A (source) travels at 8.00 m/s emitting at a frequency of 1400 Hz.

The speed of sound in the water is 1533 m/s.

Sub B (observer) travels at 9.00 m/s.

What is the apparent frequency heard by the observer as the subs approach each other? Then as they recede from each other?

pproaching each other:

$$f' = \left(\frac{v + v_o}{v - v_s}\right) f = \left(\frac{1533\ \mathrm{m/s} + (+9.00\ \mathrm{m/s})}{1533\ \mathrm{m/s} - (+8.00\ \mathrm{m/s})}\right)(1400\,Hz)$$

$$= 1416\,Hz$$

Receding from each other:

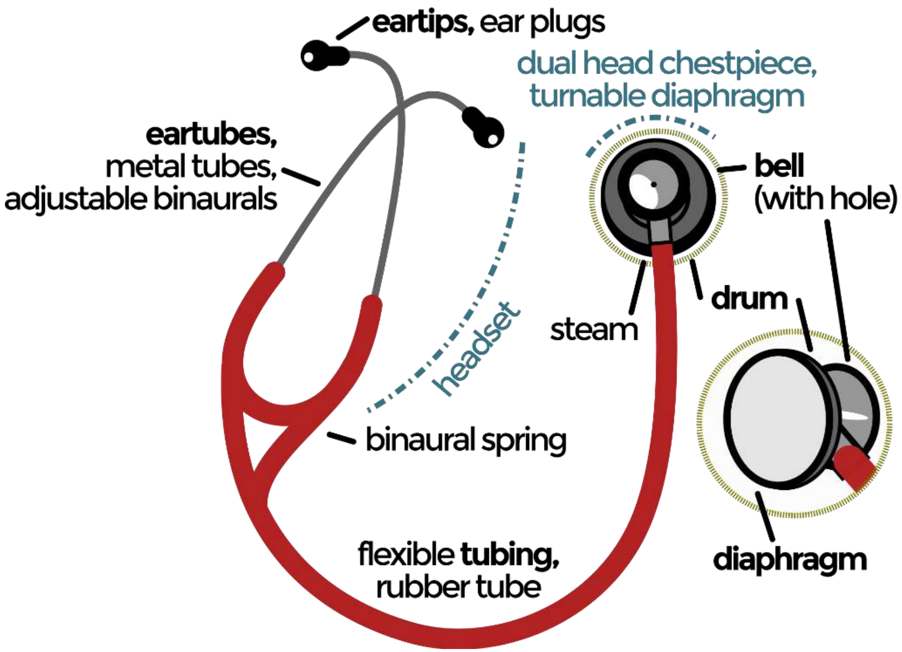
$$f' = \left(\frac{v + v_o}{v - v_s}\right) f = \left(\frac{1533\ \mathrm{m/s} + (-9.00\ \mathrm{m/s})}{1533\ \mathrm{m/s} - (-8.00\ \mathrm{m/s})}\right)(1400\,Hz)$$

$$= 1385\,Hz$$

Stethoscope

The stethoscope is the standard instrument to amplify and analyze characteristic body sounds like heart and blood flow. Which is based on the principle of sound transmission through a tube with both ends closed.

stethoscope works on the principle of multiple reflection of sound.



The parts of the stethoscope include the eartips, eartubes, tubing, headset, stem, chest-piece, diaphragm and bell. The sounds that are created from the patients body are picked up through the diaphragm or bell end of the stethoscope, which is pressed against the patients chest, back or stomach of the patient.

The disc and the tube of the stethoscope amplify small sounds such as the sound of a patient's lungs, heart and other sounds inside the body, making them sound louder. The amplified sounds travel up the stethoscope's tube to the earpieces that the doctor listens through

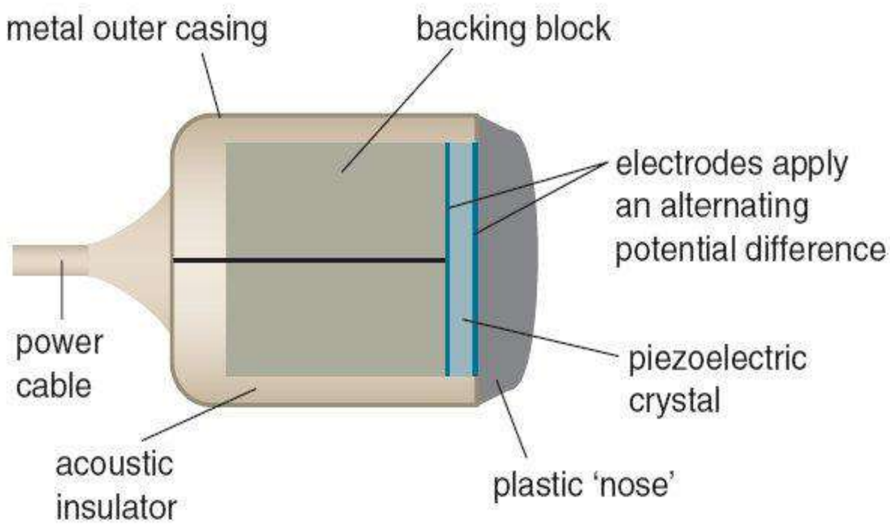
What is Ultrasound?

Ultrasound is defined as any sound wave above 20000Hz. Sound waves of this frequency are above the human audible range and therefore cannot be heard by humans. All sound waves, including ultrasound are longitudinal waves. Medical ultrasounds are usually of the order of MEGAHERTZ (1-15MHz). Ultrasound as all sound waves are caused by vibrations and therefore cause no ionisation and are safe to use on pregnant women. Ultrasound is also able to distinguish between muscle and blood and show blood movement.

When an ultrasound wave meets a boundary between two different materials some of it is refracted and some is reflected. The reflected wave is detected by the ultrasound scanner and forms the image.

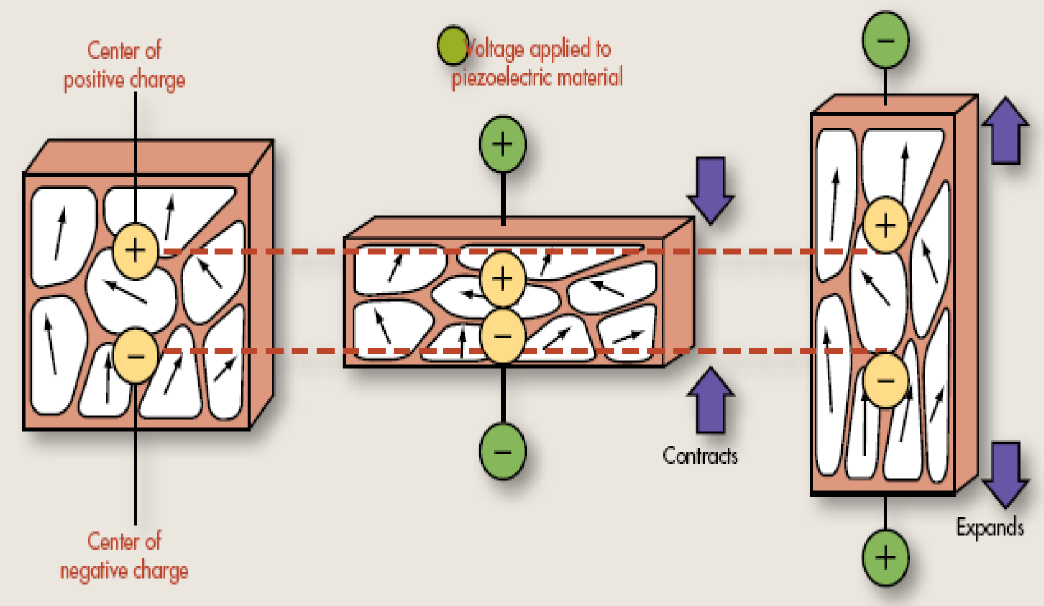
producing a sound wave

Ultrasound waves are produced by a transducer. A transducer is a device that takes power from one source and converts into another form ,i.e electricity into sound waves. The sound waves begin with the mechanical movement (oscillations) of a crystal that has been excited by electrical pulses.



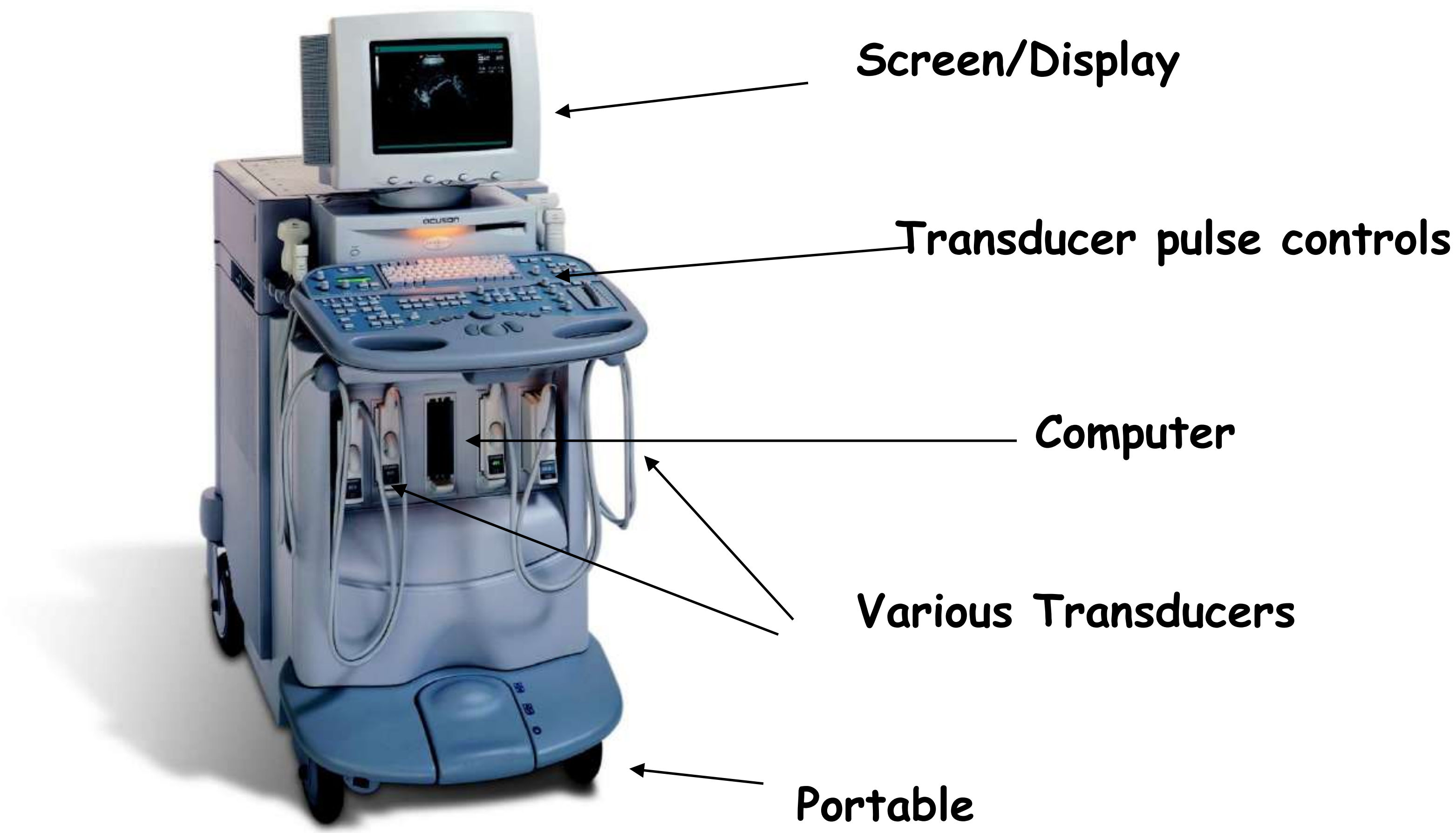
Piezoelectric effect

When a potential difference is applied across certain crystals (piezoelectric) the crystals themselves deform and contract a little. If the potential difference applied is alternating then the crystal vibrates at the same frequency and sends out ultrasonic waves. For ultrasound - lead zirconate titanate (PZT) crystals are used. This process also works in reverse. The piezoelectric crystal acts a receiver of ultrasound by converting sound waves to converting alternating voltages and as a transmitter by converting alternating voltages to sound waves



1. The piezoelectric effect causes crystal materials like quartz to generate an electric charge when the crystal material is compressed, twisted, or pulled. The reverse also is true, as the crystal material compresses or expands when an electric voltage is applied.

Ultrasound Equipment




girl at 30 weeks sleeping


ID:_
PWR16
12:06:06
1.5CM
C3.75
15HZ
4/0/2
55/ 84
13.5CM
B LP REC
SCIENCEphotoLIBRARY

A-Scan

A-Scan (Amplitude scan)

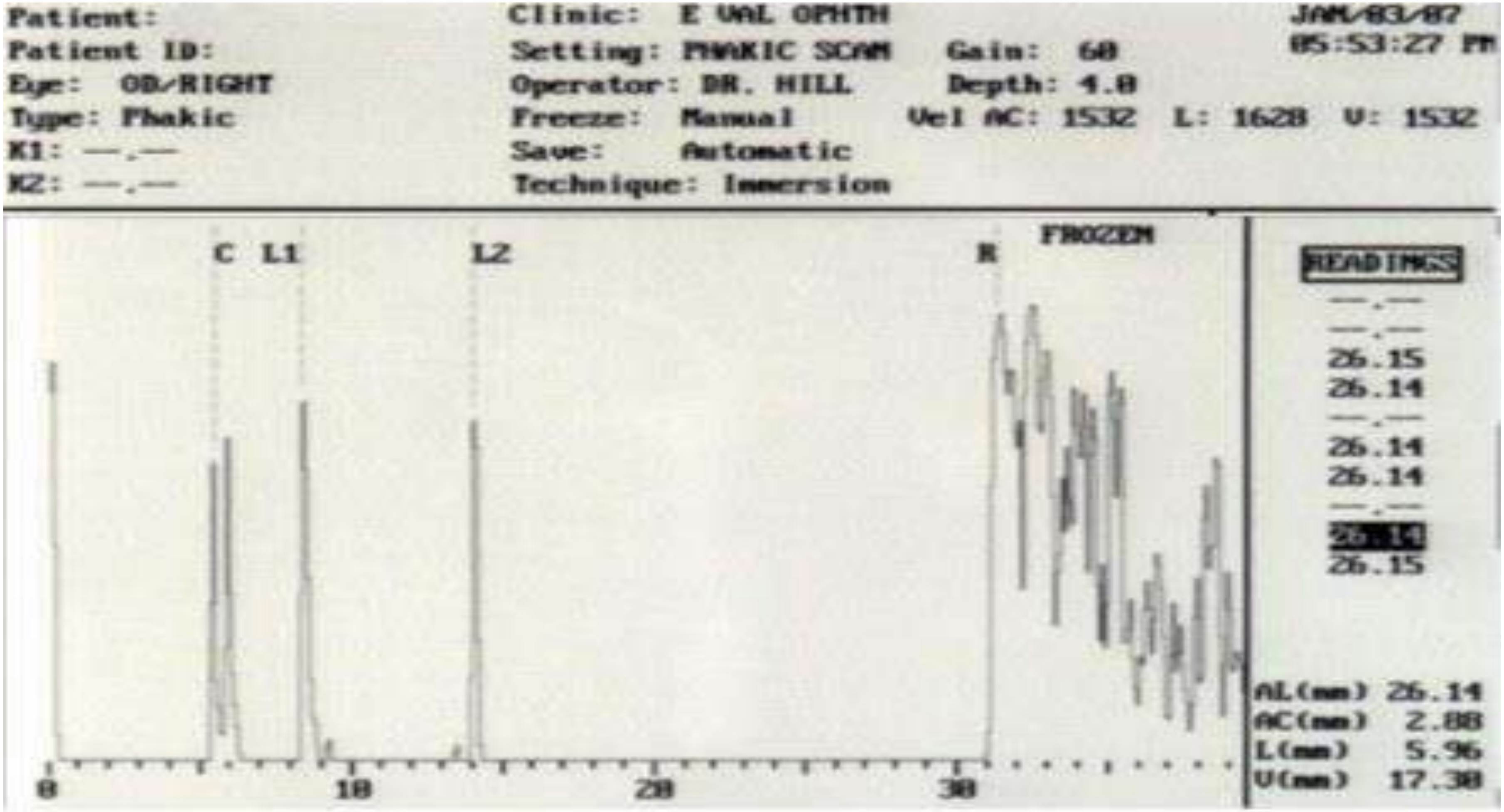
Pulses of ultrasound sent into the body, reflected ultrasound is detected and appear as vertical spikes on a CRO screen(figure).

The horizontal positions of the ‘spikes’ indicate the time it took for the wave to be reflected.

• Gives no photo image

•A-scan can be used to measure the depth of a structures in the body by sending a pulses of ultrasound into the body .The sound(echoes) is reflected from the body and the detected echo is converted into electric signal and displayed as the vertical deflection R on cathode ray tube, and then measure the time required to the receive the signal . This time can be converted to distance by using the velocity of sound.

A-scan

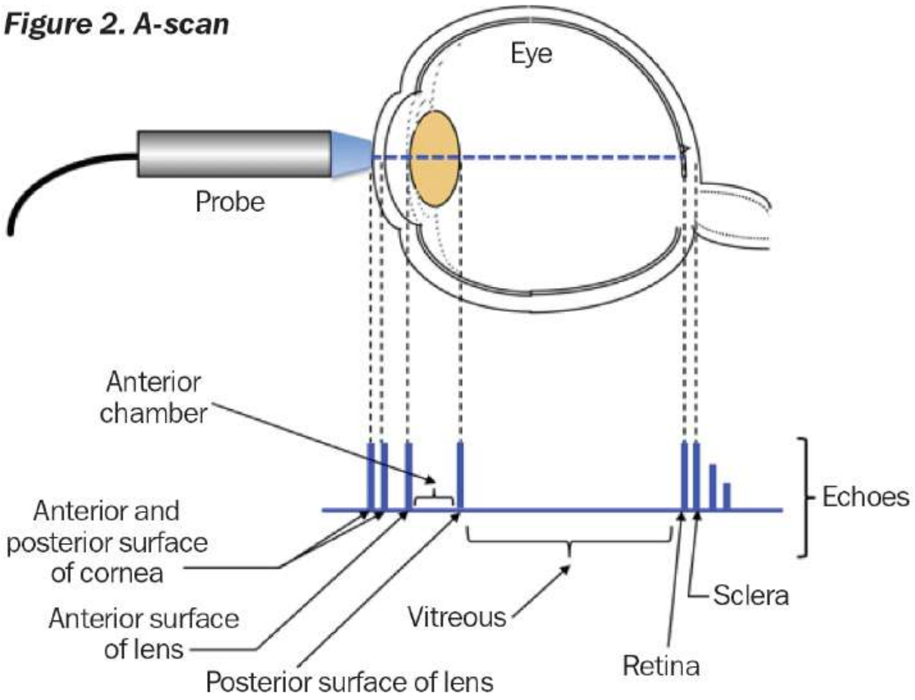

Patient:
Patient ID:
Eye: OD/RIGHT
Type: Phakic
K1: —.—
K2: —.—
Clinic: E VAL OPHTH
Setting: PHAKIC SCAN
Operator: DR. HILL
Freeze: Manual
Save: Automatic
Technique: Immersion
Gain: 60
Depth: 4.0
Vel AC: 1532 L: 1628 V: 1532
JAN/03/07
05:53:27 PM
C L1 L2 R
FROZEN
READINGS
—.—
—.—
26.15
26.14
—.—
26.14
26.14
—.—
26.14
26.15
AL(mm) 26.14
AC(mm) 2.88
L(mm) 5.96
V(mm) 17.30
0
10
20
30

A-scan Ultrasound is used for:

1. diagnostic testing in Opthalmology practices. This device can determine the length of the eye (figure 2) and can be useful in diagnosing common sight disorders. A-scans are also extremely beneficial in cataract surgeries, as they enable the Opthalmologist to determine the power of the intraocular lens (IOL) needed for the artificial implant. Another use for A-scans is diagnosing and measuring masses in the eyes.

2.Commonly used to measure size of foetal head.

Figure 2. A-scan



B - Scan

The B-scan is a brightness modulation display. The principles are the same as for the A –scan except that the transducer is moved.

As a result each echo produces a dot on the oscilloscope at a position corresponding to the location of the reflecting surface . The brightness is proportional to the echo amplitude .

B –scan provide information about the internal structure of the body.

The two – dimensional B –scan display echoes from both dimensions of a plane in a body , as shown in figure.

B –scans have been used in diagnosis studies of

1. eye
2 . Liver - frequency used is 2 – 3 MHz.
3 . Breast-frequency used is 2 – 3 MHz
4 . Heart
5 . Fetus
6 . Spleen , pancreas
7 . Detect pregnancy as early as fifth week and provide information on the size , location , and change with time of a fetus is extremely useful in both normal deliveries and cases such as abnormal bleeding and threatened abortion .

The frequency used is in the range 1.5 – 3 MHz .

Figure 1 : B -scan

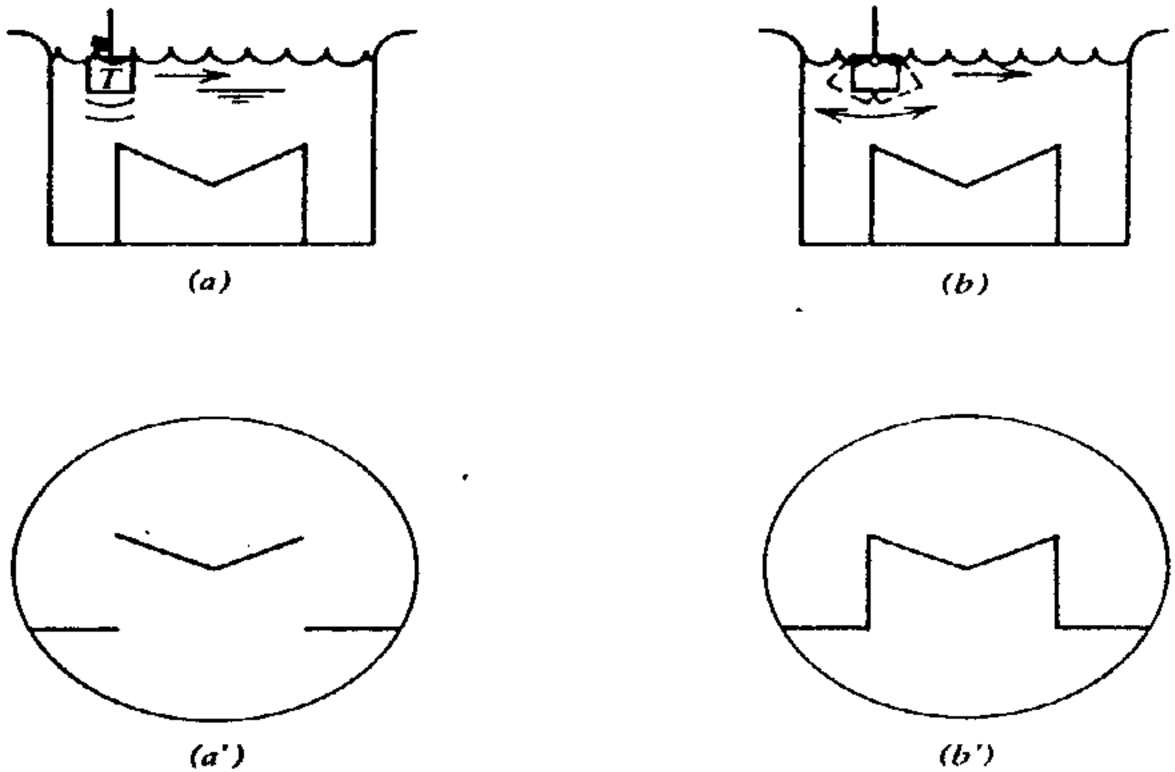


Figure 12.17. Schematic of B scan method. (*a*) As the transducer *T* moves to the right it produces echoes from the submerged object. (*a'*) The storage oscilloscope shows a dot corresponding to the location of each echo received. The dots outline the top surface of the object. (*b*) When the transducer is rocked as it is moved to the right it produces echoes from other surfaces. (*b'*) The resulting scan shows the sides of the object.

Medical Physics

Lectures in General Physics for Medical Sciences Students

By

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Chapter 8 - Light and Optics

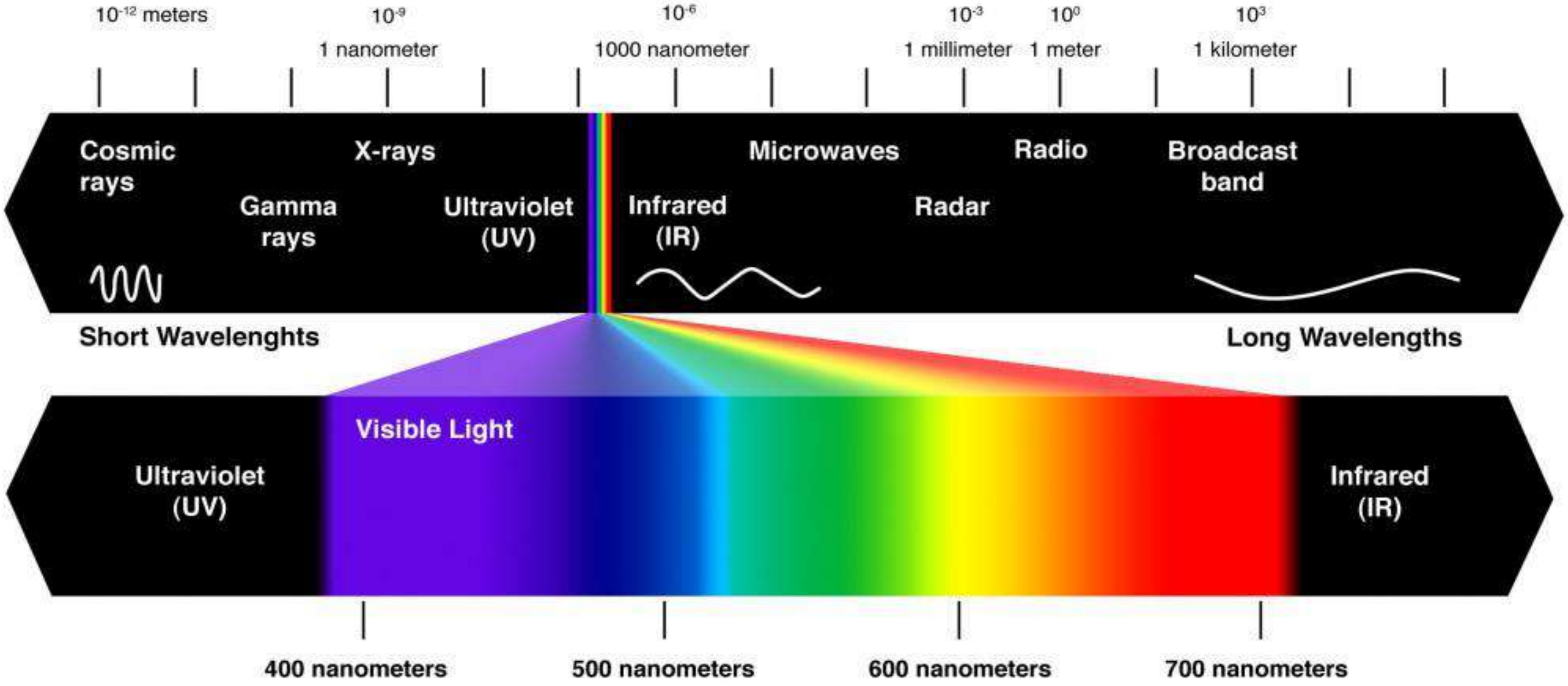
Introduction to Light

Light is a form of electromagnetic radiation.

Speed of light = 3×10^{8} m/s

Light represents energy transfer from the source to the observer.

Spectrum of light



The Nature of Light

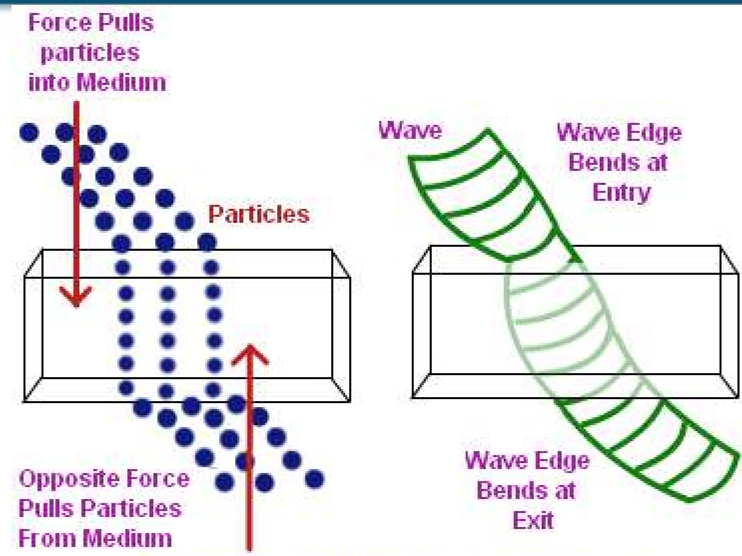
Before the beginning of the nineteenth century, light was considered to be a stream of particles.

During the nineteenth and 20th century, other

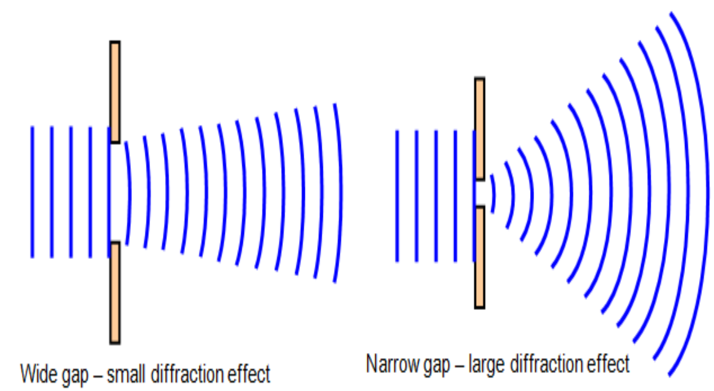
In view of other developments in the 20th century, light must be regarded as having a dual nature.

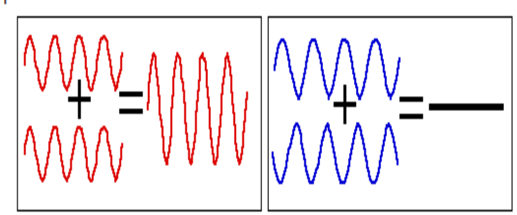
- Light behaves both as a wave and as a particle. As a wave it produces interference and diffraction, which are of minor importance in medicine. As a particle it can be absorbed by a single molecule. When a light photon is absorbed its energy is used in a various ways. It can cause an electrical change.

Ray optics (sometimes called *geometric* optics) involves the study of the propagation of light. It uses the assumption that light travels in a straight-line path in a uniform medium and changes its direction when it meets the surface of a different medium



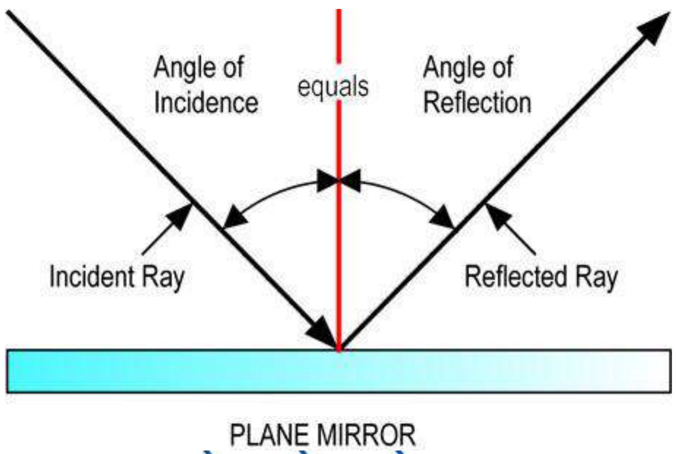
Refraction of Particles and Wave





Constructive Interference
Destructive Interference

Reflection of Light



A ray of light, the *incident ray*, travels in a medium.

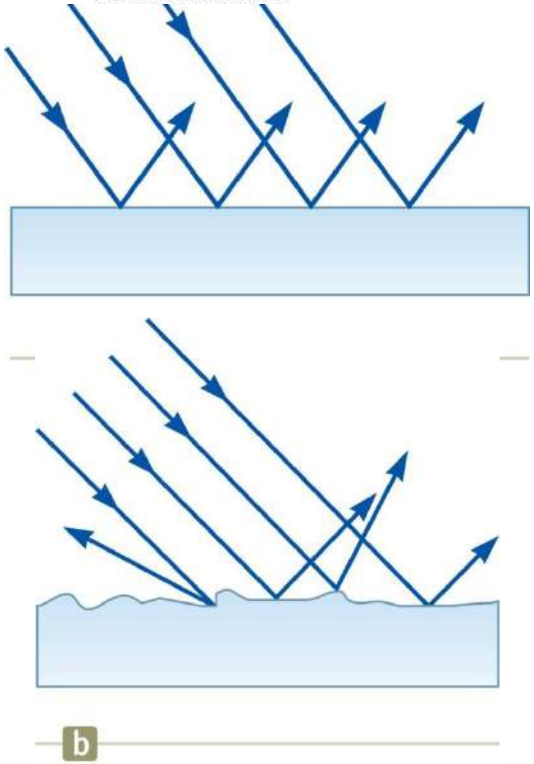
When it encounters a boundary with a second medium, part of the incident ray is reflected back into the first medium.

- There are two types of reflection:

Specular reflection is reflection from a smooth surface.

The reflected rays are parallel to each other.

All reflection in this text is assumed to be specular.



Diffuse reflection is reflection from a rough surface.

The reflected rays travel in a variety of directions.

A surface behaves as a smooth surface as long as the surface variations are much smaller than the wavelength of the light.

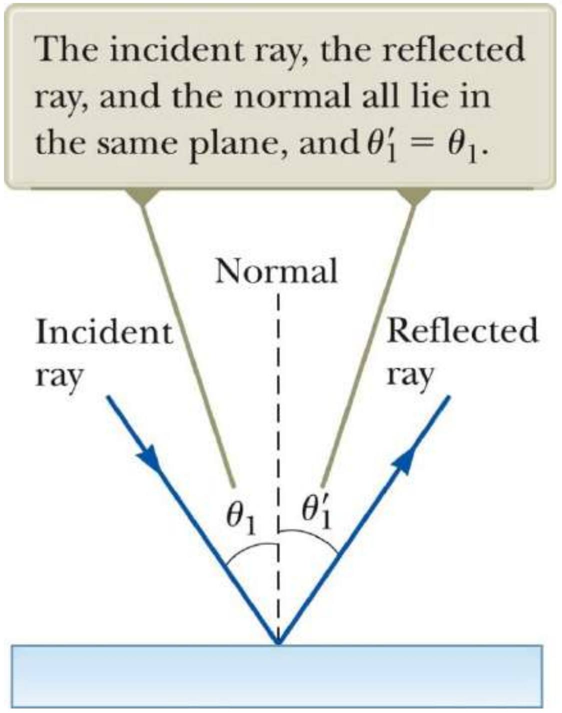
Law of Reflection

The *normal* is a line perpendicular to the surface.

The angle of reflection is equal to the angle of incidence.

$\theta_1' = \theta_1$ This relationship is called the Law of Reflection.

- The incident ray, the reflected ray and the normal are all in the same plane.



Multiple Reflections

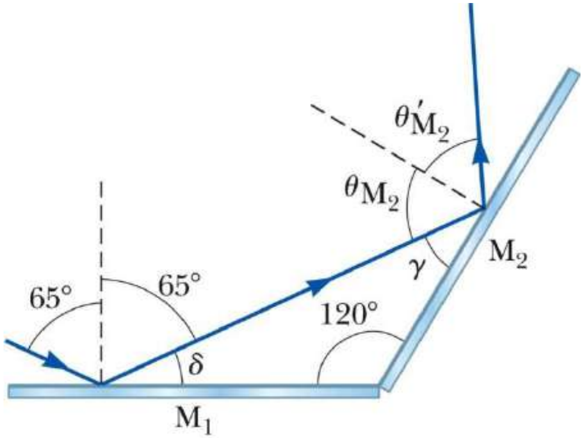
The incident ray strikes the first mirror. The reflected ray is directed toward the second mirror. There is a second reflection from the second mirror.

Retroreflection

Assume the angle between two mirrors is 90º .The reflected beam returns to the source parallel to its original path.

This phenomenon is called *retroreflection. It iis used in*

- Measuring the distance to the Moon
- Automobile taillights and Traffic signs



Refraction of Light

When a ray of light traveling through a transparent medium encounters a boundary leading into another transparent medium, part of the energy is reflected and part enters the second medium and changes its direction of propagation at the boundary.

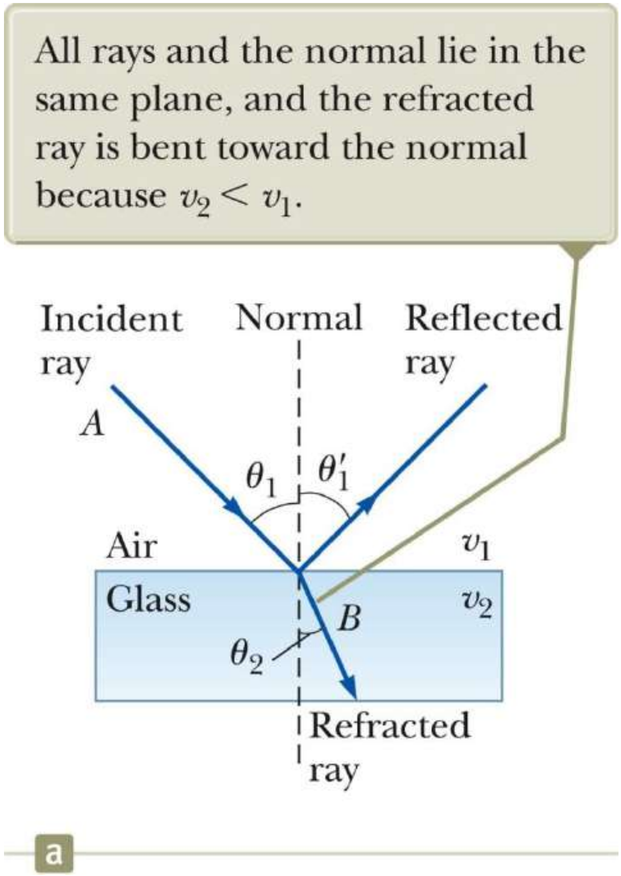
- This bending of the ray is called ***refraction.***

The incident ray, the reflected ray, the refracted ray, and the normal all lie on the same plane.

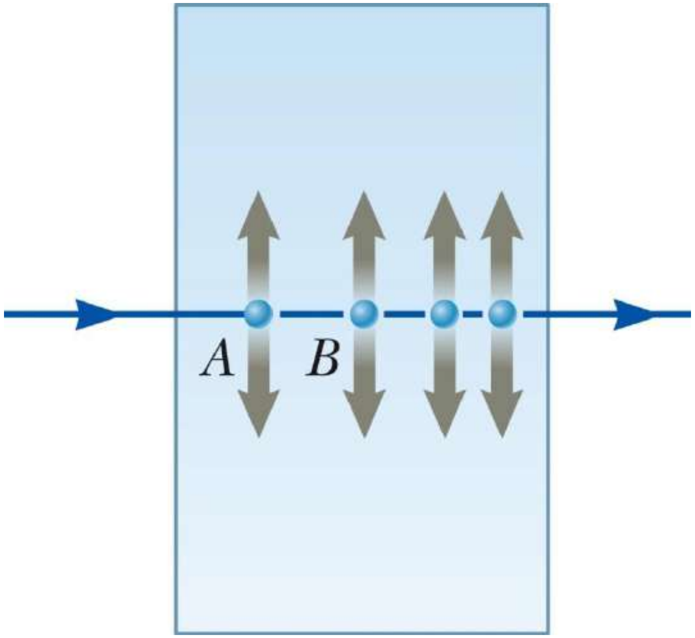
The angle of refraction depends upon the material and the angle of incidence.

$$\frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1}$$

- v_1 is the speed of the light in the first medium and v_2 is its speed in the second.



Light in a Medium



The light enters from the left.

The light may encounter an electron.

The electron may absorb the light, oscillate, and reradiate the light.

The absorption and radiation cause the average speed of the light moving through the material to decrease.

When light is absorbed, its energy generally appears as heat. This property is the basis for the use in medicine.

Sometime when a light photon is absorbed ,a lower energy light photon is emitted. This property is known a fluorescence.

The Index of Refraction

The speed of light in any material is less than its speed in vacuum.

The **index of refraction**, n, of a medium can be defined as

$$n \equiv \frac{\text{speed of light in a vacuum}}{\text{speed of light in a medium}} \equiv \frac{c}{v}$$

For a vacuum, n = 1

- We assume n = 1 for air also

For other media, n > 1

n is a dimensionless number greater than unity and is not necessarily an integer.

Snell's Law of Refraction

$n_1 \sin \theta_1 = n_2 \sin \theta_2$

- θ_1 is the angle of incidence
- θ_2 is the angle of refraction

The experimental discovery of this relationship is usually credited to Willebrord Snell and is therefore known as **Snell's law of refraction.**

Some Indices of Refraction

Indices of Refraction

Substance	Index of Refraction	Substance	Index of Refraction
Solids at 20°C		*Liquids at 20°C*	
Cubic zirconia	2.20	Benzene	1.501
Diamond (C)	2.419	Carbon disulfide	1.628
Fluorite (CaF_2)	1.434	Carbon tetrachloride	1.461
Fused quartz (SiO_2)	1.458	Ethyl alcohol	1.361
Gallium phosphide	3.50	Glycerin	1.473
Glass, crown	1.52	Water	1.333
Glass, flint	1.66		
Ice (H_2O)	1.309	*Gases at 0°C, 1 atm*	
Polystyrene	1.49	Air	1.000 293
Sodium chloride (NaCl)	1.544	Carbon dioxide	1.000 45

The Rainbow

A ray of light strikes a drop of water in the atmosphere.

It undergoes both reflection and refraction.

- First refraction at the front of the drop
  - Violet light will deviate the most.
  - Red light will deviate the least.

At the back surface the light is reflected.

It is refracted again as it returns to the front surface and moves into the air.

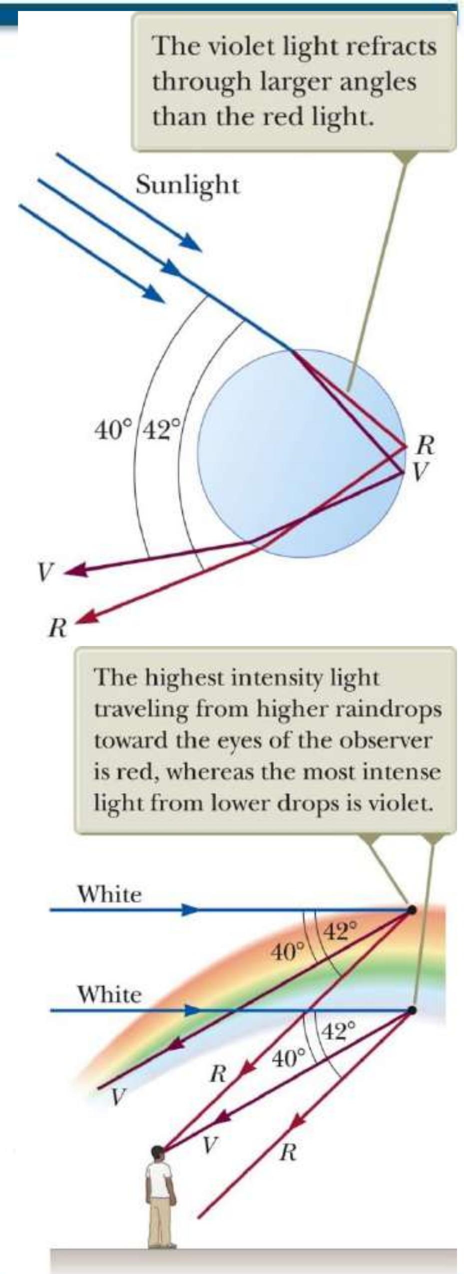
The rays leave the drop at various angles.

- The angle between the white light and the most intense violet ray is 40° .
- The angle between the white light and the most intense red ray is 42°

If a raindrop high in the sky is observed, the red ray is seen.

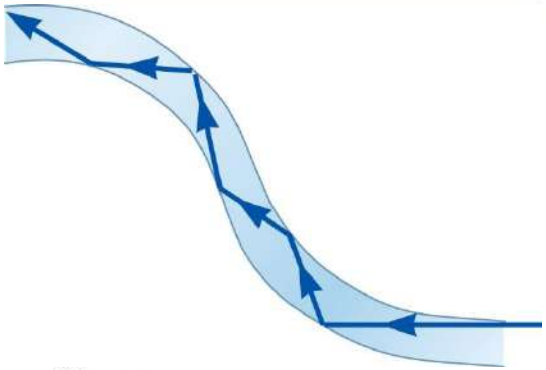
A drop lower in the sky would direct violet light to the observer.

The other colors of the spectra lie in between the red and the violet..



Fiber Optics

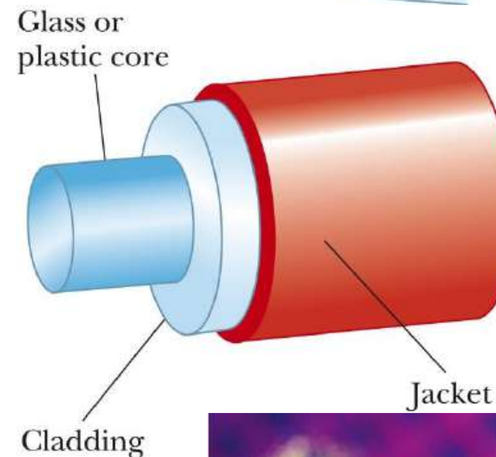
An application of internal reflection. Plastic or glass rods are used to “pipe” light from one place to another.



Applications include:

- Medical examination of internal organs
- Telecommunications

Construction of an Optical Fiber



The transparent core is surrounded by *cladding.*

- The cladding has a lower *n* than the core.
- This allows the light in the core to experience total internal reflection.

The combination is surrounded by the jacket.

A flexible light pipe is called an **optical fiber.**

A bundle of parallel fibers (shown) can be used to construct an optical transmission line.

a

Medical uses of visible light

1- Pediatricians use a shine light into the bodies of infants and observe the amount of scattered light produced in order to detect water – head or collapsed lung.

2- Pediatricians use visible light for treating jaundice in premature infants.

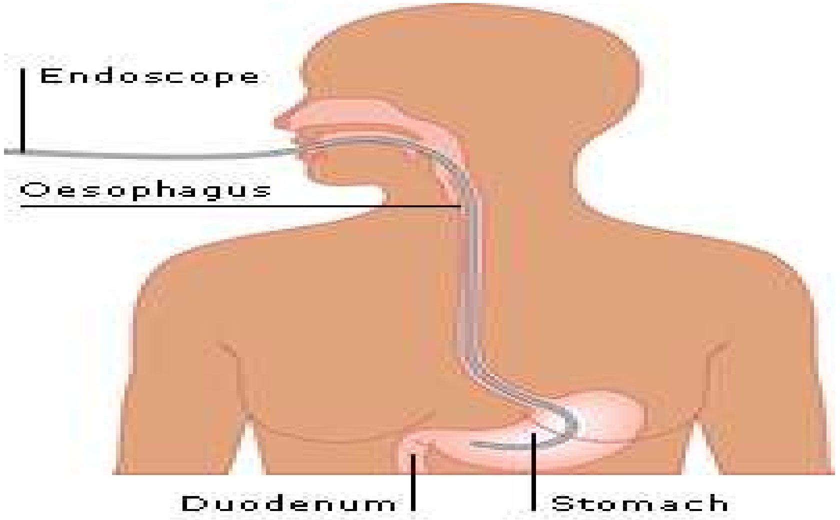
3- Light source in endoscope uses to see inside the body.

4- Physician use normal light to examine the skin.

5.The visible light used in the ophthalmoscope for looking into eyes ,and in the otoscope for looking into ears by using a concave mirror to direct light in the body and a hole in the middle of it for the physician to look through.

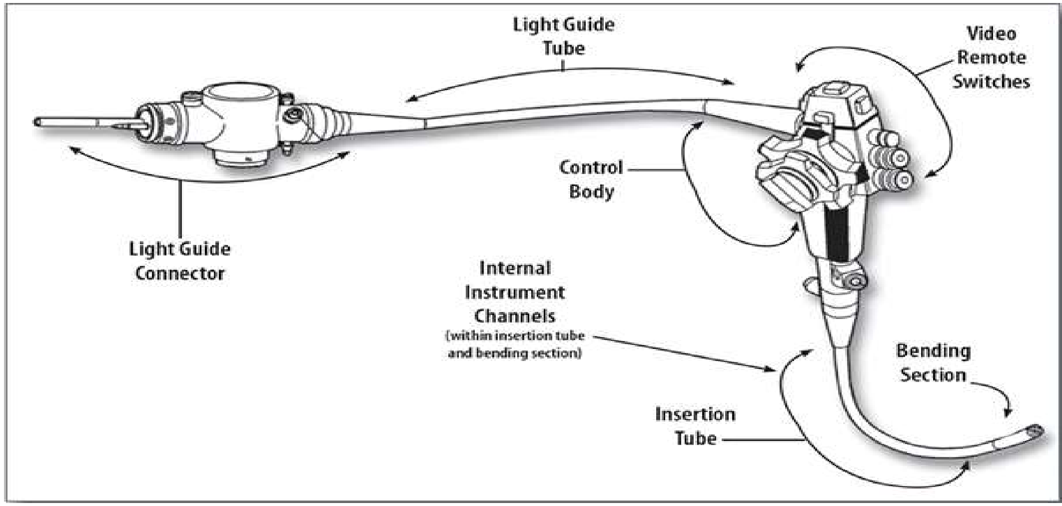
Endoscope

An endoscope works by inserting a long, thin and bendable tube into the body(figure8). On one end is a light source and in most cases also a video camera. The endoscope can be inserted through a natural opening in the body such as the throat or it can be inserted through a cut made in the skin.



Route of endoscope

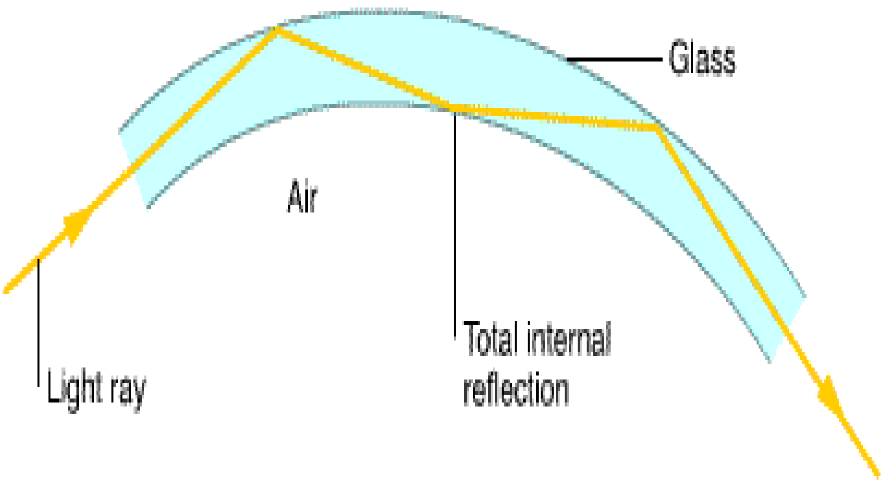
An endoscope consists of two or three optical cables. Each cable includes up to 50,000 separate optical fibers that are made from glass or plastic. One or two of these cables will carry light down into the patient's body, this illuminates where the endoscope has been inserted.



Endoscope

The light is reflected along the walls of the cable into the patient's body. The light does this due to total internal reflection(figure10), which means that for this to happen the light ray must be at an angle of 82 degrees (which is the angle required for air to glass to be internally reflected).

The other cable will carry reflected light that shines off the patient's body, this light is the image of the body. The light bounces off the glass walls as it goes up to the physician's eyepiece or into a camera. If the reflected light is carried up to a camera it will then be displayed on a TV monitor.



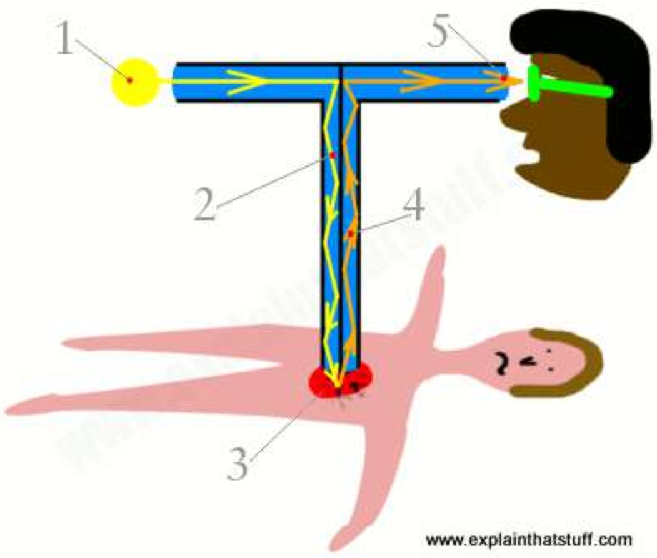


Image of Formation

Images can result when light rays encounter surfaces between two media.

Images can be formed either by reflection or refraction due to these surfaces.

Mirrors and lenses can be designed to form images with desired characteristics.

Notation for Mirrors and Lenses

The **object distance** is the distance from the object to the mirror or lens.

- Denoted by p

The **image distance** is the distance from the image to the mirror or lens.

- Denoted by q

The **lateral magnification** of the mirror or lens is the ratio of the image height to the object height.

- Denoted by M

When the object is very far away, then $p \to \infty$ and the incoming rays are essentially parallel, the image point is called the **focal point.** The distance from the mirror to the focal point is called the **focal length.** Denoted by f

- The focal length is ½ the radius of curvature.

Ray Diagrams

A *ray diagram* can be used to determine the position and size of an image.

They are graphical constructions which reveal the nature of the image.

They can also be used to check the parameters calculated from the mirror and magnification equations.

To draw a ray diagram, you need to know:

- The position of the object
- The locations of the focal point and the center of curvature.

Three rays are drawn. They all start from the same position on the object.

The intersection of any two of the rays at a point locates the image.

The third ray serves as a check of the construction.

Ray 1 is drawn from the top of the object parallel to the principal axis and is reflected through the focal point, *F.*

Ray 2 is drawn from the top of the object through the focal point and is reflected parallel to the principal axis.

Ray 3 is drawn through the center of curvature, C, and is reflected back on itself.

Image Formed by a Thin Lens

A thin lens is one whose thickness is small compared to the radii of curvature. It used in optical instruments: Cameras, Telescopes, Microscopes

Thin Lens Equation

The relationship among the focal length, the object distance and the image distance is the same as for a mirror.

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$

Diopters

Optometrists and ophthalmologists usually prescribe lenses measured in *diopters.* The power *P* of a lens in diopters equals the inverse of the focal length in meters.

- $P = 1/f$

The **lateral magnification** of the image is

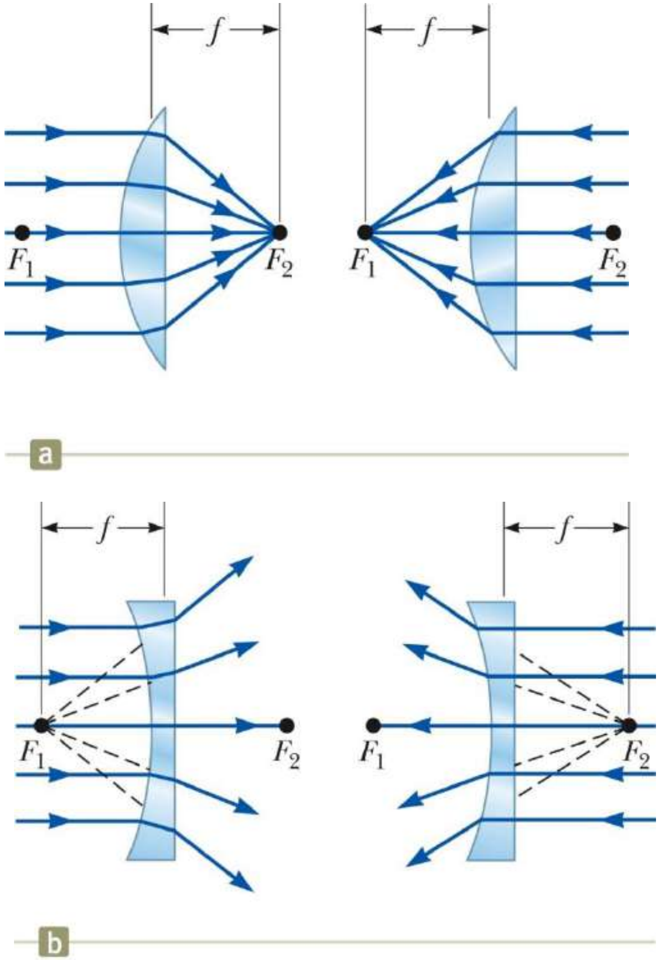
$$M=\frac{h'}{h}=-\frac{q}{p}$$

Notes on Focal Length and Focal Point of a Thin Lens

Because light can travel in either direction through a lens, each lens has two focal points. One focal point is for light passing in one direction through the lens and one is for light traveling in the opposite direction.

However, there is only one focal length.

Each focal point is located the same distance from the lens.



Focal Length of a Converging Lens

The parallel rays pass through the lens and converge at the focal point.

The parallel rays can come from the left or right of the lens.

Focal Length of a Diverging Lens

The parallel rays diverge after passing through the diverging lens.

The focal point is the point where the rays appear to have originated.

Ray Diagrams for Thin Lenses – Converging

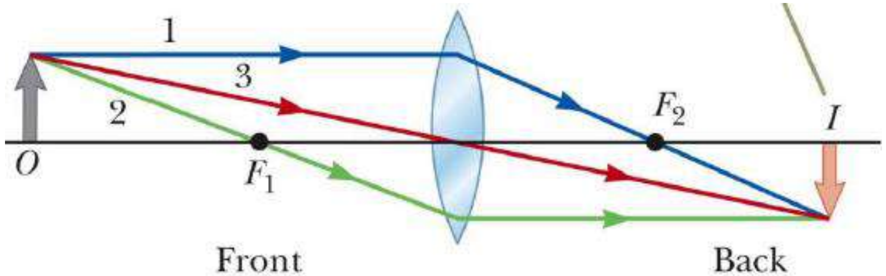
Ray diagrams are convenient for locating the images formed by thin lenses or systems of lenses. For a converging lens, the following three rays are drawn:

- Ray 1 is drawn parallel to the principal axis and then passes through the focal point on the back side of the lens.
- Ray 2 is drawn through the center of the lens and continues in a straight line.
- Ray 3 is drawn through the focal point on the front of the lens (or as if coming from the focal point if $p < f$) and emerges from the lens parallel to the principal axis.

Ray Diagram for Converging Lens, $p > f$

The image is real and inverted.

The image is on the back side of the lens.

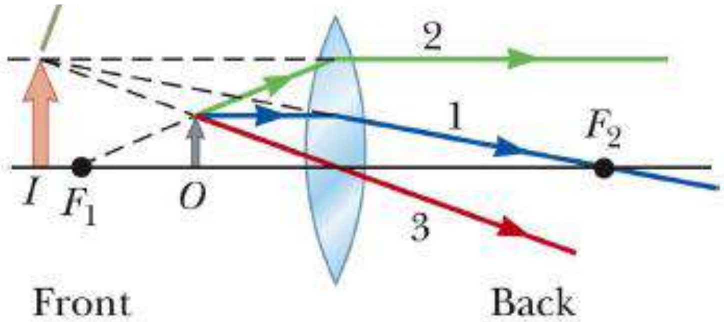


Ray Diagram for Converging Lens, $p < f$

The image is virtual and upright.

The image is larger than the object.

The image is on the front side of the lens.



Ray Diagrams for Thin Lenses – Divergir

For a diverging lens, the following three rays are drawn:

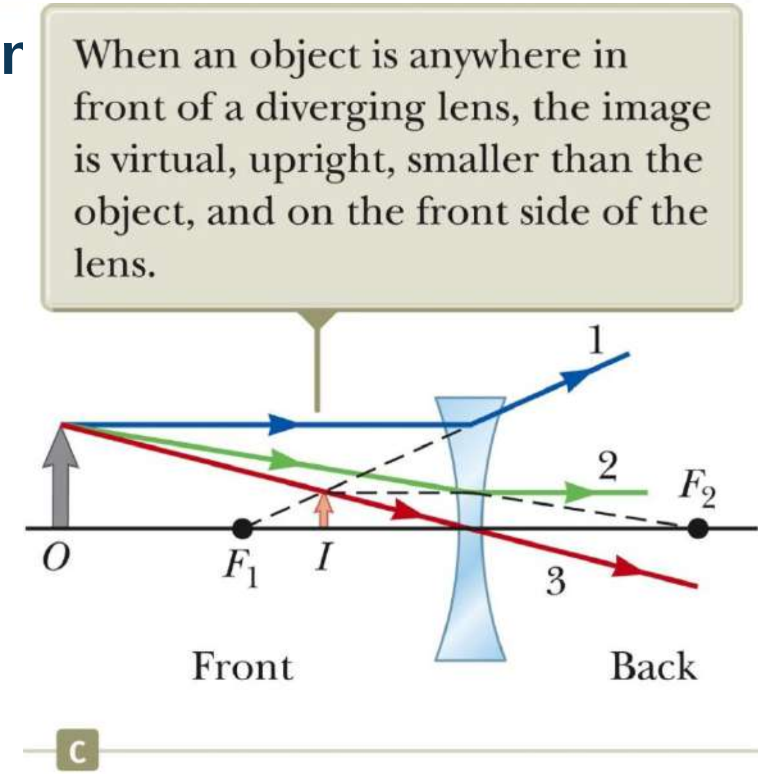
- Ray 1 is drawn parallel to the principal axis and emerges directed away from the focal point on the front side of the lens.
- Ray 2 is drawn through the center of the lens and continues in a straight line.
- Ray 3 is drawn in the direction toward the focal point on the back side of the lens and emerges from the lens parallel to the principal axis.

The image is virtual.

The image is upright.

The image is smaller.

The image is on the front side of the lens.



Combinations of Thin Lenses

The image of the first lens is treated as the object of the second lens.

The image formed by the second lens is the final image of the system.

Then a ray diagram is drawn for the second lens.

The same procedure can be extended to a system of three or more lenses.

The overall magnification is the product of the magnification of the separate lenses.

Two Lenses in Contact

Consider a case of two lenses in contact with each other:

- The lenses have focal lengths of f_1 and f_2.

For the combination of the two lenses $$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

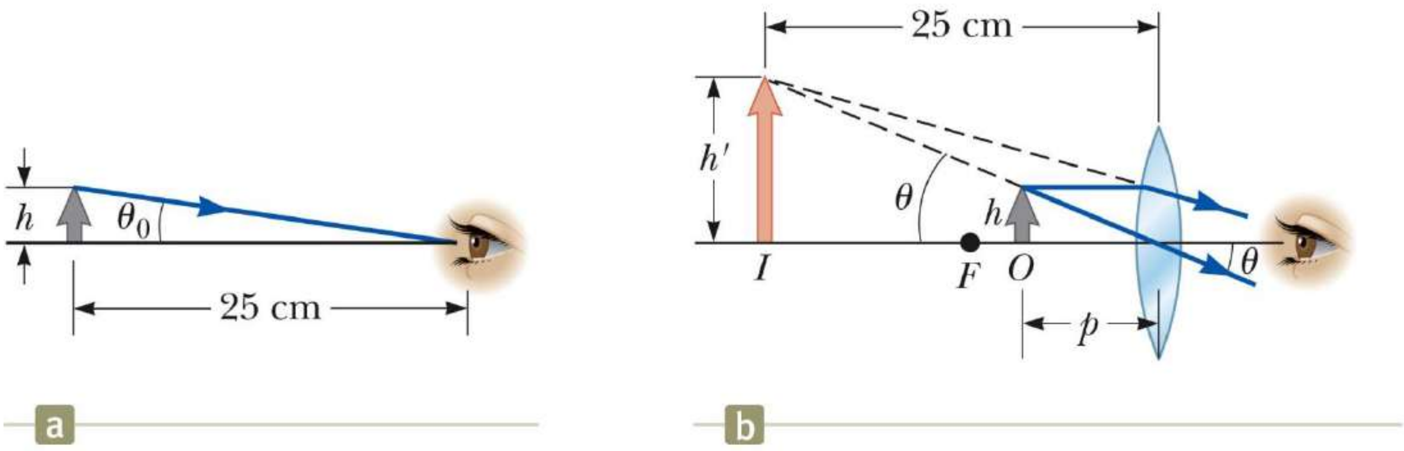
Two thin lenses in contact with each other are equivalent to a single thin lens having a focal length given by the above equation.

Simple Magnifier

A simple magnifier consists of a single converging lens.

This device is used to increase the apparent size of an object.

The size of an image formed on the retina depends on the angle subtended by the eye.



When an object is placed at the near point, the angle subtended is a maximum.

- The near point is about 25 cm.

When the object is placed near the focal point of a converging lens, the lens forms a virtual, upright, and enlarged image.

Compound Microscope

A compound microscope consists of two lenses.

- Gives greater magnification than a single lens
- The objective lens has a short focal length,

  $f_o < 1$ cm
- The eyepiece has a focal length, f_e of a few cm.

The lenses are separated by a distance *L.*

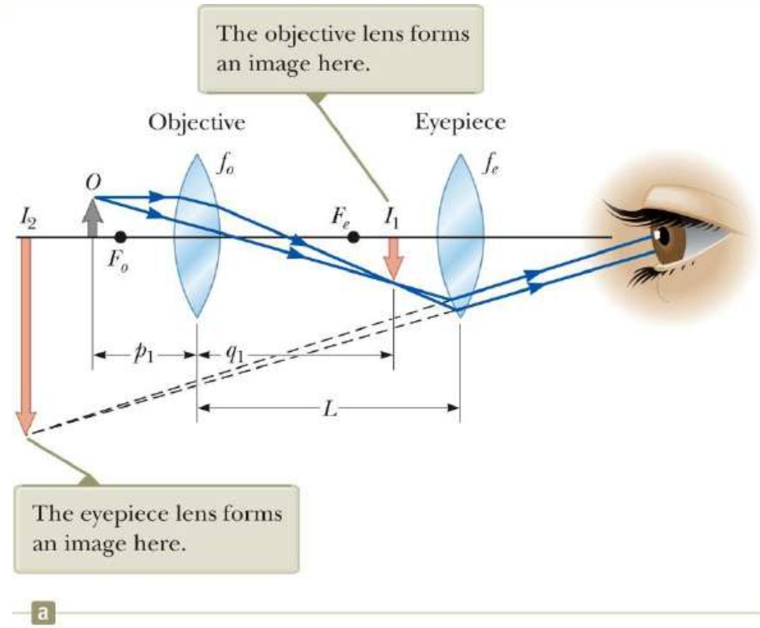
- *L* is much greater than either focal length.

The object is placed just outside the focal point of the objective.

- This forms a real, inverted image
- This image is located at or close to the focal point of the eyepiece.

This image acts as the object for the eyepiece.

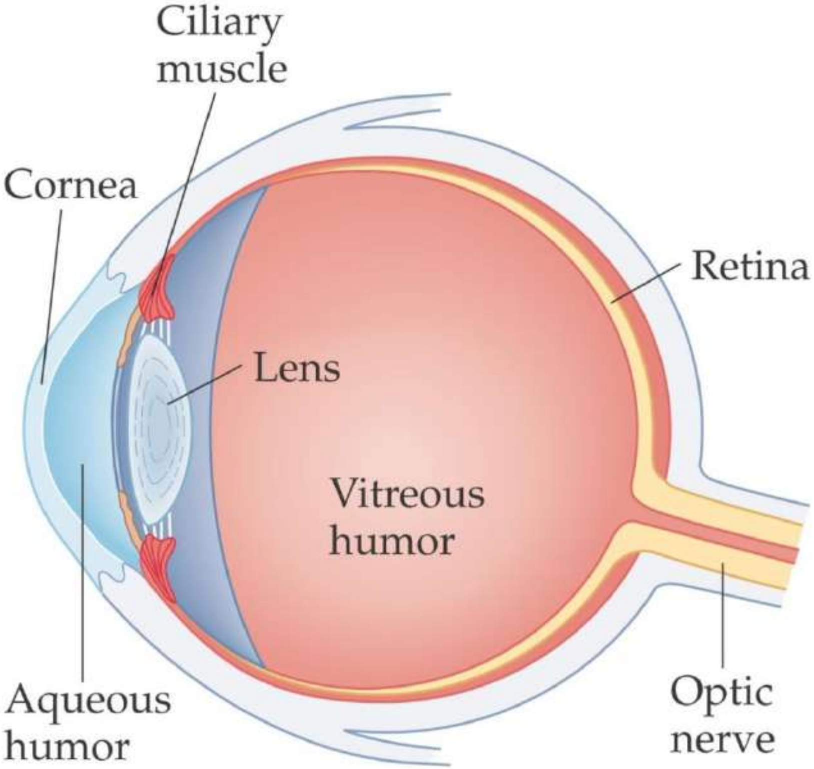
- The image seen by the eye, I_2, is virtual, inverted and very much enlarged.



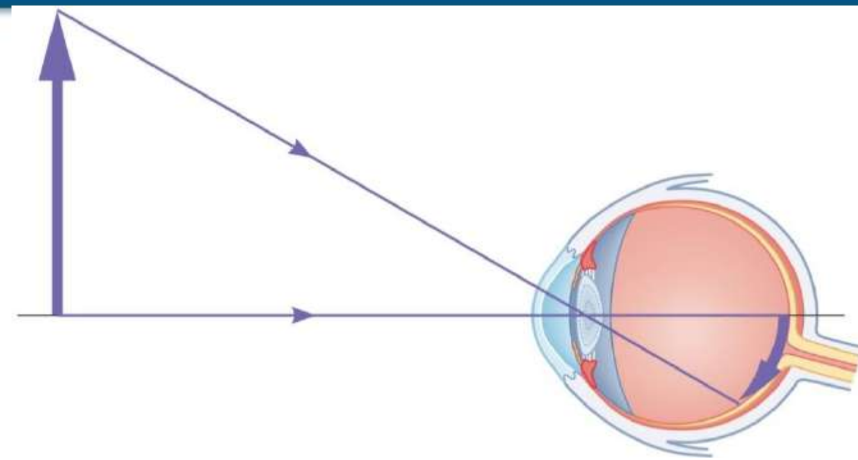
Eye and vision, The Human Eye

Light passes through the cornea of the human eye and is focused by the lens on the retina. The ciliary muscles change the shape of the lens, so it can focus at different distances. The vitreous and aqueous humors are transparent. Rods and cones on the retina convert the light into electrical impulses, which travel down the optic nerve to the brain.

The cornea focuses by bending (refracting) the light rays. The amount of bending depends on the curvatures of its surfaces and the speed of light in the lens compared with that in the surrounding material.

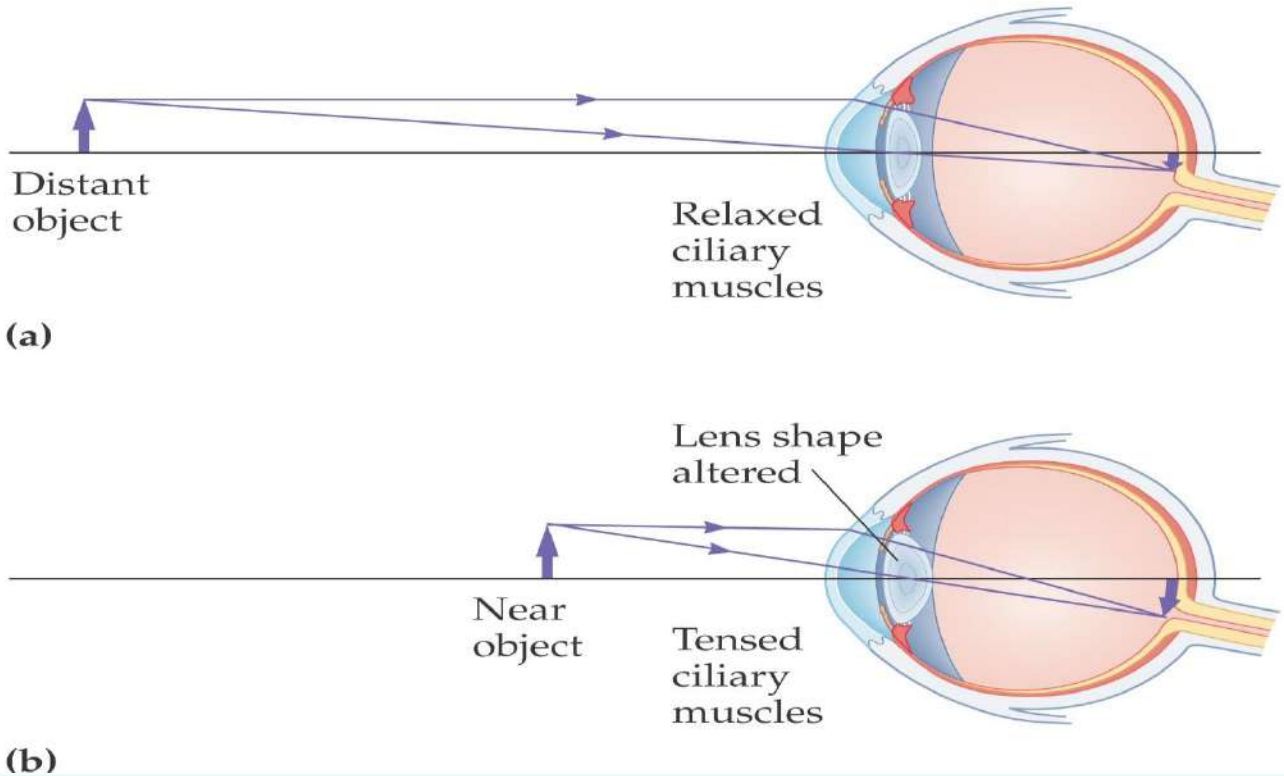


The Human Eye



The eye produces a real, inverted image on the retina. Why don’t things look upside down to us? The brain adjusts the image to appear properly.

The ciliary muscles adjust the shape of the lens to accommodate near and far vision.



The Human Eye

The near point is the closest point to the eye that the lens is able to focus. For those with normal vision, it is about 25 cm from the eye, but increases with age as the lens becomes less flexible.

The far point is the farthest point at which the eye can focus; it is infinitely far away, if vision is normal.

1-If the cornea is curved too much the eye is near sighted(myopia).
2-Not enough curvature results in far sight ness (Hyperemia).
3-Uneven curvature produces astigmatism.
4-As people get older, their lenses lose some accommodation, presbyopia (old sight) results when the lens has lost nearly all of its accommodation

The index of refraction is nearly constant for all corneas, but the curvature varies considerably from one person to another and is responsible for most our defective vision.

The Retina – The light detector of the eye

The retina, the light sensitive part of the eye, converts the light images into electrical nerve impulses that are sent to the brain.

The absorption of a light photon in photoreceptor triggers an electrical signal to brain-an action potential.

The light photon apparently cause a photochemical reaction in the photoreceptor

which in some way initiates the action potential.

1-Infrared photons have insufficient energy and thus are not seen.

2-Ultraviolet photons have sufficient energy, but absorbed before they reach the retina and also are not seen.

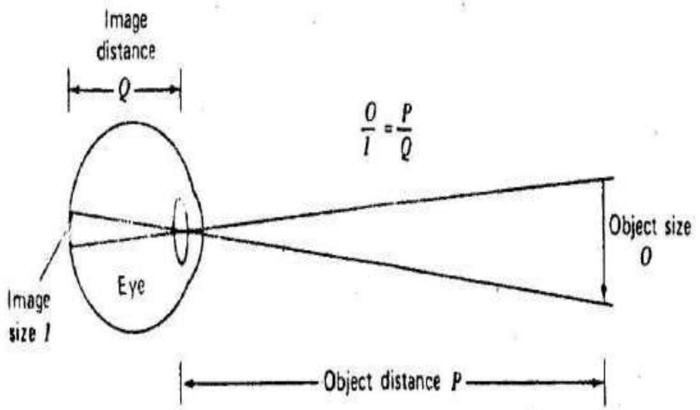
The image on the retina is very small.

I: is image size

Q: is image distance

O: is object size and P: is object distance

Thus we can write O/P=I/Q



Detective vision and its corrections

There a relation between the focal length F ,the object distance P , and the image distance Q of a thin lens.

1/F = 1/P + 1/Q

If F is measured in meters, then 1/F is the strength in Diopters (D), Thus**, a** positive (converging) lens with a focal length of 0.1 m has a strength of 10 D .

The focal length F of a negative (divergence) lens is considered to be negative . A negative lens with a focal length of -0.5 m has a strength of -2D.

The focal length F of a combination of two lenses with focal length F1 and F2 is given by **1/F = (1/F1)+ (1/F2)**

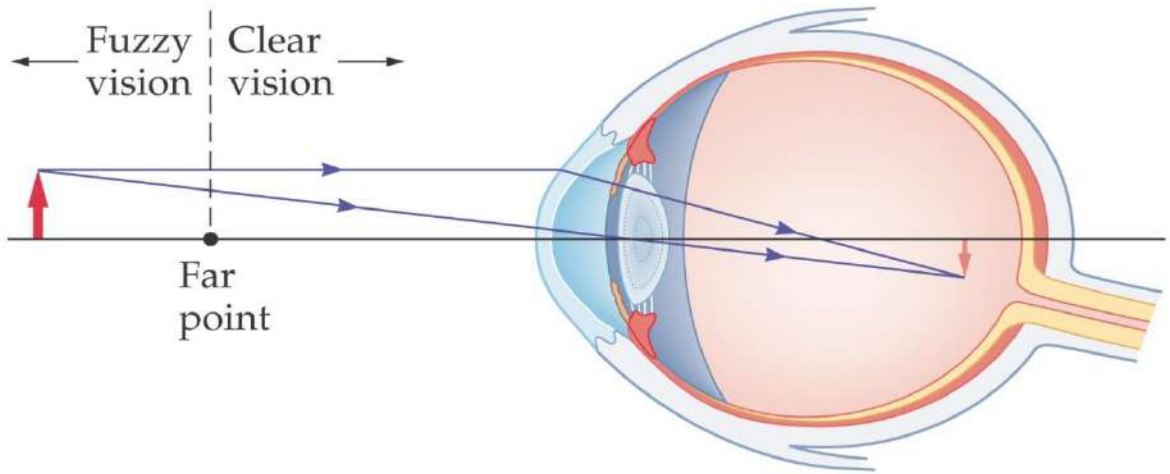
Example: Assume lens A with focal length F_A = 0.33m is combined with a lens B with focal length F_B =0.25m. What is the focal length of the combination? What is the dioptric strength of the combinations?

$1/F = 1/F_A + 1/F_B = 1/0.33 + 1/0.25 = 1/0.143$ Or F = 0.143m.

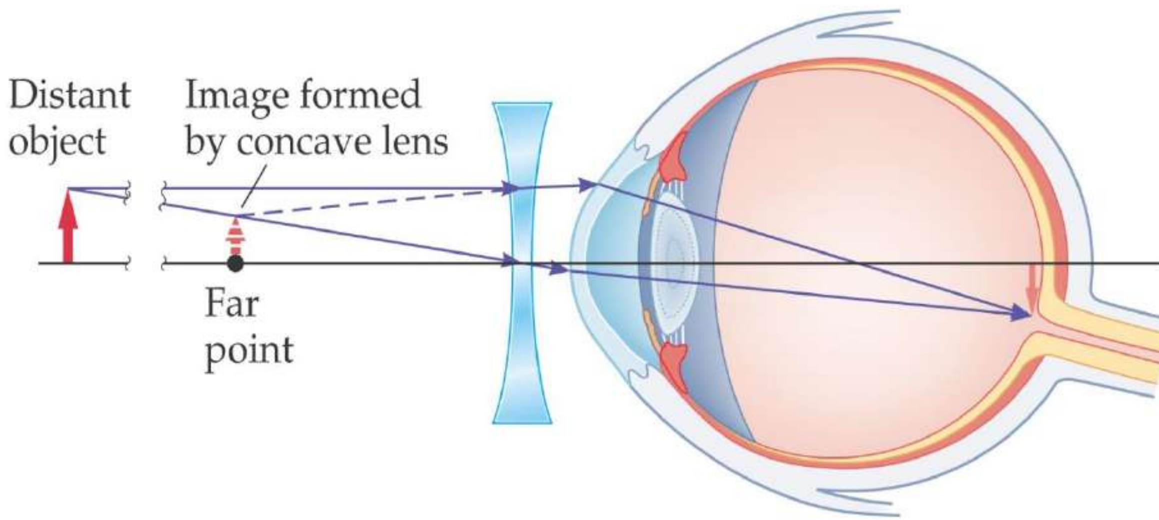
note that lens A is 3 D and lens B is 4 D. The combination is the sum ,or 7 D.

Myopia
Farsightedness

A nearsighted person has a far point that is a finite distance away; objects farther away will appear blurry. This is due to the lens focusing too strongly, so the image is formed in front of the retina.



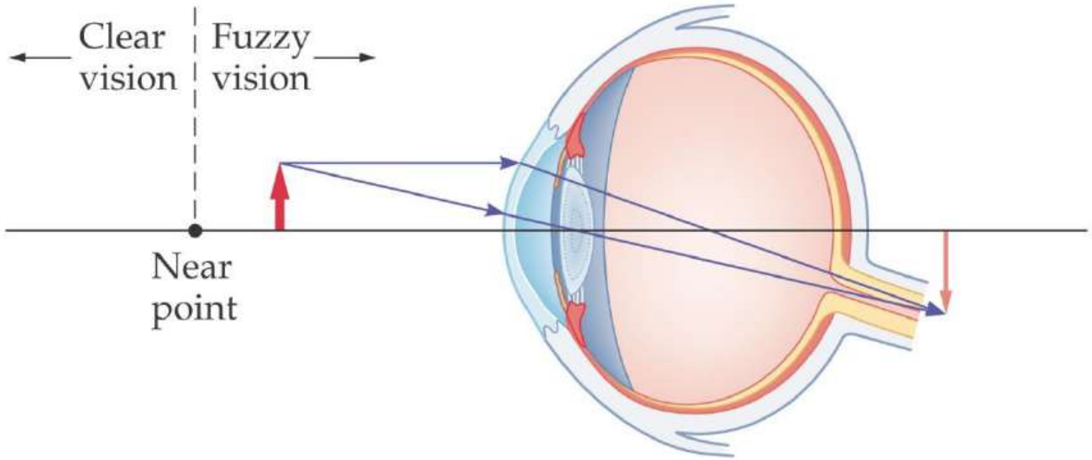
To correct this, a diverging lens is used. Its focal length is such that a distant object forms an image at the far point:



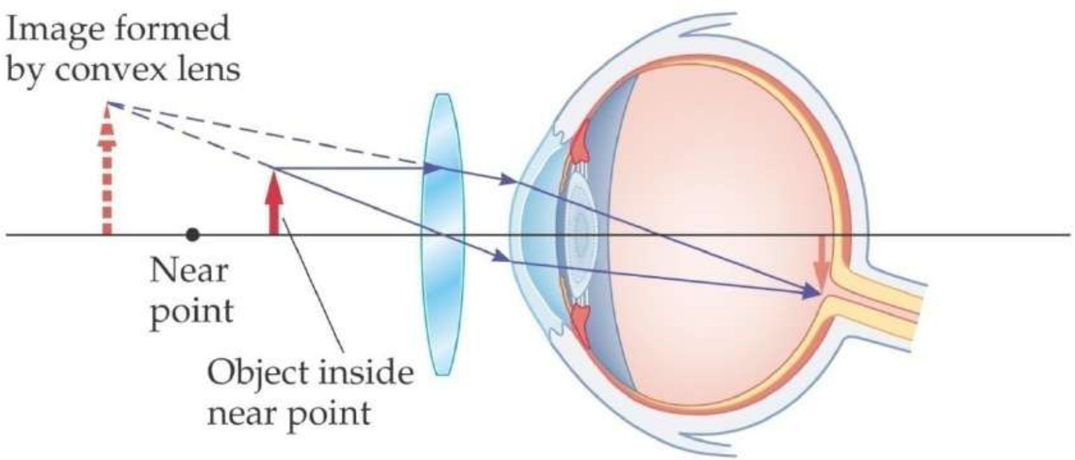
Hyperemia

Nearsightedness

A person who is farsighted can see distant objects clearly, but cannot focus on close objects – the near point is too far away. The lens of the eye is not strong enough, and the image focus is behind the retina.



To correct farsightedness, a converging lens is used to augment the converging power of the eye. The final image is past the near point:



Example

Let us determine the strength of a lens needed to correct a myopic eye with a far point of 1m. We consider the image distance(lens to retina) to be 2cm(0.02m).

Myopia: A person who is focusing an object at 1m has a lens strength of

$1/F = (1/1.0)+(1/0.02) = 51\ D$

An eye able to focus at infinity has a strength of $1/F=(1/\infty)+(1/0.02) = 50\ D$

$51\ D - 50D = 1D$

Thus a myopic person with a far point 1m has 1 D, and a negative lens of -1.0 D will correct his vision.

Hyperemia: Let us consider afar sighted eye with a near point of 2.0 m. what power lens will let this person read comfortably at 0.25 m?

The strength of a good eye focused at 0.25 m is given by $1/F=(1/0.25)+(1/0.02) = 4+50 = 54D$. An eye focused at 2m has a strength of

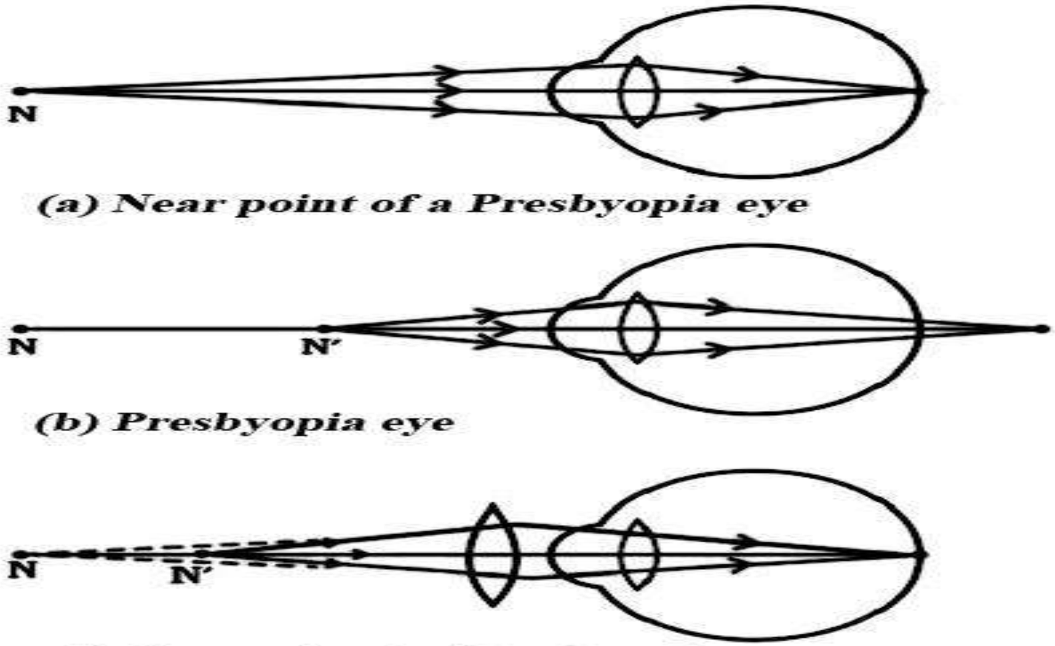
$1/F= (1/2.0) + (1/0.02) = 0.5 + 50 = 50.5\ D$

A corrective lens of 54-50.5= +3.5 D would prescribed for his eye.

Presbyopia (old sight)

As people get older the cillary muscles weaken and lens losses some of its elasticity.

The power of accommodation diminishes with age. This defect is corrected by two parts of lenses upper half of each lens is diverging and corrects the myopia when the wears is looking ahead at distance objects, the lower half corrects the presbyopia with a suitable converging lens, and the wearer looks through this part when reading



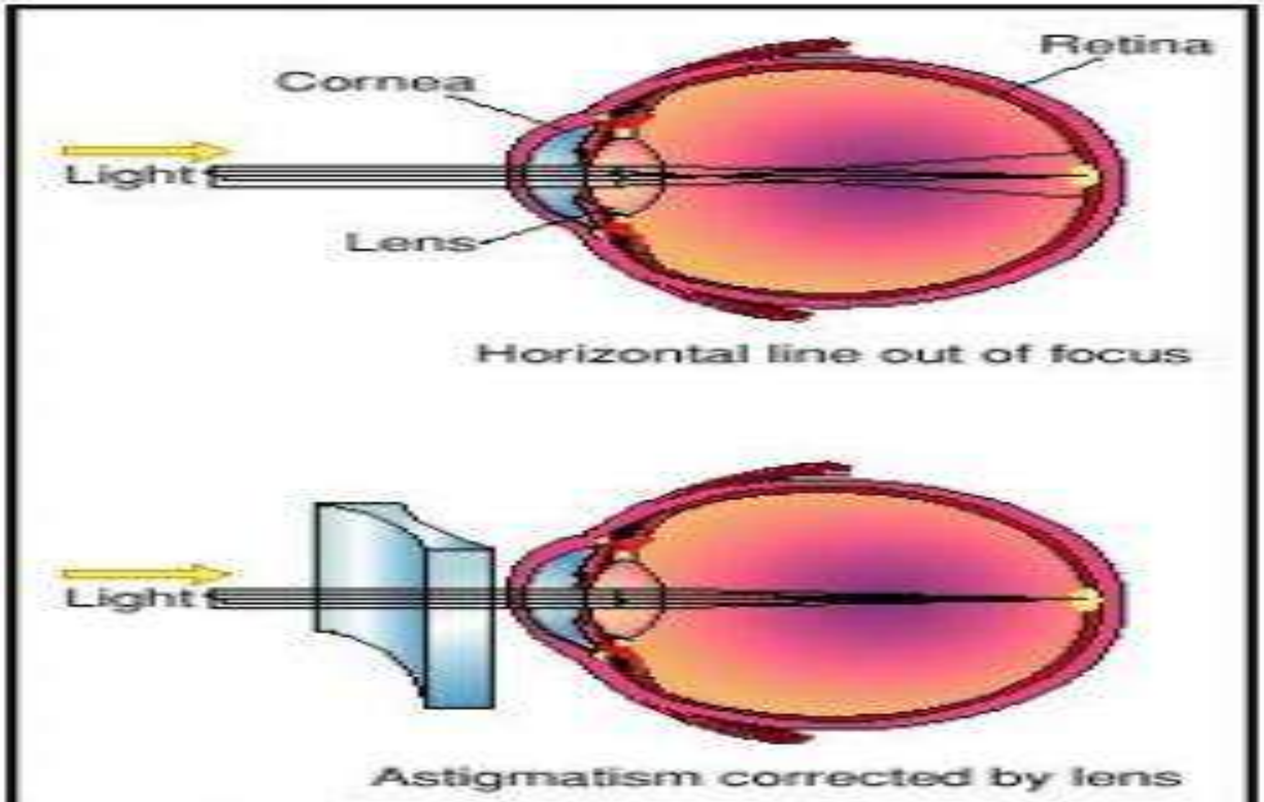
(a) Near point of a Presbyopia eye

(b) Presbyopia eye

(c) Correction for Presbyopia eye

Astigmatism

When astigmatism is present, point objects do not form point images on the retina. This is normally due to the corneas unequal curvature in different directions. If the curvature is greater in a horizontal section than in the vertical section, rays brought to a focus more quickly in the horizontal than in the vertical plane. The defect is corrected by the use of cylindrical spectacle lenses



Medical Physics

Lectures in General Physics for Medical Sciences Students

By

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Chapter 9 - Electricity

Electric Charges

There are two kinds of electric charges

- Called positive and negative

Conductors

Electrical conductors are materials in which some of the electrons are free electrons.

- Examples of good conductors include copper, aluminum and silver.

Insulators

Electrical insulators are materials in which all of the electrons are bound to atoms.

- Examples of good insulators include glass, rubber and wood..

Semiconductors

The electrical properties of semiconductors are somewhere between those of insulators and conductors.

Examples of semiconductor materials include silicon and germanium.

- Semiconductors made from these materials are commonly used in making electronic chips.

Point Charge

The term **point charge** refers to a particle of zero size that carries an electric charge.

- The electrical behavior of electrons and protons is well described by modeling them as point charges.

The force is attractive if the charges are of opposite sign.

The force is repulsive if the charges are of like sign.

Quantization of Electric Charges

The electric charge, q, is said to be quantized.

The SI unit of charge is the **coulomb** (C).

- Electric charge exists as discrete packets.
- $q = \pm Ne$
  - N is an integer
  - e is the fundamental unit of charge
  - $|e| = 1.6 \times 10^{-19}$ C
  - Electron: $q = -e$
  - Proton: $q = +e$

The electrical force

Charles Coulomb (1736 – 1806 French physicist) measured the magnitudes of electric forces between two small charged spheres.

The electrical force between two point charges is given by Coulomb's Law. Mathematically,

$$F_e = k_e \frac{|q_1||q_2|}{r^2}$$

the **Coulomb constant,** k_e = 8.9876 x 10^9 N·m²/C² = $1/(4\pi\varepsilon_o)$

- ε_o = 8.8542 x 10^{-12} C² / N·m² is the **permittivity of free space.**

Electric Field

An **electric field** is said to exist in the region of space around a charged object This charged object is the **source charge.**

When another charged object, the **test charge**, enters this electric field, an electric force acts on it.

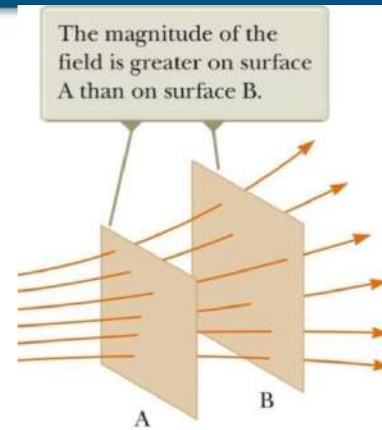
The electric field vector, $\vec{\mathbf{E}}$, at a point in space is defined as the electric force acting on a positive test charge, q_o, placed at that point divided by the test charge:

The SI units of $\vec{\mathbf{E}}$ are N/C.

$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}_e}{q_o} = k_e \frac{q}{r^2}\hat{\mathbf{r}}$$

Electric Field Lines

The number of lines per unit area through a surface perpendicular to the lines is proportional to the magnitude of the electric field in that region.

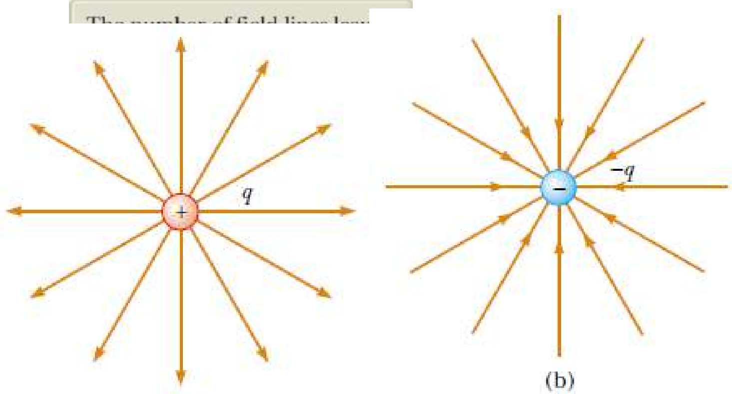


For a positive point charge:

The field lines are directed away from the source charge in all directions.

For a negative point charge:

The field lines are directed toward the source charge in all directions.

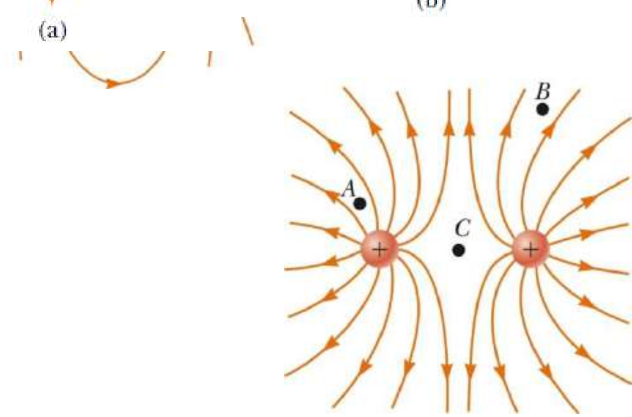


Electric Field Lines – Dipole

The charges are equal and opposite. The number of field lines leaving the positive charge equals the number of lines terminating on the negative charge.

Electric Field Lines – Like Charges

The charges are equal and positive.The same number of lines leave each charge since they are equal in magnitude.



Electrical Potential Energy

When a test charge is placed in an electric field, it experiences a force. $\vec{\mathbf{F}}_e = q_o\vec{\mathbf{E}}$

For a finite displacement of the charge from A to B, the work is done by the field or **the change in potential energy** is $\Delta U = U_B - U_A = -q_o \int_A^B \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$

Electric Potential

The potential energy per unit charge, U/q_o, is the **electric potential.**

The electric potential is $V = \dfrac{U}{q_o}$

The potential is a scalar quantity. Because energy is a scalar.

Units of the electric potential is volt. **1 V ≡ 1 J/C**. In addition, 1 N/C = 1 V/m

As a charged particle moves in an electric field,

The electric **potential difference** between two points A and B can be simplified if the electric field is uniform:

$$V_B - V_A = \Delta V = -\int_A^B \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -E\int_A^B d\mathbf{s} = -Ed$$

Then the potential due to a point charge at some point *r* is: $V = k_e \dfrac{q}{r}$

The electric potential due to several point charges is: $V = k_e \sum_i \dfrac{q_i}{r_i}$

Example: The Electric Potential Due to Two Point Charges

A charge q_1 = 2.00 μC is located at the origin, and a charge q_2= 6.00 μC is located at (0, 3.00) m, as shown in Figure

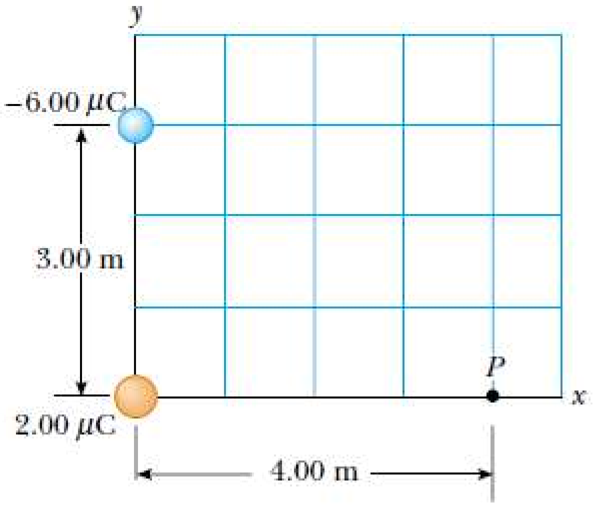
(A) Find the total electric potential due to these charges at the point *P*, whose coordinates are (4.00, 0) m.

Solution

$$V_P = k_e\left(\frac{q_1}{r_1} + \frac{q_2}{r_2}\right)$$

$$V_P = (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}) \times \left(\frac{2.00 \times 10^{-6}\ \mathrm{C}}{4.00\ \mathrm{m}} - \frac{6.00 \times 10^{-6}\ \mathrm{C}}{5.00\ \mathrm{m}}\right)$$

$$= -6.29 \times 10^3\ \mathrm{V}$$



(B) Find the electric force between the two charges

$$F_e = k_e \frac{|q_1|\,|q_2|}{r^2}$$

Capacitors

Capacitors are devices that store electric charge.

Examples of where capacitors are used include:

- radio receivers
- filters in power supplies
- to eliminate sparking in automobile ignition syst
- energy-storing devices in electronic flashes

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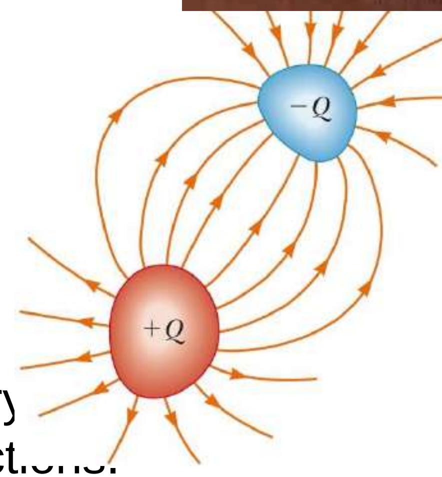
Makeup of a Capacitor



A capacitor consists of two conductors.

- These conductors are called plates.
- When the conductor is charged, the plates carry charges of equal magnitude and opposite direct...

A potential difference exists between the plates due to the charge.

Definition of Capacitance

The **capacitance**, *C*, of a capacitor is defined as the ratio of the magnitude of the charge on either conductor to the potential difference between the conductors.

$$C \equiv \frac{Q}{\Delta V}$$

The capacitance of a given capacitor is constant.

The SI unit of capacitance is the **farad** (F).

The farad is a large unit, typically you will see microfarads (mF) and picofarads (pF).

For a parallel capacitor:

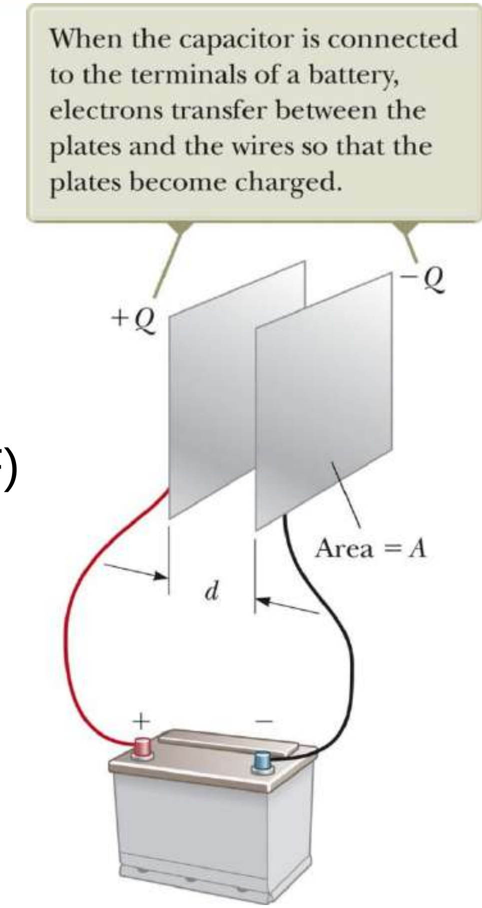
$$C = \frac{Q}{\Delta V} = \frac{Q}{Ed} = \frac{Q}{Qd / \varepsilon_o A} = \frac{\varepsilon_o A}{d}$$

- *A* is the area of each plate, the area of each plate is equal
- *Q* is the charge on each plate, equal with opposite signs

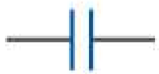
A dielectric is a nonconducting material that, when placed between the plates of a capacitor, increases the capacitance and Increase the maximum operating voltage. Dielectrics include rubber, glass, and waxed paper.

For a parallel-plate capacitor, $C = \kappa (\varepsilon_0 A) / d$

κ is the dielectric constant of the material.



Capacitor symbol



Example: A parallel-plate capacitor of dimensions 2.0 cm by 3.0 cm separated by a 1.0-mm thickness of paper, $\kappa = 3.7$ for paper. Find its capacitance.

$$C = \kappa \frac{\epsilon_0 A}{d} = 3.7\left(\frac{(8.85 \times 10^{-12}\,\mathrm{C^2/N\cdot m^2})(6.0 \times 10^{-4}\,\mathrm{m^2})}{1.0 \times 10^{-3}\,\mathrm{m}}\right)$$

$$= 20 \times 10^{-12}\,\mathrm{F} = 20\,\mathrm{pF}$$

- For a lipid bilayer, $\varepsilon = 5\mathrm{x}10^{-11}\,F/m$ and $d = 50\ \text{Å} = 5\mathrm{x}10^{-9}\ mm$. Thus, the capacitance per unit area for an unmyelinated axon of 5 nm thickness is:

$$C_m = \frac{C}{A} = \frac{\epsilon}{d} = \frac{5\times10^{-11}}{5\times10^{-9}} = 10^{-2}F/m^2 \text{(Unmyelinated axon)}$$

- For myelinated axons, the myelin sheath contains a membrane that wraps around the axon a couple of hundred times. This multilayer arrangement effectively increases the thickness of the lipid bilayer by a factor of 200 (1 μm total thickness),

so capacitance per unit area for a myelinated axon is:

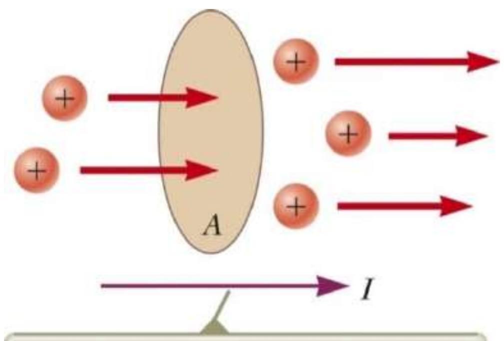
$$C_m = \frac{C}{A} = \frac{\epsilon}{d} = \frac{5\times10^{-11}}{1\times10^{-6}} = 5 \times 10^{-5}F/m^2 \text{(Myelinated axon)}$$

Some Dielectric Constants and Dielectric Strengths

Approximate Dielectric Constants and Dielectric Strengths of Various Materials at Room Temperature

Material	Dielectric Constant κ	Dielectric Strength[a] (10^6 V/m)
Air (dry)	1.000 59	3
Bakelite	4.9	24
Fused quartz	3.78	8
Mylar	3.2	7
Neoprene rubber	6.7	12
Nylon	3.4	14
Paper	3.7	16
Paraffin-impregnated paper	3.5	11
Polystyrene	2.56	24
Polyvinyl chloride	3.4	40
Porcelain	6	12
Pyrex glass	5.6	14
Silicone oil	2.5	15
Strontium titanate	233	8
Teflon	2.1	60
Vacuum	1.000 00	—
Water	80	—

Electric Current



The direction of the current is the direction in which positive charges flow when free to do so.

Most practical applications of electricity deal with electric currents.

- The electric charges move through some region of space.

Electric current is the rate of flow of charge through some region of space.

Assume charges are moving perpendicular to a surface of area *A*. If ΔQ is the amount of charge that passes through *A* in time Δt, then the average current is

$$I_{avg} = \frac{\Delta Q}{\Delta t}$$

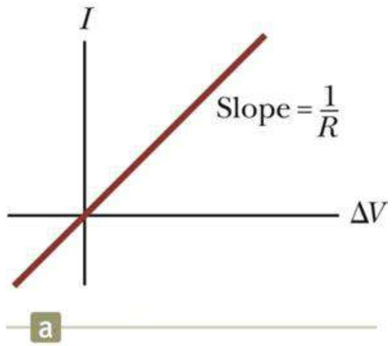
The symbol for electric current is I.

In an ordinary conductor, the direction of current flow is opposite the direction of the flow of electrons. It is common to refer to any moving charge as a *charge carrier.*

The SI unit of current is the **ampere** (A). **1 A = 1 C / s**

Ohm's Law

- Mathematically, $V=IR$
- Materials that obey Ohm's law are said to be *ohmic.* Most metals obey Ohm's law
- Materials that do not obey Ohm's law are said to be *nonohmic.*



Resistance

Resistance is $R = \rho \frac{\ell}{A}$ where ρ is the **resistivity**

Every ohmic material has a characteristic resistivity that depends on the properties of the material and on temperature.

The resistance of a material depends on its geometry and its resistivity.

SI units of resistance are *ohms* (Ω). **1 Ω = 1 V / A**

Resistance in a circuit arises due to collisions between the electrons carrying the current with the fixed atoms inside the conductor.

Most electric circuits use circuit elements called **resistors** to control the current in the various parts of the circuit.

Example

Axoplasm Resistance

- The electrical resistance R along the length of the axon follows the same principles as a wire:

$$R = \rho_a \frac{l}{\pi r^2}$$

- For both myelinated and unmyelinated neurons, the resistivity ρ_a of the axoplasm is 2.0 Ω.m.

- If the average neuron has an axon 1 mm long and a 5μm radius, we can find that the resistance of the axoplasm $R_{axoplasm} = 2.5\text{x}10^7\ \Omega$. This huge value indicates that axons are actually poor electrical conductors.

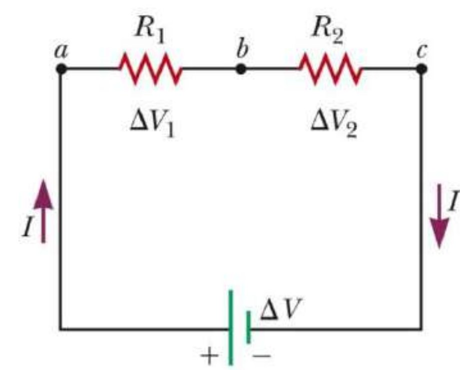
Resistors in Series and in Parallel

For a **series combination** of resistors, the currents are the same in all the resistors $I = I_1 = I_2$

The equivalent resistance has the same effect on the circuit as the original combination of resistors.

$$R_{eq} = R_1 + R_2 + R_3 + \dots$$

A circuit diagram showing the two resistors connected in series to a battery

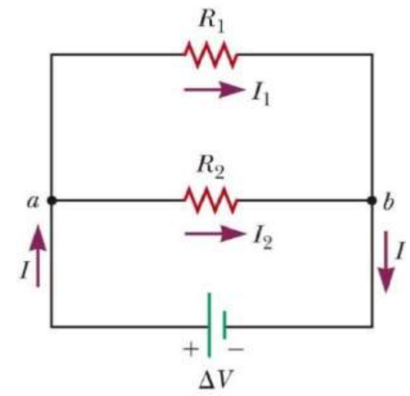


For a **parallel combination** of resistors, The potential difference across each resistor is the same because each is connected directly across the battery terminals. $\Delta V = \Delta V_1 = \Delta V_2$

Equivalent Resistance

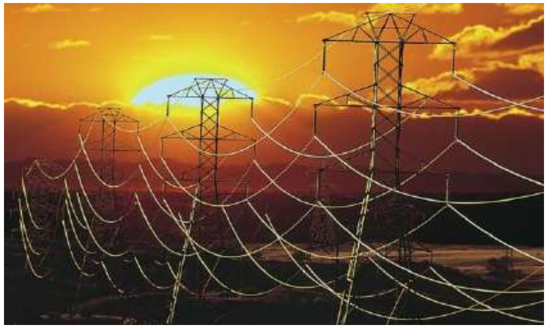
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

A circuit diagram showing the two resistors connected in parallel to a battery



Electric Power

The **power** is the rate at which the energy is delivered to the resistor.



The power is given by the equation P = I ΔV.

Applying Ohm's Law, alternative expressions can be found:

$$P = I\,\Delta V = I^2 R = \frac{(\Delta V)^2}{R}$$

Units: I is in A, R is in Ω, ΔV is in V, and P is in W (Watt)

Example Power in an Electric Heater

An electric heater is constructed by applying a potential difference of 120 V to a Nichrome wire that has a total resistance of 8.00 Ω. Find the current carried by the wire and the power rating of the heater.

Solution

Because $\Delta V = IR$, we have

$$I = \frac{\Delta V}{R} = \frac{120\ \text{V}}{8.00\ \Omega} = 15.0\ \text{A}$$

We can find the power rating as

$$\mathcal{P} = I^2 R = (15.0\ \text{A})^2(8.00\ \Omega) = 1.80 \times 10^3\ \text{W}$$

$$\mathcal{P} = 1.80\ \text{kW}$$

RC Circuit

In direct current circuits containing capacitors, the current may vary with time.

- The current is still in the same direction.

An RC circuit will contain a series combination of a resistor and a capacitor.

Electrical Safety

Electric shock can result in fatal burns.

Electric shock can cause the muscles of vital organs (such as the heart) to malfunction.

The degree of damage depends on:

- The magnitude of the current
- The length of time it acts
- The part of the body touched by the live wire
- The part of the body in which the current exists

Effects of Various Currents

5 mA or less

- Can cause a sensation of shock
- Generally little or no damage

10 mA

- Muscles contract
- May be unable to let go of a live wire

100 mA

- If passing through the body for a few seconds, can be fatal
- Paralyzes the respiratory muscles and prevents breathing

In some cases, currents of 1 A can produce serious burns.

- Sometimes these can be fatal burns

No contact with live wires is considered safe if the voltage is greater than 24 V.

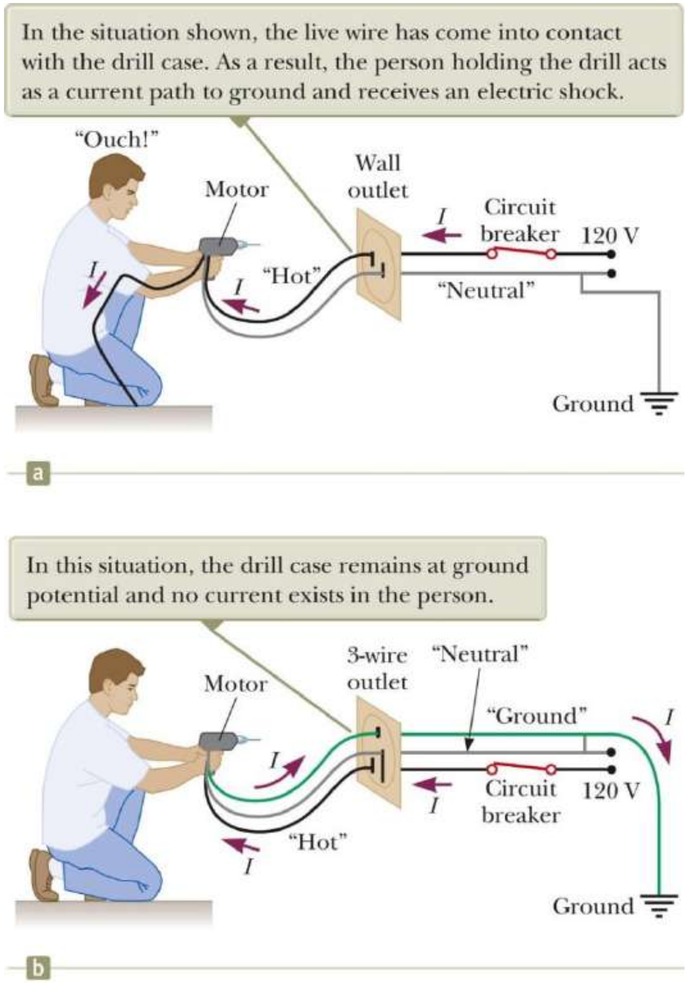
Ground Wire

Electrical equipment manufacturers use electrical cords that have a third wire, called a ground.

This safety ground normally carries no current and is both grounded and connected to the appliance.

If the live wire is accidentally shorted to the casing, most of the current takes the low-resistance path through the appliance to the ground.

If it was not properly grounded, anyone in contact with the appliance could be shocked because the body produces a low-resistance path to ground.



Ground-Fault Interrupters (GFI)

Special power outlets

Used in hazardous areas

Designed to protect people from electrical shock

Senses currents (< 5 mA) leaking to ground

Quickly shuts off the current when above this level

Electricity Within the Body

Electricity plays an important role in medicine .

There are two aspects of electricity and magnetism in medicine :

1.electrical and magnetic effects generated inside the body ,

2.applications of electricity and magnetism to the surface of the body.

The electricity generated inside the body serves for the control and operation of the nerves , muscles ,and organs.

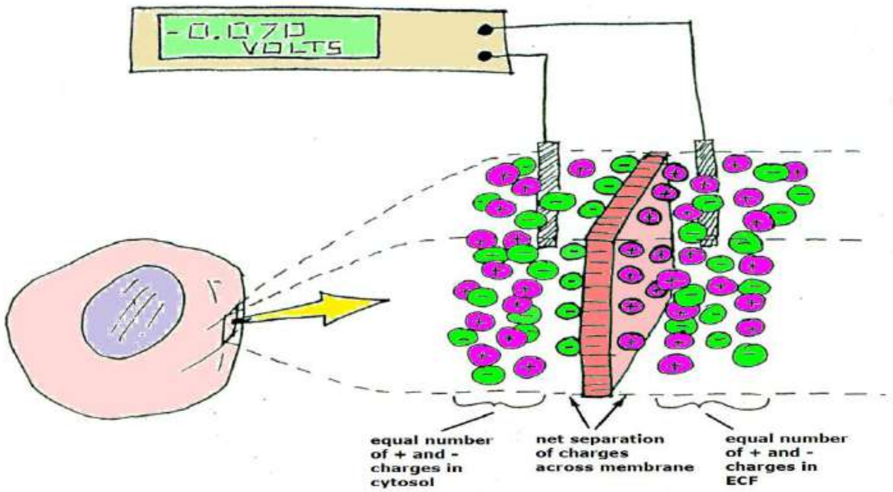
The forces of muscles are caused by the attraction and repulsion of electrical charges.

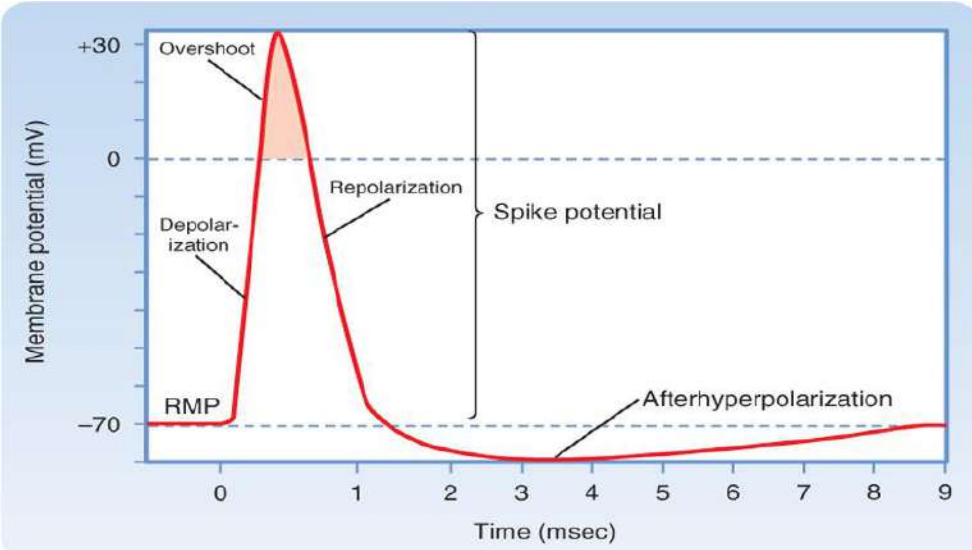
The action of the brain is basically electrical. All nerve signals to and from the brain involve the flow of electrical currents.

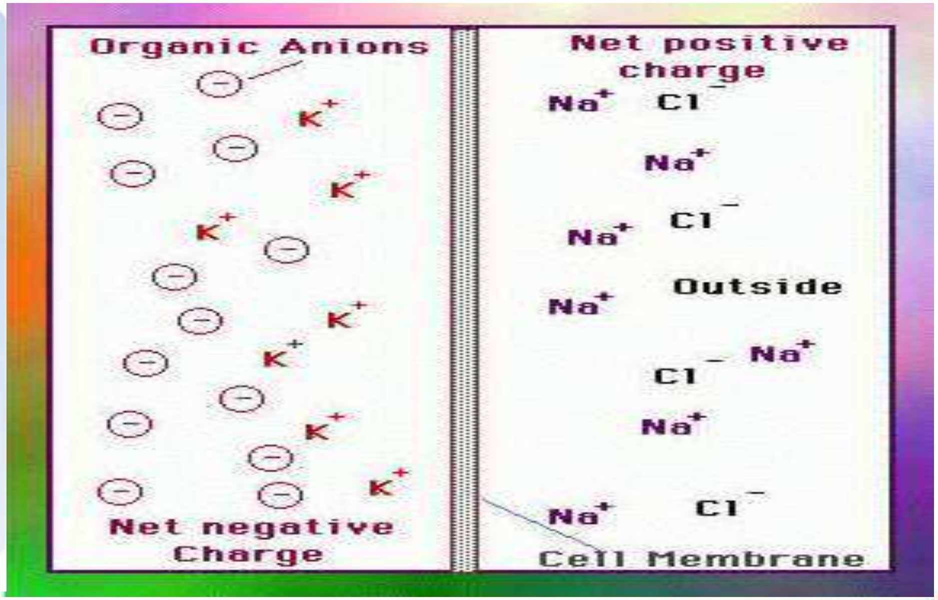
One means of obtaining diagnostic information about muscles is to measure their electrical activity .

The transition of the action potential from the axon into the muscle causes muscle contraction.

Potential difference between inside and outside the cell





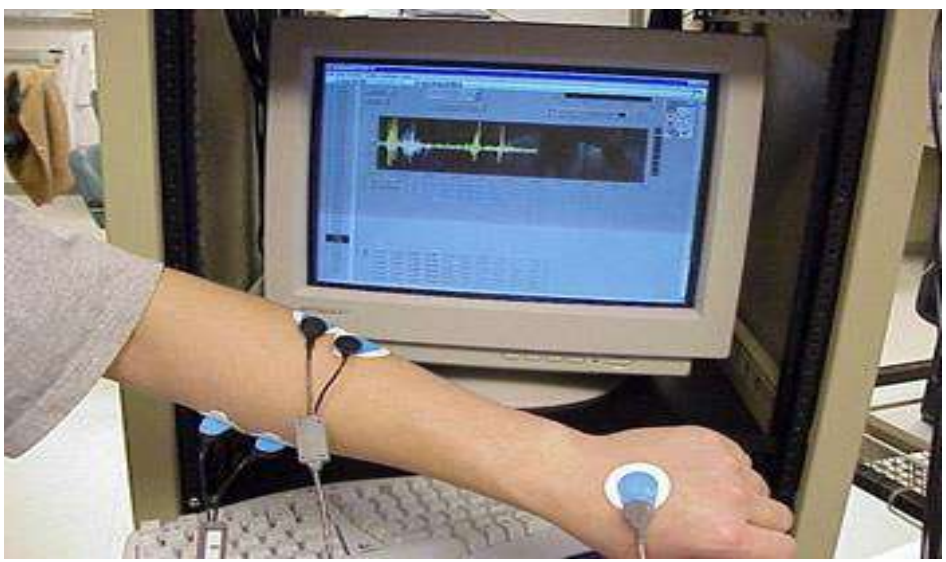


Electromyography (EMG)

Electromyography is a technique of recording electric activity produced by the muscles at rest and during contraction as shown in figures.

This technique is used for investigation of various neurological conditions and determinate the site and duration of action potential of muscle relaxants.

The nerve conduction velocity can be determined using EMG machine.

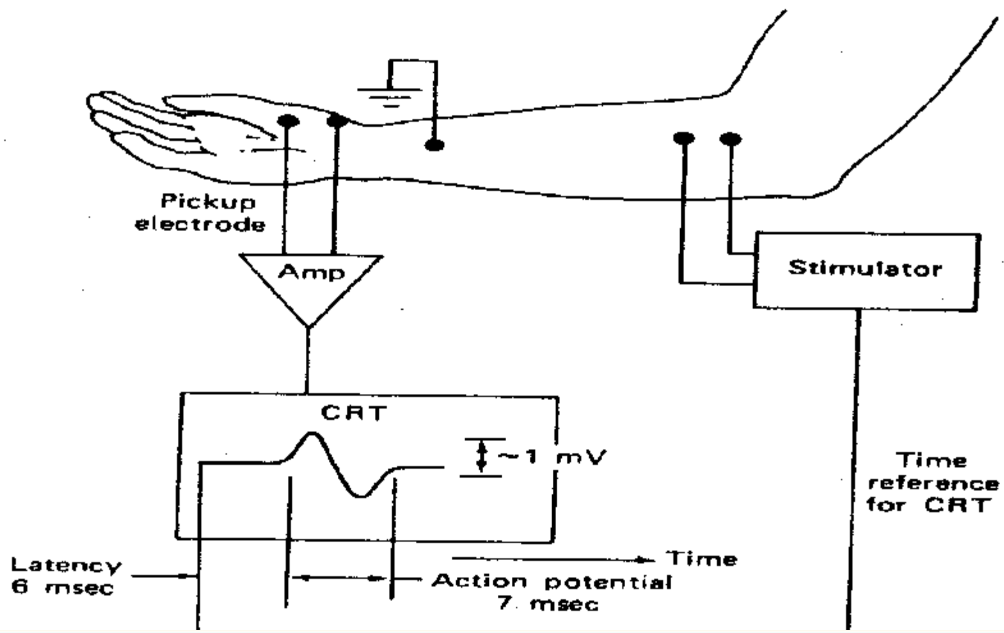


Muscle action potential picked up by electrodes placed near the surface of interest . There are different types of electrodes ; surface , needle, and disc electrodes.

EMG signal can be recorded by applying stimuli to ulnar nerve with surface electrodes and observing the contraction of muscles.

One nerve supply 100 –300 muscle fibers which make up a motor unit ; so when a nerve is stimulated a large of muscle fibers are activated.

EMG electrodes record the electrical activity from several fibers , so single muscle cell are usually not monitored in an EMG examination, because it is difficult to isolate a single fiber.



Surface electrode

Electrical signals from the heart

The rhythmical action of the heart is controlled by an electrical signal initiated by spontaneous stimulation of special muscle cells located in the right atrium .These cells make up the senatorial (SA) node, or pacemaker. The SA node fires at regular intervals

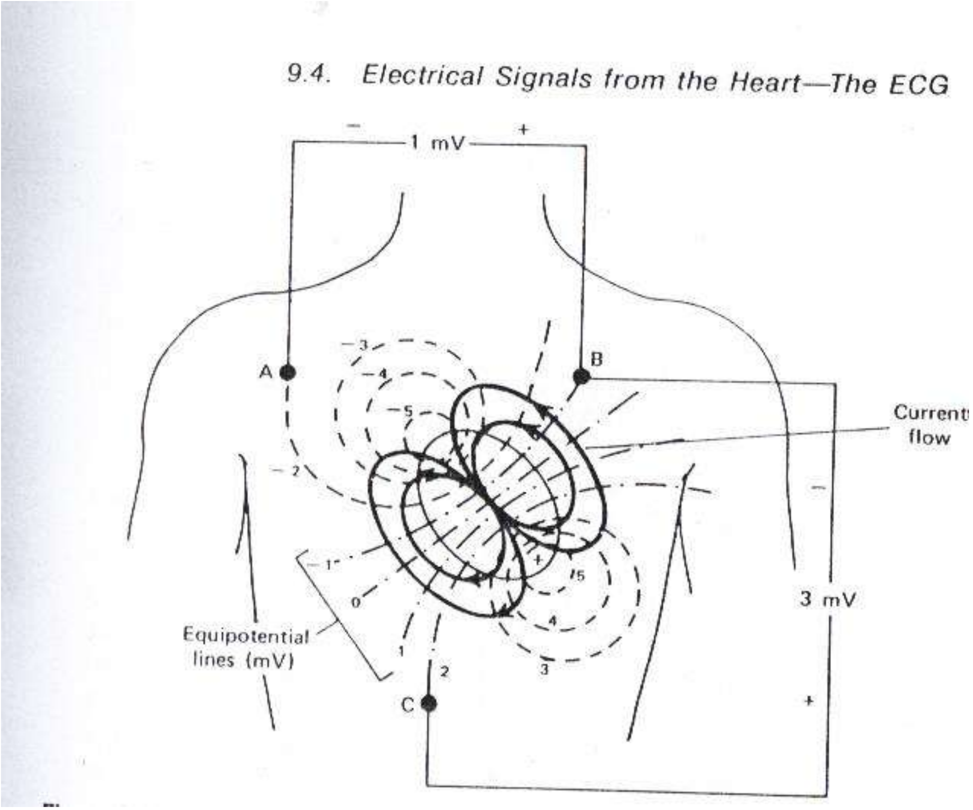
The electrical signal from the SA node initiates the depolarization of the nerves and muscles of both atria causing the atria to contract and pump blood into the ventricles.

Re -polarization of the atria follows

The electrical signal then passes into the atrioventricullar node (AV) node, which initiates the depolarization of the right and left ventricles , causing them to contract and force blood into the pulmonary and general circulation's .The ventricle nerves and muscles then repolarize and the sequence begins again.

The nerves and muscles of the heart can be regarded as sources of electricity enclosed in an electrical conductor.

The potential distribution on the chest at the moment when the ventricles are one half depolarized . Electrodes located at A, B, and C would indicate the potentials at that moment



An electric dipole is produced when equal positive and negative charges are separated from each other. It can be represented by a vector.

The electrical (cardiac) potential that we measure on the surfaces of the body is merely the instantaneous projection of the electric dipole vector in a particular direction. As the vector changes with time, so does the projected potential.

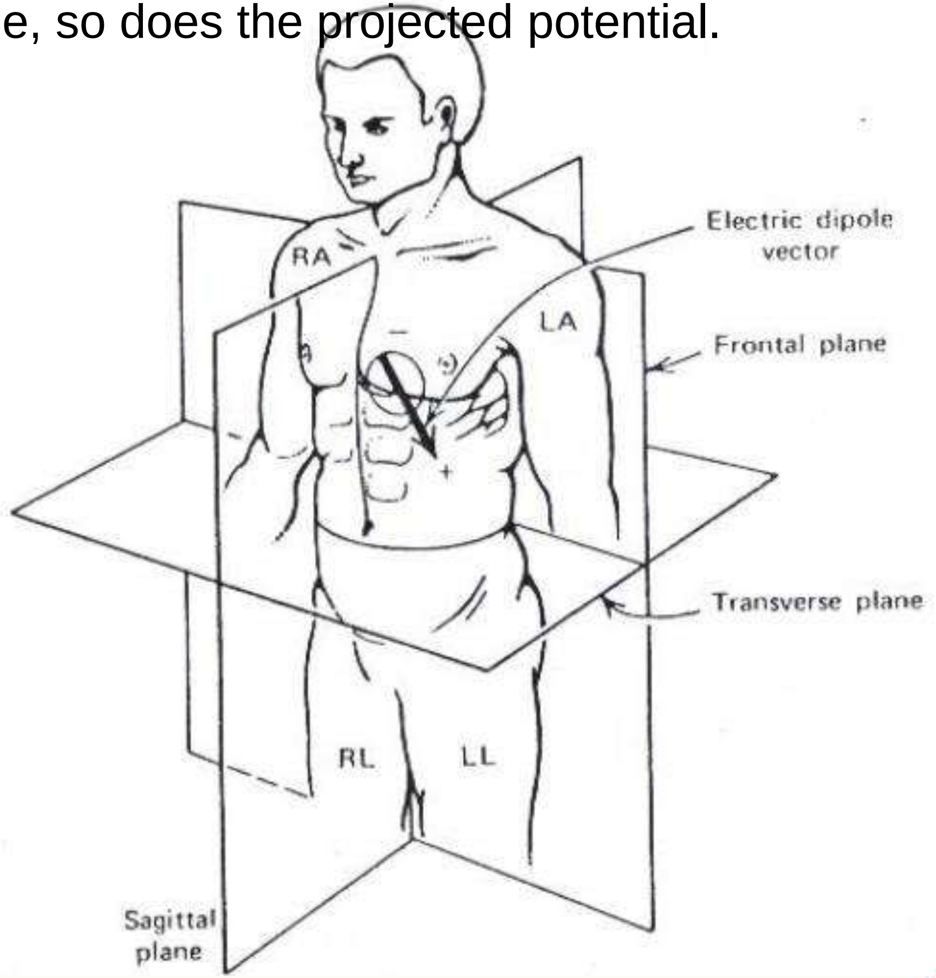


Figure :**electrocardiographic (ECG)** planes and an electric dipole vector **RA, LA , RL** an **LL** indicate electrode locations on the right and left arms and legs.

The wave form of ECG is some time positive and in other cases it is negative. The sign of the waveform depends upon the direction of the electric dipole vector and the polarity and position of the electrodes.

Electrocardiograph (ECG)

The potentials produced by the heart spread to the surface of the and detected by electrodes placed there. The process of recording these potentials is known as **ECG** . The potentials are small so that they require to be electrically amplified before they are recorded (figure).

Figure: Typical ECG . P represents the atrial depolarization and contraction,
The QRS complex indicates the ventricular depolarization,
The ventricular contraction between S and T
T represents the ventricular repolarization

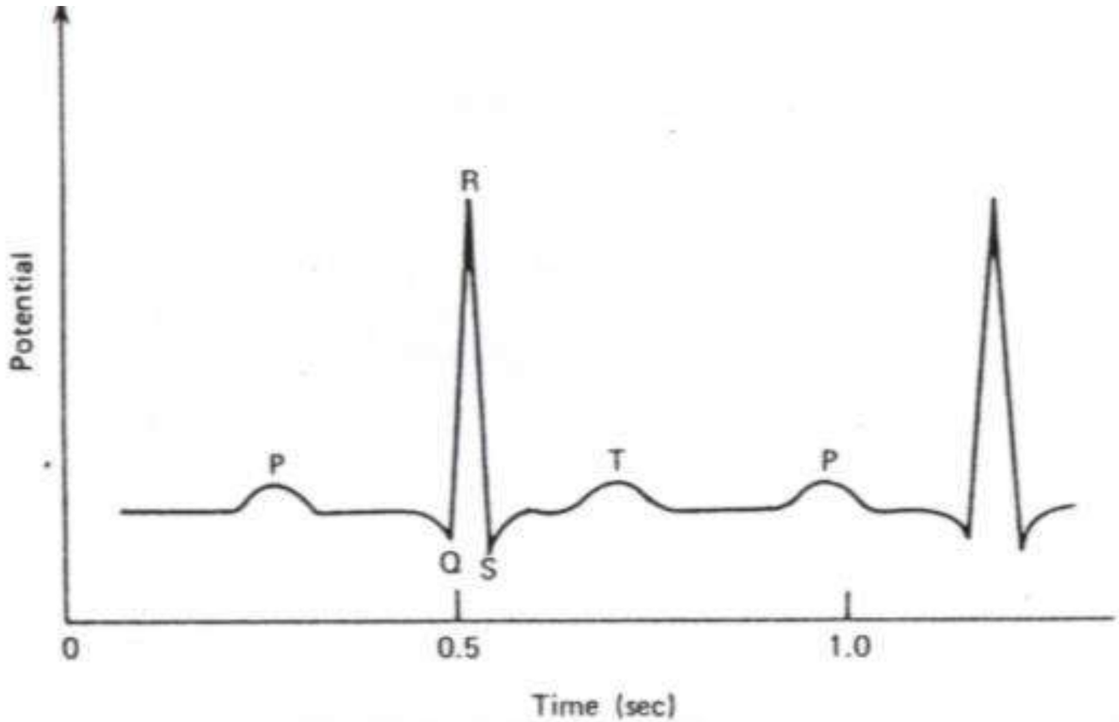
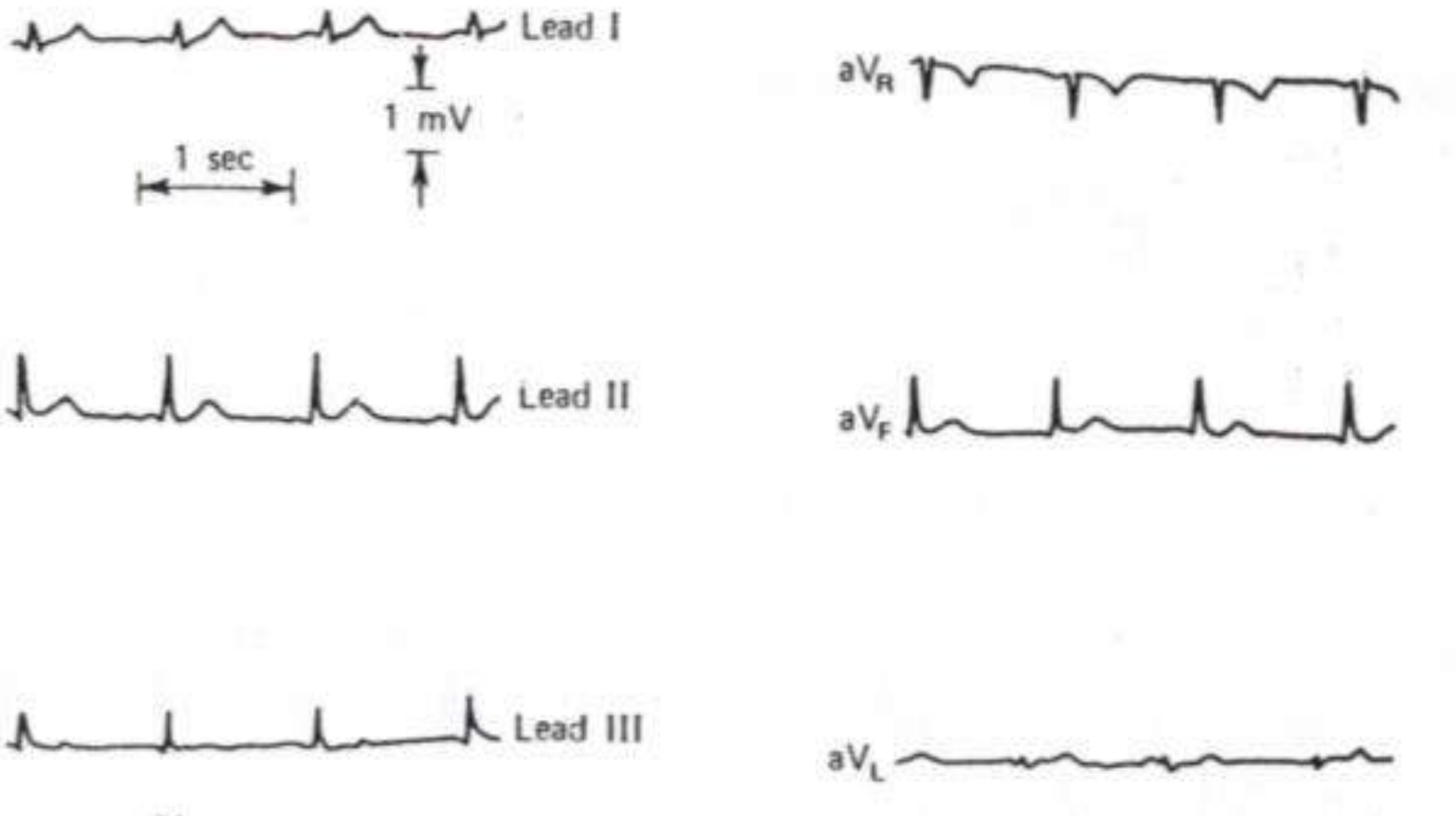


Figure: Six frontal plane ECG s for a normal subject .

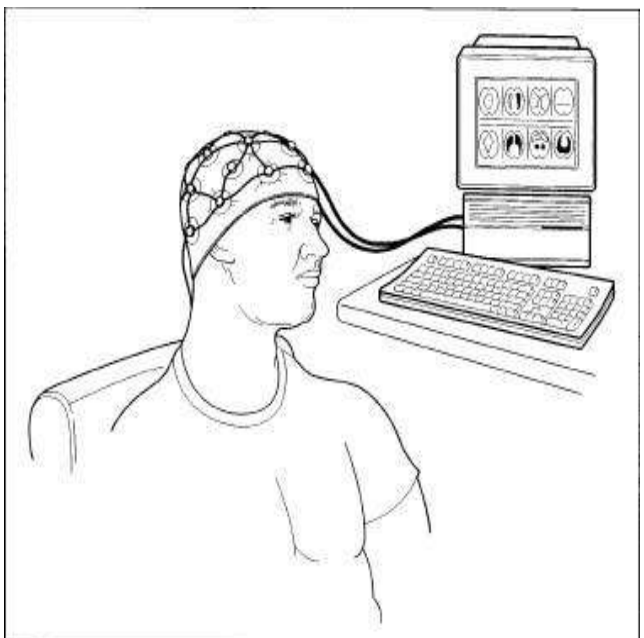


Electroencephalograph (EEG)

EEG is a technique of recording electrical activity of the brain through the intact skull.

Electrodes are applied on the scalp and potential difference recorded and amplified and present for interpretation as an inked tracing on moving paper.

Machines in common use have eight or sixteen or more channels so that it is possible to record the activity from different areas of the head simultaneously



The technique is relatively simple and entirely harmless and may give information which is of great important in neurological diagnosis.

The frequency of the EEG signals depend on the mental activity of the subject. For example a relaxed person usually has an EEG signal composed primarily of frequencies from 8 to 13 Hz, or alpha waves

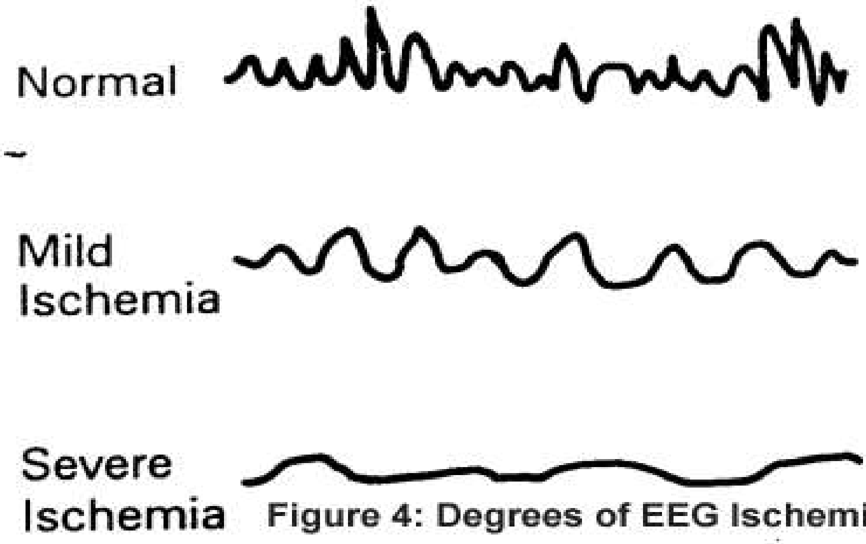


Figure 4: Degrees of EEG Ischemia

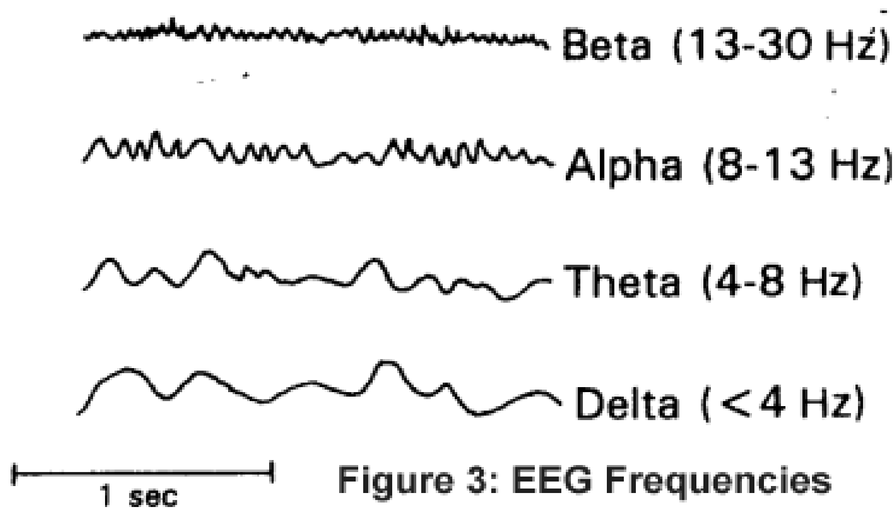


Figure 3: EEG Frequencies

EEG as investigation method of brain activity

The main present clinical application of EEG are the following:

1 . to investigate lesion in the brain, because lesion can provided abnormal activity of the brain . Abnormality in the signals could be in its amplitude , width or its sequence.

2. Abnormality in EEG output occurs with people having epilepsy. EEG may be help to distinguish between different type of epilepsy.

3. Many medically conditions produce cerebral complications that can be simply detected.

4 . Spinal cord abnormality can be detected and investigated using EEG technique.

Electrodes used, type, and characteristics

Electrodes used in EEG are of special design , and must have the following characteristics:

1.Electrode impedance must be less than5 kΩ, between 2-5 kΩ, to avoid drop in the signal potential.

2 . Electrodes used must be very high purity, because impurity

increased the signal artifacts.

3 . All electrodes used should have the same input impedance to avoid the recording unbalance due to the phase shift.

4 . All electrodes should be stable potential, because unstable potential will produce artifacts very much larger than EEG signal.

5 . Electrodes must be cheap, easy to apply, easy to prepare, and to maintain, and it should be without hazard to patient.

Medical Physics

Lectures in General Physics for Medical Sciences Students

By

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Chapter 10 - Radiation

Some Properties of Nuclei

All nuclei are composed of protons and neutrons except hydrogen with a single proton

The **atomic number** *Z* equals the number of protons in the nucleus.

- Sometimes called the charge number

The **neutron number** *N* is the number of neutrons in the nucleus.

The **mass number** *A* is the number of **nucleons** in the nucleus.

- $A = Z + N$
- Nucleon is a generic term used to refer to either a proton or a neutron
- The mass number is not the same as the mass.

A **nuclide** is a specific combination of atomic number and mass number that represents a nucleus. $^{A}_{Z}X$

- X is the chemical symbol of the element.

Example:

$^{27}_{13}Al$

- Mass number is 27
- Atomic number is 13
- Contains 13 protons. Contains 14 (27 – 13) neutrons

More Properties

The nuclei of all atoms of a particular element must contain the same number of protons.

They may contain varying numbers of neutrons.

- **Isotopes** of an element have the same Z but differing N and A values.
- The natural abundance of isotopes can vary.
- Isotope example:

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

Charge

The proton has a single positive charge, *e.*

The electron has a single negative charge, - *e.*

- $e = 1.6 \times 10^{-19}$ C

The neutron has no charge.

Mass

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

- 1 u = 1.660 539 x 10^{-27} kg
- Based on definition that the mass of one atom of ^{12}C is exactly 12 u

Mass can also be expressed in MeV/c^2.

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

Masses of Selected Particles in Various Units

Particle	Mass kg	u	MeV/c^2
Proton	$1.672\,62 \times 10^{-27}$	1.007 276	938.28
Neutron	$1.674\,93 \times 10^{-27}$	1.008 665	939.57
Electron	$9.109\,39 \times 10^{-31}$	$5.485\,79 \times 10^{-4}$	0.510 999
^1_1H atom	$1.673\,53 \times 10^{-27}$	1.007 825	938.783
^4_2He nucleus	$6.644\,66 \times 10^{-27}$	4.001 506	3 727.38
$^{12}_6C$ atom	$1.992\,65 \times 10^{-27}$	12.000 000	11 177.9

Size of Nucleus

Rutherford concluded that the positive charge of the atom was concentrated in a sphere whose radius was no larger than about 10^{-14} m.

- He called this sphere the nucleus.

These small lengths are often expressed in femtometers (fm) where 1 fm = 10^{-15} m. Also called a fermi

Since the time of Rutherford, many other experiments have concluded the following:

- Most nuclei are approximately spherical.
- Average radius is $r = a\,A^{1/3}$
  - a = 1.2 x 10^{-15} m
  - A is the mass number

There are very large repulsive electrostatic forces between protons.

- These forces should cause the nucleus to fly apart.

The nuclei are stable because of the presence of another, short-range force, called the **nuclear force.**

Binding Energy

The total energy of the bound system (the nucleus) is less than the combined energy of the separated nucleons.

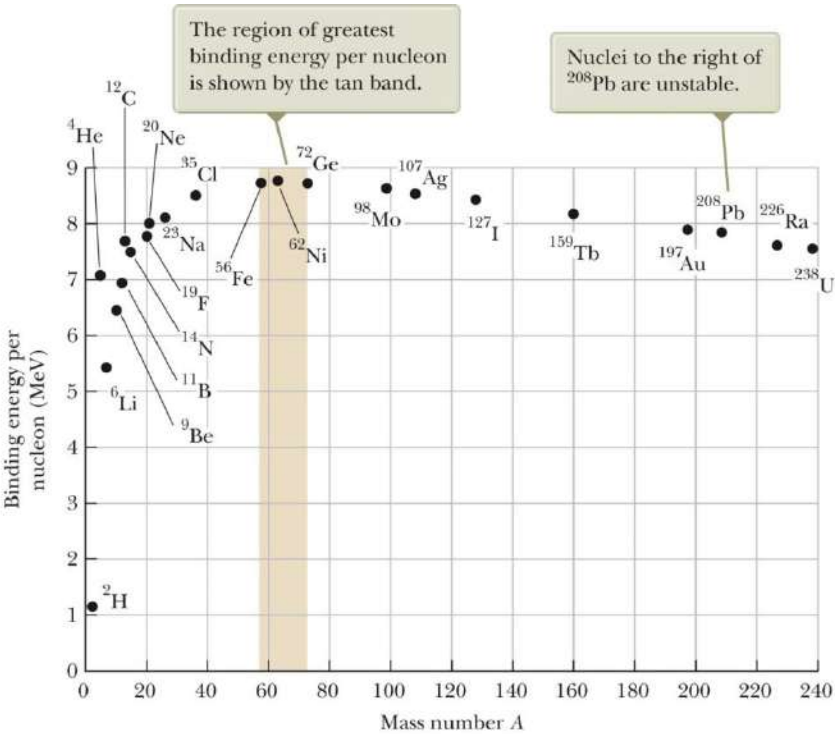
- This difference in energy is called the **binding energy** of the nucleus.
  - It can be thought of as the amount of energy you need to add to the nucleus to break it apart into its components.

The binding energy can be calculated from conservation of energy and the Einstein mass-energy equivalence principle:

$E_b = [Zm_p + NM_n – M(^A_Z X)] \times 931.494$ MeV/u

- M_p is the mass of the proton
- $M(^A_Z X)$ represents the atomic mass of an atom of the isotope $(^A_Z X)$
- M_n is the mass of the neutron

- The masses are expressed in atomic mass units and E_b will be in MeV.



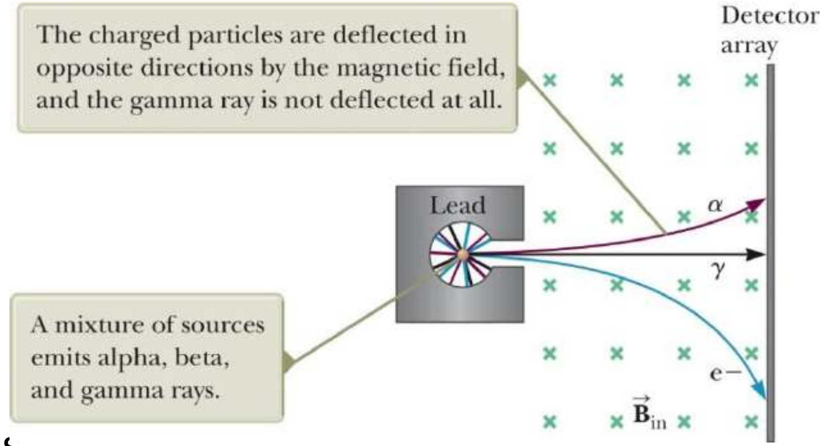
Radioactivity

Radioactivity is the spontaneous emission of radiation.

- Discovered by Becquerel in 1896

Experiments suggested that radioactivity was the result of the decay, or disintegration, of unstable nuclei.

Three types of radiation can be emitted.



- **Alpha particles**
  - The particles are ^{4}He nuclei.
  - Barely penetrate a piece of paper
- **Beta particles**
  - The particles are either electrons or positrons.
    - A **positron** is the antiparticle of the electron.
    - It is similar to the electron except its charge is +e.
    - Can penetrate a few mm of aluminum
- **Gamma rays**
  - The “rays” are high energy photons.
  - Can penetrate several cm of lead

The Decay Constant

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

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

- λ is called the **decay constant** and determines the probability of decay per nucleus per second.
- N is the number of undecayed radioactive nuclei present.
- N_o is the number of undecayed nuclei at time t = 0.

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

$$R = \left|\frac{dN}{dt}\right| = \lambda N = R_o e^{-\lambda t}$$

- $R_o = N_o\lambda$ is the decay rate at t = 0.
- The decay rate is often referred to as the activity of the sample.

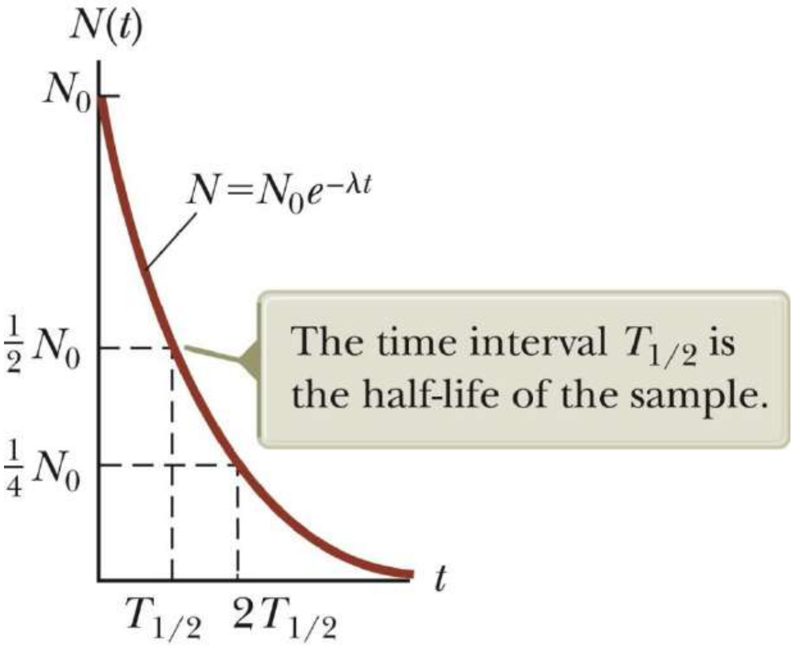
Decay Curve and Half-Life

The decay curve follows the equation $N = N_o e^{-\lambda t}$

The **half-life** is also a useful parameter.

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

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



During the first half-life, ½ of the original material will decay.

During the second half-life, ½ of the remaining material will decay, leaving ¼ of the original material remaining.

Summarizing, the number of undecayed radioactive nuclei remaining after *n* half-lives is $N = N_o (½)^n$

- *n* can be an integer or a noninteger.

Units

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

- 1 Ci ≡ 3.7×10^{10} decays/s

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

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

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

Marie Curie [1867 – 1934] Polish scientist

Shared Nobel Prize in Physics in 1903 for studies in radioactive substances

- Shared with Pierre Curie and Becquerel

Won Nobel Prize in Chemistry in 1911 for discovery of radium and polonium

Natural Radioactivity

Unstable nuclei found in nature. They give rise to ***natural radioactivity.*** Three series of natural radioactivity exist.

- Uranium, Actinium, Thorium

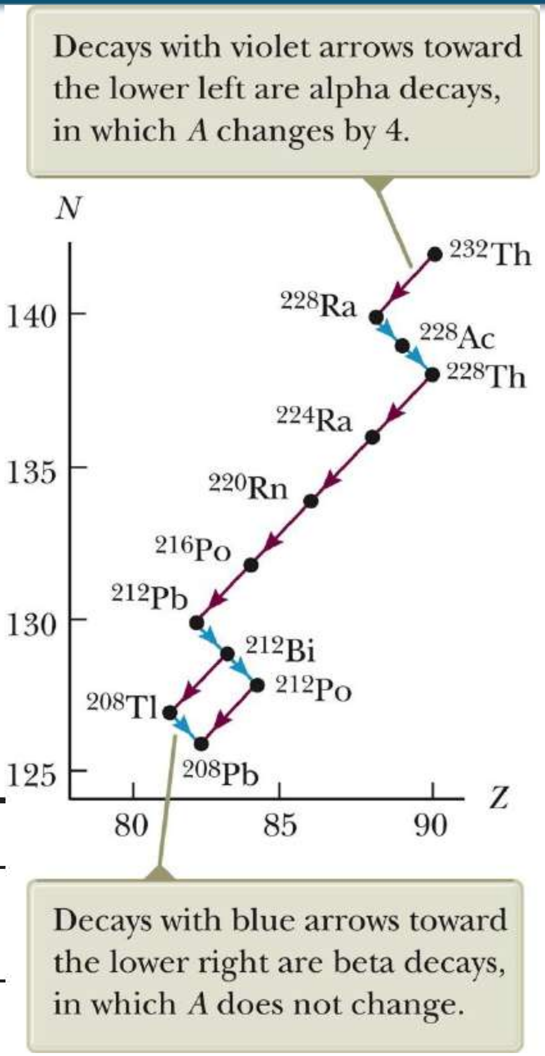
Nuclei produced in the laboratory through nuclear reactions. They exhibit ***artificial radioactivity***

Some radioactive isotopes are not part of any decay series.

Decay Series of ^{232}Th:

Processes through a series of alpha and beta decays

Series starts with ^{232}Th, branches at ^{212}Bi, Ends with a stable isotope of lead, ^{208}Pb



The Four Radioactive Series

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

Example: The Activity of Carbon

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

(A) Determine the number N_0 of nuclei in the sample at t =0.

The molar mass of $^{11}_{6}C$ is approximately 11.0 g/mol.

$$n = \frac{3.50 \times 10^{-6}\text{ g}}{11.0\text{ g/mol}} = 3.18 \times 10^{-7}\text{ mol}$$

$$N_0 = 3.18 \times 10^{-7}\text{ mol}(6.02 \times 10^{23}\text{ nuclei/mol}) = 1.92 \times 10^{17}\text{ nuclei}$$

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

$$\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{20.4\text{ min}}\left(\frac{1\text{ min}}{60\text{ s}}\right) = 5.66 \times 10^{-4}\text{ s}^{-1}$$

$$R_0 = \lambda N_0 = (5.66 \times 10^{-4}\text{ s}^{-1})(1.92 \times 10^{17}) = 1.08 \times 10^{14}\text{ Bq}$$

$$R = R_0 e^{-\lambda t} = (1.08 \times 10^{14}\text{ Bq})e^{-(5.66\times10^{-4}\text{ s}^{-1})(2.88\times10^{4}\text{ s})} = 8.96 \times 10^{6}\text{ Bq}$$

Example: Radioactive Dating

A piece of charcoal containing 25.0 g of carbon is found in some ruins of an ancient city. The sample shows a ^{14}C activity R of 250 decays/min. How long has the tree from which this charcoal came been dead? the ratio of ^{14}C to ^{12}C in the live sample was 1.3×10^{12}

$$\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{(5\,730\text{ yr})(3.16 \times 10^{7}\text{ s/yr})} = 3.83 \times 10^{-12}\text{ s}^{-1}$$

1- Calculate the number of moles in 25.0 g of carbon:

$$n = \frac{25.0\text{ g}}{12.0\text{ g/mol}} = 2.083\text{ mol}$$

2- Find the number of ^{12}C nuclei and find the number of 14C nuclei *before* decay

$$N(^{12}\text{C}) = 2.083\text{ mol}(6.02 \times 10^{23}\text{ nuclei/mol}) = 1.25 \times 10^{24}\text{ nuclei}$$

$$N_0(^{14}\text{C}) = (1.3 \times 10^{-12})(1.25 \times 10^{24}) = 1.63 \times 10^{12}\text{ nuclei}$$

3-Find the initial activity of the sample:

$$R_0 = \lambda N_0 = (3.83 \times 10^{-12}\text{ s}^{-1})(1.63 \times 10^{12}\text{ nuclei}) = 6.24\text{ decays/s} = 374\text{ decays/min}$$

4- Evaluate *t*

$$e^{-\lambda t} = \frac{R}{R_0} \quad \rightarrow \quad -\lambda t = \ln\left(\frac{R}{R_0}\right) \quad \rightarrow \quad t = -\frac{1}{\lambda}\ln\left(\frac{R}{R_0}\right)$$

$$t = -\frac{1}{3.83 \times 10^{-12}\text{ s}^{-1}} \ln\left(\frac{250\text{ min}^{-1}}{374\text{ min}^{-1}}\right) = 1.06 \times 10^{11}\text{ s} = 3.3 \times 10^{3}\text{ yr}$$

Exposure

The act or condition of being subject to irradiation. Exposure can be either

External exposure (irradiation by sources outside the body)

Internal exposure (irradiation by sources inside the body).

Exposure can be classified as either normal exposure or potential exposure; either occupational, medical or public exposure; and, in intervention situations, either emergency exposure or chronic exposure. The term exposure is also used in radiodosimetry to express the amount of ionization produced in air by ionizing radiation.

The process of taking radionuclides into the body by inhalation or ingestion or through the skin.

There are several possible routes of intake of radio nuclides into the body, intake by:

Ingestion, inhalation, injection uptake by wounds, uptake through intact skin

Radiation Damage

Radiation absorbed by matter can cause damage.

The degree and type of damage depend on many factors.

- Type and energy of the radiation
- Properties of the matter

Radiation damage in the metals used in the reactors comes from neutron bombardment.

- They can be weakened by high fluxes of energetic neutrons producing metal fatigue.
- The damage is in the form of atomic displacements, often resulting in major changes in the properties of the material.

Radiation damage in biological organisms is primarily due to ionization effects in cells.

- Ionization disrupts the normal functioning of the cell.

Types of Damage in Cells

Somatic damage is radiation damage to any cells except reproductive ones.

- Can lead to cancer at high radiation levels
- Can seriously alter the characteristics of specific organisms

Genetic damage affects only reproductive cells.

- Can lead to defective offspring

Damage Dependence on Penetration

Damage caused by radiation also depends on the radiation's penetrating power.

- Alpha particles cause extensive damage, but penetrate only to a shallow depth.
  - Due to their charge, they will have a strong interaction with other charged particles.
- Neutrons do not interact with material and so penetrate deeper, causing significant damage.
- Gamma rays can cause severe damage, but often pass through the material without interaction.

Dose

A measure of the radiation received or 'absorbed' by a target. The quantities termed absorbed dose, organ dose, equivalent dose, effective dose, committed equivalent dose or committed effective dose are used, depending on the context. The modifying terms are often omitted when they are not necessary for defining the quantity of interest

Dose limit

The value of the effective dose or the equivalent dose to individuals from controlled practices that shall not be exceeded.

Units of Radiation Exposure

The **roentgen** (R) is defined as

- That amount of ionizing radiation that produces an electric charge of 3.33×10^{-10} C in 1 cm^3 of air under standard conditions.
- Equivalently, that amount of radiation that increases the energy of 1 kg of air by 8.76×10^{-3} J .

One **rad** (radiation absorbed dose)

- That amount of radiation that increases the energy of 1 kg of absorbing material by 1×10^{-2} J.

The **RBE** (relative biological effectiveness)

- The number of rads of x-radiation or gamma radiation that produces the same biological damage as 1 rad of the radiation being used.
- Accounts for type of particle which the rad itself does not

The **rem** (radiation equivalent in man)

- Defined as the product of the dose in rad and the RBE factor
  - Dose in rem = dose in rad x RBE

Radiation Levels

Natural sources – rocks and soil, cosmic rays

- Called *background radiation.* It is about 0.13 rem/yr

Upper limit suggested by US government is 0.50 rem/yr

Occupational:

- 5 rem/yr for whole-body radiation
- Certain body parts can withstand higher levels
- Ingestion or inhalation is most dangerous
- About 50% of the people exposed to a dose of 400 to 500 rem will die.

New SI units of radiation dosages: the ***gray*** **(Gy)** and the ***sievert*** **(Sv).**

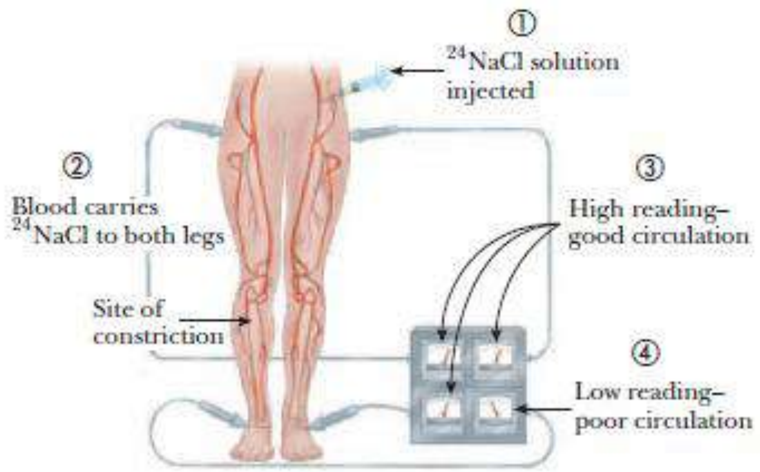
Units for Radiation Dosage

Quantity	SI Unit	Symbol	Relation to Other SI units	Older Unit	Conversion
Absorbed dose	gray	Gy	= 1 J/kg	rad	1 Gy = 100 rad
Dose equivalent	sievert	Sv	= 1 J/kg	rem	1 Sv = 100 rem

Applications of Radiation

Tracing

- Radioactive particles can be used to trace chemicals participating in various reactions.
  - Example, ^{131}I to test thyroid action
  - Also to analyze circulatory system
  - Also useful in agriculture and other applications



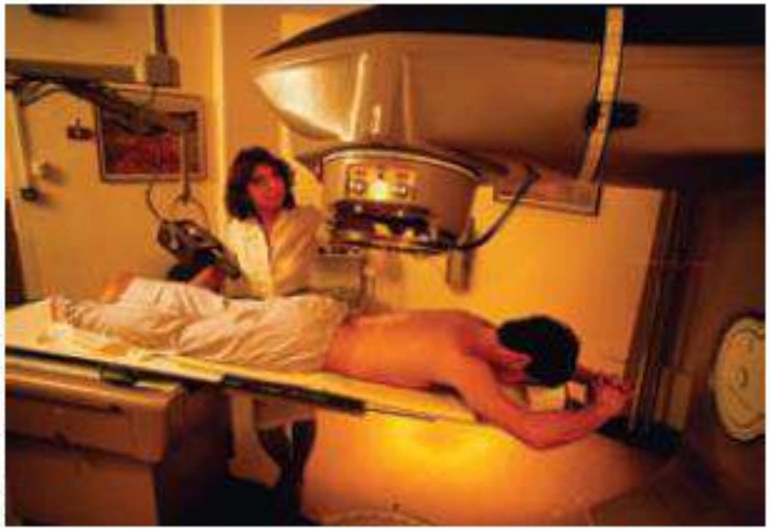
Materials analysis

- *Neutron activation analysis* uses the fact that when a material is irradiated with neutrons, nuclei in the material absorb the neutrons and are changed to different isotopes.

Applications of Radiation

Radiation therapy

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



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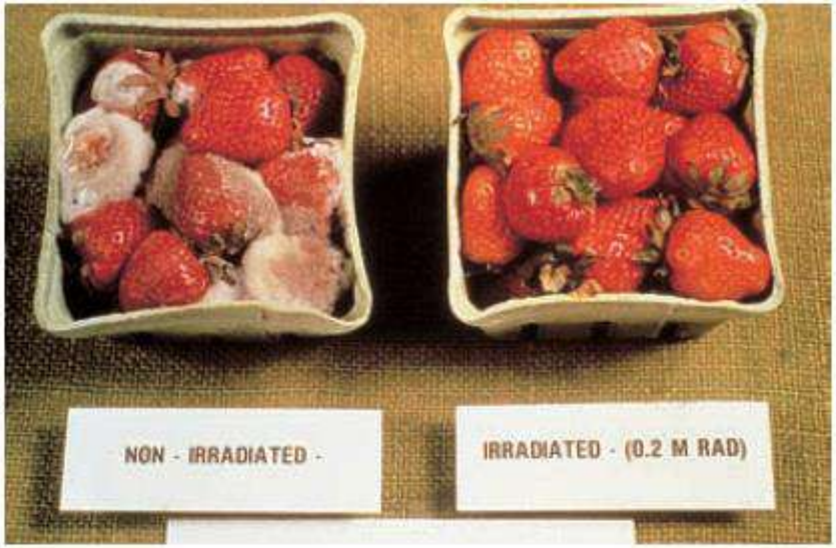
Food preservation

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



Council for Agricultural Science & Technology

X-Rays

Properties of x-rays

The X-rays are a form of electromagnetic radiation similar to radio waves, microwaves, visible light and gamma rays.

X-ray photons are highly energetic and have enough energy to break up molecules and hence damage living cells.

When x-rays hit a material some are absorbed and others pass through.

Generally, the higher the energy the more x-rays will pass through. This is what gives x-rays the power to "see inside" things.

X-rays cannot be steered by electric and magnetic fields like alpha, beta and other charged particles.

Production of X-rays

X-ray production whenever electrons of high energy strike a heavy metal target, like tungsten or copper. When electrons hit this material, some of the electrons will approach the nucleus of the metal atoms where they are deflected because of there opposite charges (electrons are negative and the nucleus is positive, so the electrons are attracted to the nucleus). This deflection causes the energy of the electron to decrease, and this decrease in energy then results in forming an x-ray.

Absorption of X-rays occurs when x-rays pass through materials due to energy loss by: photo electric effect, Compton Scattering, Pair Production.

Attenuation of X-rays: intensity reduces with distance

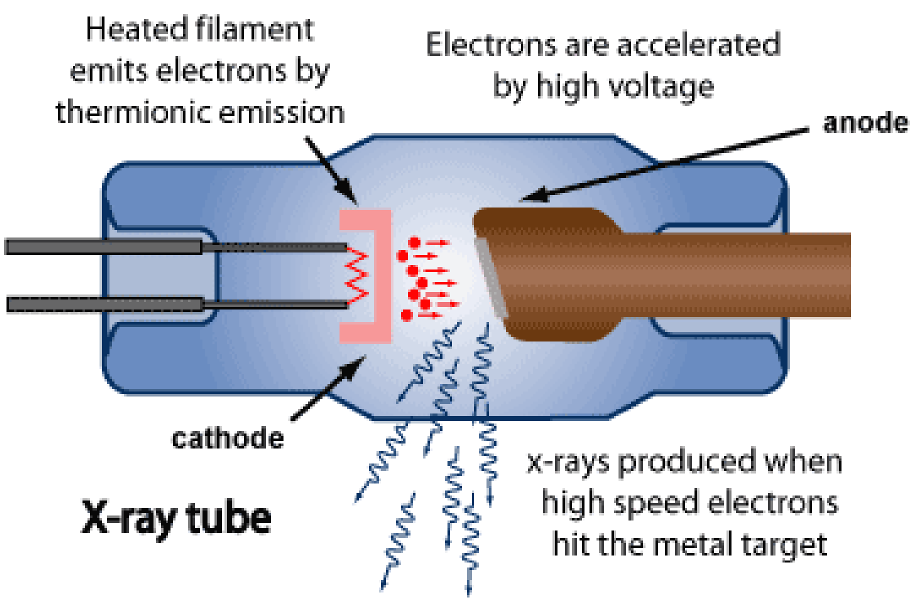
$I = I_0 e^{-\mu x}$

I is the photon intensity of x-rays at depth x from the surface.

I_0 is the initial intensity of x-ray.

x is the depth of x-rays from the surface.

μ is the absorption coefficient



Uses of X-rays

1- diagnosis 2- treatment of cancers (radiotherapy) with high energy X-rays.

X-ray workers…

1) wear a film badge to check the amount of radiation they get.

2) wear lead aprons while the machine is in use.

3) verify that the machine is in an enclosed room and the controls are in a separate room.

4) ensure that that there is no entry into the X-ray room while the machine is in use.

Dangers of X-rays

1- water ionises to produce free radicals which produce H_2O_2

2- enzymes & DNA are damaged

3- parts of cells are damaged

4- cell division is damaged (→ mutations)

5- tissue & organ damage

6- life expectancy shortens

7- mutations cause gene alterations in populations

Lasers

The word **LASER** is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. The technological and research applications of lasers are due to the unique properties of laser light.

Properties of Laser Light

This lab consists of a series of experiments which will familiarize you with these unique properties of laser light namely, that laser light is

- ✓ bright (intense),
- ✓ of one color (monochromatic),
- ✓ directional (collimated) and in phase (coherent).
- ✓ has a small angle of divergence, even over long distances.

Lasers – Operation

It is equally probable that an incident photon would cause atomic transitions upward or downward. (Stimulated absorption or stimulated emission)

If a situation can be caused where there are more electrons in excited states than in the ground state, a net emission of photons can result.

- This condition is called *population inversion.*

The photons can stimulate other atoms to emit photons in a chain of similar processes.

The many photons produced in this manner are the source of the intense, coherent light in a laser.

Conditions for Build-Up of Photons

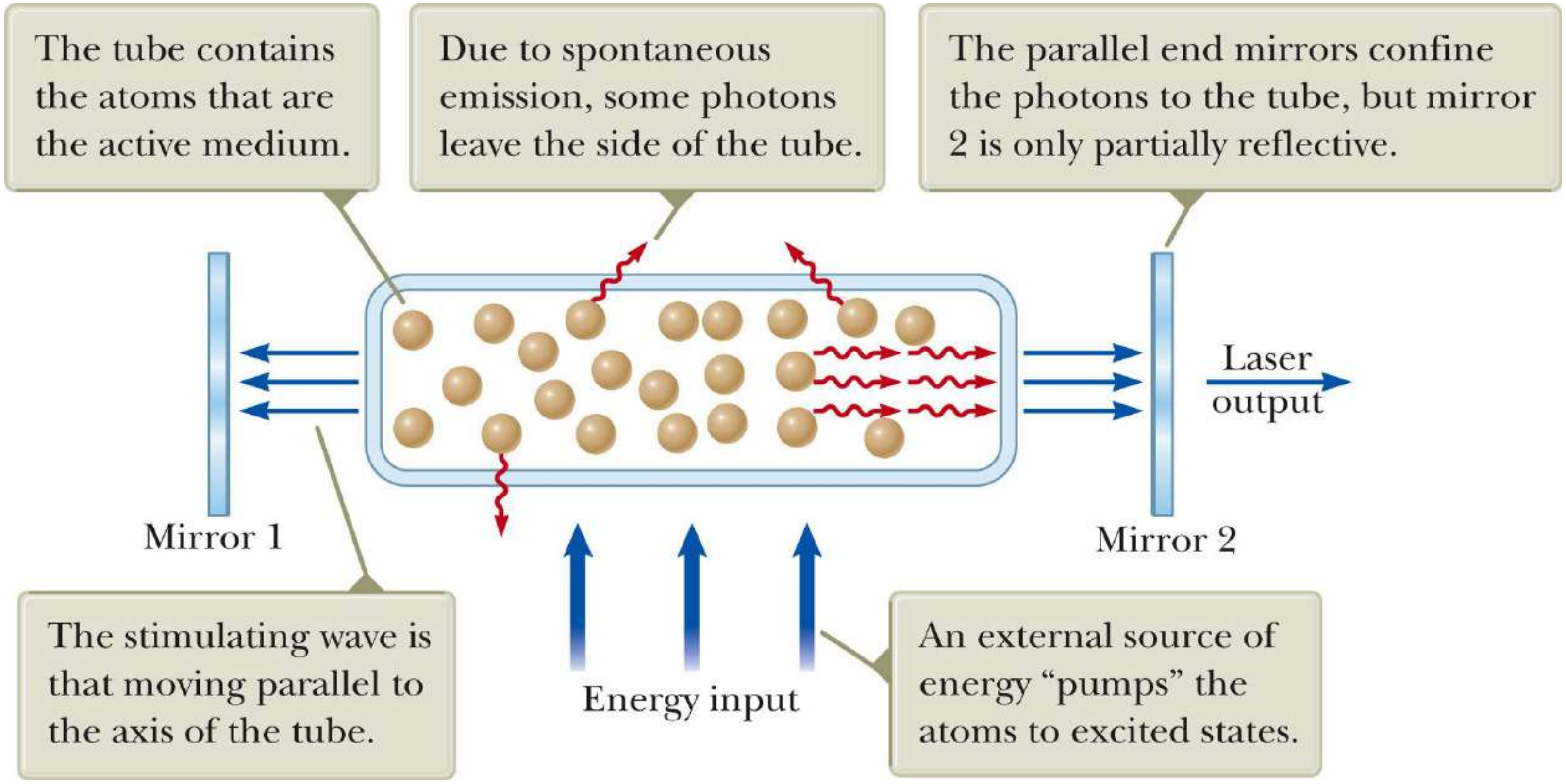
The system must be in a state of population inversion.

The excited state of the system must be a metastable state.

- In this case, the population inversion can be established and stimulated emission is likely to occur before spontaneous emission.

The emitted photons must be confined in the system long enough to enable them to stimulate further emission. This is achieved by using reflecting mirrors.

Laser Design – Schematic

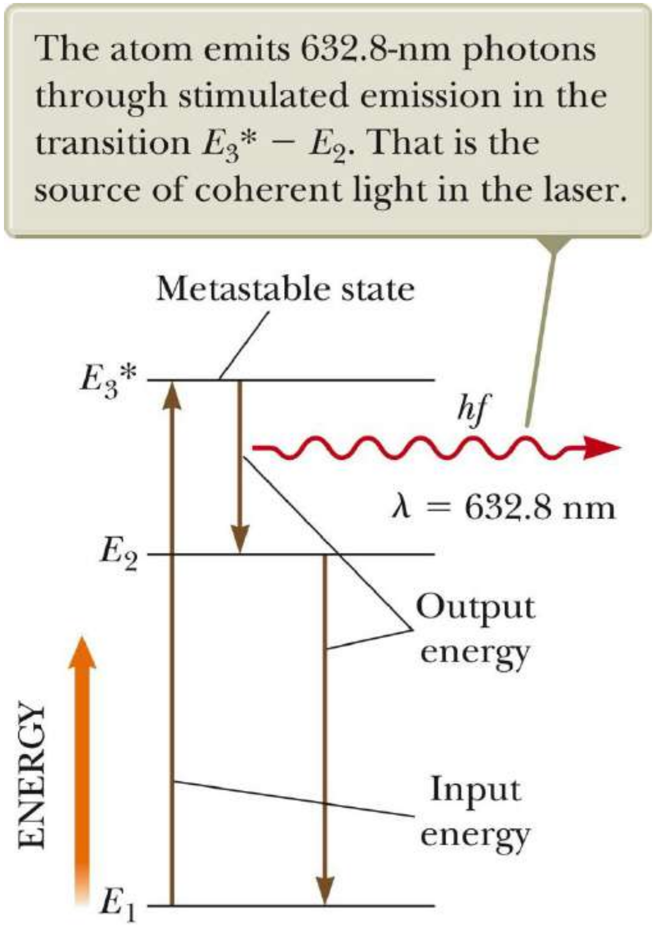


Energy-Level Diagram for Neon in a Helium-Neon Laser

The atoms emit 632.8-nm photons through stimulated emission.

The transition is E_3* to E_2

- * indicates a metastable state



Laser Applications

Applications include:

- Medical and surgical procedures, it does less damage to normal tissues.
- Precision surveying and length measurements
- Precision cutting of metals and other materials
- Telephone communications
- Biological and medical research

Nuclear Magnetic Resonance (NMR)

A nucleus has spin angular momentum.

Shown is a vector model giving possible orientations of the spin and its projection on the *z* axis.

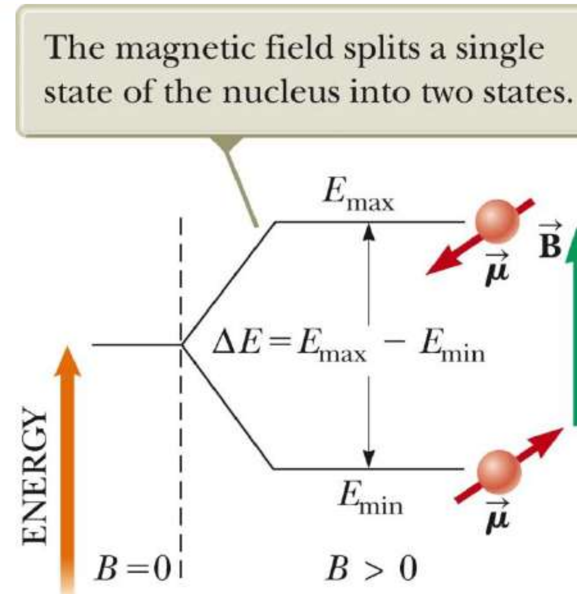
The magnitude of the spin angular momentum is

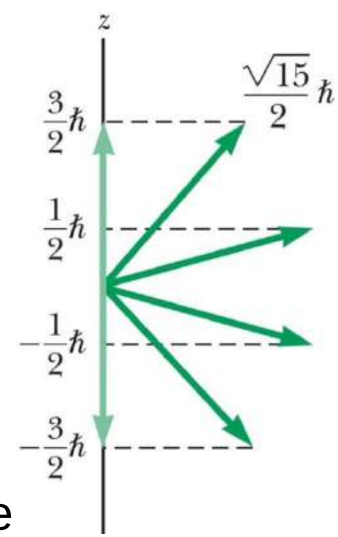
$$\sqrt{I\,(I+1)}\hbar$$

I is the nuclear spin quantum number.

For a nucleus with spin ½, there are only two allowed states E_{max} and E_{min}

It is possible to observe transitions between two spin states using NMR.





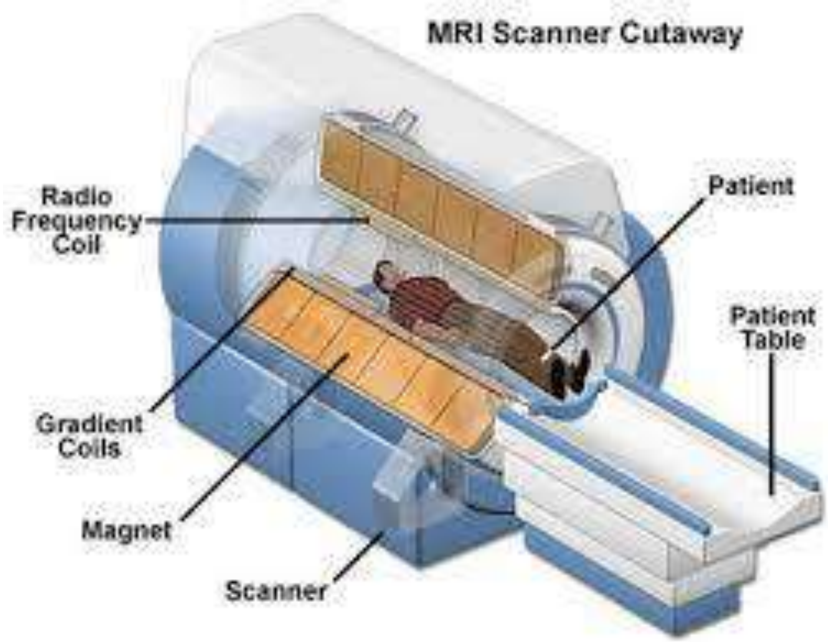
MRI

An MRI (Magnetic Resonance Imaging) is based on NMR.

Because of variations in an external field, hydrogen atoms in different parts of the body have different energy splittings between spin states. The resonance signal can provide information about the positions of the protons.

Magnetic Resonance Imaging (MRI)

MRI scanning uses magnetism, radio waves, and a computer to produce images of body structures.

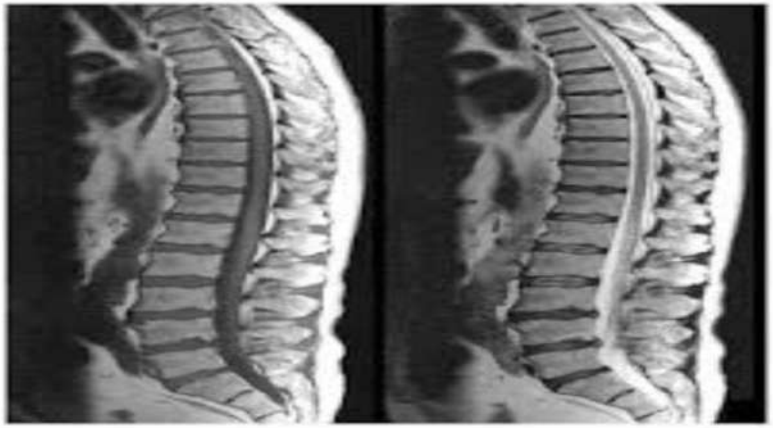


MRI scanning is painless and does not involve x-ray radiation.

Patients with heart pacemakers, metal implants, or metal chips or clips in or around the eyes cannot be scanned with MRI because of the effect of the magnet.

Claustrophobic sensation can occur with MRI scanning.

Example: As in figure, pictures of an MRI of the spine. This patient had a herniated disc between vertebrae L4 and L5. The resulting surgery was a discectomy.



CT Scan

A computerized tomography (CT) scan combines a series of X-ray images taken from different angles around your body and uses computer processing to create cross-sectional images (slices) of the bones, blood vessels and soft tissues inside your body. CT scan images provide more-detailed information than plain X-rays do.

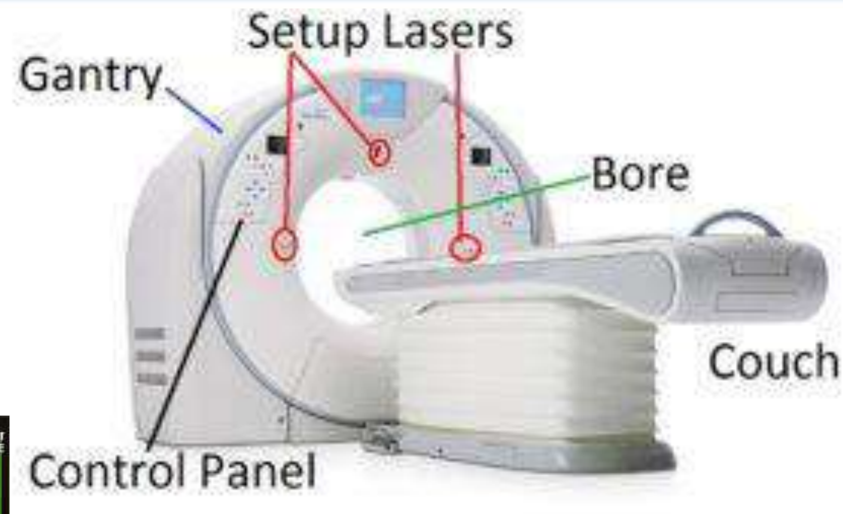
A CT scan uses x-ray technology to create detailed images of the body and inner body structures.

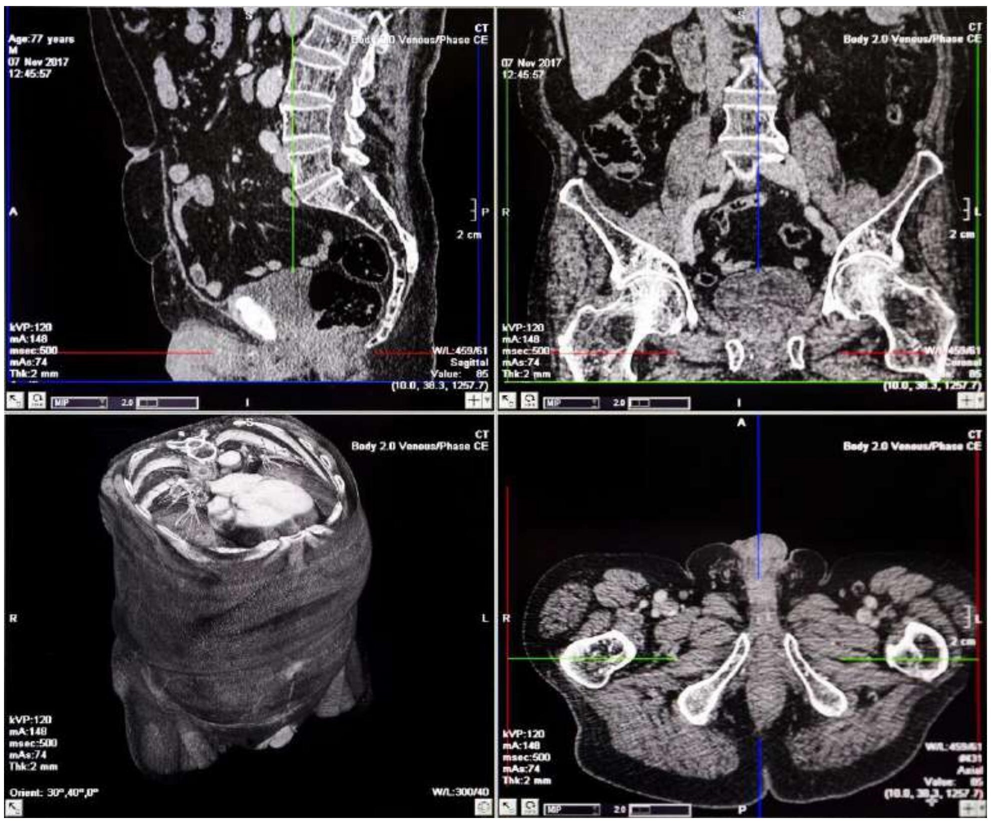
CT scans usually take about five to ten minutes to complete and are generally less expensive than other types of diagnostic scans like MRIs or PET scans.

CT scans expose the body to a moderate amount of radiation and are therefore not recommended for children or pregnant women unless absolutely necessary.

CT scans are quick, painless, and completely noninvasive. Your doctor may order a CT scan after an injury or to diagnose a potential illness.

CT Scan





PET Scan

A positron emission tomography (PET) scan is an imaging test that allows your doctor to check for diseases in your body.

PET scans are most commonly used to detect cancers, heart problems, brain disorders, and problems with the nervous system.

PET scans utilize for detecting disease on the cellular and molecular level.

PET scans work by injecting a tiny amount of radioactive tracers into the bloodstream, which the PET scan machine can then detect and analyze via 3D images.

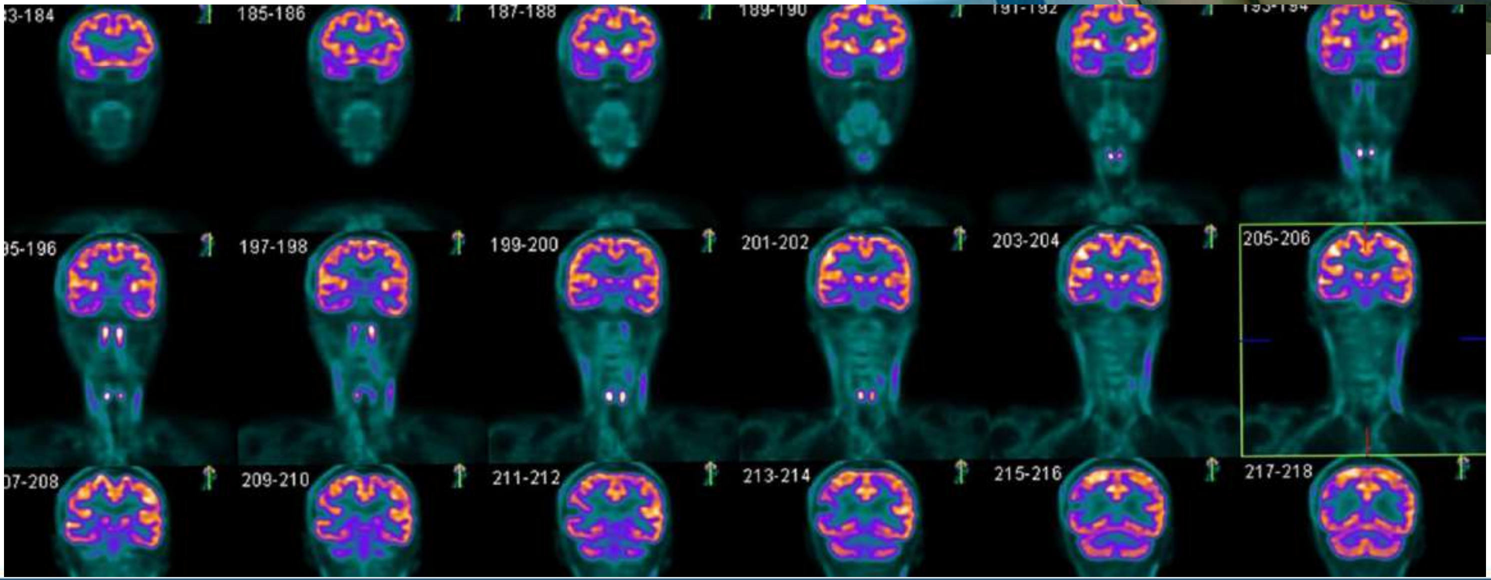
PET scans take between 2-4 hours to complete, and are significantly more expensive than CT scans.

The radiation exposure of a PET scan is about the same as an x-ray.

PET scans are excellent at analyzing the biological processes of the body and at detecting pathology such as cancer at the very earliest stages.

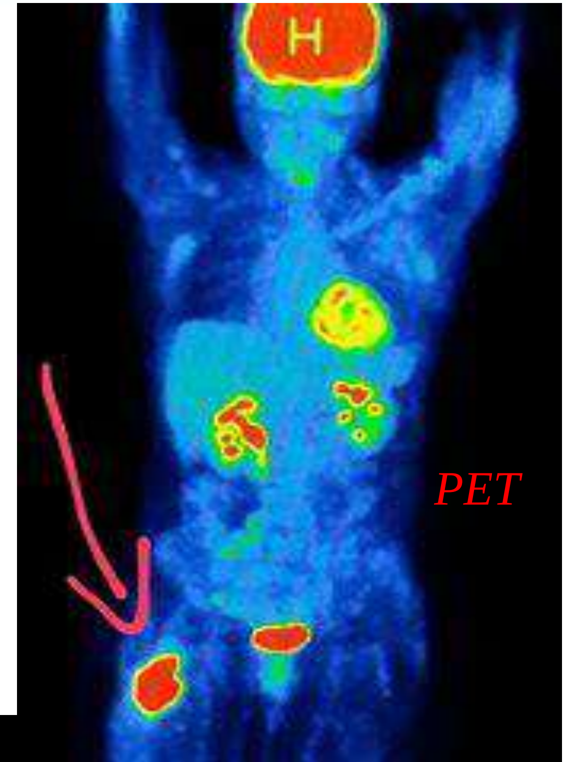
Example:

Brain PET Scan




x-ray


MRI


PET


Ultra sound


CT

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