



Medical Physics

Lec.1: Units Conversion, Coordinate Systems & Scalar Quantity

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Learning Outcomes

By the end of this Lecture the student will be able to:

- ✓ Use the British Units and conversions to SI Units
- ✓ Define the coordinate systems
- ✓ Define the Cartesian coordinate system
- ✓ Define the Polar coordinate system
- ✓ Understand the meaning of scalar quantity

What is Physics?

- ❑ Fundamental Science that Concerned with the fundamental principles of the Universe.
- ❑ Foundation of other physical sciences.
- ❑ Has simplicity of fundamental concepts.
- ❑ **Divided into six major areas:**
 1. Classical Mechanics
 2. Relativity
 3. Thermodynamics
 4. Electromagnetism
 5. Optics
 6. Quantum Mechanics

What is Medical Physics?

- ❑ **Medical Physics** is defined as the application of physics to the needs of medicine.
- ❑ The **Aims of the Medical physics** is the Application of the concepts and methods of physics to understanding the function of human body in health and disease.
- ❑ The **directions of medical physics** are: **Physics of the body**, **Application of physics in medicine**.
- ❑ **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.

What is Medical Physics?

□ Application of physics in medicine: Medical physics

Techniques are used for:

1. 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.

What is Medical Physics?

□ Application of physics in medicine: Medical physics

Techniques are used for:

2. Therapy:

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

3. Patient monitoring:

- ECG,
- Spirometer,
- Blood pressure, and
- Thermometer

What is Measurements?

- ❑ **Measurements** Used to describe natural phenomena.
- ❑ Each measurement is associated with a physical quantity.
- ❑ 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



**Why we need to
know units system
and their
conversion?**

The Greek alphabet

A, α	alpha	H, η	eta	N, ν	nu	T, τ	tau
B, β	beta	Θ, θ	theta	Ξ, ξ	xi	Y, υ	upsilon
Γ, γ	gamma	I, ι	iota	O, o	omicron	Φ, ϕ, φ	phi
Δ, δ	delta	K, κ	kappa	Π, π	pi	X, χ	chi
E, ε, ϵ	epsilon	Λ, λ	lambda	P, ρ, ϱ	rho	Ψ, ψ	psi
Z, ζ	zeta	M, μ	mu	$\Sigma, \sigma, \varsigma$	sigma	Ω, ω	omega

Unit Prefixes

1 $\mu\text{m} = 10^{-6}$ m (size of some bacteria and living cells)

1 km = 10^3 m (a 10-minute walk)

1 $\mu\text{g} = 10^{-6}$ g (mass of a grain of salt)

1 g = 10^{-3} kg (mass of a paper clip)

1 ns = 10^{-9} s (time for light to travel 0.3 m)





Standards and Units

- 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.
- **Length**, **time**, and **mass** are three **fundamental** quantities of physics.
- The **International System** (SI for **Système International**) is the most widely used system of units.
- In SI units, **length** is measured in **meters**, **time** in **seconds**, and **mass** in **kilograms**.

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)



Standards and Units

- 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:
 - $1 \text{ mm} = 10^{-3} \text{ m}$
 - $1 \text{ mg} = 10^{-3} \text{ g}$

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			



The British system of units

◇ These units (also called **British Imperial system of units**) are used only in the United States, India, Malaysia, Sri Lanka, Hong Kong, and some Caribbean islands.

◇ **British units** are now officially defined in terms of SI units as follow:

- Length: 1 inch = 2.54 cm
- Force: 1 pound = 4.448221615260 newton's

Imperial System

An old British system of measuring units including inch, foot, yard, mile, ounce, pound, gill, pint, and gallon.

LENGTH

1 inch = 2.54 cm
1 foot = 30.48 cm
1 mile = 1.609 km

AREA

1 sq. foot = 0.0929 sq. m
1 rood = 1,011.7 sq. m
1 acre = 0.4047 hectare

VOLUME

1 fluid ounce = 28.4 ml
1 pint = 0.568 l
1 gallon = 4.546 l

WEIGHT

1 ounce = 28.349 gm
1 pound = 0.453 kg
1 stone = 6.350 kg



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]

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

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}	MLT^{-2}
energy (or work)	Joule J N m, $\text{kg m}^2/\text{s}^2$	$\text{kg m}^2\text{s}^{-2}$	ML^2T^{-2}
power	Watt W N m/s $\text{kg m}^2/\text{s}^3$	Nms^{-1} $\text{kg m}^2\text{s}^{-3}$	ML^2T^{-3}
pressure (or stress)	Pascal P, N/m^2 , kg/m/s^2	Nm^{-2} $\text{kg m}^{-1}\text{s}^{-2}$	$\text{ML}^{-1}\text{T}^{-2}$
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.
- 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.

Example: Given the equation: $x = \frac{1}{2} at^2$ 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.



Unit Consistency and Conversions

- Any equation **must be dimensionally consistent**.
- Terms to be added **or** equated **must always** have the same units.
- **Always** carry units through calculations.
- **Convert to standard units**, by forming a ratio of the same physical quantity in two different units, and multiply.
- **For example**, to find the number of seconds in 3 min, **we write**:

$$3 \text{ min} = (3 \cancel{\text{ min}}) \left(\frac{60 \text{ s}}{1 \cancel{\text{ min}}} \right) = 180 \text{ s}$$



Conversion of Units

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

$$15.0 \text{ in} = ? \text{ cm}$$

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

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



Unit Conversion

- ◇ We **often need to** change the units in which a physical quantity is expressed.
- ◇ We do so by a **method called chain-link conversion.**
- ◇ **In this method** we multiple the original value by a conversion factor (a ratio of units that is equal to unity).
- ◇ **For example**, $1 \text{ min} = 60 \text{ s}$, then $(1 \text{ min}/60 \text{ s}) = 1$ as well as $(60 \text{ s}/1 \text{ min}) = 1$



Unit Conversion

Example: Let's find number of minutes in 150 seconds:

Answer: $150s = 150s \times 1 = 150s \times (1 \text{ min} / 60 \text{ s}) = 2.5 \text{ min}$

Example: The top speed is 130 km/h of a vehicle, express this speed in meters per second?

Answer: since 1 mile = 1.609 km = 1609 m, 1 km = 1000 m,
1 h = 3600 s.

$$130 \text{ km/h} = \left(\frac{130 \text{ km}}{1 \text{ h}} \right) \left(\frac{1000 \text{ m}}{1 \text{ km}} \right) \left(\frac{1 \text{ h}}{3600 \text{ s}} \right) = 36.1 \text{ m/s}$$



Unit Conversion

Example: How many square centimeters in a square meter? (Note that $1 \text{ m} = 100 \text{ cm}$)

Answer:

$$1 \text{ m}^2 = (1 \text{ m})^2 = \left[1 \text{ m} \left(\frac{100 \text{ cm}}{1 \text{ m}} \right) \right]^2 = [100 \text{ cm}]^2 = 10,000 \text{ cm}^2$$

Length

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

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

$$1 \text{ ft} = 0.3048 \text{ m}$$

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

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

$$1 \text{ yd} = 0.9144 \text{ m}$$

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

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

$$1 \text{ mi} = 5280 \text{ ft}$$

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

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

Area

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

$$1 \text{ ft}^2 = 0.0929 \text{ m}^2 = 144 \text{ in.}^2$$

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

Volume

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

$$1 \text{ ft}^3 = 1728 \text{ in.}^3 = 2.83 \times 10^{-2} \text{ m}^3$$

$$1 \text{ L} = 1000 \text{ cm}^3 = 1.0576 \text{ qt} = 0.0353 \text{ ft}^3$$

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

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

Mass

$$1000 \text{ kg} = 1 \text{ t (metric ton)}$$

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

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

Force

$$1 \text{ N} = 0.2248 \text{ lb}$$

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

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

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

$$1 \text{ ft/s}^2 = 0.3048 \text{ m/s}^2 = 30.48 \text{ cm/s}^2$$

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

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

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

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

PERCENTAGE ERROR & DEGREE OF ACCURACY

Percent error is the difference between an estimated value and the true or exact value, expressed in percentage.

$$\text{Percentage error} = \frac{|\text{Approximate value} - \text{Exact value}|}{|\text{Exact value}|} \times 100\%$$

PERCENTAGE ERROR & DEGREE OF ACCURACY

Example:

If a student measured the temperature of boiling water to be 98.5°C, the percentage error is:

$$\text{Percentage error} = \frac{|98.5 - 100|}{|100|} \times 100\% = \frac{1.5}{100} \times 100\% = 1.5\%$$

The degree of accuracy & Absolute error

- ❑ **Degree of accuracy** is a measure of how exact a stated value is to the actual value being described.
- ❑ Accuracy may be affected by rounding, the use of significant figures or ranges in measurement.
- ❑ **Absolute error** is the difference between the actual and the measured value (symbol \pm).

$$\text{Relative error} = \frac{|\text{absolute error}|}{\text{measured value}}$$

$$\text{Percentage error} = \frac{\text{absolute error}}{\text{measured value}} \times 100\%$$

PERCENTAGE ERROR & DEGREE OF ACCURACY

Example:

A truck is measured as 22.5 meters long, accurate to 0.1 of a meter.

Accurate to 0.1 m means it could be up to $\frac{0.1}{2} = 0.05$ m either way:

Length = 22.5 ± 0.05 m

So it could really be anywhere between 22.45 m and 22.55 m long.

Thus

Absolute error = 0.05

$$\text{Percentage error} = \frac{0.05}{22.5} \times 100\% \\ \cong 0.2\%$$

INDICES

- **Indices** explain how many copies of the base number are multiplied.

$$a^1 = a$$

$$a^2 = a \times a$$

$$a^n = a \times a \times \dots n \text{ times}$$

- For example, 25 is a power, where 2 is called the **base** and 5 is called the **index** or **exponent**.
- Descartes in 1637 was the first to use this shorthand definition 2^4 for $2 \times 2 \times 2 \times 2$.

Indices satisfy the following rules:

1) where n is *positive whole* number

$$\mathbf{a^n = a \times a \times a \times a \dots n \text{ times}}$$

$$\text{e.g. } 2^3 = 2 \times 2 \times 2 = 8$$

2) Negative powers.....

$$\mathbf{a^{-n} = \frac{1}{a^n}}$$

$$\text{e.g. } \mathbf{a^{-2} = \frac{1}{a^2}}$$

e.g. where $a = 2$

$$2^{-1} = \frac{1}{2} \text{ or } 2^{-2} = \frac{1}{2 \times 2} = \frac{1}{4}$$

Indices satisfy the following rules:

3) A Zero power

$$a^0 = 1$$

e.g. $8^0 = 1$

4) A Fractional power

$$a^{\frac{1}{n}} = \sqrt[n]{a}$$

e.g. $9^{\frac{1}{2}} = \sqrt[2]{9} = \sqrt{9} = 3$

$$8^{\frac{1}{3}} = \sqrt[3]{8} = 2$$

All indices satisfy the following rules

Rule 1

$$a^m \cdot a^n = a^{m+n}$$

e.g. $2^2 \cdot 2^3 = 2^5 = 32$

Rule 2

$$\frac{a^m}{a^n} = a^{m-n}$$

e.g. $\frac{2^3}{2^2} = 2^{3-2} = 2^1 = 2$

All indices satisfy the following rules

note: if $m = n$,

$$\text{then } \frac{a^m}{a^n} = a^{m-n} = a^0 = 1$$

note: $\frac{a^m}{a^{-n}} = a^{m-(-n)} = a^{m+n}$

note: $\frac{a^{-m}}{a^n} = a^{-m-n} = \frac{1}{a^{m+n}}$

All indices satisfy the following rules

Rule 3

$$(a^m)^n = a^{m.n}$$

e.g. $(2^3)^2 = 2^6 = 64$

Rule 4

$$a^n \cdot b^n = (ab)^n$$

e.g. $3^2 \times 4^2 = (3 \times 4)^2 = 12^2 = 144$

Likewise,

$$\frac{a^n}{b^n} = \left(\frac{a}{b}\right)^n \quad \text{if } b \neq 0$$

e.g.

$$\frac{6^2}{3^2} = \left(\frac{6}{3}\right)^2 = 2^2 = 4$$

INDICES

	<i>Laws of Indices</i>	<i>Laws of Logarithm</i>
Zero Exponents	$a^0 = 1$	$\log_a 1 = 0$
Identity	$a^1 = a$	$\log_a a = 1$
Product	$a^m \cdot a^n = a^{m+n}$	$\log_a(m \cdot n) = \log_a(m) + \log_a(n)$
Quotient	$\frac{a^m}{a^n} = a^{m-n}$	$\log_a \frac{m}{n} = \log_a(m) - \log_a(n)$
Negative Exponents	$a^{-n} = \frac{1}{a^n}$	$\log_a \frac{1}{n} = -\log_a n$
Properties of Equality	If $a = b$, $a^n = b^n$	$\log_a(a^n) = n$ or $a^{\log_a(n)} = n$

INDICES

Common Base Property of Equality	If $a^m = a^n$, $m = n$	If $\log_a(m) = \log_a(n)$, then $m = n$
Power	$(a^m)^n = a^{m \cdot n}$	$\log_a(m^n) = n \cdot \log_a(m)$
Power of a Product	$(a \cdot b)^m = a^m b^m$	
Power of a Quotient	$\left(\frac{a}{b}\right)^n = \frac{a^n}{b^n}$	
Rational Exponents	$a^{\frac{m}{n}} = \sqrt[n]{a^m}$	
Change of Base		$\log_a(m) = \frac{\log_x(m)}{\log_x(a)}$

INDICES

Example:

Simplify a) $8^{\frac{2}{3}}$ b) $\sqrt{9^{-3}}$ c) 11^0

SOLUTION tips

$$\begin{aligned} \text{a) } 8^{\frac{2}{3}} &= \left(8^{\frac{1}{3}}\right)^2 \\ &= \left(\sqrt[3]{8}\right)^2 \\ &= (2)^2 = 4 \end{aligned}$$

$$a^{\frac{m}{n}} = \sqrt[n]{a^m}$$

$$\begin{aligned} \text{b) } \sqrt{9^{-3}} &= (\sqrt{9})^{-3} \\ &= \frac{1}{(3)^3} = \frac{1}{27} \\ \text{c) } 11^0 &= 1 \end{aligned}$$

$$\begin{aligned} a^{-n} &= \frac{1}{a^n} \\ a^0 &= 1 \end{aligned}$$

INDICES

Example:
Simplify

a) $(16x^6)^{\frac{1}{2}}$

b) $\left(\frac{3}{4}\right)^{-2}$

c) $30x^5y^4 \div 6xy$

SOLUTION tips

$$\begin{aligned} \text{a) } (16x^6)^{\frac{1}{2}} &= 16^{\frac{1}{2}} \times (x^6)^{\frac{1}{2}} \\ &= 4^{2 \times \frac{1}{2}} \times x^{6 \times \frac{1}{2}} \\ &= 4 \times x^3 = 4x^3 \end{aligned}$$

$$(a^m)^n = a^{m \cdot n}$$

$$\begin{aligned} \text{b) } \left(\frac{3}{4}\right)^{-2} &= \left(\frac{4}{3}\right)^2 \\ &= \frac{4^2}{3^2} = \frac{16}{9} \end{aligned}$$

$$a^{-n} = \frac{1}{a^n}$$

$$\begin{aligned} \text{c) } 30x^5y^4 \div 6xy &= \frac{30x^5y^4}{6xy} = \frac{30}{6} \times \frac{x^5}{x} \times \frac{y^4}{y} \\ &= 5x^{5-1}y^{4-1} = 5x^4y^3 \\ &= 5x^4y^3 \end{aligned}$$

LOGARITHMS

- ❑ Invented by the Scottish mathematician John Napier, logarithm is the power to which a number must be raised in order to get another number.
- ❑ Logarithm is written as “ $\log_b x$ ” and read as “log to base b of x”.
- ❑ A logarithm is a mirror image of an indices. You can convert an exponential equation into an equation $y = \log_b x$ is equivalent to $b^y = x$. vice versa.
 $2 = \log_{10} 100$ is equivalent to $10^2 = 100$

LOGARITHMS

□ A Logarithm is a mirror image of an index

If $m = b^n$ then $\log_b m = n$

The log of m to base b is n

If $y = x^n$ then $n = \log_x y$

The log of y to the base x is n

e.g.

$1000 = 10^3$ then $3 = \log_{10} 1000$

$0.01 = 10^{-2}$ then $-2 = \log_{10} 0.01$

LOGARITHMS

□ Using Rules of Indices, the following rules of

$$1) \log_b(x \times y) = \log_b x + \log_b y$$

$$\text{eg. } \log_{10}(2 \times 3) = \log_{10} 2 + \log_{10} 3$$

$$2) \log_b \left(\frac{x}{y} \right) = \log_b x - \log_b y$$

$$\text{eg. } \log_{10} \left(\frac{3}{2} \right) = \log_{10} 3 - \log_{10} 2$$

$$3) \log_b x^m = m \cdot \log_b x$$

$$\text{e.g. } \log_{10} 3^2 = 2 \log_{10} 3$$

LOGARITHMS

□ From the above rules, it follows that

$$(1) \quad \log_b 1 = 0$$

(since $\Rightarrow 1 = b^x$, hence x must=0)

e.g. $\log_{10} 1 = 0$

and therefore,

$$\log_b \left(\frac{1}{x}\right) = -\log_b x$$

e.g. $\log_{10} (1/3) = -\log_{10} 3$

LOGARITHMS

□ From the above rules, it follows that

$$(2) \quad \log_b b = 1$$

(since $\Rightarrow b = b^x$, hence x must = 1)

e.g. $\log_{10} 10 = 1$

$$(3) \quad \log_b \left(\sqrt[n]{x} \right) = \frac{1}{n} \log_b x$$

A Note of Caution:

- ❑ All logs must be to the same base in applying the rules and solving for values
- ❑ The most common base for logarithms are logs to the base 10, or logs to the base e ($e = 2.718281\dots$)
- ❑ Logs to the base e are called Natural Logarithms

$$\text{If } y = \exp(x) = e^x \quad \ln x$$

$$\text{Then } \log_e y = x \quad \text{or} \quad \ln y = x$$

QUESTION



Medical Physics

Lec.3: Force, Newton's Laws & their applications

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Learning Outcomes

By the end of this Lecture the student will be able to:

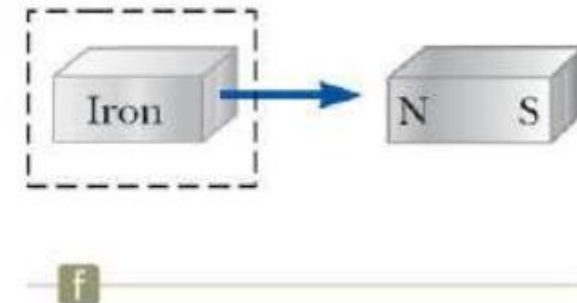
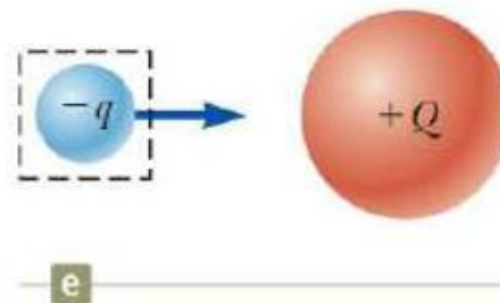
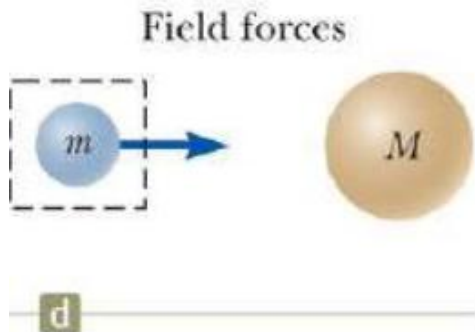
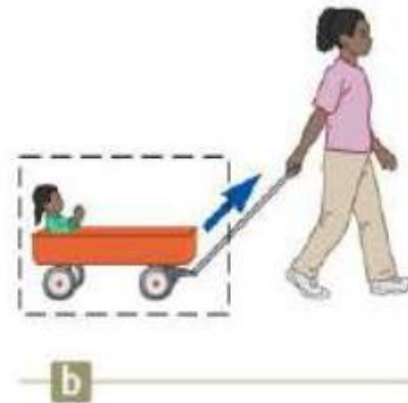
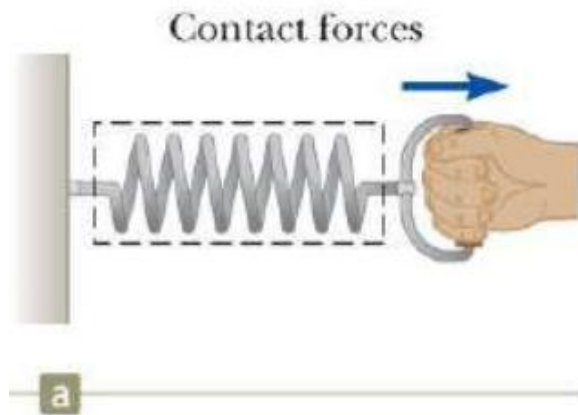
- ✓ Define the Newton's First Law
- ✓ Define the Newton's Second Law
- ✓ Define the Newton's Third Law
- ✓ Define the meaning of equilibrium
- ✓ Define the meaning of lever
- ✓ Define the meaning of levers in human body

Physics of the Body & Forces on and in the Body

- **Physics of the body** is the understanding of the human body physical aspect **such as**; forces on and in the body, work, energy, power of the body, heat, blood flow, respiration, electricity, circulation and hearing.
- A **force** is the act that causes an acceleration. Formulated by Sir Isaac Newton (1642 – 1727).
- The **Fundamental Forces** are:
 1. Gravitational force: Between objects
 2. Electromagnetic forces: Between electric charges
 3. Nuclear force: Between subatomic particles
 4. Weak forces: Arise in certain radioactive decay processes
- **Note**: These are all **field forces**, and are importance in our study of the forces affecting the human body.

Physics of the Body & Forces on and in the Body

- **Classes of Forces:** (1) **Contact forces** involve physical contact between two objects, such as forces in a, b, c. (2) **Field forces** act through empty space such as forces in d, e, f.



Physics of the Body & Forces on and in the Body

➤ Forces **ON** and **IN** the Body

The fundamental origins of forces, only the gravitational and electrical forces are importance in study of the forces affecting the human body.

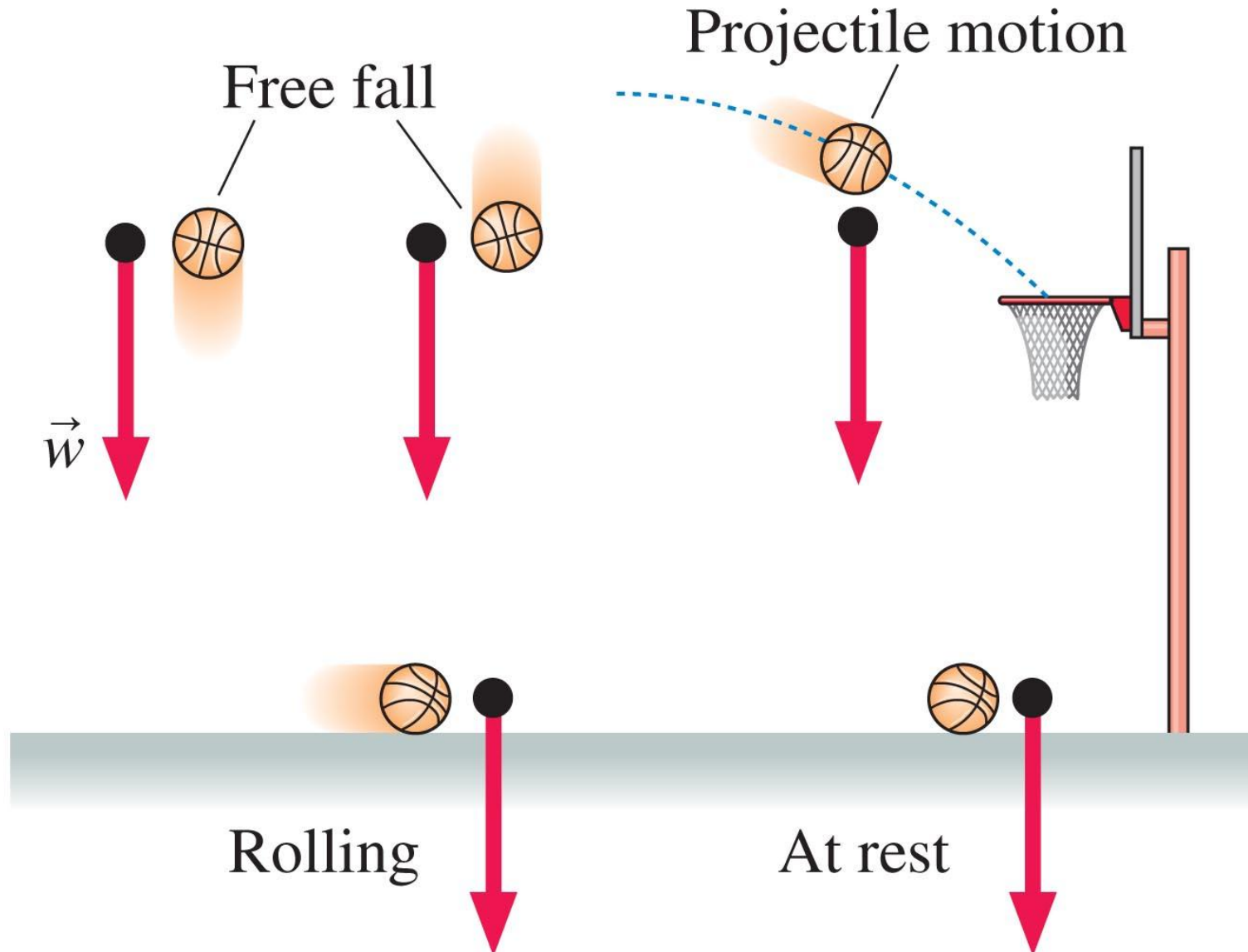
➤ The types of forces **IN** the body are:

- Muscular forces that cause the blood to circulate and the lungs to take in air.
- Molecular forces (bone, calcium atom).
- Electric forces.
- Gravitational forces.

➤ The types of forces **ON** the body are:

- I. Statics, when the body in equilibrium.
- II. Dynamics, when the body is accelerated.
- III. Friction is involved in both statics and dynamics.

Important forces 1 : Weight \vec{w} (non-contact or long-range force)



Weight is the force of gravity exerted by the earth on an object, its magnitude is

$$W = mg$$

[always points down]

Important forces 1 : Gravitational Force \vec{F}_g (non-contact force)

The gravitational force, \vec{F}_g , is the force that the earth exerts on an object. This force is directed toward the center of the earth. Its magnitude is called the weight of the object.

$$\vec{w} = \vec{F}_g = m \vec{g}$$

Where F is the force, m is the mass, g is the acceleration of gravity, 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 also.

Note about units:

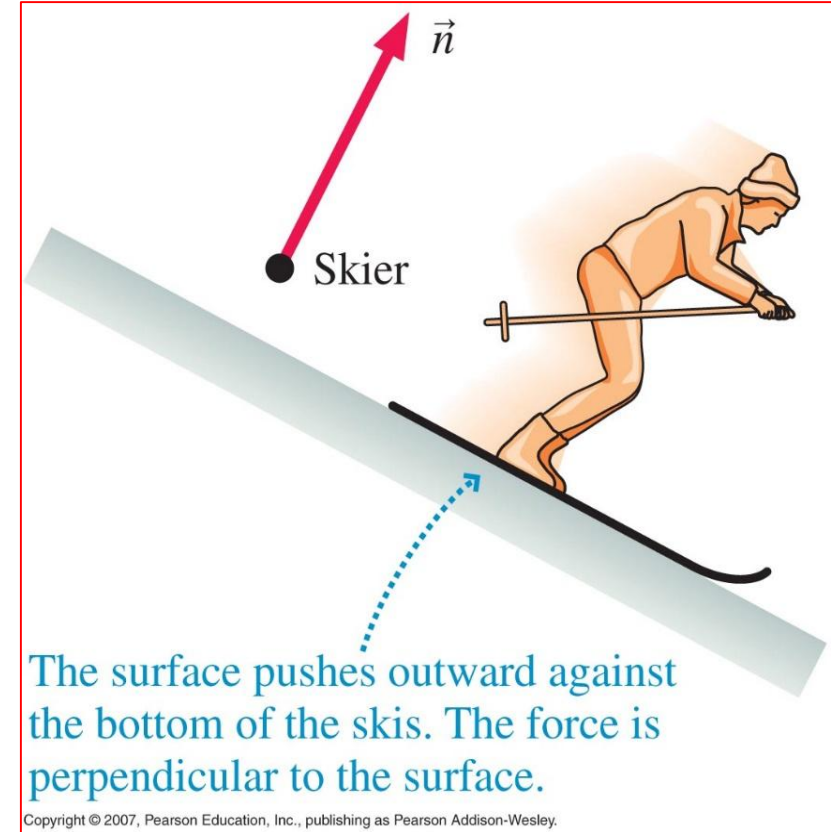
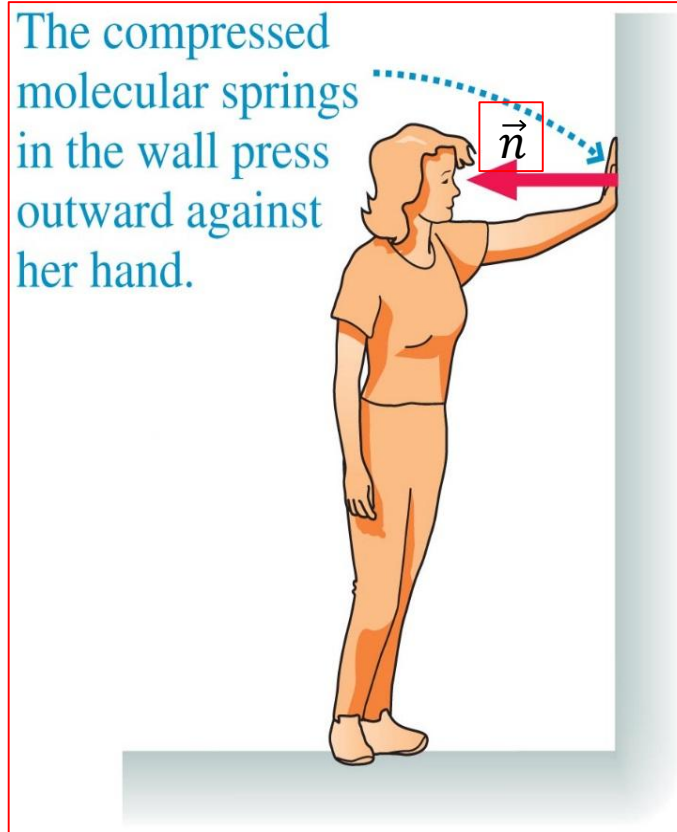
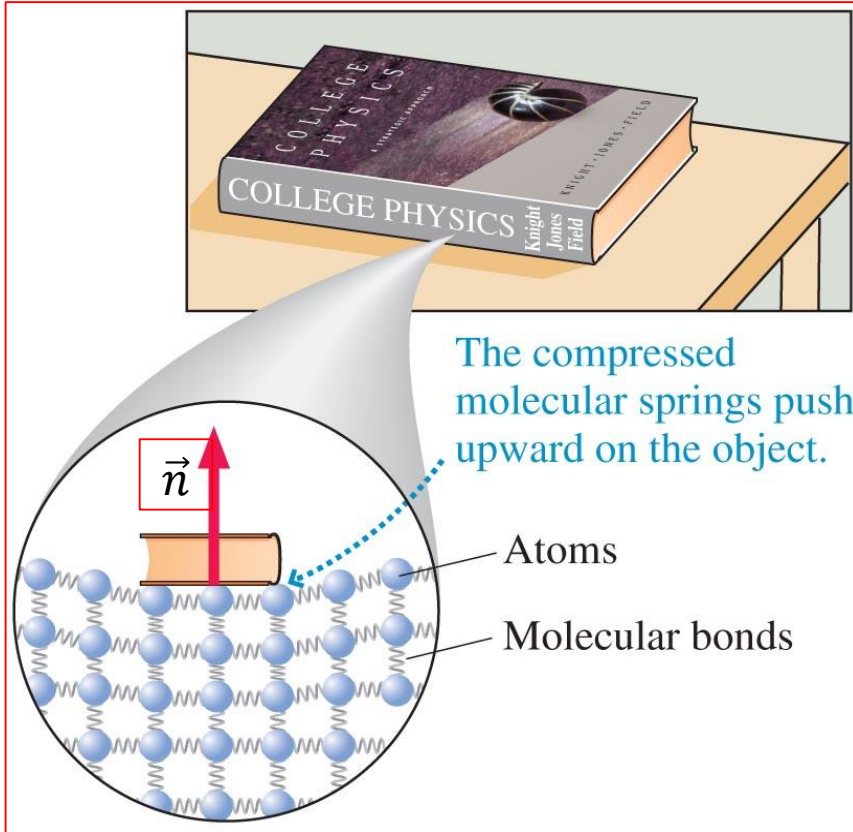
Kilogram is not a unit of weight.

1 kg \approx 2.2 lb is an equivalence valid only on the Earth's surface.

➤ The **medical effects of gravitational force**;

1. The formation of varicose veins in the legs as the venous blood travels against the force of gravity on its way to the heart. That 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.
2. The medical effect of gravity on the skeleton (on the bones), in some way contributes to healthy bones.
3. 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.

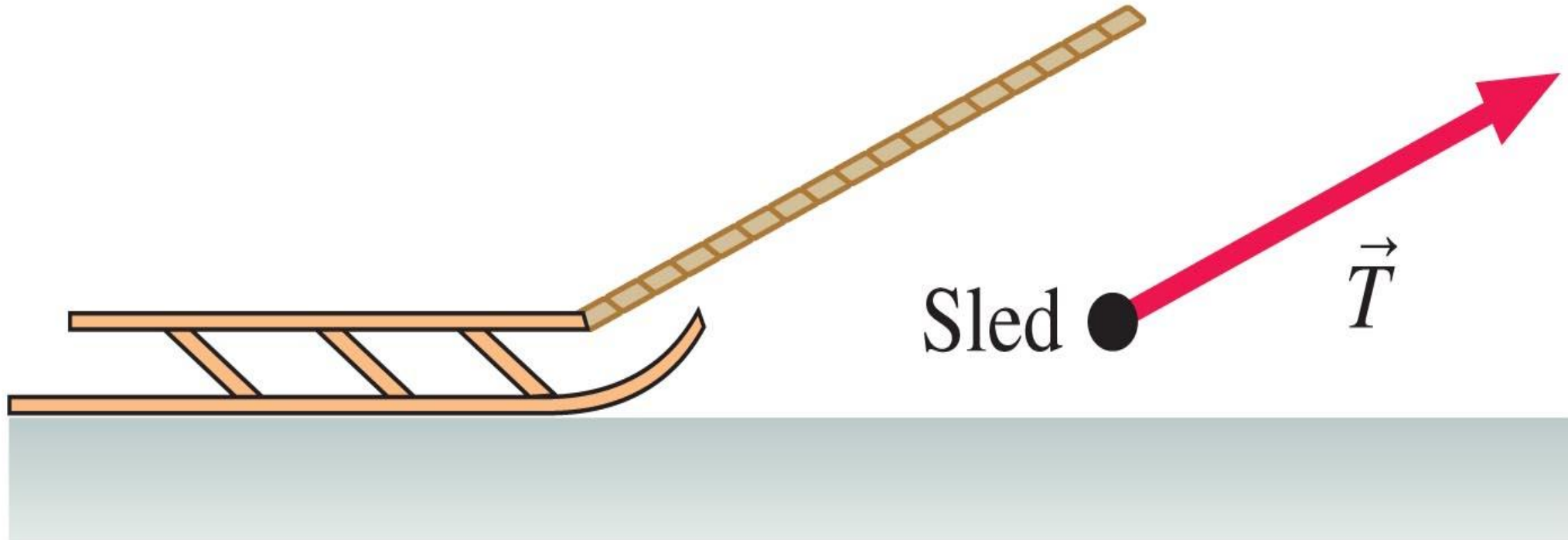
Important forces 2 : Normal force \vec{n} (contact force)



Normal force is always **perpendicular** to surface

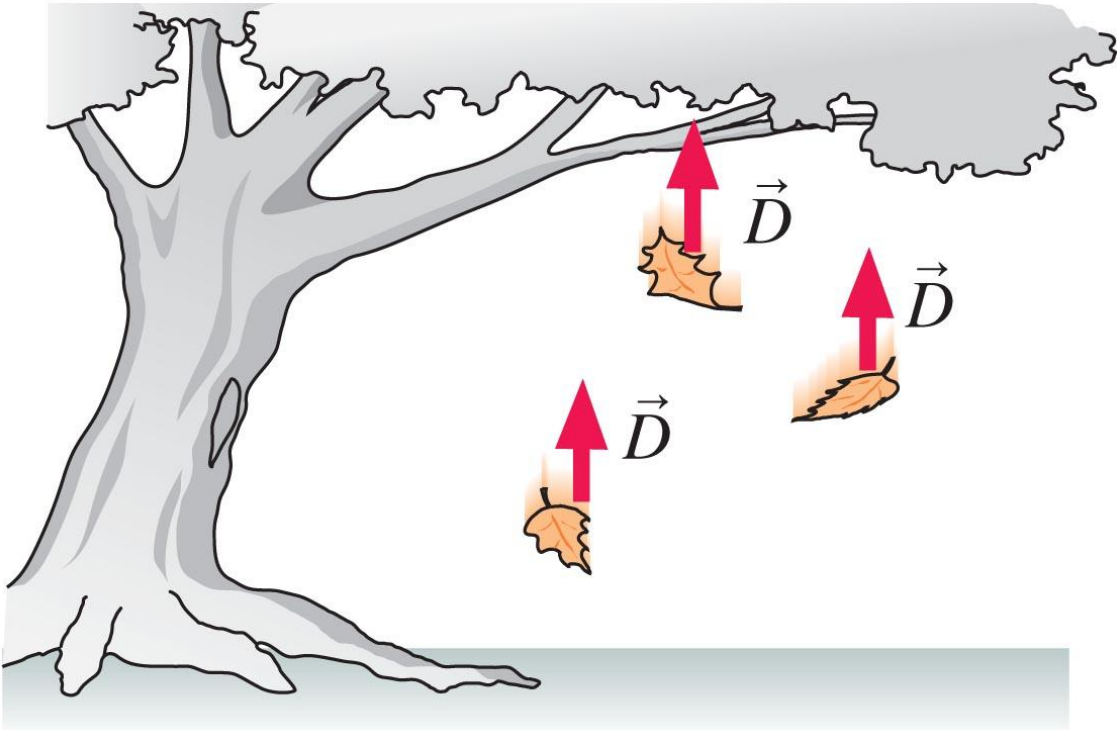
Important forces 3 : Tension force \vec{T} (contact force)

The rope exerts a tension force on the sled.

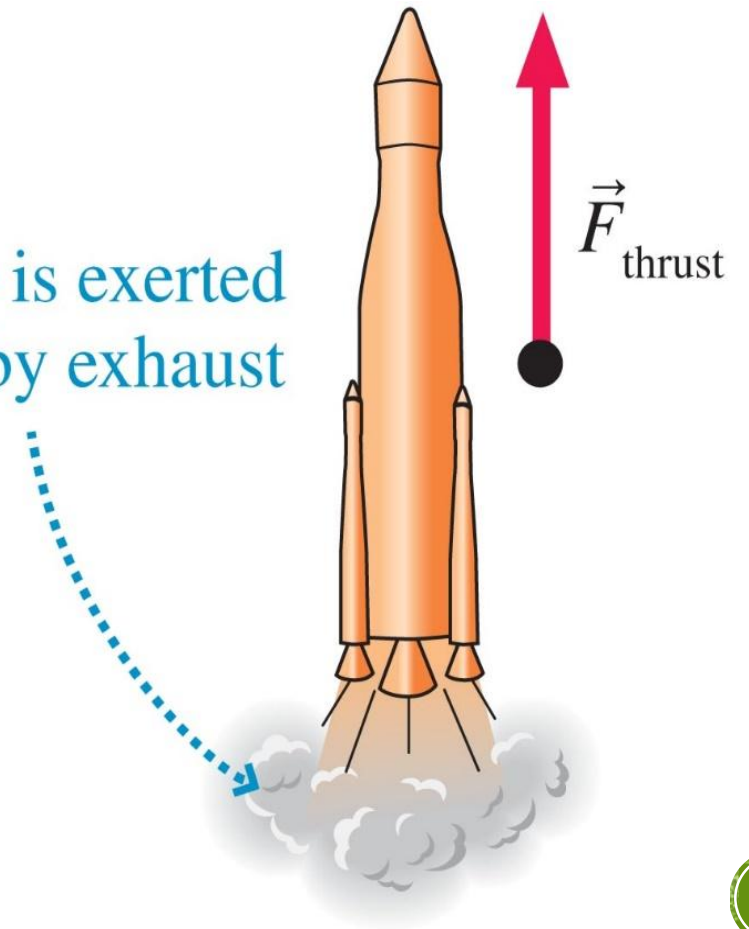


Important forces 4 : **Drag force** \vec{D} and **Thrust** \vec{T} **forces** (contact force)

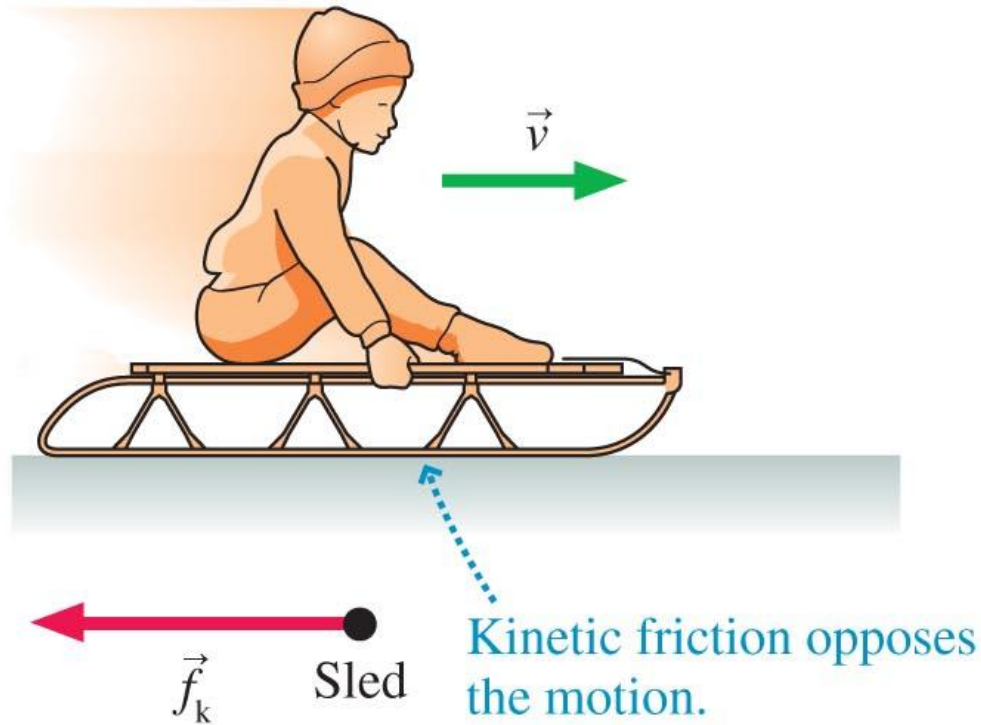
Air resistance is a significant force on falling leaves. It points opposite the direction of motion.



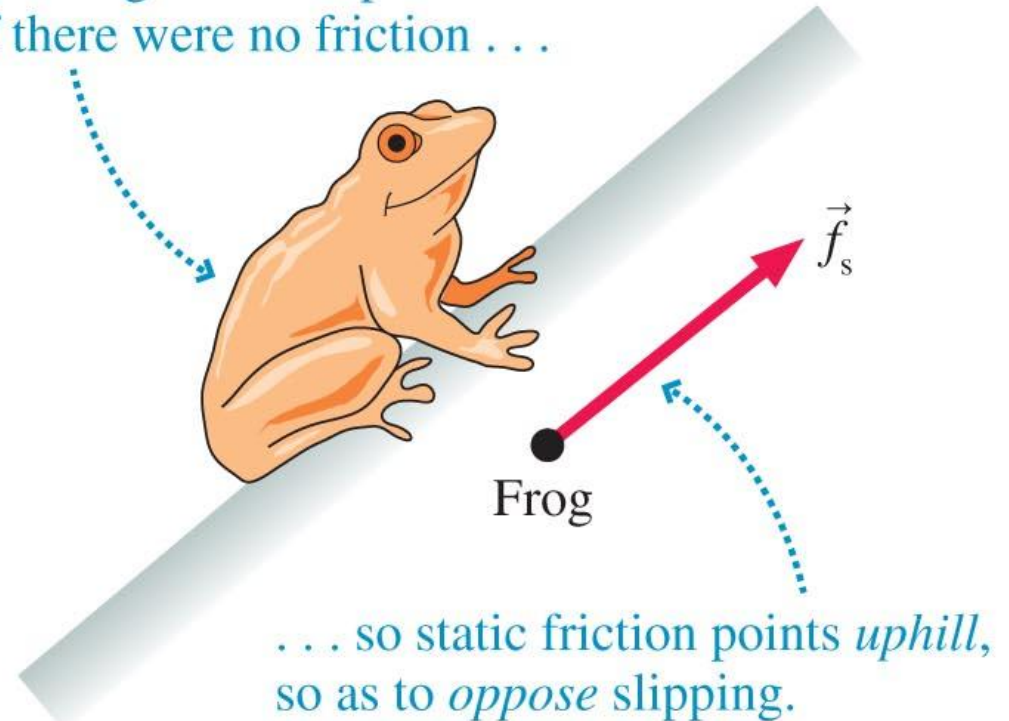
Thrust force is exerted on a rocket by exhaust gases.



Important forces 5 : Friction forces – Kinetic friction \vec{f}_k and Static friction \vec{f}_s (contact forces)



The frog would slip *downhill* if there were no friction . . .



Friction is always **parallel** to surface

Important forces 5 : Friction forces – Friction and energy loss due to friction appear every day in our life. The maximum force of friction F is

$$\vec{F} = \mu N$$

Where N is a normal force. μ is the coefficient between the two surfaces. The value of μ depends upon the two materials in contact, and it is essentially independent of the surface area, as shown in Table below.

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.

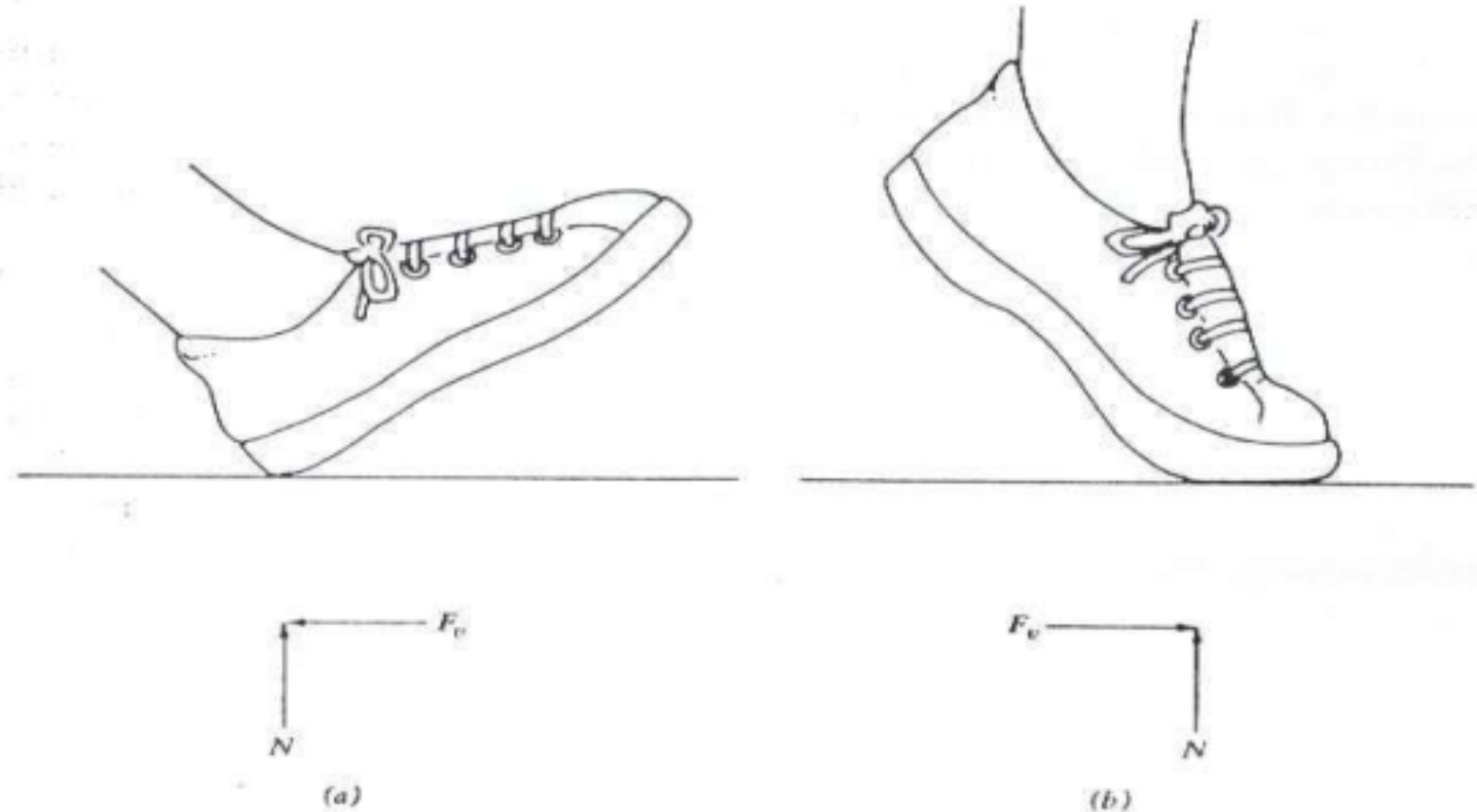


Figure 2.9. Normal walking. (a) Both a horizontal frictional component of force F_v and a vertical (normal) component of force N exist on the heel as it strikes the ground. Friction between the heel and surface prevents the foot from slipping forward. (b) When the foot leaves the ground the frictional 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.

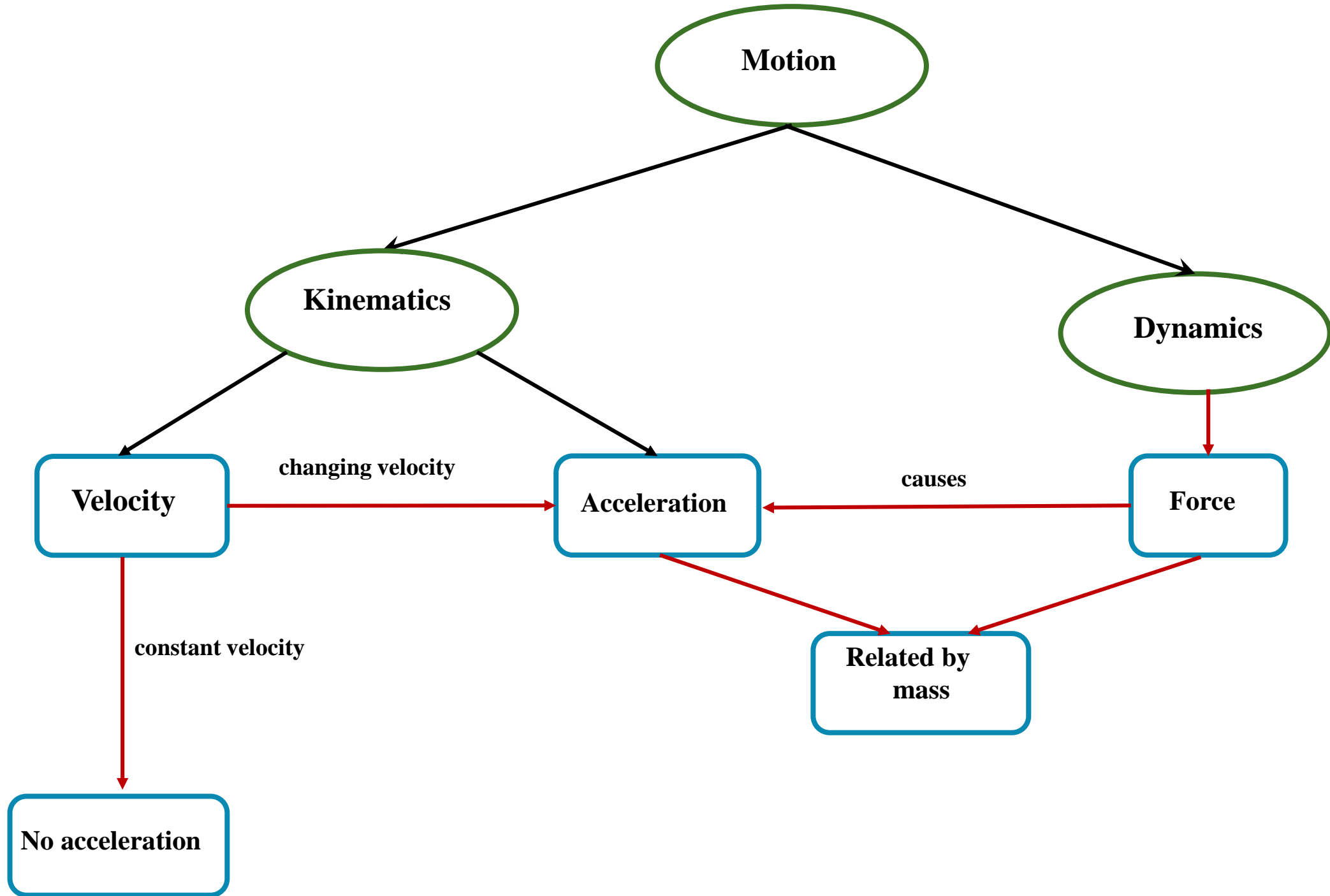
The coefficient of friction in bone joints is very small (Table 1).

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

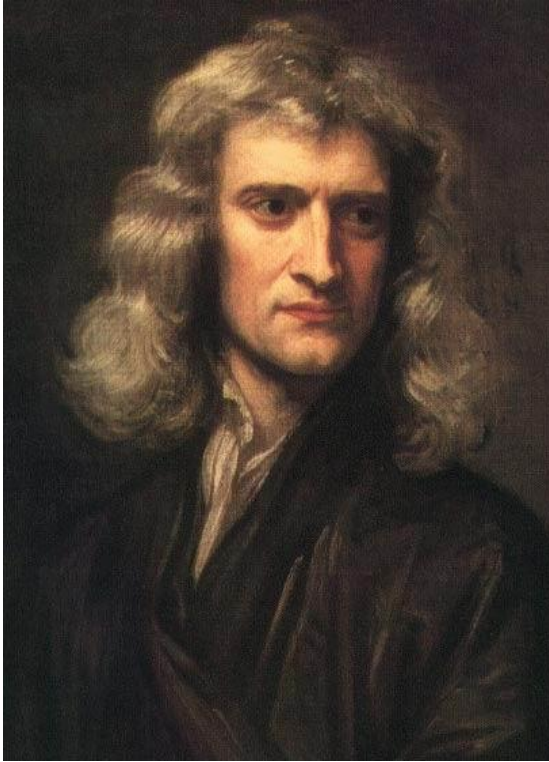
The synovial fluid in the joint is involved in the lubrication.

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

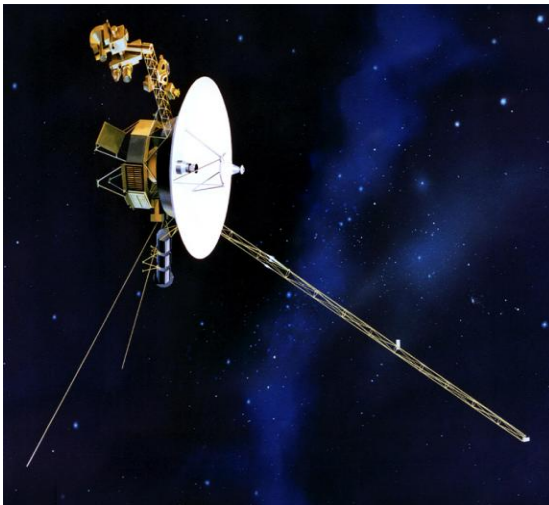
For example, if you swallow a piece of dry toast you become painfully aware of this lack of lubricant.



1st Law of Motion



- **A body at rest will tend to stay at rest.**
- A body in motion will tend to stay in motion unless acted upon by an external force.



$$F = 0$$

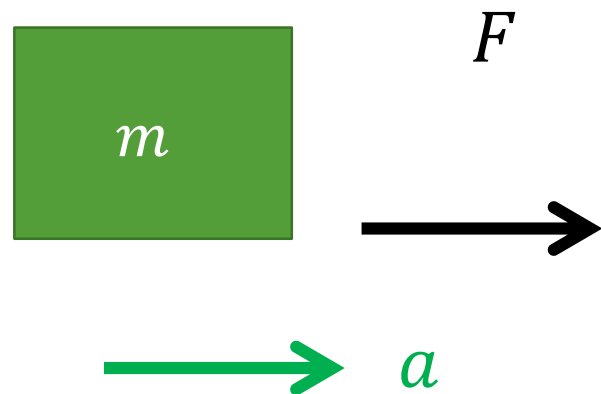
$$v \sim 7,000 \text{ m/s}$$

1st Law of Motion

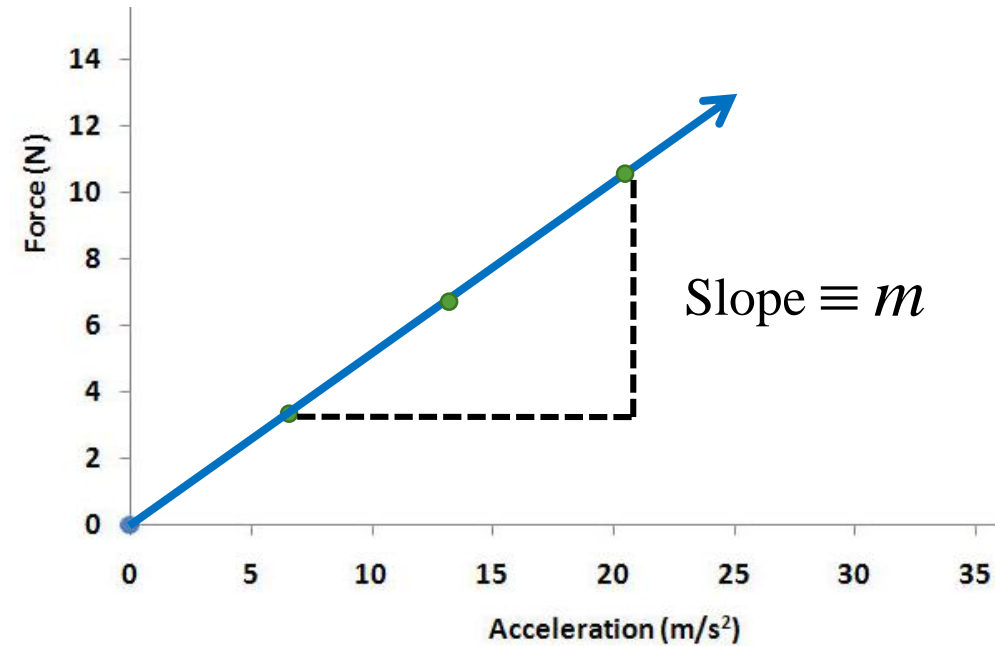
- **States that** an object at rest will remain at rest and an object in motion will remain in motion with a constant velocity unless acted on by a net external force.
- **We can conclude that** any isolated object is either at rest or moving at a constant velocity
- The First Law **also** allows the 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 and weight **are** two different quantities.
- Weight **will** vary with location.
- $m_{\text{earth}} = 3 \text{ kg}$; $m_{\text{moon}} = 3 \text{ kg}$
- $w_{\text{earth}} = 30 \text{ N}$; $w_{\text{moon}} \sim 6 \text{ N}$

2nd Law of Motion

An object that is acted upon by an external force “**F**” will have an acceleration, “**a**” that is proportional to this force and in the same direction.



F	a
0	0
F_1	a_1
F_2	a_2
F_3	a_3
...	...



Force is proportional to acceleration

$$F \propto a$$

Single Force:

$$F = ma$$

Multiple Forces:

$$\text{vector sum of forces} = \sum_i F_i = ma$$

$$\Rightarrow \mathbf{F}_{\text{net}} = \mathbf{ma}$$

2nd Law of Motion

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.

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

$\sum \vec{F}$ is the net force. May also be called the **total force**, or **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:

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

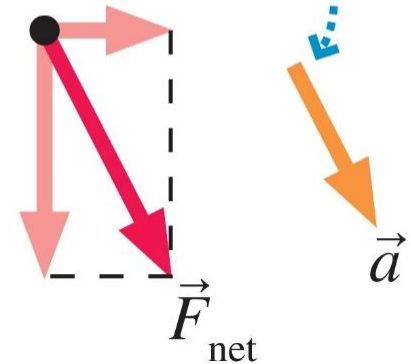
Newton's Second Law

A net force \vec{F}_{net} acting on an object results in the object experiencing an acceleration \vec{a} that is directly related to the net force \vec{F}_{net} acting on it and inversely proportional to its mass m

$$\vec{F}_{net} = m\vec{a} \quad \Rightarrow \quad \vec{a} = \frac{\vec{F}_{net}}{m}$$

Effect Cause

The acceleration is in the direction of \vec{F}_{net} .



If we add up all the (vector) forces acting on an object to find \vec{F}_{net} , and $\vec{F}_{net} \neq \mathbf{0}$, then the object will experience an **acceleration** in the same direction as

$$\vec{F}_{net}. \text{ Unit of force : } [F_{net}] = [m\vec{a}] = kg \cdot \frac{m}{s^2} \equiv N(\text{Newton})$$

Example

Two forces, F_1 and 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

Solution

$$(a) \sum F = F_1 + F_2 = (20i + 15j) \text{ N}$$

$$\sum F = ma \therefore 20i + 15j = 5 a$$

$$a = (4i + 3j) \text{ m/s}^2 \text{ or } a = 5 \text{ m/s}^2$$

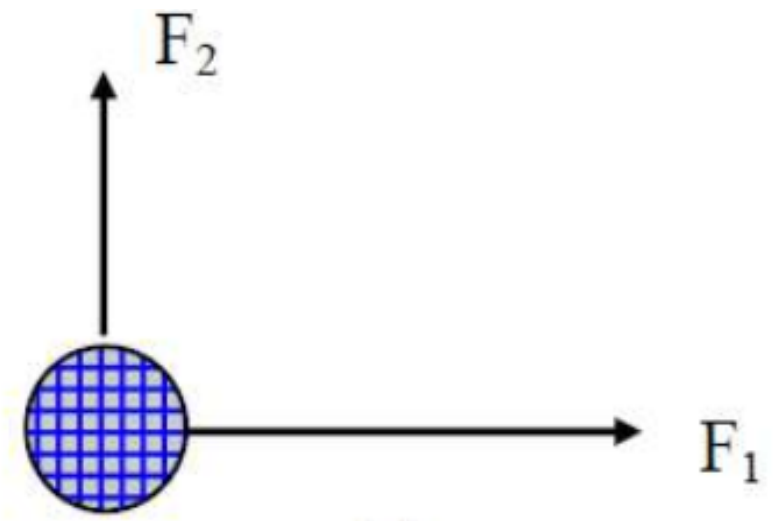
$$(b) F_{2x} = 15 \cos 60 = 7.5 \text{ N}$$

$$F_{2y} = 15 \sin 60 = 13 \text{ N}$$

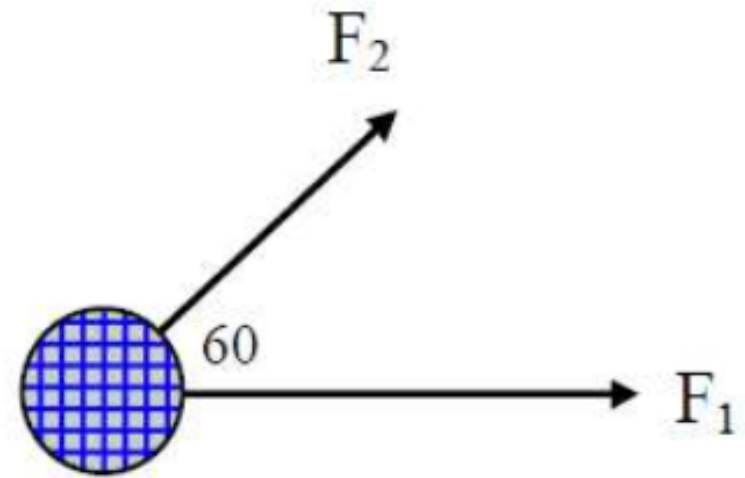
$$F_2 = (7.5i + 13j) \text{ N}$$

$$\sum F = F_1 + F_2 = (27.5i + 13j) = ma = 5 a$$

$$a = (5.5i + 2.6j) \text{ m/s}^2 \text{ or } a = 6.08 \text{ m/s}^2$$



(a)

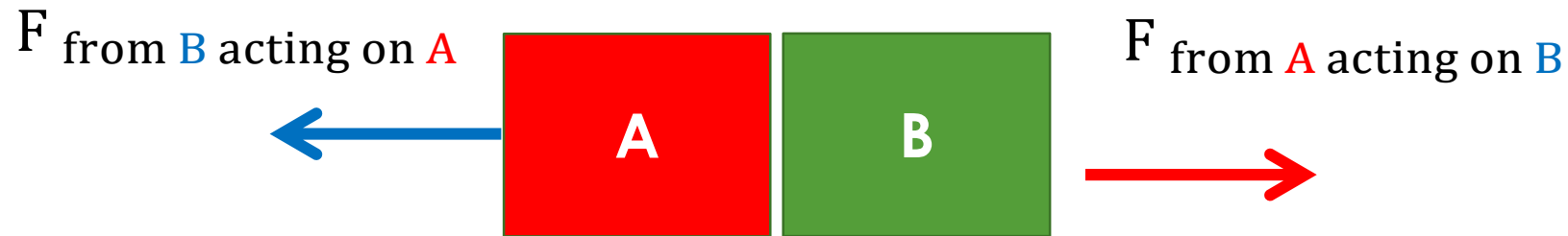


(b)

3rd Law of Motion

If object “A” acts on object “B” with a force “F” then object “B” acts on object “A” with a force of the same magnitude but opposite in direction.

“For every action, there is an opposite reaction.”



Words to the Wise:

- 3rd law describes how two objects interact.
It does not describe how the net force acting upon one object causes it to accelerate!
- 2nd law describes how the net force on one object causes this object to accelerate.
It does not describe how two objects interact!

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*.

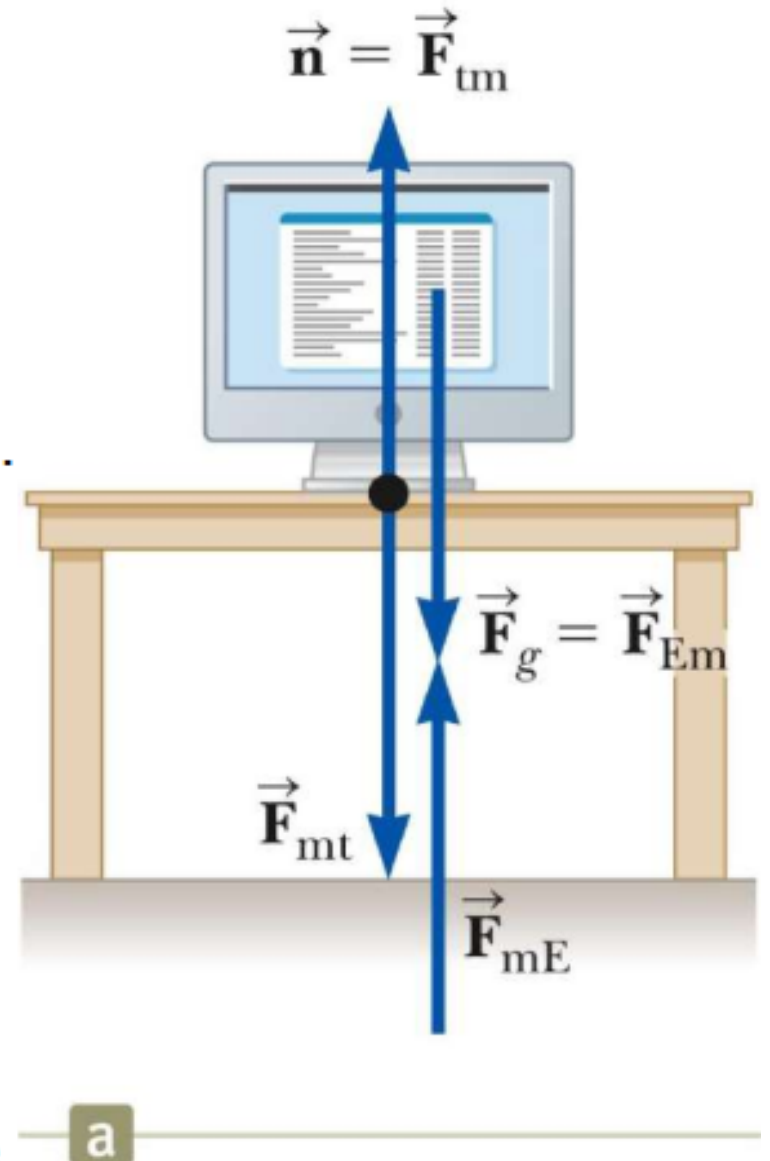
The action force is equal in magnitude to the reaction force and opposite in direction.

- 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.



Recap : Solving Force and Motion problems

Specific forces

Weight \vec{w}

Normal force \vec{n}

Tension force \vec{T}

Drag force \vec{D}

Static friction

Kinetic friction

Newton's second law

A net force \vec{F}_{net} acting on an object results in the object experiencing an acceleration \vec{a} that is directly related to the net force \vec{F}_{net} acting on it and inversely proportional to its mass m

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m}$$

Check your understanding

Are the following statements true or false?

1) If the net force on an object is zero, the object is at rest.

False. The object could be moving with constant velocity.

2) If an object is moving with constant velocity, there is no force acting on it.

False. It only means that the **net force** is zero. There could very well be multiple forces acting on the object that balance each other out.

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

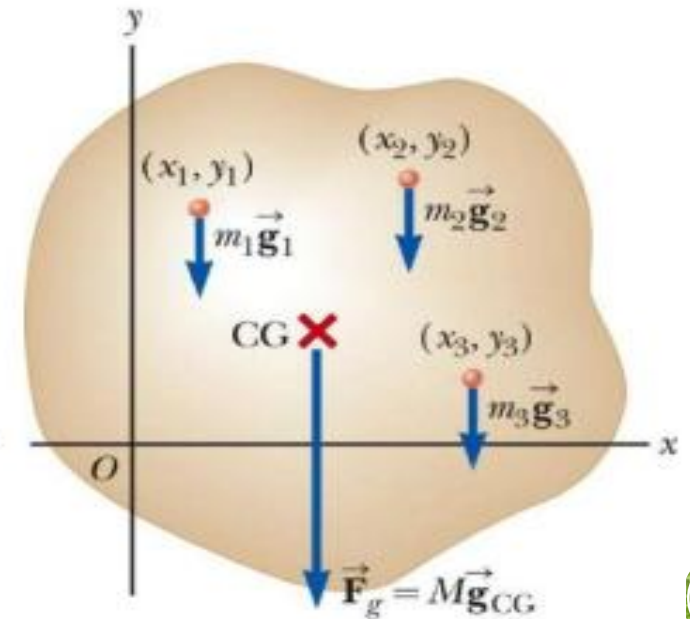
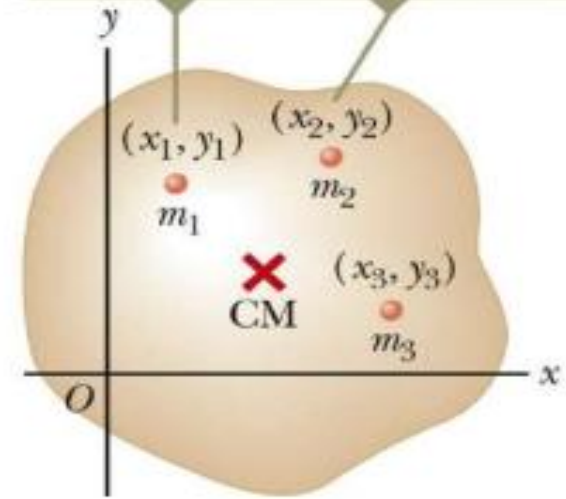
$$x_{CM} = \frac{\sum_i m_i x_i}{\sum_i m_i}$$

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.

Each particle of the object has a specific mass and specific coordinates.



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.

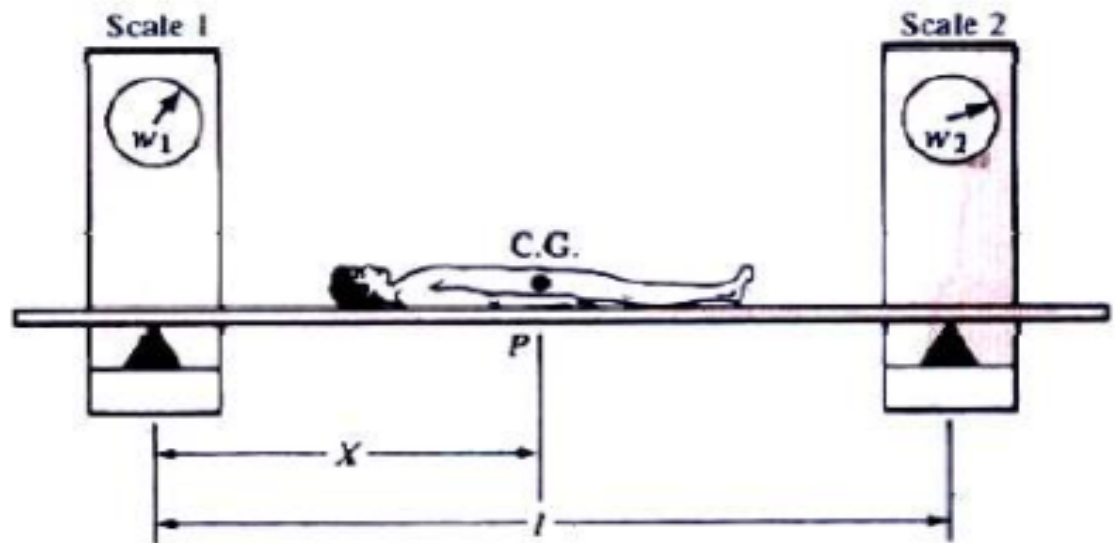
When a person lies on the board the scales read w_1 and w_2 .

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

□ The torque about point P is

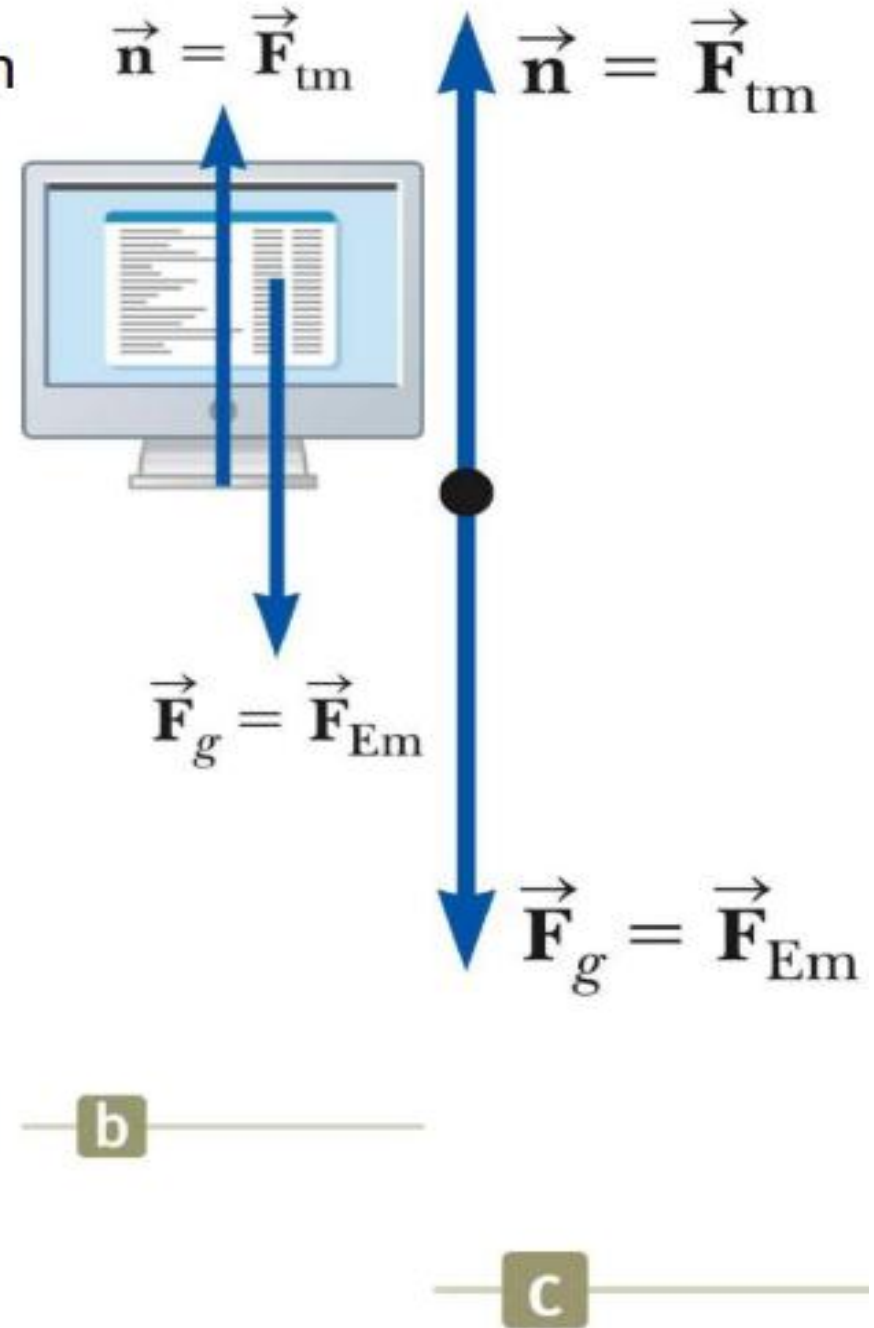
$$Xw_1 - (l - X)w_2 = 0$$

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



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.



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.
- The **special case** is both of these velocities are equal to zero. This is called **static equilibrium**.
- **Static equilibrium** is a common situation in many applications.

Rigid Object in Equilibrium

- In **equilibrium model** a particle moves with constant velocity because the net force acting on it is zero.
- For an **object to be in equilibrium**, a **second condition of equilibrium** must be satisfied, that involves the rotational motion of the object.

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

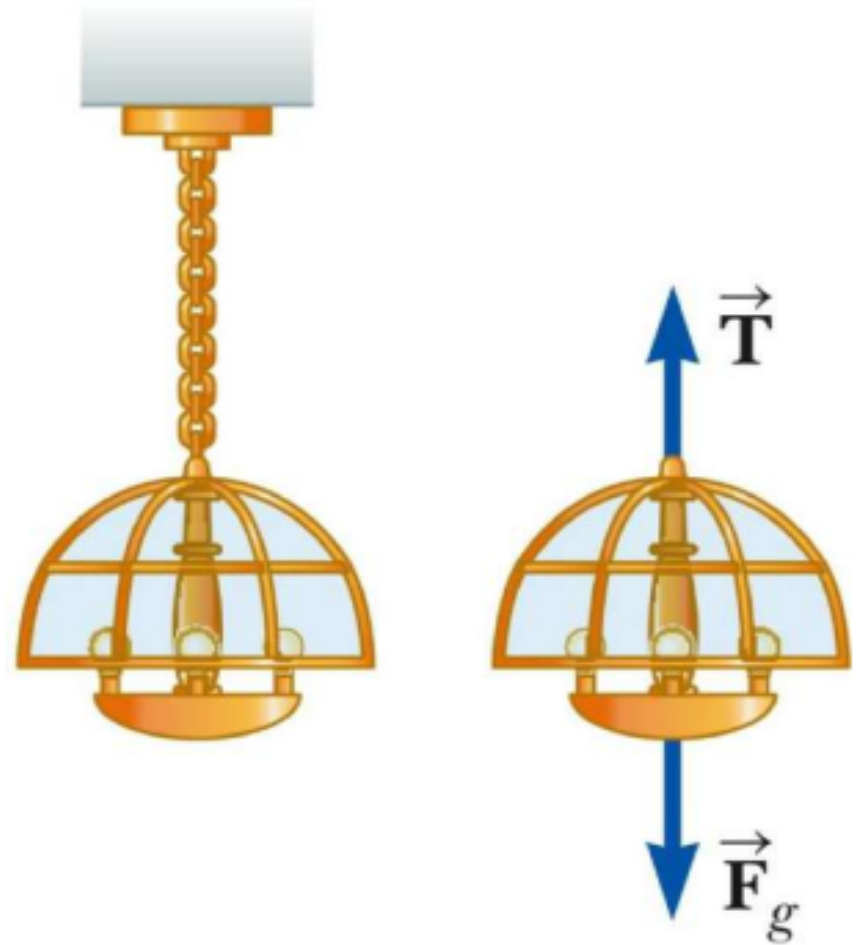
A lamp is suspended from a chain of negligible mass.

The forces acting on the lamp are:

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

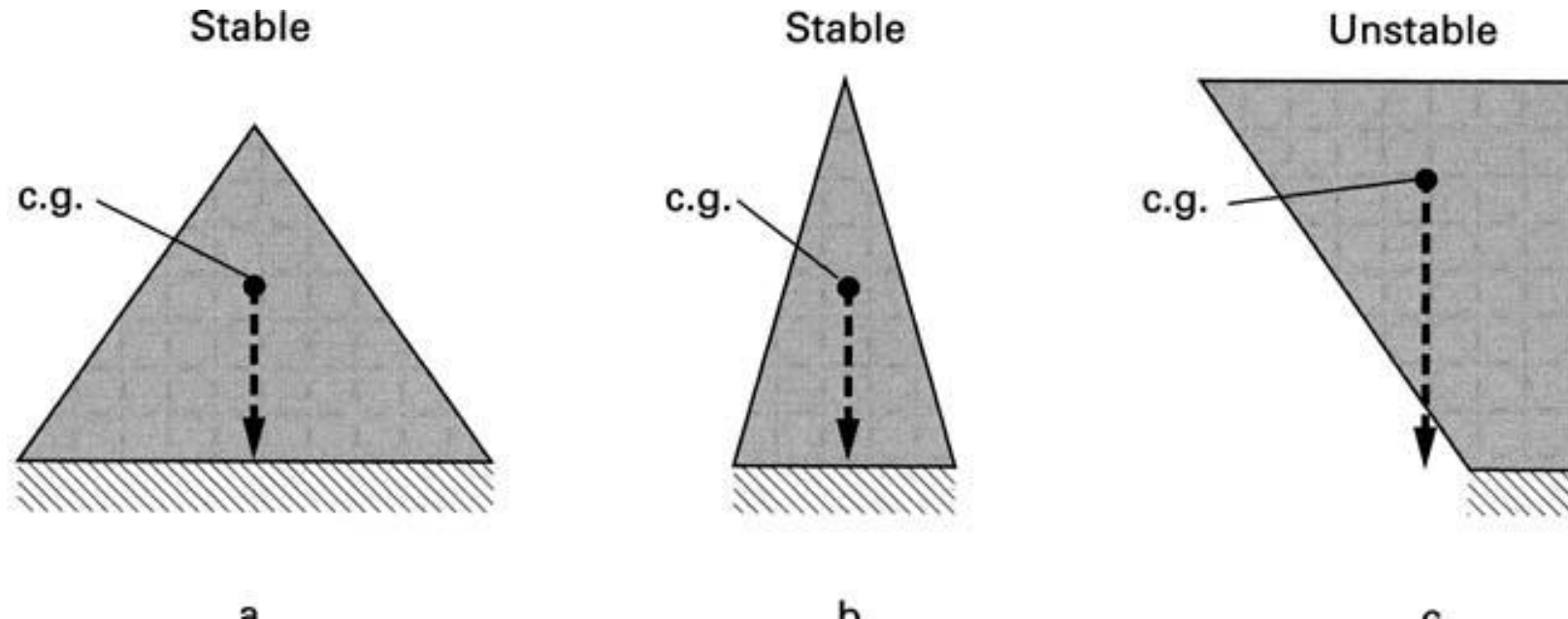
Applying equilibrium gives

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



Equilibrium and Stability

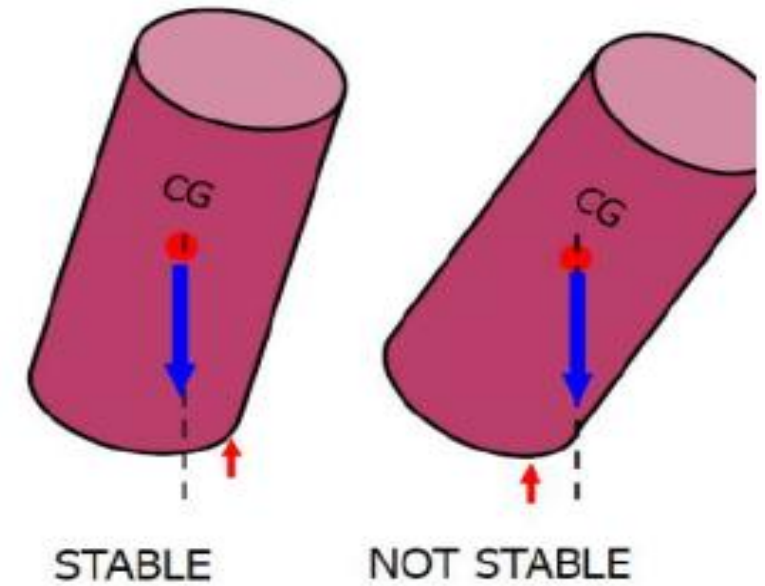
- A body is in **static equilibrium** if the vectorial sum of ALL the forces **and** the torques acting on the body is zero.
- A body is in **stable equilibrium** under the action of gravity if its center of mass/gravity (**c.g.**) is directly over its base of support (Fig. a, b).
- If the center of mass is outside the base, the torque produced by the weight tends to topple the body (Fig. c).



Stability

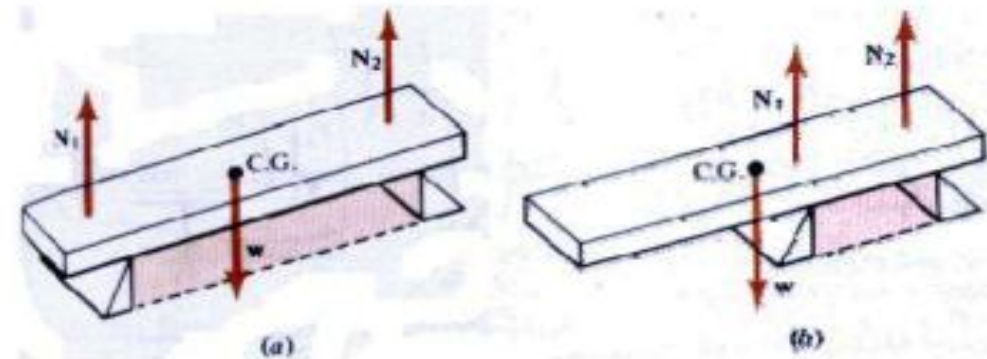
Why things fall over

- 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.



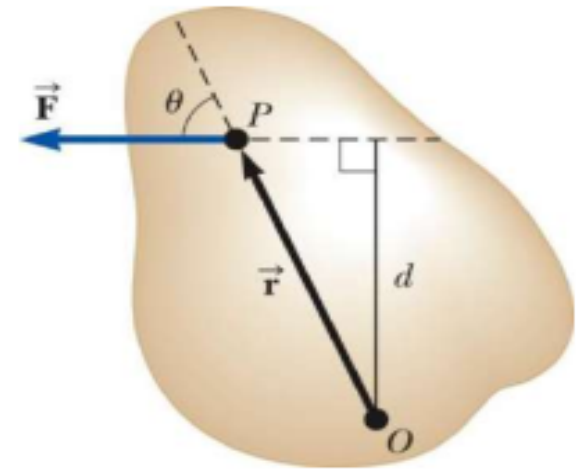
The beam is in equilibrium

The beam is not in equilibrium

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:

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

- $\Sigma \tau_z = 0$

Equilibrium Laws

1. Objects are stationary (**static**), they are in a state of equilibrium when the sum of forces in any direction is zero;

$$\sum F_i = 0, \quad f_1 + f_2 + f_3 + f_4 = 0 \quad (\text{First condition of equilibrium})$$

2. The sum of the torques about any axis is zero;

$$\sum T = \sum F \cdot I = 0 \quad (\text{Second condition of equilibrium})$$

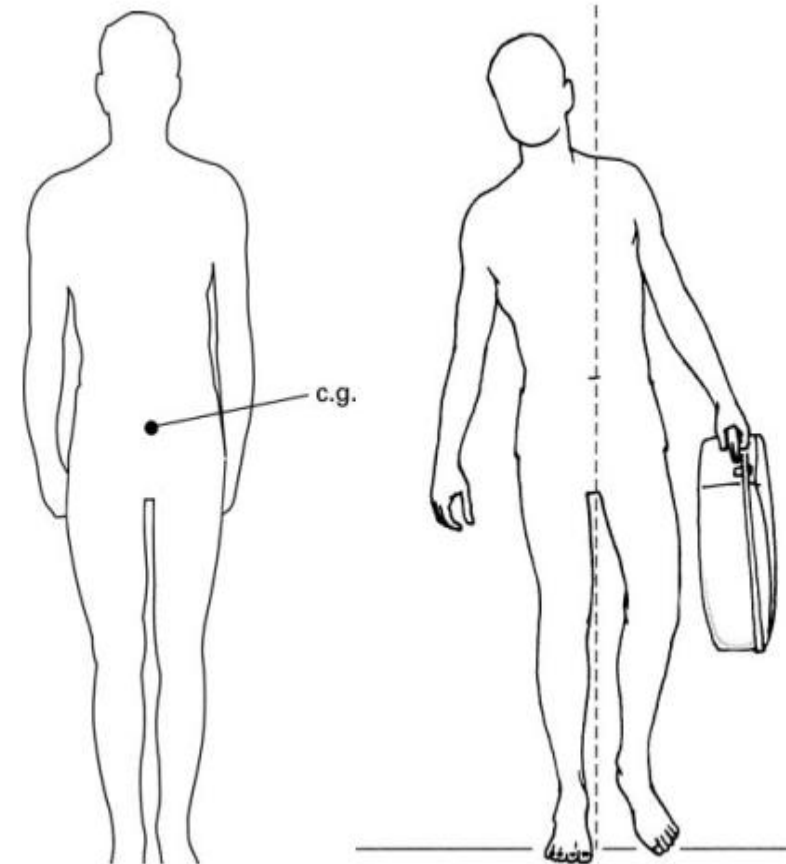
where, **T** = the torque, **F** = the force, **I** = the vertical distance from the pivot, (fulcrum point) to the line action of the force.

3. The sum of clock wise torque = sum of counter clock wise torque.

$$\sum T_{cw} = \sum T_{ccw}$$

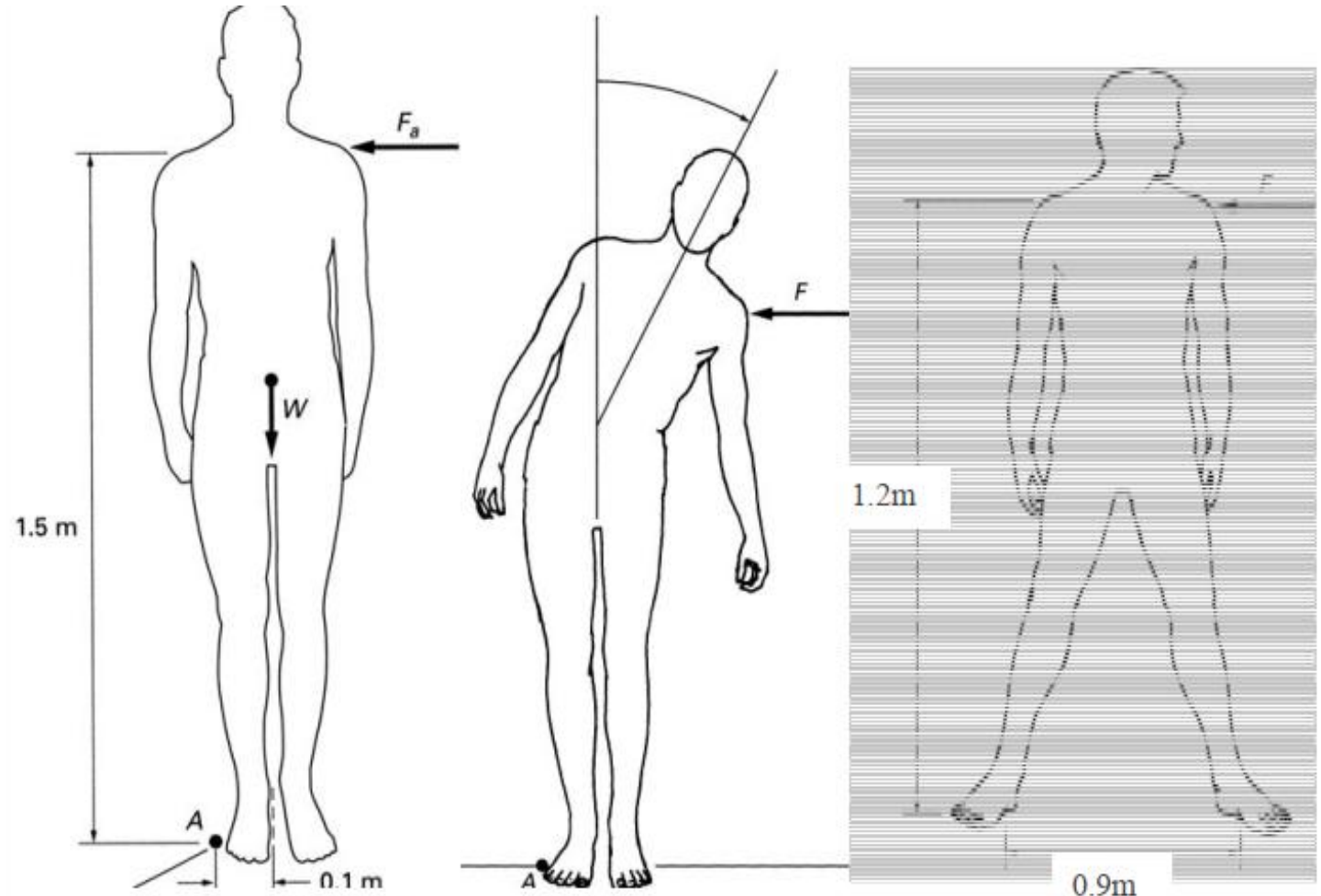
Equilibrium considerations for the human Body

- The center of gravity (**c.g**) of a person with arms at the side is at approximately 56% of the person's height measured from the soles of the feet.
- The center of gravity (**c.g**) shifts as the person moves and bends.
- The act of balancing requires maintenance of the center of gravity above the feet.
- A person falls when his center of gravity is displaced beyond the position of the feet.
- **For example**, when a person carries a weight in one arm, the other arm swings away from the body and the torso bends away from the load.



Stability of the human body under the action of an external force

- The body **may be** subject to forces other than the downward force of weight.
- Let us **calculate** the magnitude of the force applied to the shoulder **that will** topple a person standing at rigid attention.
- The assumed dimensions of the person are as shown.

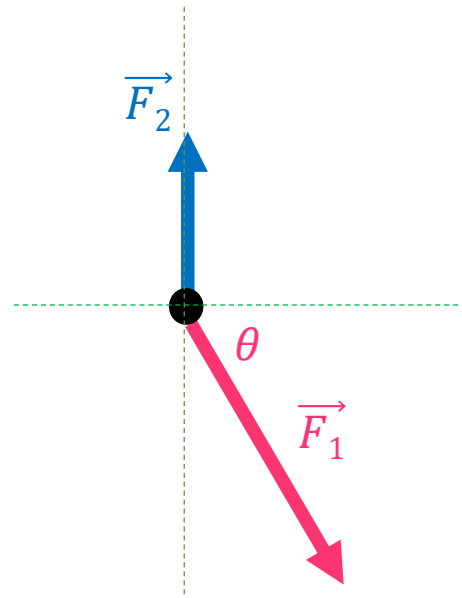


a) Force applied to an erect person. b) Compensating for a side-pushing force c) Increased stability resulting from spreading the legs.

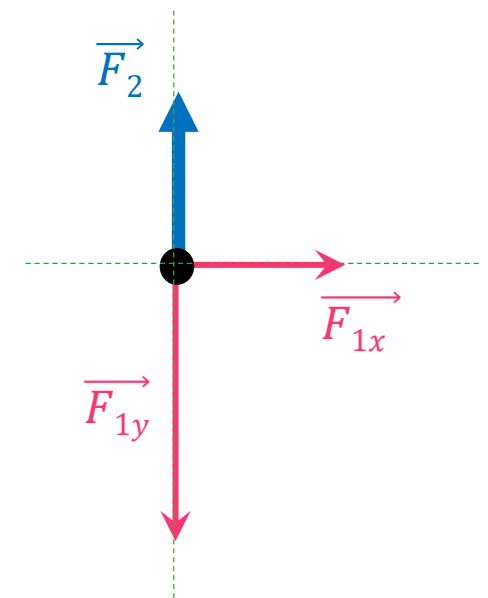
Adding Forces (all rules of vector addition apply)

Step 1: Resolve each vector into components

Step 2: Add components of each vector

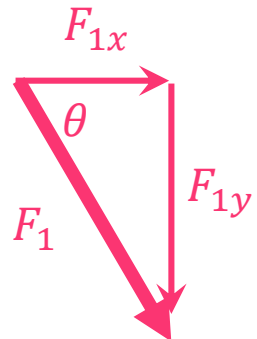


Decompose F_1 into x and y components



$$\vec{F}_{2x} = 0 \hat{x}$$

$$\vec{F}_{2y} = F_2 \hat{y}$$

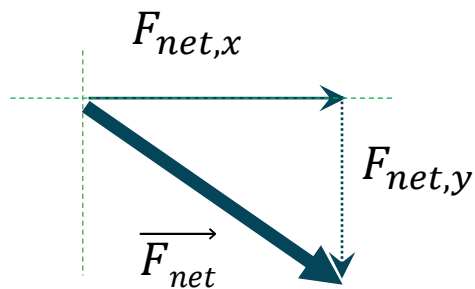


$$\vec{F}_{1x} = F_1 \cos \theta \hat{x}$$

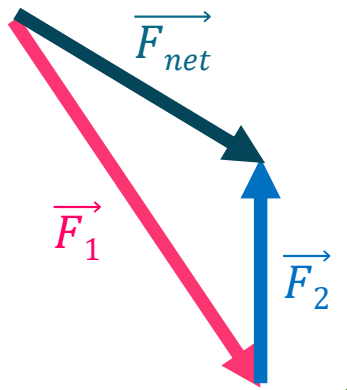
$$\vec{F}_{1y} = -F_1 \sin \theta \hat{y}$$

$$F_{net,x} = F_{1x} + F_{2x} = F_1 \cos \theta$$

$$F_{net,y} = F_{1y} + F_{2y} = F_2 - F_1 \sin \theta$$



OR:
Join vectors head-to-tail



The Object Under a Net Force, the dynamical force

According to second law of Newton, the force is equal

$$\mathbf{F} = m\mathbf{a} = \Delta(m\mathbf{v}) / \Delta t$$

where $m\mathbf{v}$ is the momentum

Example: Forces acting on the crate:

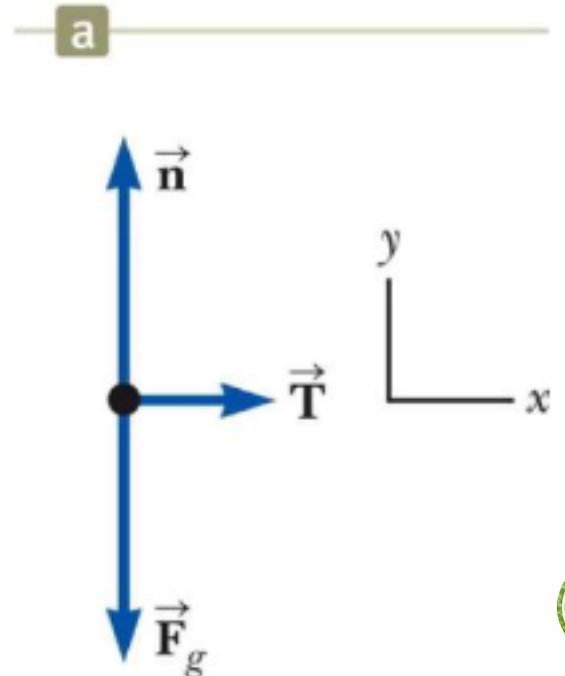
- A tension, acting through the rope, is the magnitude of force \vec{T}
- The gravitational force, \vec{F}_g
- The normal force, \vec{n} , exerted by the floor

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)



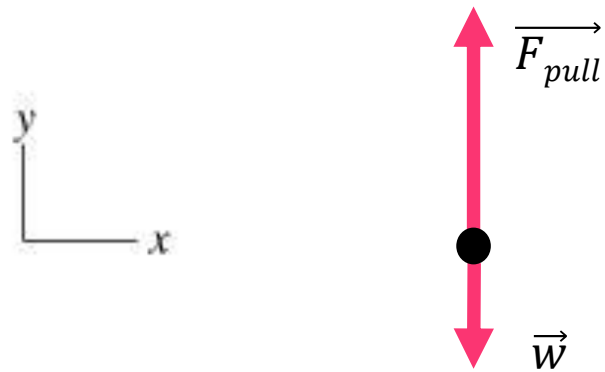
Problem-solving

A human arm with **10kg** is lifted straight up with a constant force of **148N**.

Calculate the net force acting on the human arm **and** its acceleration.

Remember $|\vec{w}| = mg$

Step 1 : Draw a free body diagram



Step 2 : Find the vector sum of forces

$$\begin{aligned}\vec{F}_{net} &= \vec{F}_{pull} + \vec{w} \\ &= 148 \text{ N} - (10)(9.8) \text{ N} \\ &= 148 \text{ N} - 98 \text{ N}\end{aligned}$$

$$\vec{F}_{net} = 50 \text{ N}$$

Step 3 : Set $\vec{F}_{net} = m\vec{a}$

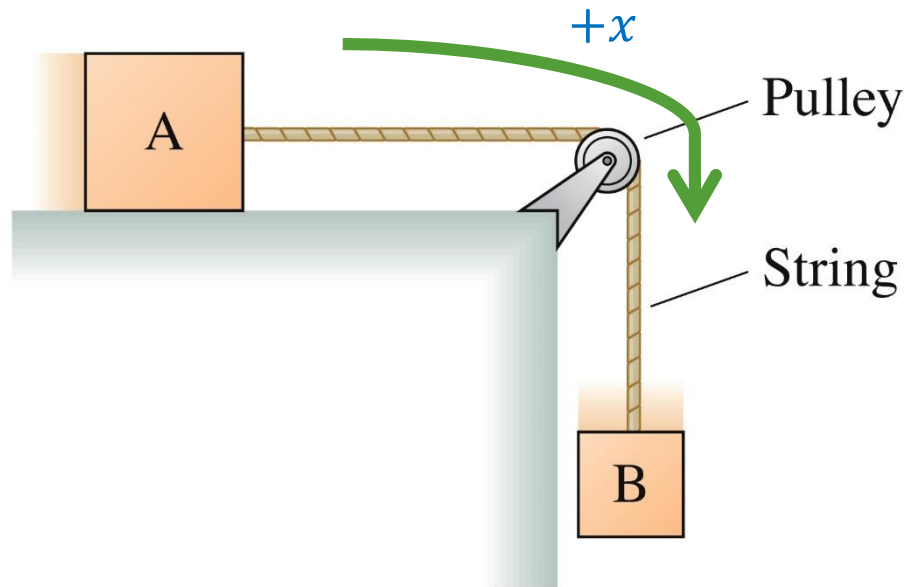
$$50 \text{ N} = (10 \text{ kg}) a$$

$$\Rightarrow a = \frac{50 \text{ N}}{10 \text{ kg}}$$

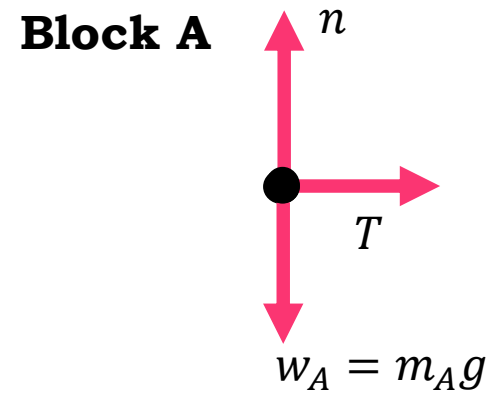
$$a = 5 \text{ m/s}^2$$

Problem-solving

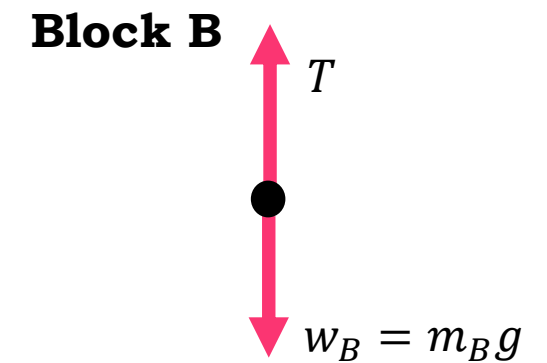
Block **A**, with mass **4.0 kg**, sits on a frictionless table. Block **B**, with mass **2.0 kg**, hangs from a rope connected through a pulley to block **A**. What is the acceleration of block **A**?



* The direction of the rope is defined as the $+x$ -axis



$$F_{net} = T = m_A a$$



$$F_{net} = +w_B - T = m_B a$$

$$\Rightarrow w_B - m_A a = m_B a$$

$$\Rightarrow m_B g - m_A a = m_B a$$

$$\Rightarrow a = \frac{m_B g}{(m_B + m_A)}$$

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 ?

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

the force developed on impact is

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

$$F = 1200 \text{ Newton}$$

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 ?

$$F = \Delta (mv) / \Delta t = 50 \times 4.5 / 0.2 = 1125 \text{ N}$$

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.

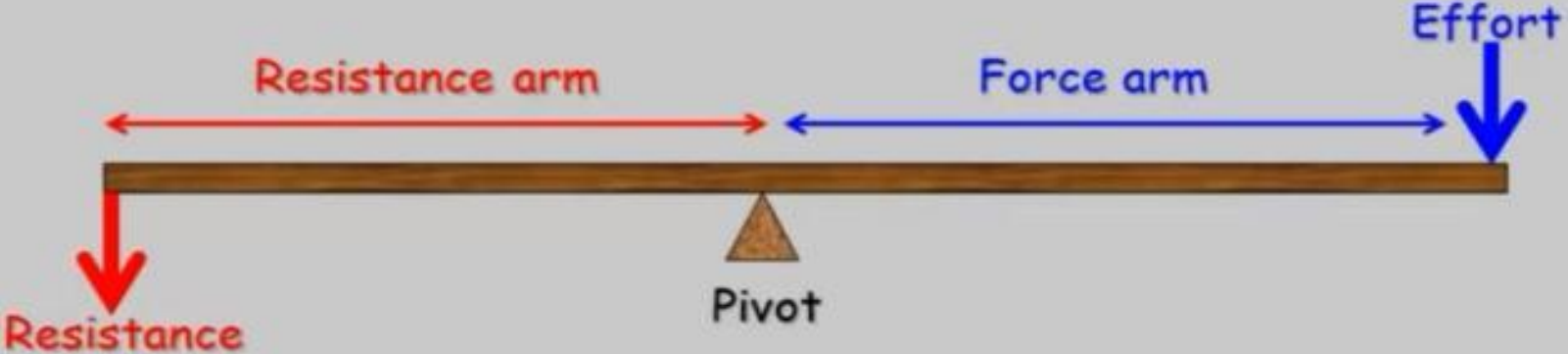
$$F = \Delta (mv) / \Delta t = 4 \times 15 / 0.002 = 3 \times 10^4 \text{ N}$$

The kind of levers in the body

- Many of the **muscle** and **bone** systems of the body act as levers.

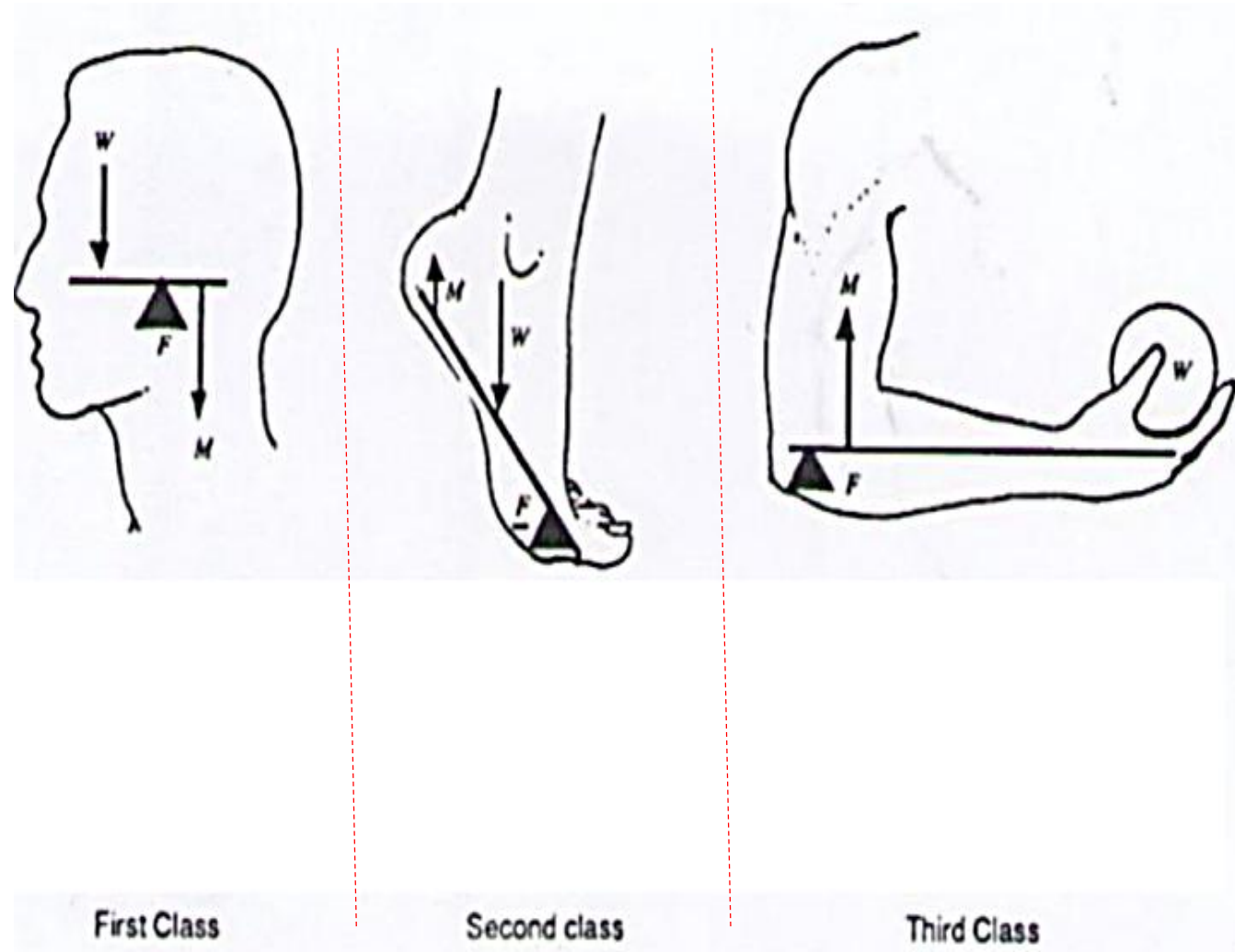
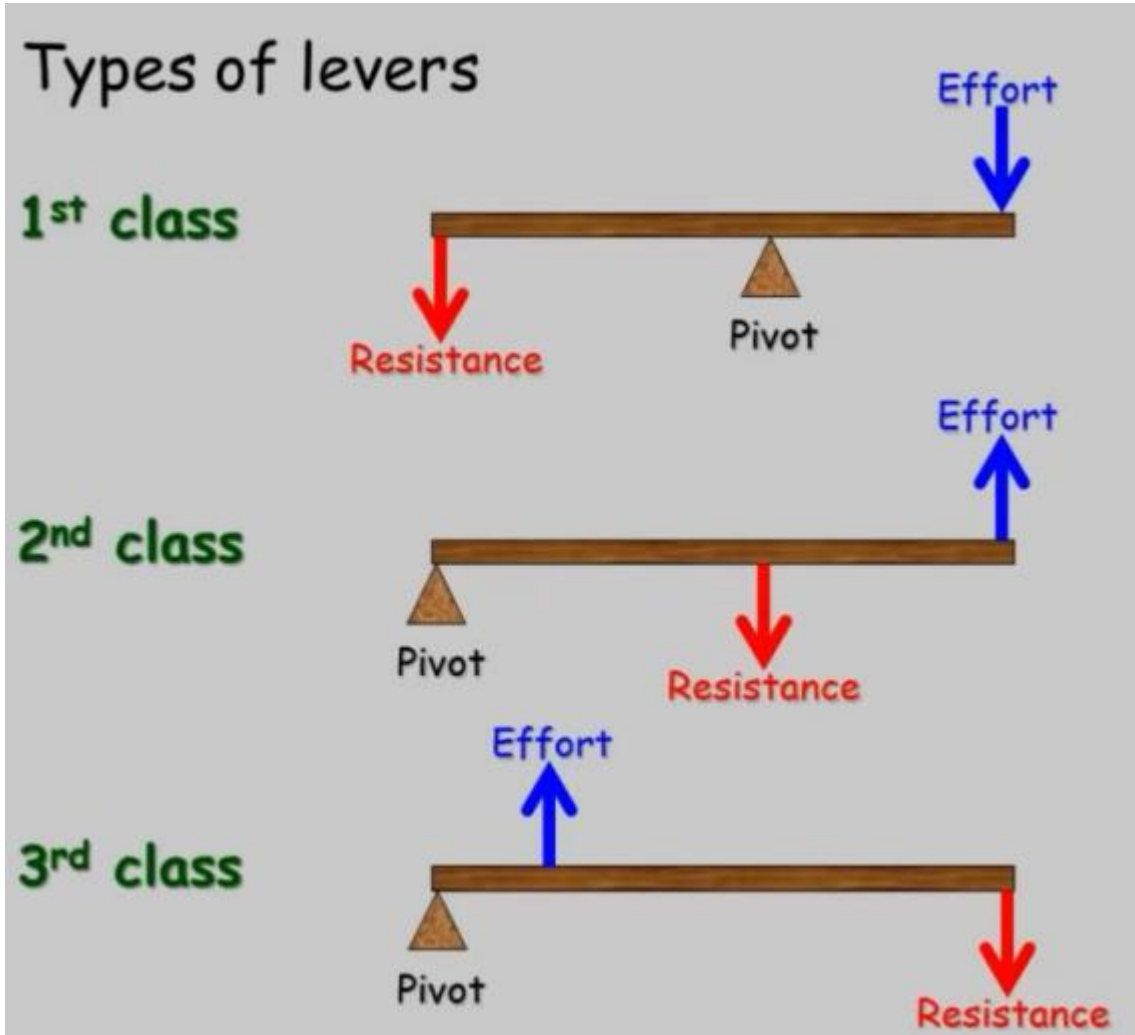
Definition and Uses of Levers

- Change the direction of the effort force.
- Increase force.
- Gain distance.



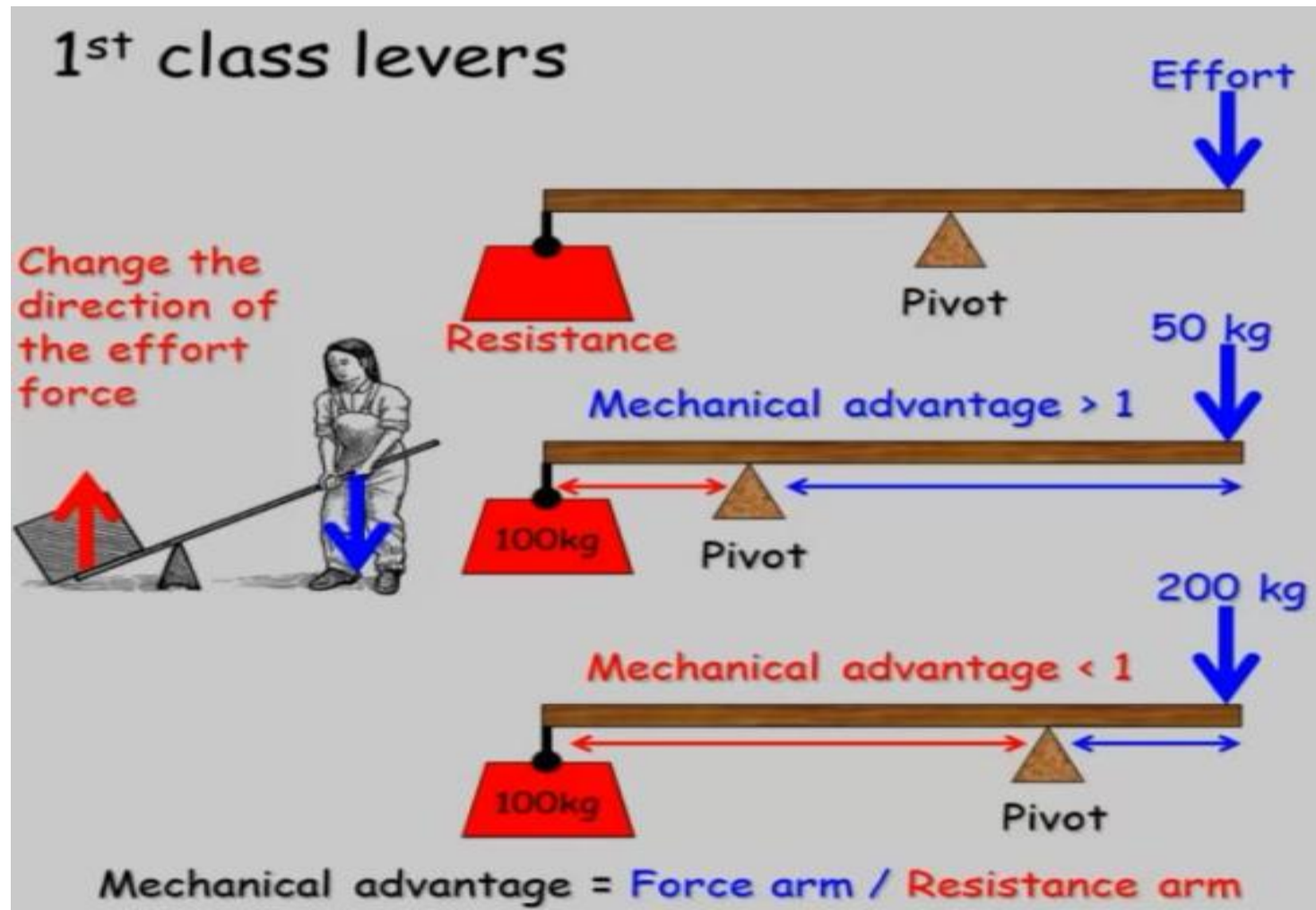
Equilibrium: $\text{Effort} \times \text{Force arm} = \text{Resistance} \times \text{Resistance arm}$
Mechanical advantage = $\text{Force arm} / \text{Resistance arm}$

The kind of levers in the body



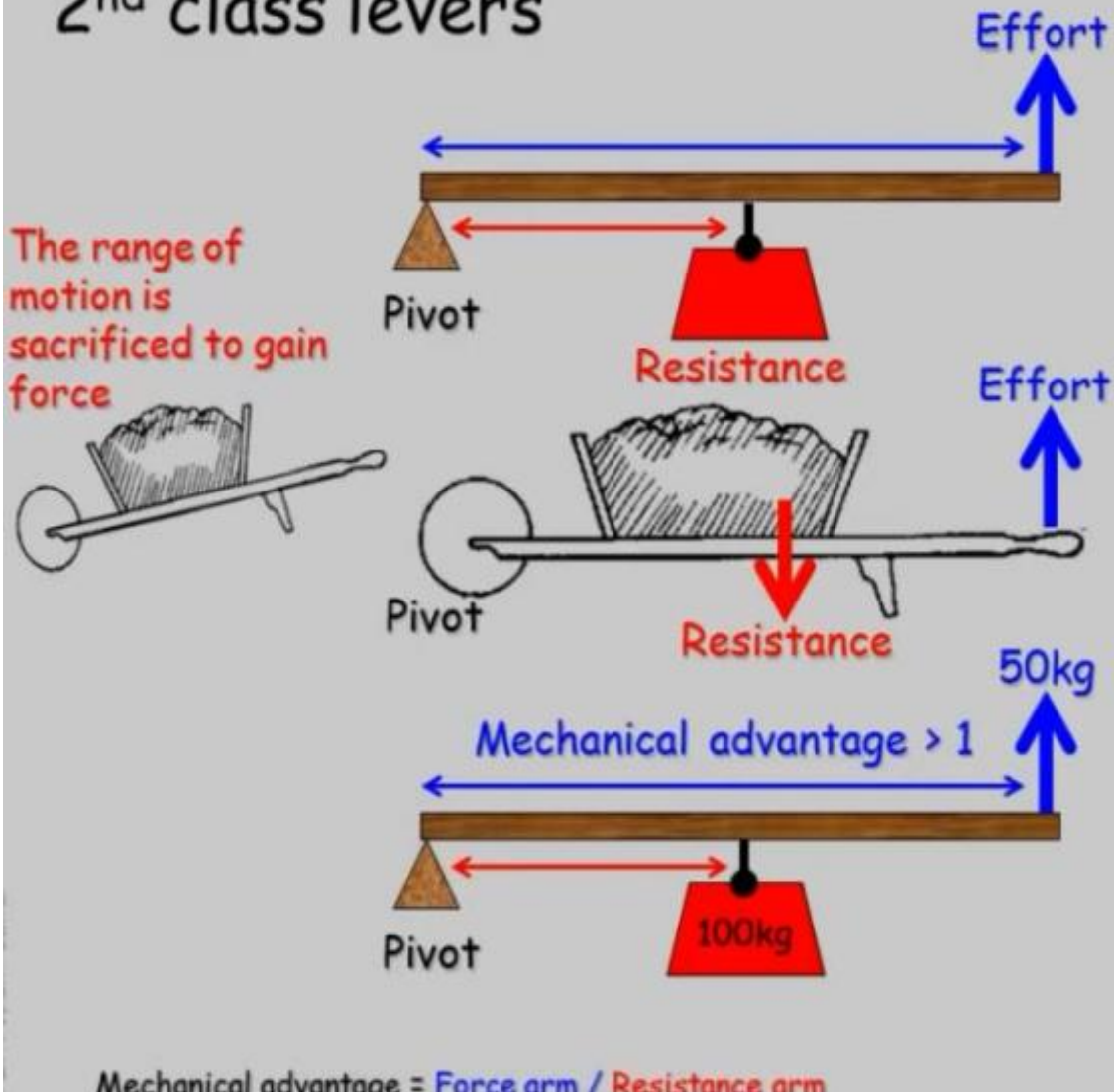
The kind of levers in the body

- In **first class lever**; the fulcrum **P** between the **resistance force W** (weight) and the **effort force** the muscle force **M**. In the head of human; **W** is the weight, **M** is the muscle force, **F** is the force at the fulcrum **P**.



The kind of levers in the body

2nd class levers



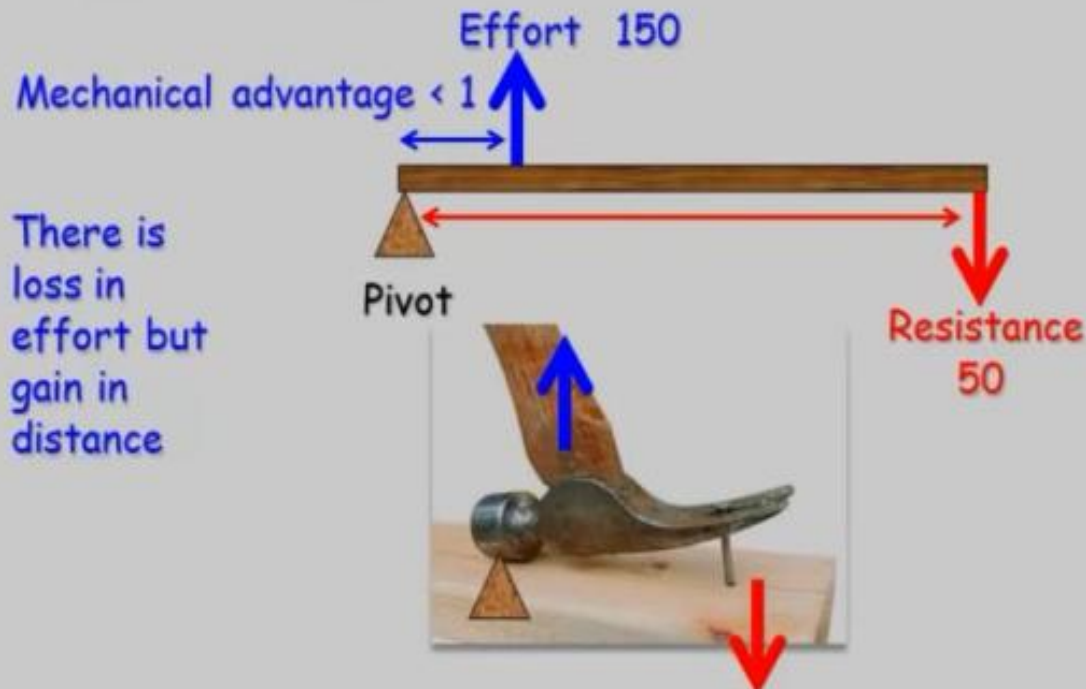
class levers Anatomical example



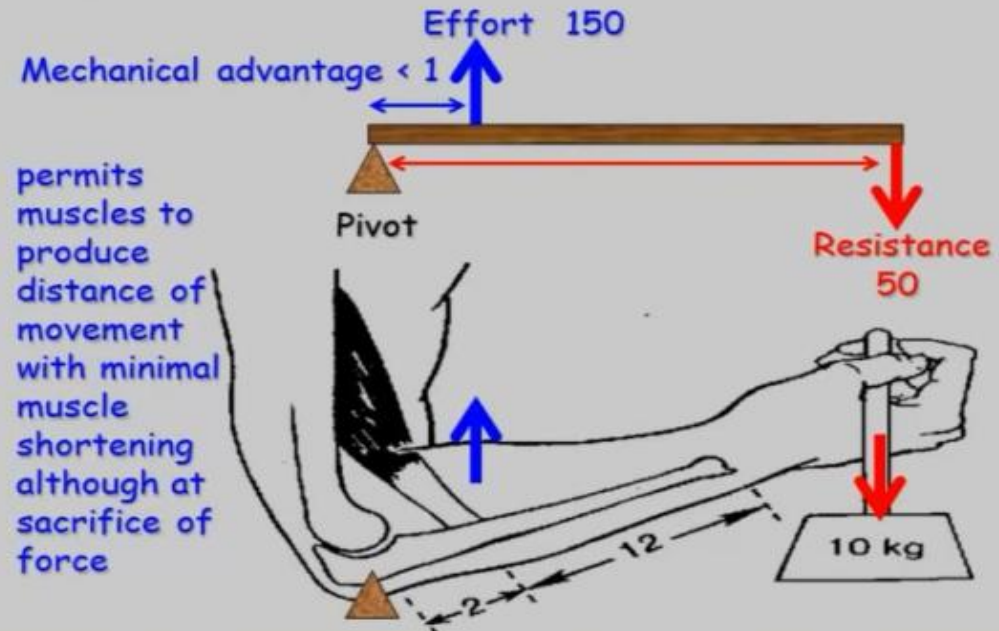
The kind of levers in the body

- In **third class lever**, the hand, the lever system in the body is the case of the biceps muscle and the radius bone acting to support a weight **W** in the hand. Where **R** is the **reaction force** of the humerus on the ulna, **M** is the muscle force supplies by the biceps, and **W** is the weight in the hand. The force and dimensions where the weight of the tissue and bones of the hand and arm **H** at their center of gravity.

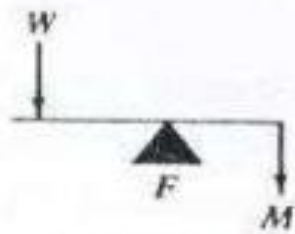
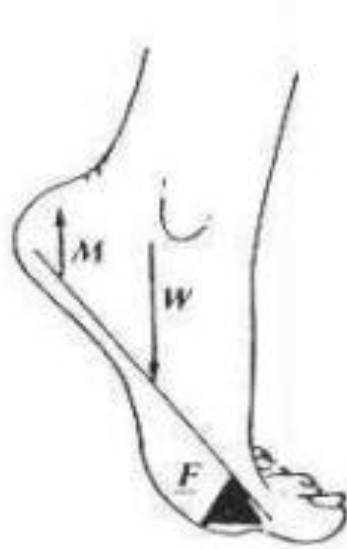
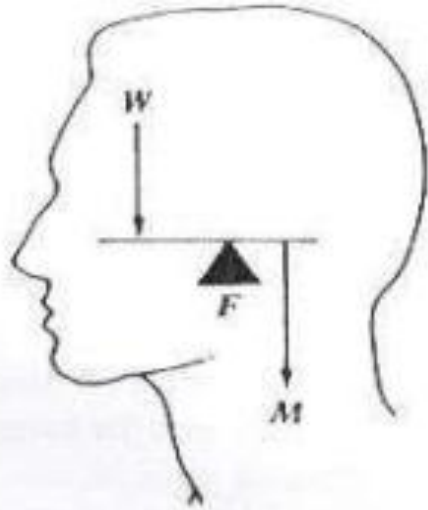
3rd class levers



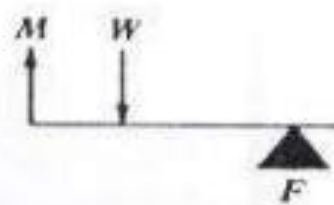
3rd class levers



3rd class levers are the most common levers in the body



First class



Second class



Third class

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.

Levers in Body

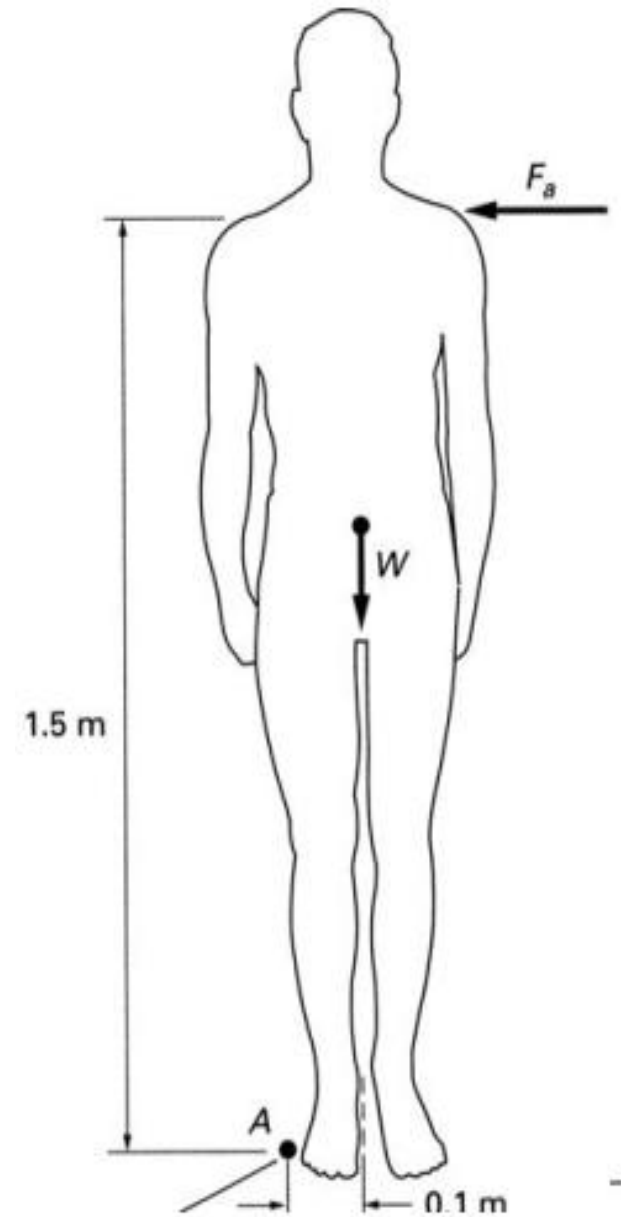
- ❖ In the absence of the force, the person is in **stable equilibrium** because his center of mass is above his feet, which are the base of support.
- ❖ The applied force F_a tends to topple the body.
- ❖ When the person topples, he will do so by pivoting around **point A**—assuming that he does not slide, and the mass m of the person is **70 kg**.
- ❖ The **counterclockwise torque** T_a about this point produced by the applied force is;

$$T_a = F_a \times 1.5 \text{ m}$$

- ❖ The **opposite restoring torque** T_w due to the person's weight is;

$$T_w = W \times 0.1 \text{ m}$$

- ❖ The **restoring torque produced by the weight** is therefore 68.6 N-m.



Levers in Body

The person is on the verge of toppling when the magnitudes of these two torques are just equal;

that is

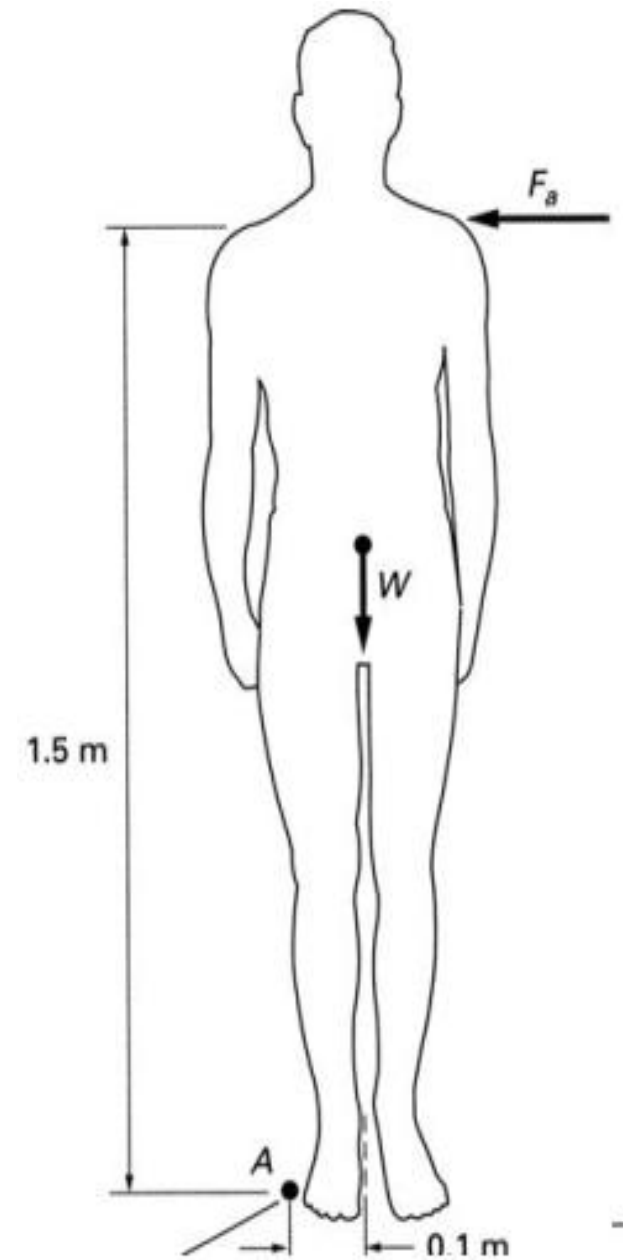
$$\mathbf{T_a = T_w}$$

Then,

$$\mathbf{F_a \times 1.5\ m = 68.6\ N.m}$$

Therefore, the force **required to topple an erect person** is:

$$\mathbf{F_a \times 1.5\ m / 68.6\ N.m = 45.7\ N}$$



- Actually, a person can withstand a much greater sideways force without losing balance by bending the torso in the direction opposite to the applied force as shown in **Fig. B**.
- Stability against a toppling force is also increased by spreading the legs, as shown in **Fig. C**

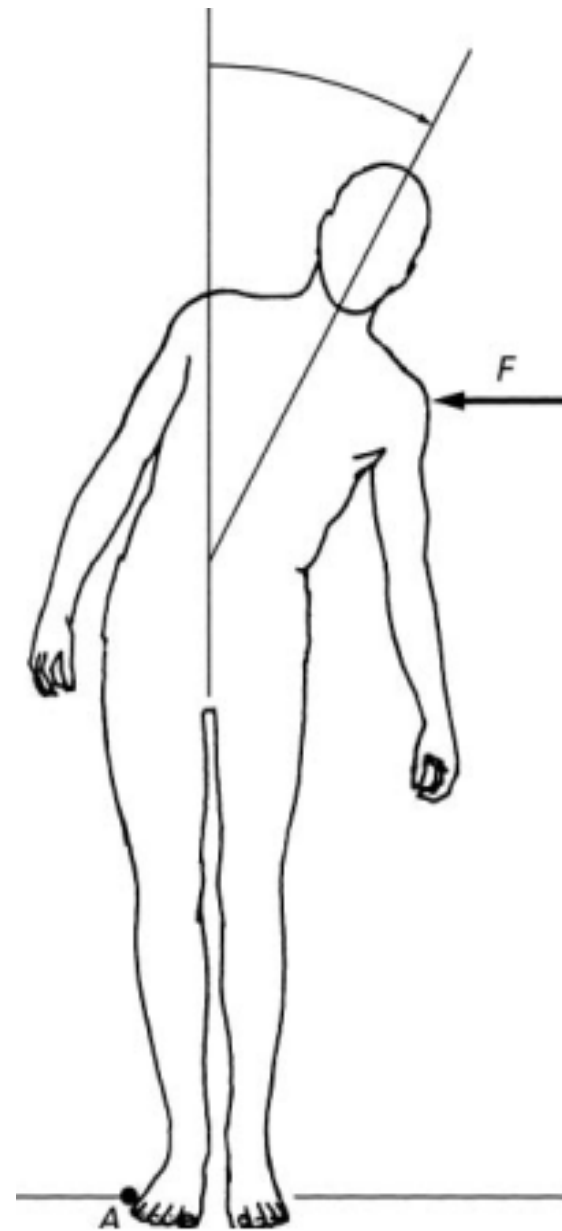


Fig. B

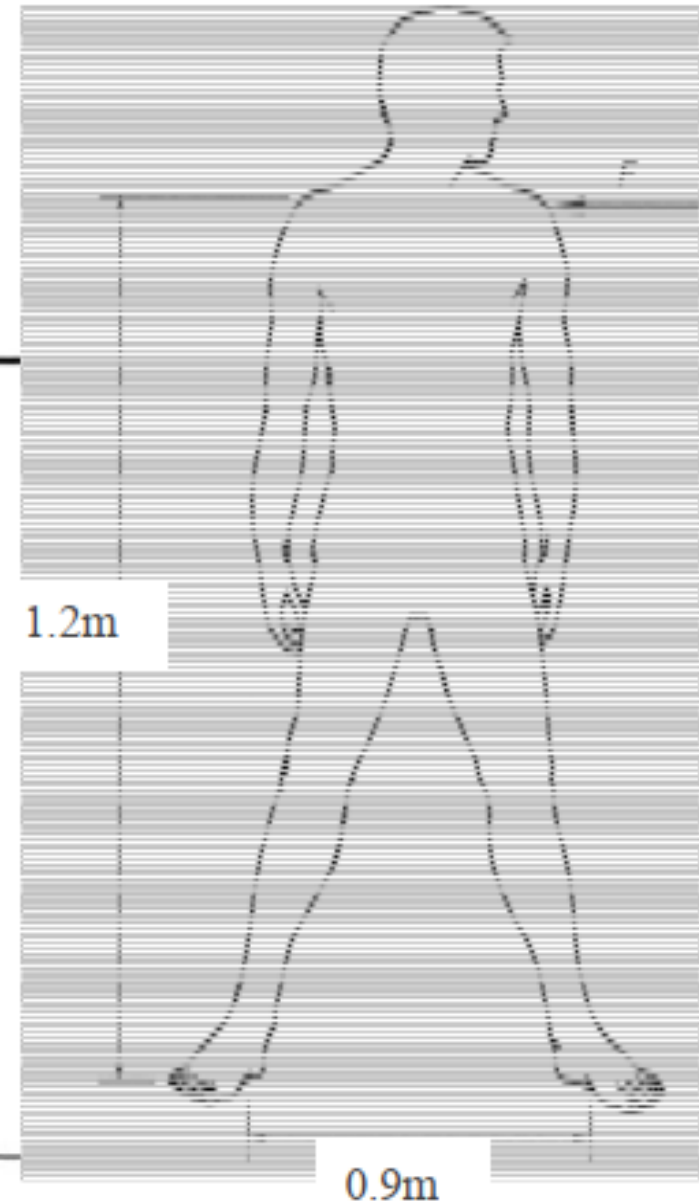


Fig. C

- A simplest class of the Levers in human body is the biceps muscle and radius bone acting to support a weight ($W = 20\text{ N}$) cached by hand,
- There are two torques (where **Torque = Force × distance**), one tend to rotate the arm in clockwise direction and the other tend to rotate in counter clockwise direction, such as:

$$\mathbf{T_{ccw} = T_{cw}}$$

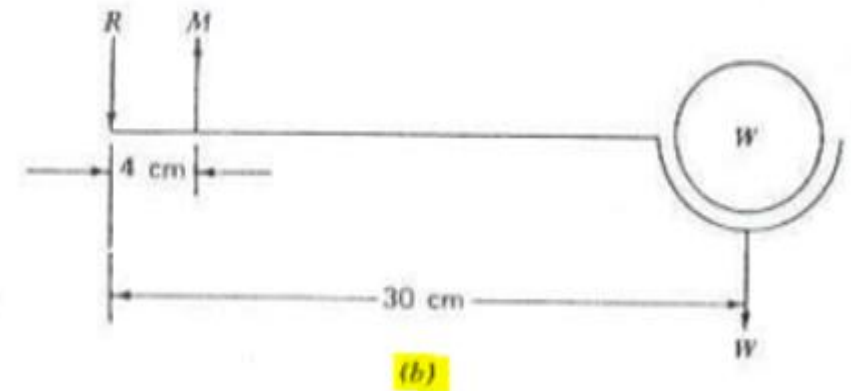
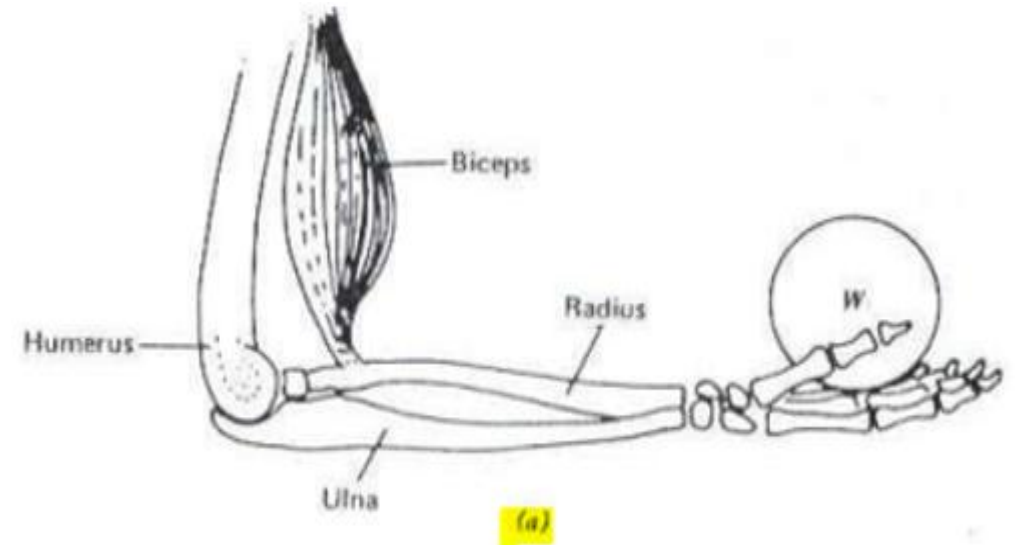
$$\mathbf{T_M = T_w}$$

Since the force M has distance 4cm for the joint, and the weight has distance 30cm form the joint, we have:

$$\mathbf{M \times 0.04 = W \times 0.3}$$

$$\mathbf{M \times 0.04 = 20 \times 0.3}$$

$$\mathbf{M = 15\text{ N}}$$



When we consider the weight of the arm as another force in last example, we have weight of the forearm and hand (which is force) called $H = 15\text{N}$, the center of gravity of the forearm and hand is at point has distance 14cm .

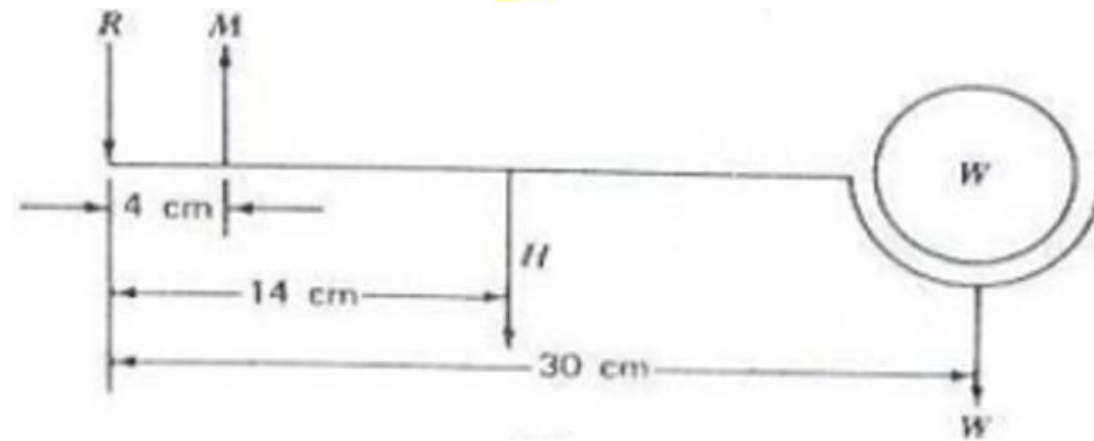
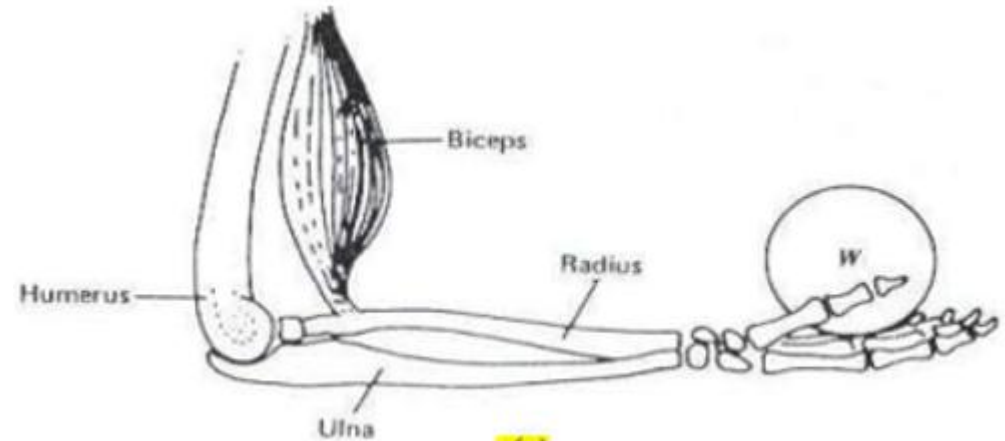
Therefore we have

$$\mathbf{T_{ccw} = T_{cw}}$$

$$\mathbf{T_M = T_w + T_H}$$

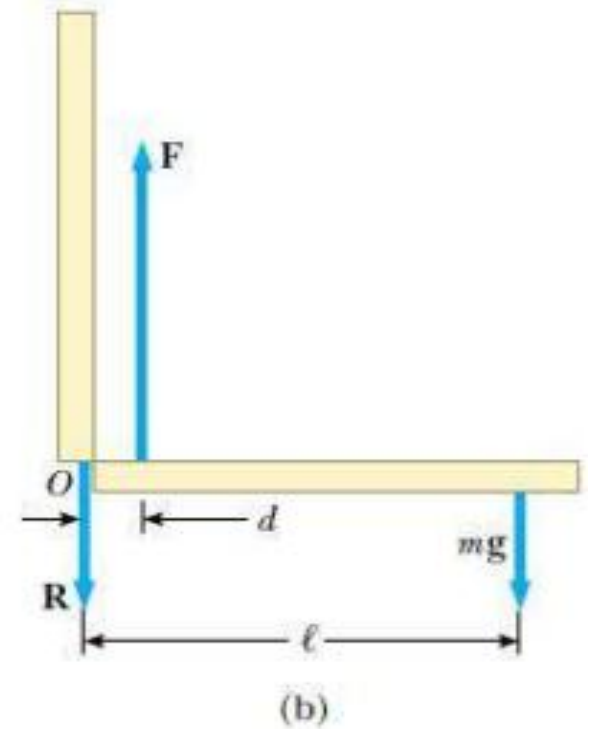
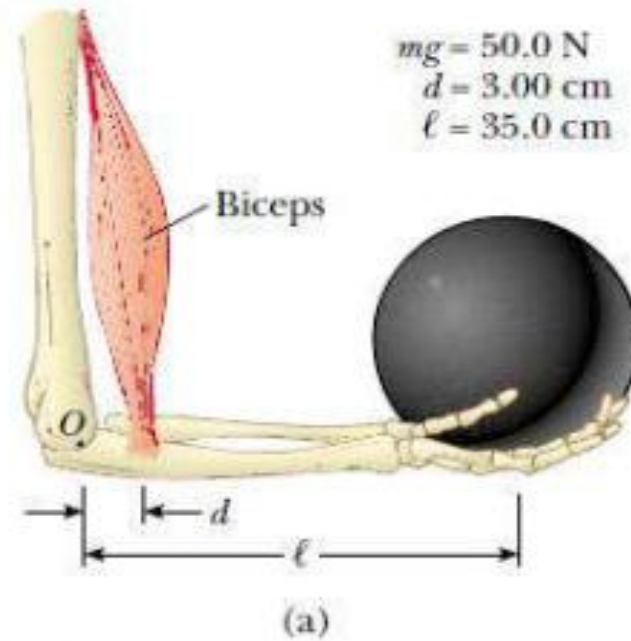
$$\mathbf{M \times 0.04 = W \times 0.3 + H \times 0.14}$$

$$\mathbf{M = 67.5\text{ N}}$$



Example A Weighted Hand

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



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

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

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

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

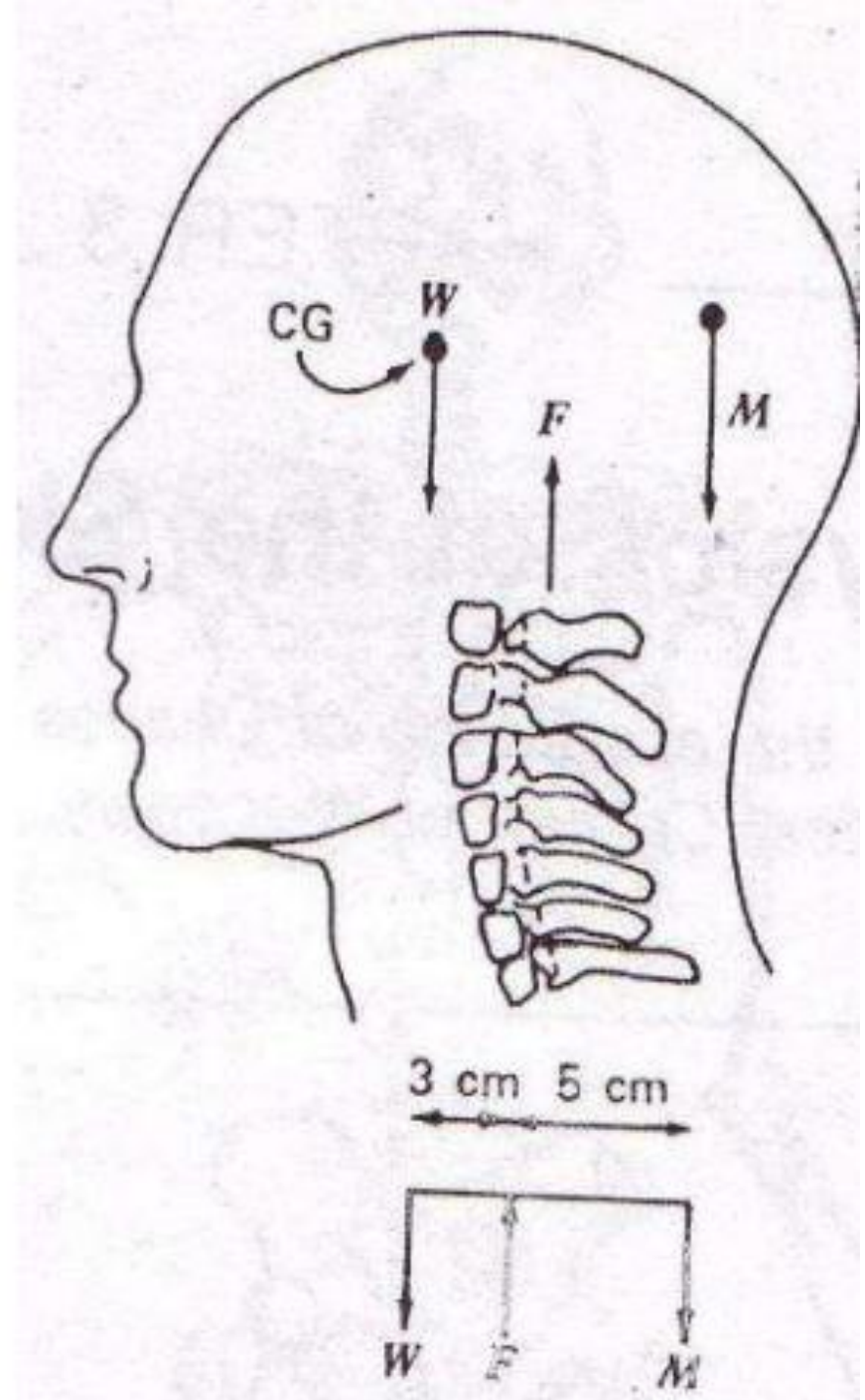
- ◆ This value for F can be substituted into to give $R = 533 \text{ N}$. As this example shows, the forces at joints and in muscles can be extremely large.

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.

- Find F and M .
- If the area of the first cervical vertebra, which the head rests on, is 5 cm^2 , find the stress on it.
- 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 ($1.7 \times 10^8 \text{ N/m}^2$).



Answer

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

The distance between F and M = 5 cm

$$M \times 0.05 = W \times 0.3$$

$$M = 0.6 W$$

W = 4 kg Or W = 40 N

M = 0.6 x 40 = 24 N

F = W + M = 64 N

(b) The stress is $64/5 \times 10^{-4}$

stress = $1.28 \times 10^5 \text{ N/m}^2$

The mass of body is 70 kg

The mass of head is 4 kg

In standing position = $70 - 4 = 66 \text{ kg}$

The stress = $66 \times 9.8 / 5 \times 10^{-4} = 1.3 \times 10^6 \text{ N/m}^2$

Which is less 1 % of the maximum compression strength .

QUESTION



Medical Physics

Lec.4: Work, Power & their applications

Dr. AQEEL SALIM

Dr. AQEEL SALIM

What are the 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.

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

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.

Energy: is the capacity to do work

- This notion makes sense even in a colloquial context:
 - hard to get **work** done when you are tired (low on **energy**).
 - **work** makes you tired: you've used up **energy**.
- The **energy** can be defined more precise by specifying exactly what we mean by **work**.

What is Energy?

- ❑ The idea of **energy** is a more abstract concept.
- ❑ An object which has a mass and velocity is described as having a **kinetic energy**.
- ❑ Similarly, an object which has a mass and is located at a certain point in a conservative force field is described as having a **potential energy**.
- ❑ **Energy** has several important properties, **and** the most important property of energy **is that** it is **conserved**.

Units of Energy

- ❖ **Force** is a mass times an acceleration:
 - ❑ mass has units of kilograms.
 - ❑ acceleration is m/s^2
 - ❑ **force** is then has $\text{kg}\cdot\text{m/s}^2$, which we call **Newton's (N)**
- ❖ **Energy** has the units : **Joules**

Some forms of energy

Mechanical Energy



Kinetic energy



Gravitational Potential Energy



Spring Potential Energy

Thermal Energy



Other forms include



Some forms of energy

Kinetic: Associated with **motion**

Translational kinetic energy results from motion of **center of mass**

$$K = \frac{1}{2}mv^2$$

Rotational kinetic energy results from **rotation about center of mass**

$$K_{\text{rot}} = \frac{1}{2}I\omega^2$$

Potential: Associated with **position** (having the *possibility* of moving)

Gravitational potential energy comes from the potential of **falling a height**

$$U_g = mgy$$

Elastic (spring) potential energy comes from the potential of **snapping back**

$$U_s = \frac{1}{2}k(\Delta x)^2$$

Thermal: Associated with microscopic motion of molecules

Typically arises from **friction** in this course

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.

$$K.E = \frac{1}{2} m v^2$$

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

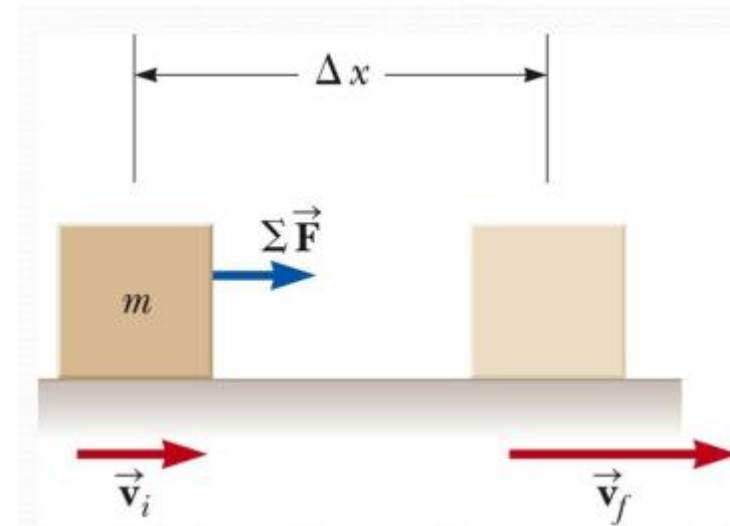
$$W_{ext} = \int_{x_i}^{x_f} \sum F dx = \int_{x_i}^{x_f} ma dx$$

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

$$W_{ext} = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$$

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

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

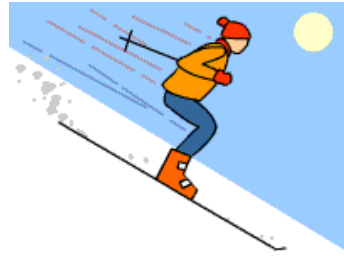


Kinetic Energy

- **Kinetic Energy**: is the energy of motion.
- Moving things carry energy in the amount:

$$K.E = \frac{1}{2} m v^2$$

- Note the v^2 dependence:
 - a car at 60 mph is 4 times **more dangerous than** a car at 30 mph
 - hurricane-force winds at 100 mph **are much more destructive** (4 times) **than** 50 mph gale-force winds
 - a bullet shot from a gun is at least 100 times **as destructive as** a *thrown* bullet, even if you can throw it a tenth as fast as you could shoot it



Numerical examples of kinetic energy

- A baseball (mass is 0.145 kg = 145 g) moving at 30 m/s (67 mph) has kinetic energy:

$$\begin{aligned} \text{K.E.} &= \frac{1}{2} \times (0.145 \text{ kg}) \times (30 \text{ m/s})^2 \\ &= 65.25 \text{ kg} \cdot \text{m}^2/\text{s}^2 \approx 65 \text{ J} \end{aligned}$$

- A quarter (mass = 0.00567 kg = 5.67 g) flipped about four feet into the air has a speed on reaching your hand of about 5 m/s. The kinetic energy is:

$$\begin{aligned} \text{K.E.} &= \frac{1}{2} \times (0.00567 \text{ kg}) \times (5 \text{ m/s})^2 \\ &= 0.07 \text{ kg} \cdot \text{m}^2/\text{s}^2 = 0.07 \text{ J} \end{aligned}$$

More numerical examples

- A 1500 kg car moves down the freeway at 30m/s (67 mph)

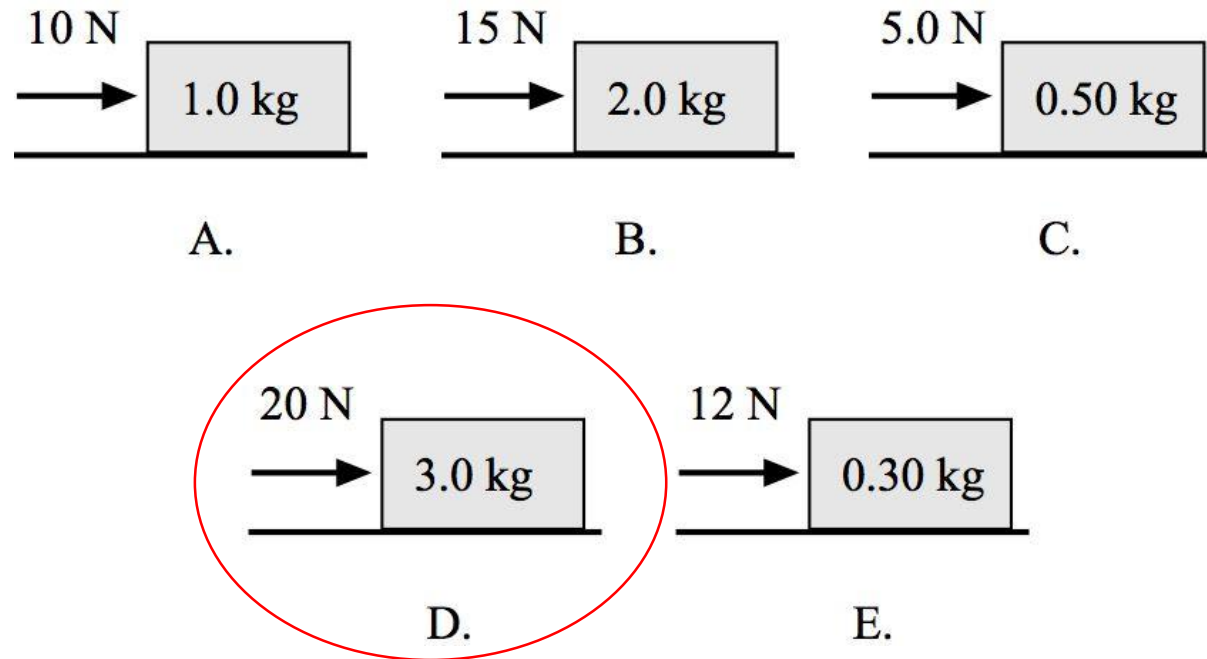
$$\begin{aligned} \text{K.E.} &= \frac{1}{2} \times (1500 \text{ kg}) \times (30 \text{ m/s})^2 \\ &= 675,000 \text{ kg} \cdot \text{m}^2/\text{s}^2 = 675 \text{ kJ} \end{aligned}$$

- A 2 kg (~4.4 lb) fish jumps out of the water with a speed of 1m/s (2.2 mph)

$$\begin{aligned} \text{K.E.} &= \frac{1}{2} \times (2 \text{ kg}) \times (1 \text{ m/s})^2 \\ &= 1 \text{ kg} \cdot \text{m}^2/\text{s}^2 = 1 \text{ J} \end{aligned}$$

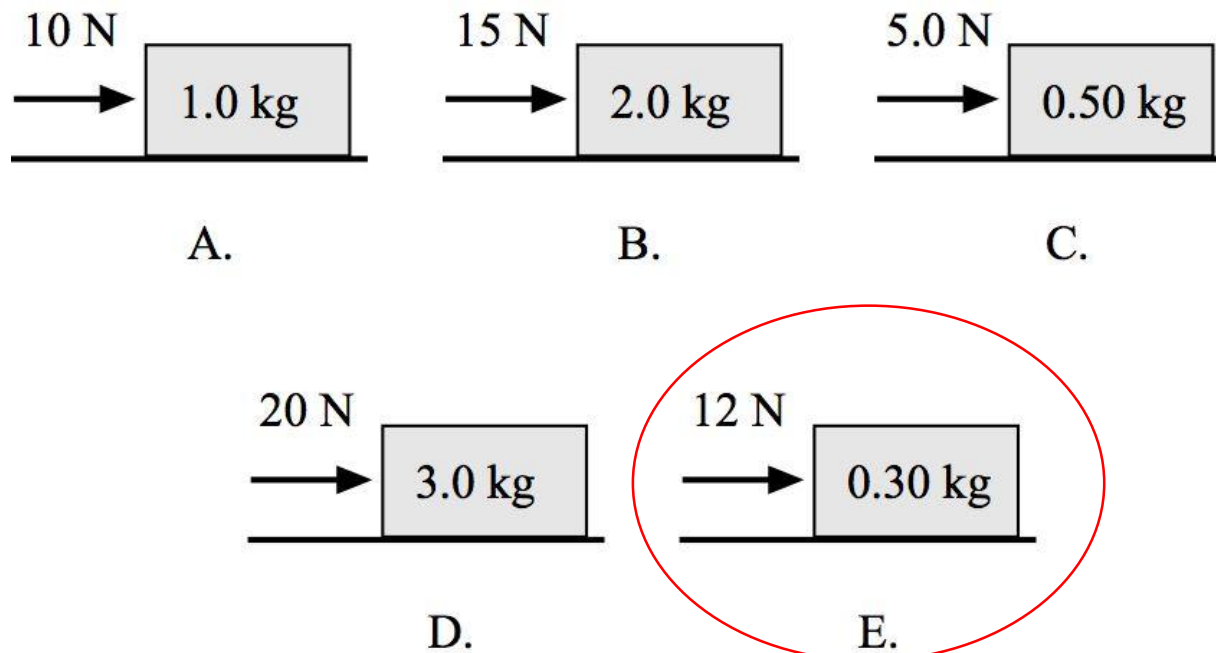
Check Your Understanding

Each of the boxes, with masses noted, is pulled for 10m across a level, frictionless floor by the noted force. Which box experiences the largest change in kinetic energy?



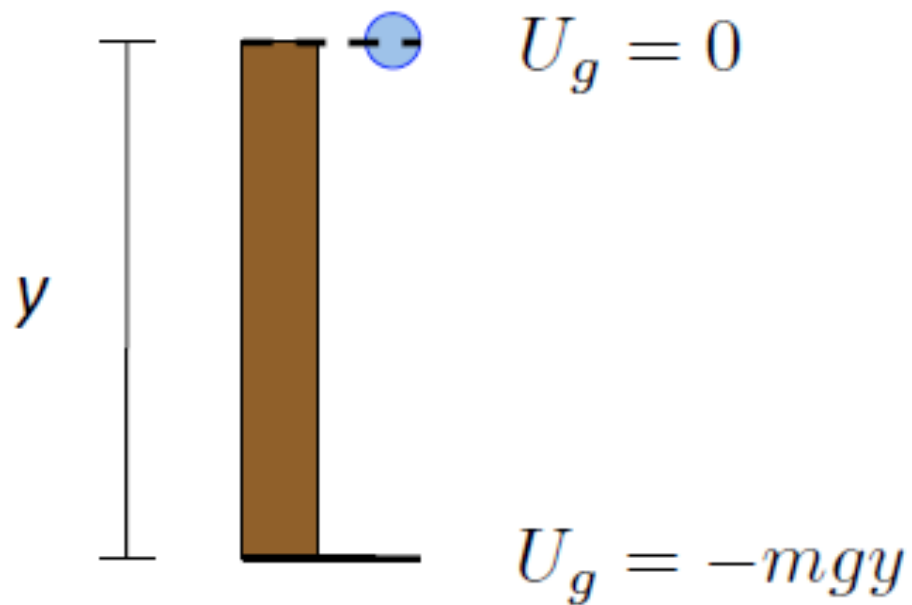
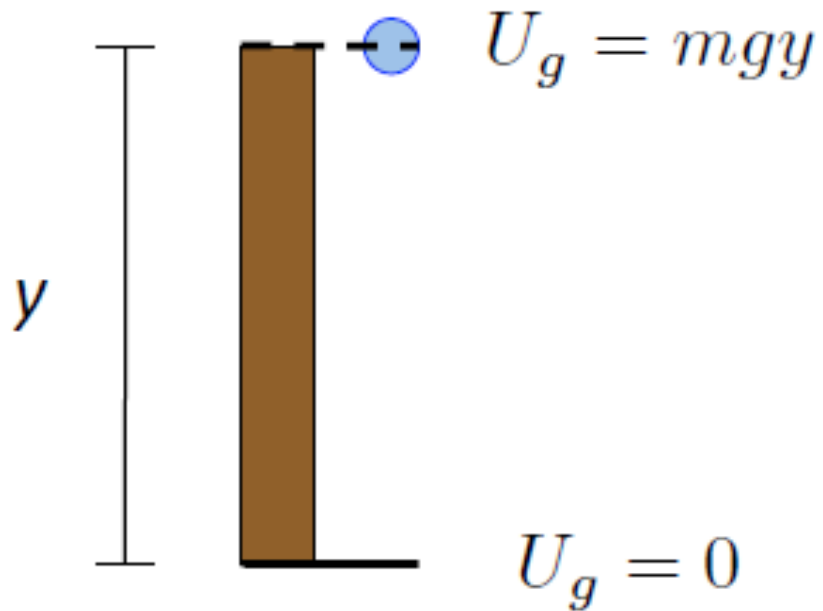
Check Your Understanding

Each of the boxes starts at rest and is then pushed for 2m across a level, frictionless floor by a rope with the noted force. Which box has the highest final speed?



Potential energy and reference levels

- ❑ The **potential energy** is a function of the height of an object.
- ❑ The level of **zero potential energy** can be arbitrarily defined, usually considered at the sea level or flat earth area.



Gravitational Potential Energy

- It takes *work* to lift a mass against the pull (force) of the gravity.
- The *force of gravity* is $m \cdot g$ where m is the mass, and g is the gravitational acceleration:

$$\mathbf{F} = \mathbf{m} \cdot \mathbf{g} \quad (\text{note the similarity to } \mathbf{F} = \mathbf{m} \cdot \mathbf{a})$$

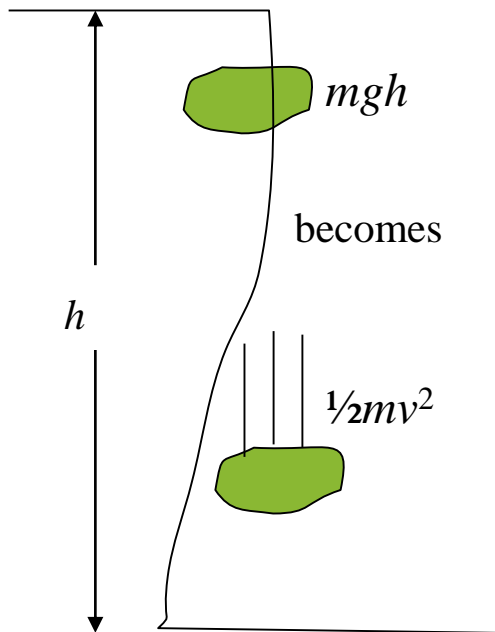
- $g = 9.8 \text{ m/s}^2$ on the surface of the earth.
- Lifting an object a height h against the gravitational force requires an energy input (work) of:

$$\Delta \mathbf{E} = \mathbf{W} = \mathbf{F} \cdot \mathbf{h} = \mathbf{m} \cdot \mathbf{g} \cdot \mathbf{h}$$

- Rolling a boulder up a hill and perching it on the edge of a cliff gives it *gravitational potential energy* that can be later released when the boulder is fall down.

First Example of Energy Exchange

- **When** the boulder **falls off** the cliff, the boulder picks up speed, and therefore gains **kinetic energy**.
- **Where does this energy come from??**
 - ⇒ from the **gravitational potential energy**
- The higher the cliff, the more kinetic energy the boulder will have when it reaches the ground,



Energy is conserved, so

$$\frac{1}{2}mv^2 = mgh$$

Can figure out $\rightarrow v$, since $v^2 = 2gh$

Examples of Gravitational Potential Energy

- How much gravitational potential energy does a 70kg high-diver have on the 10meter platform?

$$\begin{aligned}mgh &= (70 \text{ kg}) \times (10 \text{ m/s}^2) \times (10 \text{ m}) \\ &= 7,000 \text{ kg} \cdot \text{m}^2/\text{s}^2 = 7 \text{ kJ}\end{aligned}$$

- How massive would a book have to be to have a potential energy of 40J sitting on a shelf two meters off the floor?

$$\begin{aligned}mgh &= m \times (10 \text{ m/s}^2) \times (2 \text{ m}) = 40 \text{ J} \\ \text{so } m &\text{ must be } 2 \text{ kg}\end{aligned}$$

Example – Ball in Free Fall

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

Conceptualize: Use energy instead of motion

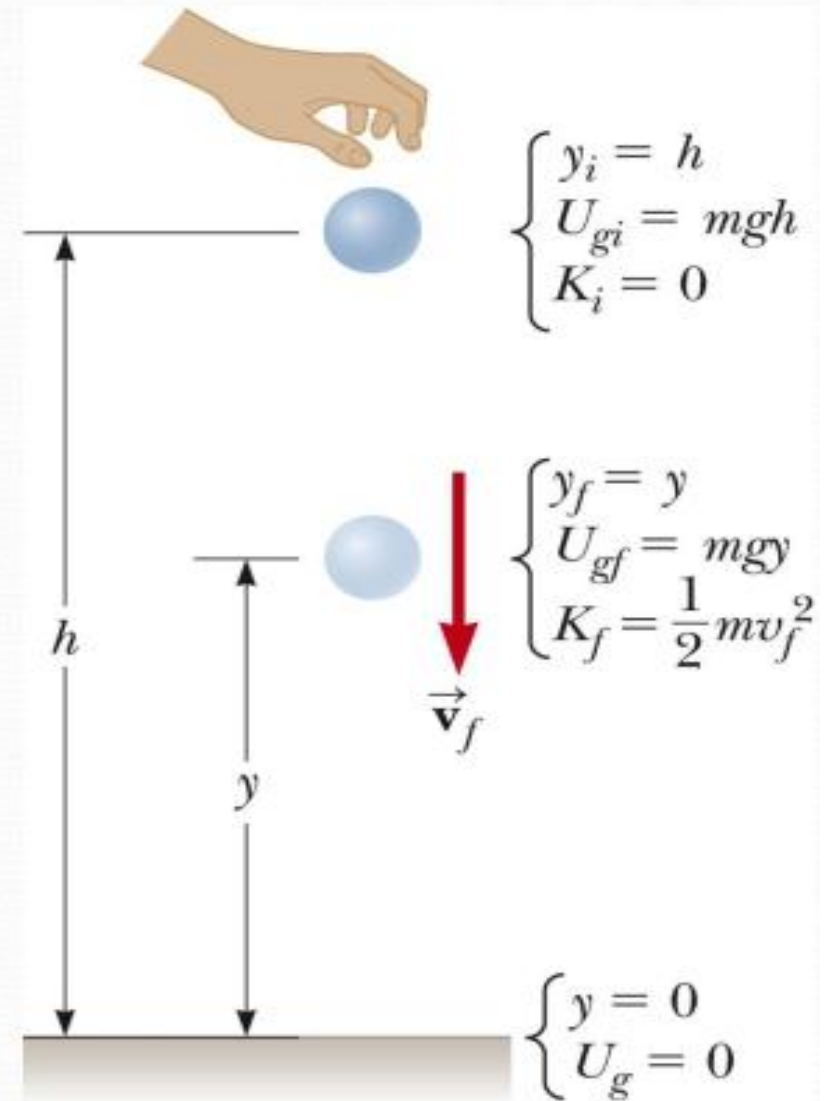
Categorize:

- 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 $v_f = \sqrt{2g(h - y)}$

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



The Energy of Heat



- **Hot things** have more energy than **cold things**.
- **Heat** is a **kinetic energy** on microscopic scales: **it means** the vibration or otherwise fast motion of individual atoms/molecules.
- Even though **heat is a kinetic energy**, **it is** hard to derive the same useful work out of it **because** the motions are ***random***.
- **Heat** is **quantified by calories** (or **Btu**):
 - One **calorie**: (4.184 J) energy need to raise **one gram** of H_2O a $1^\circ C$.
 - One **Calorie**: (4184 J) energy need to raise **one kilogram** of H_2O a $1^\circ C$.
 - One **Btu**: (1055 J) energy need to raise **one pound** of H_2O a $1^\circ F$.

Energy of Heat, continued

- Since water has a density of one gram per cubic centimeter, 1 cal heats 1 c.c. of water 1°C , and likewise, 1 kcal (Calorie) heats one liter of water 1°C .
- **Example:** What is the heat a 2-liter bottle of Coke from the 5°C refrigerator temperature to 20°C room temperature?
- **Answer:** it requires 30 Calories, or 122.5 kJ.
- **Food Calories** (with the “big” C) has units *Calorie* or kilocalories (*kcal*).

Chemical Energy

- **Electrostatic energy** (associated with charged particles, like electrons) is stored in the chemical bonds of substances.
- Rearranging these bonds can release energy.
- **Typically**, a one mole is equal to **6.022×10^{23} molecules/particles.**

Chemical Energy Examples

- Burning a **wooden match** (a match is about 0.3 grams) releases about one Btu, this is **3516.667 J/g**.
- Burning **coal** releases about 20kJ per gram of chemical energy, this is **4.78 Cal/g**.
- Burning **gasoline** releases about 39kJ per gram, this is **9.321 Cal/g**.

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.

1. **Work** – transfers energy by applying a force and causing a displacement of the point of application of the force.
2. **Mechanical Wave** – **transfers** energy by allowing a disturbance to propagate through a medium.
3. **Heat** – the mechanism of energy **transfer** that is driven by a temperature difference between two regions in space.
4. **Matter Transfer** – matter physically **crosses** the boundary of the system, carrying energy with it.
5. **Electrical Transmission** – energy **transfer** into or out of a system by electric current.
6. **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 lightbulb by *electromagnetic radiation*.



f

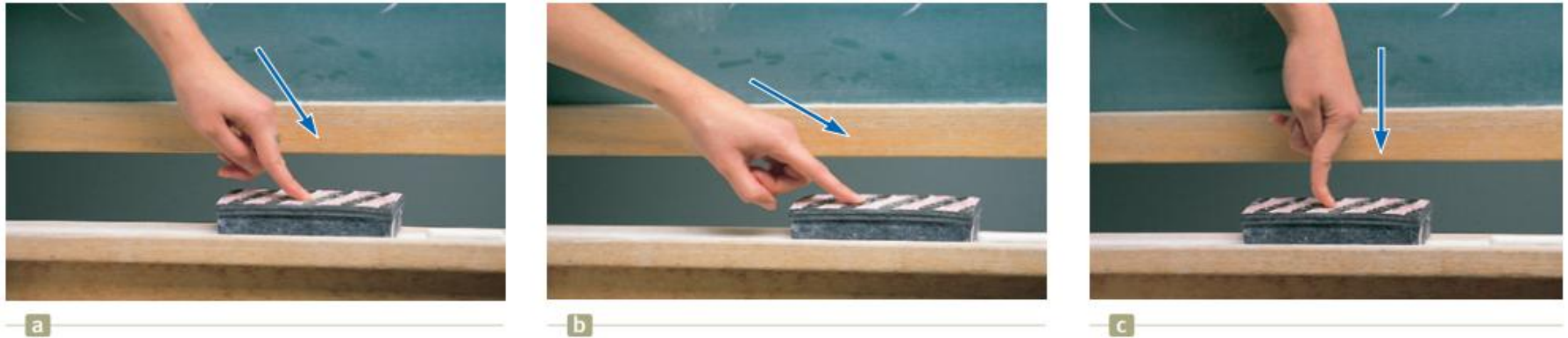
Introduction to Work

- ❑ When **energy** transfers across the boundary of a system, the amount of energy stored in the system changes.
- ❑ The **work** is a mechanism for transferring energy into or out of a system.
- ❑ One example of doing work on a system is that the system changes its speed: a common experience is to push on an object and observe it changing its state from rest to motion.

Introduction to Work

- ❑ **Work** is one process by which energy is transferred from one form to another.
- ❑ **Work** describes how much energy has changed from one form to another, and what sort of process was involved.
- ❑ **For example**, a falling object gains kinetic energy and loses potential energy, and this transformation occurs because the gravitational field of the Earth does work on the object to accelerate it.

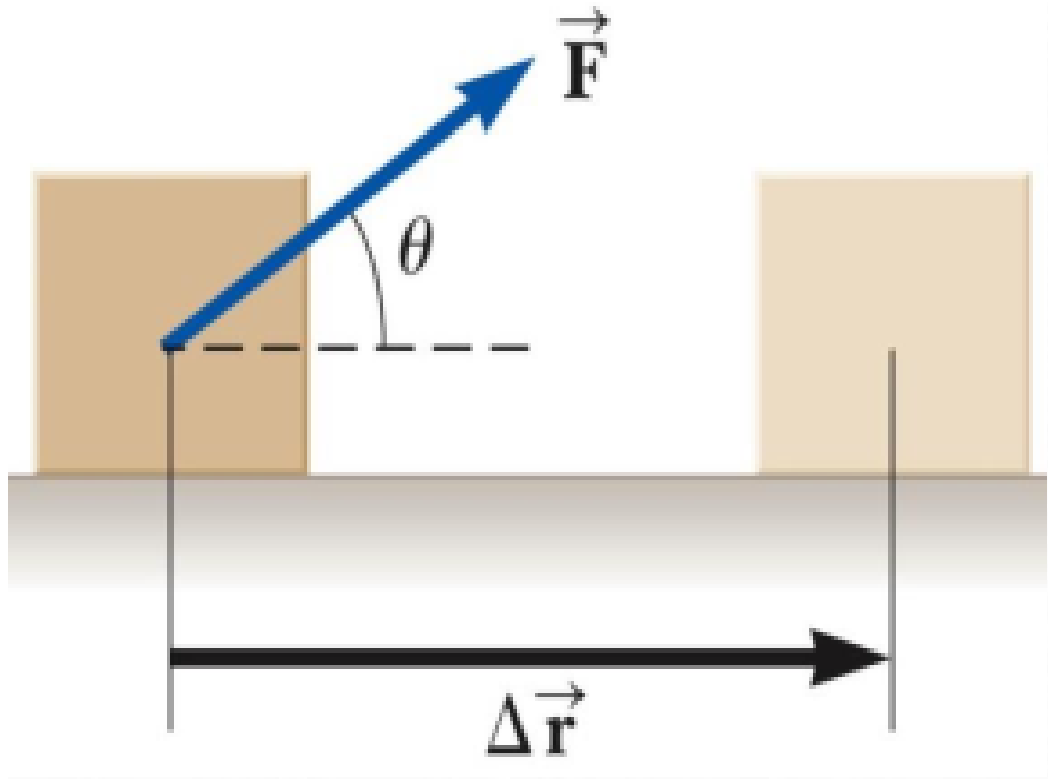
Introduction to Work



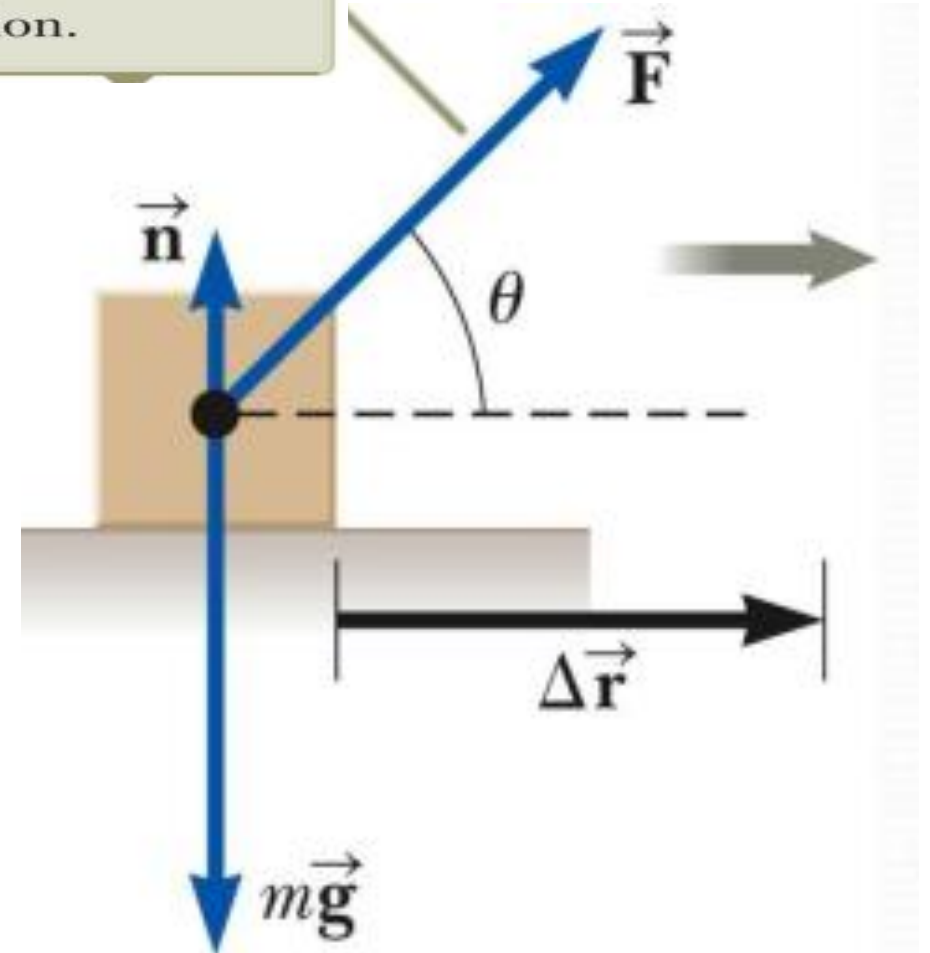
To understand what work as an influence on a system means to the physicist, consider the situation illustrated in Figure above. A force is applied to a chalkboard eraser, which we identify as the system, and the eraser slides along the tray. If we want to know how **effective the force** is in moving the eraser, we must consider not only the magnitude of the force but also its direction. Notice that the finger in the Figure above applies forces in three different directions on the eraser. Assuming the magnitude of the applied force is the same in all three photographs, the push applied in **Figure-b** is more effective in moving the eraser than the push in **Figure-a**.

On the other hand, **Figure-c** shows a situation in which the applied force **does not move** the eraser at all, regardless of how hard it is pushed. **These results suggest that** when analyzing forces to determine the influence they have on the system, we must consider the vector nature of forces. We must also consider the magnitude of the force.

Work done by a constant force



\vec{F} is the only force that does work on the block in this situation.



Work: more than just unpleasant tasks

- **Work** is the application of a *force through a displacement*:

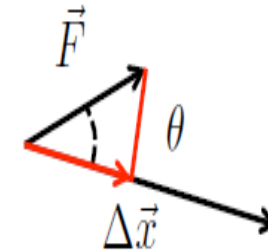
$$W = \vec{F} \cdot \overrightarrow{\Delta x}$$

➤ **W** is the *work* done,

➤ **F** is the *force* applied,

➤ **Δx** is the *displacement* through which the force acts.

- **NOTE:** Only the force that acts in the direction of motion counts towards work.

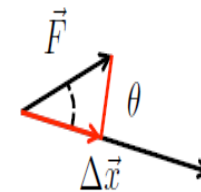


Picks off the component of F parallel to Δx .

Work Definition

□ The **work** (**W**) done on a system by a force is calculated as the product of the magnitude **F** of the **force**, the magnitude Δx of the **displacement** of the point of application of the force, and **cos(θ)**, **where θ** is the **angle** between the force and displacement vectors:

$$W = F \Delta x \cos \theta$$

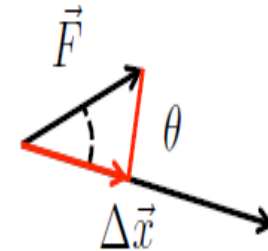


Picks off the component of F parallel to Δx .

Work done by a constant force

- **Work** done on an object by a constant force applied to the object **is defined to be** the product of the force and the displacement of the object in the direction of the force.
- For an object that moves only in the **x-direction**, work done is:

$$W = \vec{F} \cdot \overrightarrow{\Delta x}$$



Picks off the component of F parallel to Δx .

- The **force** and **displacement** are **vectors**. Then:

$$W = |\vec{F}| |\overrightarrow{\Delta x}| \cos \theta$$

The ability to do work is called **Energy** of the system (unit of both work and energy – Joule (J))

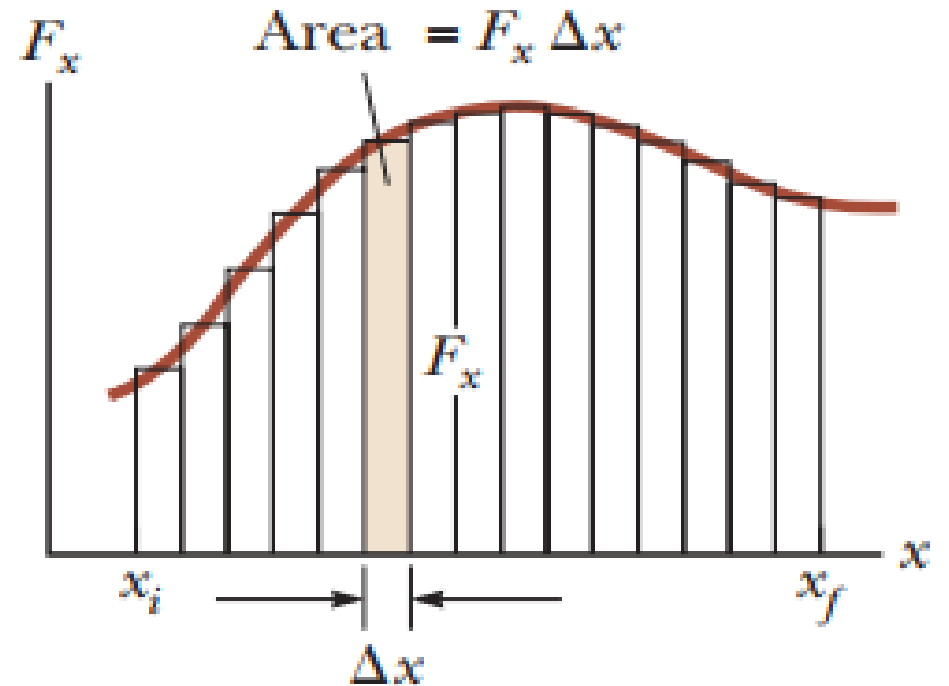
Work Done by a Varying Force

- Now consider a object being displaced along the x-axis under the action of a **force** that varies with position.
- In such a situation, we can not use previous equation to calculate the work done by the force **because** this relationship applies only when \vec{F} is **constant** in **magnitude** and **direction**.

Work Done by a Varying Force

- The red-brown curve shows a varying force applied on an object that moves from **initial position** x_i to **final position** x_f .
- Imagine a object undergoing a very small displacement Δx , shown in the figure. The x – component F_x of the force **is approximately** constant over this small interval; for this small displacement.
- Then, we can approximate the work done on the object by the force.

The total work done for the displacement from x_i to x_f is approximately equal to the sum of the areas of all the rectangles.



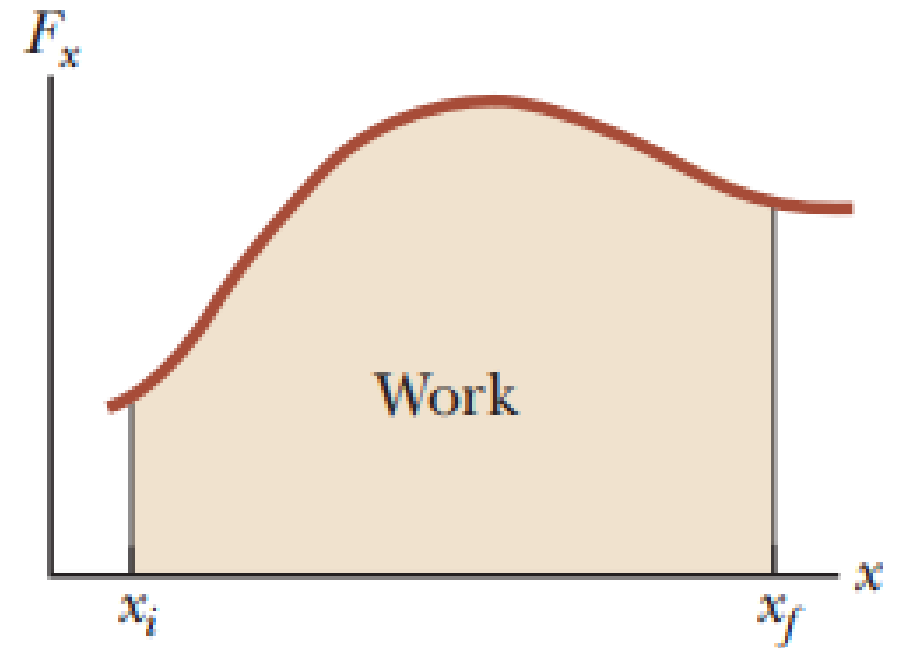
Work Done by a Varying Force

- If the F_x versus x curve is divided into a large number of such intervals, the total work done for the displacement from x_i to x_f is approximately equal to the sum of a large number of such terms:

$$W \approx \sum_{x_i}^{x_f} F_x \Delta x$$

$$W = \int_{x_i}^{x_f} F_x dx$$

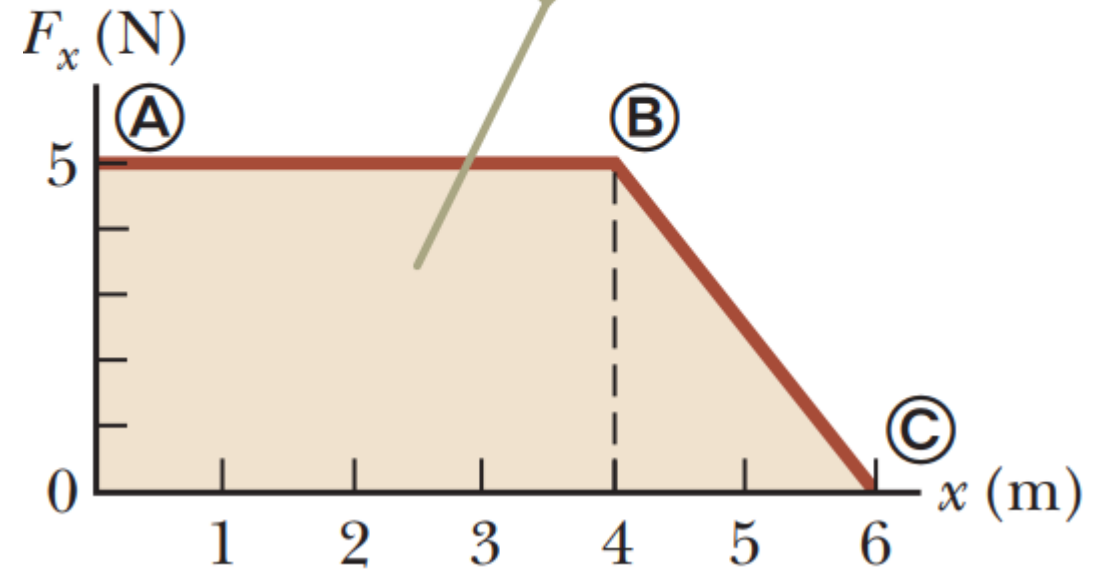
The work done by the component F_x of the varying force as the particle moves from x_i to x_f is *exactly* equal to the area under the curve.



Calculating Total Work Done from a Graph

- Consider the force varies during the motion of the particle, as shown in figure at side.
- We have work done by varying forces.
- In this case, the graphical representation in figure can be used to evaluate the work done.

The net work done by this force is the area under the curve.



Evaluate the area of the rectangle:

$$W_{\text{A to B}} = (5.0 \text{ N})(4.0 \text{ m}) = 20 \text{ J}$$

Evaluate the area of the triangle:

$$W_{\text{B to C}} = \frac{1}{2}(5.0 \text{ N})(2.0 \text{ m}) = 5.0 \text{ J}$$

Find the total work done by the force on the particle:

$$W_{\text{A to C}} = W_{\text{A to B}} + W_{\text{B to C}} = 20 \text{ J} + 5.0 \text{ J} = 25 \text{ J}$$

Units of Work

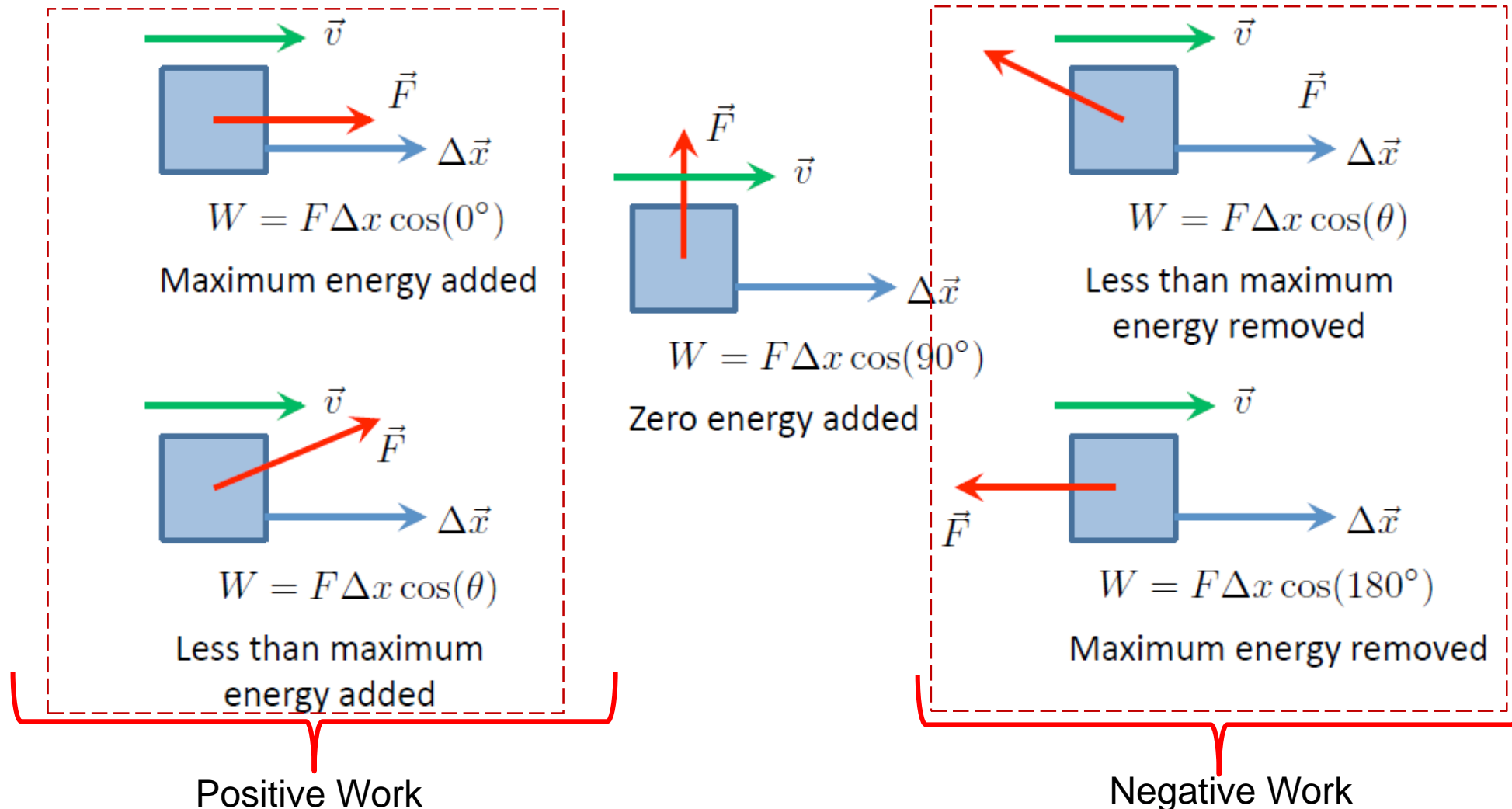
- The **units** of **work** are those of force multiplied by those of length.
- Therefore, the SI unit of **work** is a force times a displacement: units are then $(\text{kg}\cdot\text{m}/\text{s}^2)\cdot\text{m} = \text{kg}\cdot\text{m}^2/\text{s}^2 = \text{N}\cdot\text{m} = \text{Joules(J)}$.
- **One joule** is an one Newton of force acting through one meter.
- **Imperial units** of force and distance are pounds and feet, so unit of **Work** is **foot-pound**, which equals to 1.36J

Positive and Negative Work

- ❑ If W is the **work** done on a system and W is **positive**, energy is transferred to the system.
- ❑ If W is **negative**, energy is transferred from the system.
- ❑ Therefore, if a system interacts with its environment, this interaction can be described as a transfer of energy across the system boundary.
- ❑ The result is a change in the energy stored in the system.

Positive and Negative Work

The direction of the force applied **relative to** the displacement of the object determines **whether positive or negative** work is done.



Work and Energy

- It is difficult to define **energy**, other than to say that it is a physical quantity that is conserved.
- When a physical process occurs, **energy** is transferred across the boundary of a system.
- **Work is a scalar quantity.**
- The **normal force** and the **gravitational force** do no work on the object, since $\cos 90^\circ = 0$.

Work-Energy Theorem

Work done by a force on a system **is equal to** the change in mechanical energy of the system

$$W = \Delta E$$

$$W = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \dots$$

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.

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

Power

- The definition of work does not refer in any way to the time taken for the work to be done.
- **For example**, the amount of **work** is done by a runner who sprints up a hill is the same **work** done by a pedestrian who walks slowly up the hill, stopping regularly for rests.
- The **rate** at which work is done is also an important quantity.
- The rate at which work is done is the **power**.
- **Power** is the time rate of energy transfer.

Power

- The **power** is defined to be the amount of work done divided by the time it takes to do this work:

$$\text{Power} = \frac{\text{work done}}{\text{time taken}}$$

$$P = \frac{W}{\Delta t}$$

Δt is to indicate that we are specifically interested in the time taken to do the work.

The SI unit of **power** is the **watt**, which has the symbol **W**.

$$1 \text{ watt} = 1 \text{ joule/s}$$

Power

- Since the power is the work done per second, **we rewrite such that**: the work is the force multiplied by the distance, and use the fact that the velocity is the distance divided by the time:

$$P = \frac{W}{\Delta t} = \frac{Fd}{\Delta t} = F \frac{d}{\Delta t}$$

$$P = Fv$$

If **an** object is moving at constant velocity **while** a force is being applied to it (such as when there is an opposing force) then last equation will be useful.

Power numerical examples

- **Power is simply** the energy exchanged per unit time, or how fast you get work done (**Watts = Joules/sec**)
- **One horsepower = 745 W**
- Perform 100J of work in 1s, and call it 100W.
- Run upstairs, raising your 70kg (~700 N) mass 3m (2,100 J) in 3 seconds → 700W output!
- How much power does it take to lift 10kg up 2m in 2seconds?

$$mgh = (10 \text{ kg}) \times (10 \text{ m/s}^2) \times (2 \text{ m}) = 200 \text{ J}$$

$$200 \text{ J in 2 seconds} \rightarrow 100 \text{ Watts}$$

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 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.

Conservation of Energy in the Body

□ Conservation of energy in the body can be written as:

Change in stored energy = Heat lost from the body [in the body (food energy)] + 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**.

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 physiological unit of food energy is Kilocalories .

The unit of heat production = Kcal/minute \rightarrow **1 Kcal =4184 J**

Power = Joule / second = Watts

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

1 Met = 50 Kcal /hour per m² of the body surface area

Metabolic rate (MR)

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

$$1 \text{ Met} = 50 \text{ Kcal /hour per m}^2 \rightarrow 58 \text{ watts/m}^2$$

$$1 \text{ Met (for men)} = 107 \text{ watts}$$

$$1 \text{ Met (for women)} = 81.2 \text{ watts}$$

Metabolic rate: is the rate of oxidation. In oxidation process within the body heat is released as energy of metabolism.

Metabolic rate (MR)

Basal Metabolic Rate (BMR): is the lowest rate of energy consumption, or is the amount of energy needed to perform minimal body functions 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 1C° ,**there is a** change of about 10% in the metabolic rate.

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):

$$\text{Efficiency (} \epsilon \text{)} = \text{Work done / Energy consumed}$$

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.

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

Solved problems

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 ?

$$\text{External work} = m g h = 70 \times 9.8 \times 45$$

$$\text{since } 1 \text{ kcal} = 4.2 \times 10^3 \text{ J}$$

$$\begin{aligned} \text{External work} &= \frac{70 \times 9.8 \times 45}{4.2 \times 10^3} \\ &= 7.3 \text{ kcal} \end{aligned}$$

$$\begin{aligned} \text{calories needed} &= \frac{7.3 \text{ kcal}}{\text{efficiency}} = \frac{7.3}{0.15} \\ &= 49 \text{ kcal} \end{aligned}$$

Solved problems

A student eats a dinner rated at 2000 (food) Calories. He wishes 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 $2 \times 10^6 \text{ cal}$.

Converting this to joule, then the work required is

$$W = 2 \times 10^6 \text{ cal} \times 4.186 \text{ J/cal} = 8.37 \times 10^6 \text{ J}$$

QUESTION



Medical Physics

Lec.5: Electricity

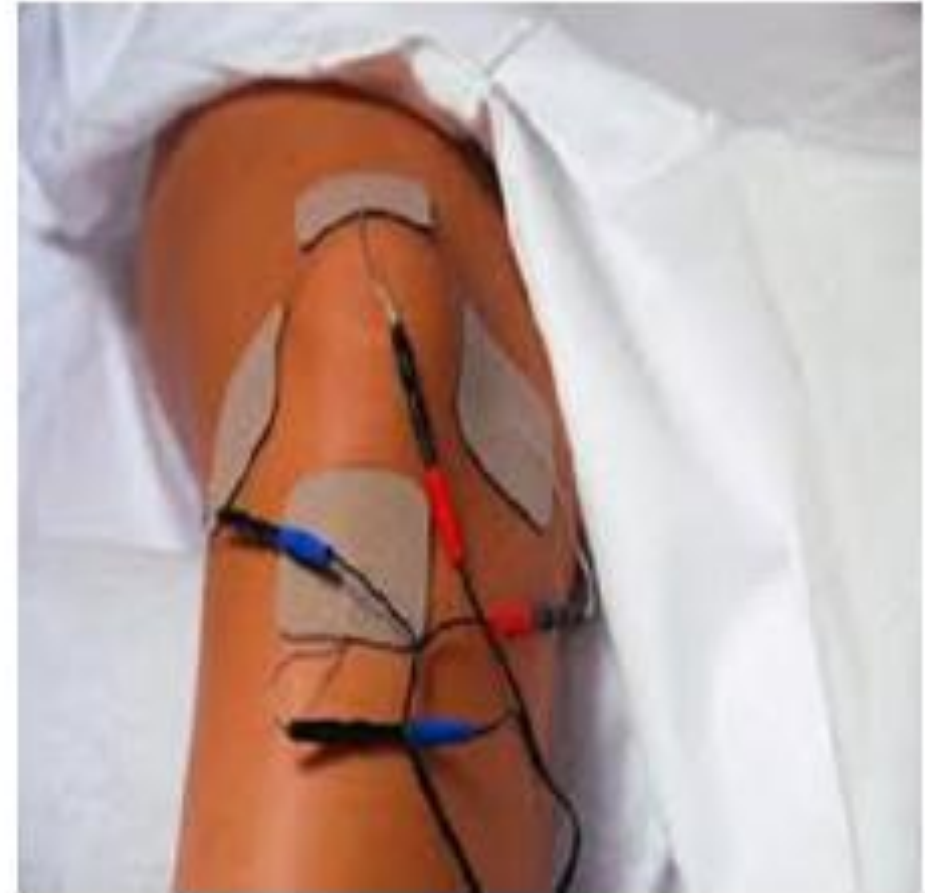
Dr. AQEEL SALIM

Learning Outcomes

By the end of this Lecture the student will be able to:

- ✓ Define the most common terminology related to electricity.
- ✓ Differentiated between different current types
- ✓ Categorize various waveforms and pulse characteristics
- ✓ Discuss the various treatment parameters that must be considered with electrical stimulation
- ✓ Explain current flow through various types of biological tissue.
- ✓ Explain muscle and nerve response to electrical stimulation.
- ✓ Enumerate the indications & contraindication of electrical stimulation.
- ✓ Be able to create a safe environment when using electrical equipment.

Why we study electricity ?



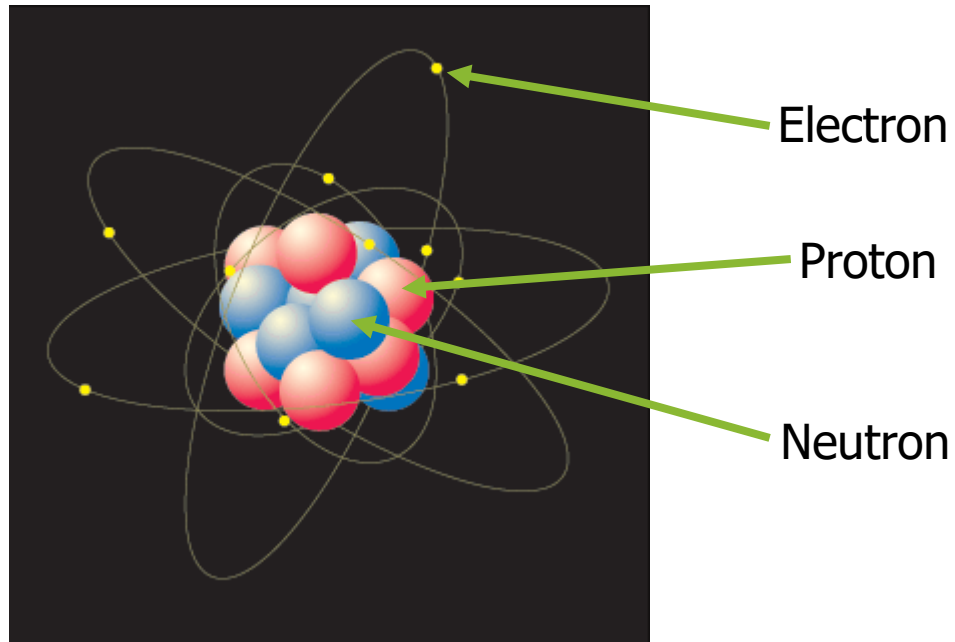
Electricity in Nature & daily life

- The most dramatic natural electrical phenomenon is **lightning**.
- **Static electricity** examples (*balloons, comb & paper, shock from a door knob*).
- Uses—photocopying, ink-jet printing.

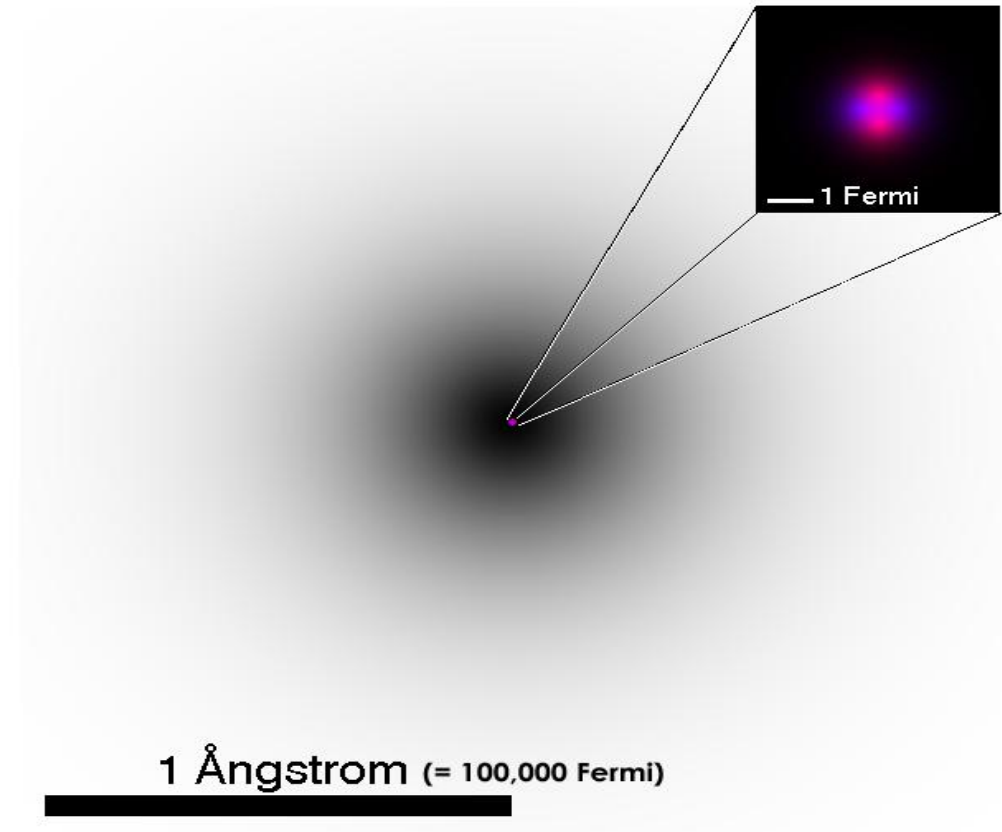


The Atom

- We know that **all atoms are made of** positive charges in the nucleus, surrounded by a cloud of tiny electrons.



Proton charge $+e$, electron charge $-e$
where $e = 1.602 \times 10^{-19} \text{ C}$



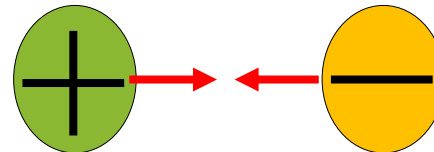
More accurate picture of the atom—the
Helium atom

Forces Between Charges

Like charges **repel** to each other



Opposite charges **attract** to each other



Electrical Stimulation Related Terms

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.

The electric charge, q , is said to be quantized.

The SI unit of charge is the **coulomb** (C).

- Electric charge exists as discrete packets.
- We will use the symbol q or Q for charge

$$q = \pm Ne$$

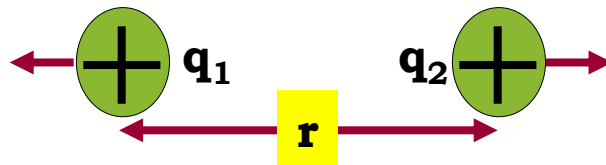
- N is an integer
- e is the fundamental unit of charge
- $|e| = 1.6 \times 10^{-19}$ C
- Electron: $q = -e$
- Proton: $q = +e$

Electric Force and Coulomb's Law

- We can measure the force of attraction or repulsion between charges q_1 and q_2



- This **force** is directly proportional to each of the charges' values, and the **force** is inversely proportional to the distance between them, **and** the **force** is directed along the line between them (i.e., along r).



Electric Force and Coulomb's Law

- The magnitude of the force is $F = k \frac{|q_1||q_2|}{r^2}$ where k is some constant of proportionality.
- This **force law** was first studied by **Coulomb** in 1785, and is called **Coulomb's Law**.
- The constant $k = 8.98755 \times 10^9$ N.m²/C² is the Coulomb constant.

Electric Force and Coulomb's Law

- **Example:** two point charges of electrons placed at distance 1cm from each other, calculate the net force on them?

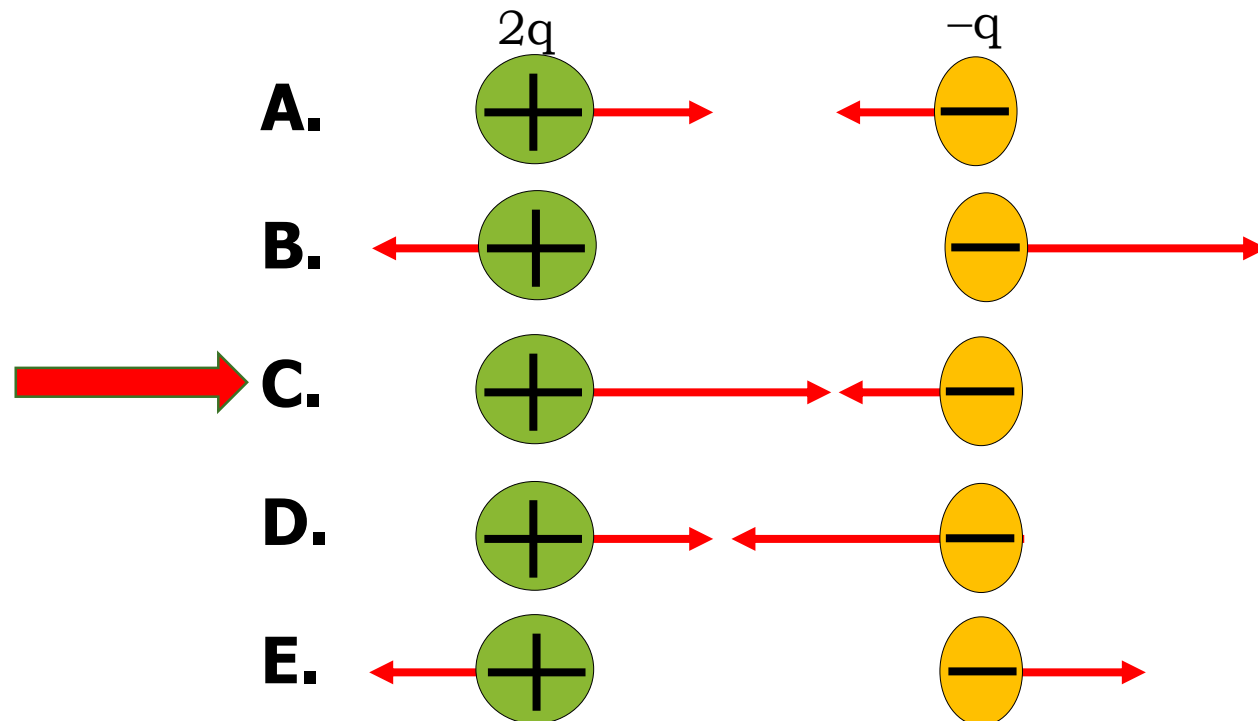
- Sol: use $k = 8.98755 \times 10^9$ N.m²/C² and

$$F = k \frac{|q_1||q_2|}{r^2}$$

- then $F = 23 \times 10^{-25}$ N

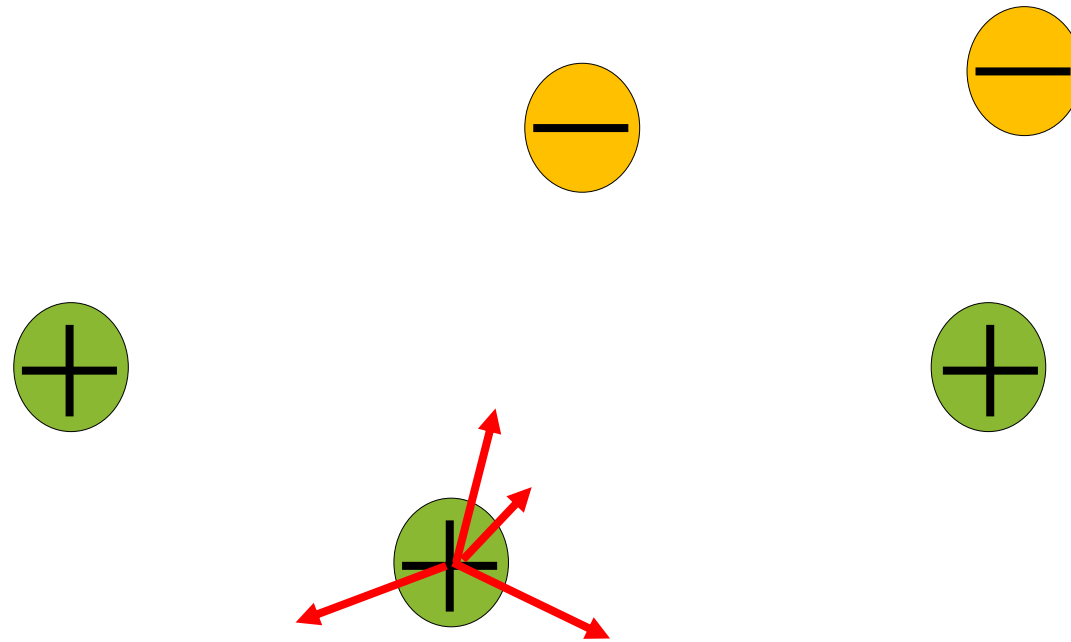
Example

Two small spheres are charged with equal and opposite charges, and are placed 30 cm apart. Then the charge on sphere-1 is doubled. Which diagram below could be considered to show the correct forces?



Case of Multiple Charges

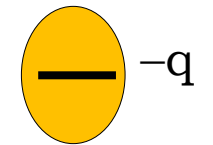
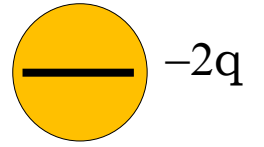
- You can determine the force on a particular charge, **by adding up** all of the forces from each charge.



Forces on one a charge due to number of other charges

Example

Where do you have to place the + charge in order for the force to balance, in the figure at right?



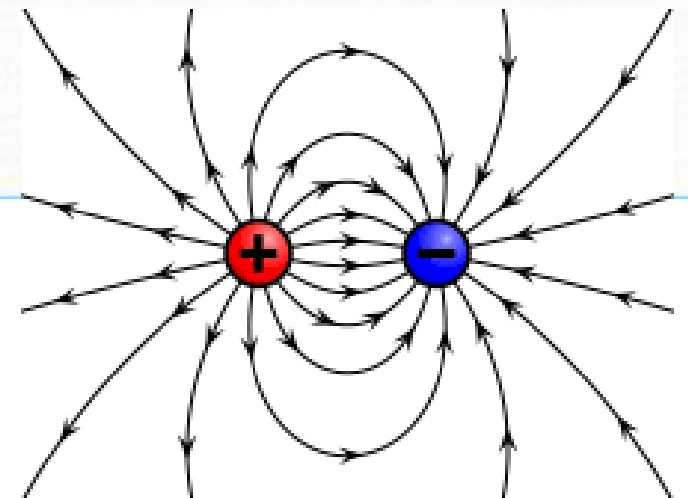
- A. Cannot tell, because + charge value is not given.
- B. Exactly in the middle between the two negative charges.
- C. On the line between the two negative charges, but closer to the $-2q$ charge.
- D. On the line between the two negative charges, but closer to the $-q$ charge.
- E. There is no location that will give force balance.

Electrical Stimulation Related Terms

Electrical 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{E} , at a point in space is defined as the electric force acting on a positive test charge, q_0 , placed at that point divided by the test charge:
- The SI units of \vec{E} are N/C.

$$\vec{E} = \frac{\mathbf{F}_e}{q_0} = k_e \frac{q}{r^2} \hat{r}$$



Electric Force and Coulomb's Law

- **Example:** two point charges of electrons placed at distance 1cm from each other, calculate the electric field of one of them?
- Sol: use $k = 8.98755 \times 10^9$ N.m²/C² and $F = k \frac{|q_1||q_2|}{r^2}$
- then $F = 23 \times 10^{-25}$ N
- Then $E = 14 \times 10^{-6}$ N/C

Capacitors

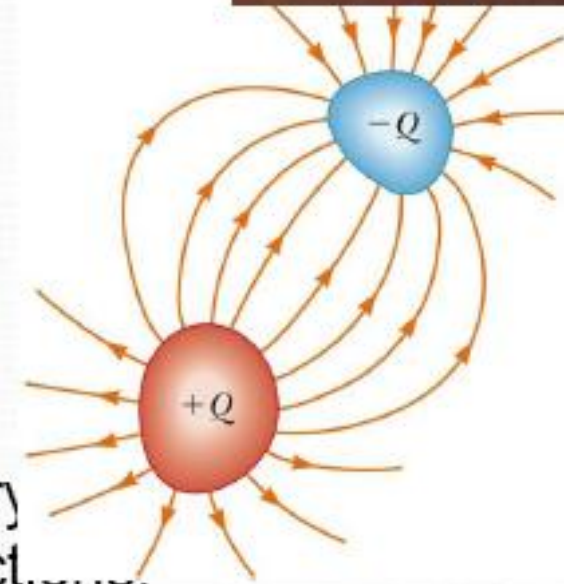
Capacitors are devices that store electric charge.

Examples of where capacitors are used include:

- radio receivers
- filters in power supplies
- to eliminate sparking in automobile ignition systems
- energy-storing devices in electronic flashes



When the two conductors of a capacitor carry charges of equal magnitude and opposite sign, the electric field is zero outside the capacitor and maximum between the plates.



Makeup of a Capacitor

A capacitor consists of two conductors.

- These conductors are called plates.
- When the capacitor is charged, the plates carry charges of equal magnitude and opposite direction.

A potential difference exists between the plates due to the charge.

Electrical Stimulation Related Terms

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.

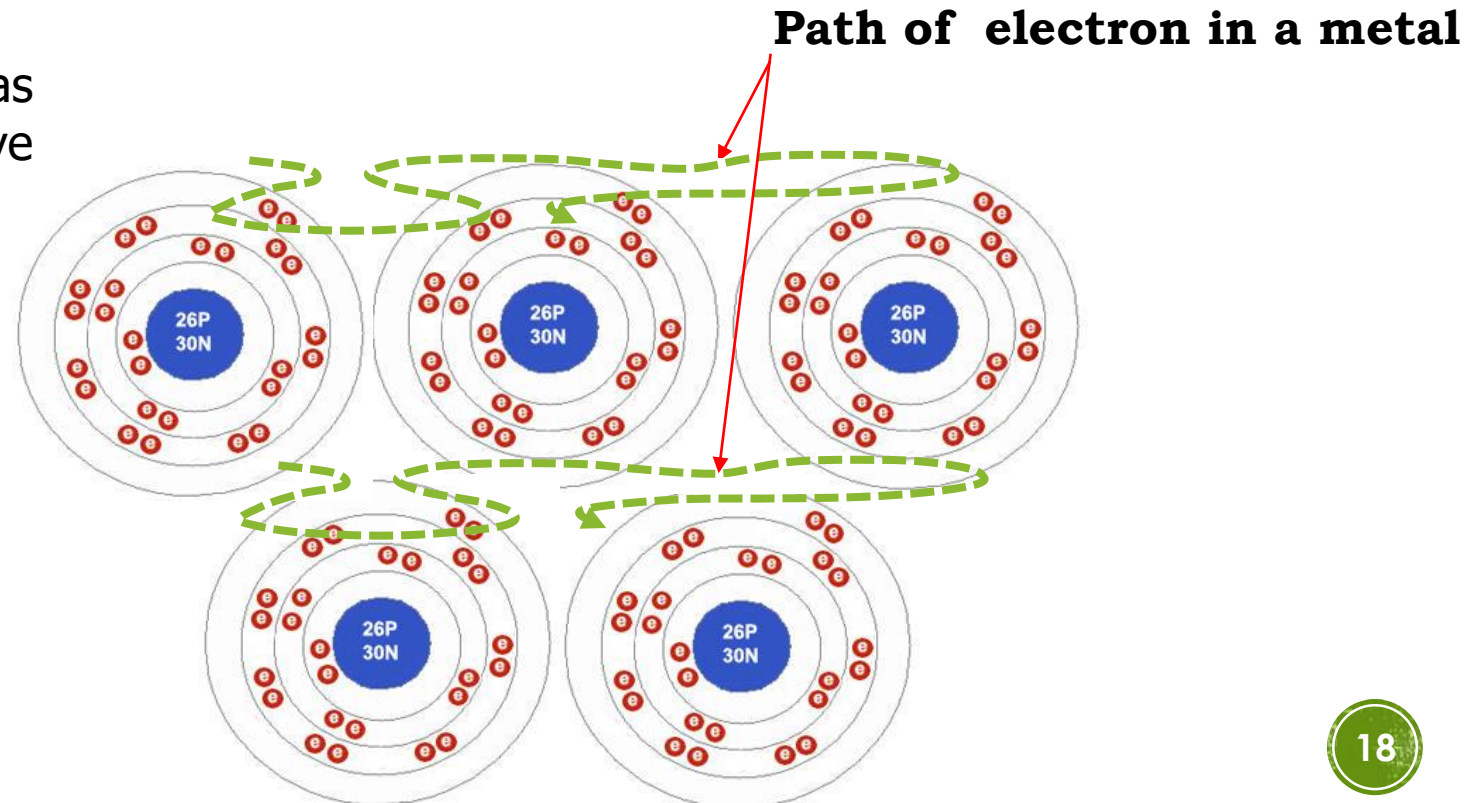
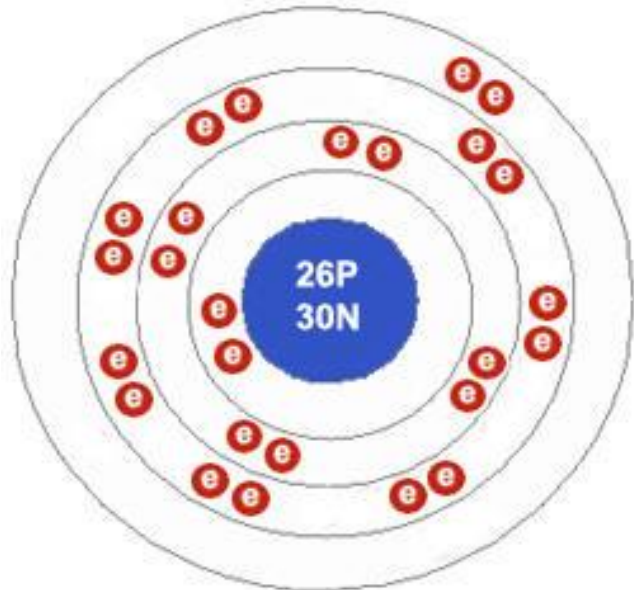
Examples of semiconductor materials include silicon and germanium.

- Semiconductors made from these materials are commonly used in making electronic chips.

Metals and Conduction

- Metals are not only a good electrical conductors, but they are also a good heat conductors.
- These are all properties that come from the ability of electrons to move easily.

This **iron atom** (26 protons, 26 electrons) has two electrons in its outer shell, which can move from one iron atom to the next in a metal.



Electrical Stimulation Related Terms

Conductor is a substance that can transport electrical charge (or current) from one point to another. It must have free $\{e^{-}\}$ in their **outer orbit** that can be pushed along metals .

Higher conductance materials:

free flow of e^{-} ,

- ❶ Silver, Copper,
- ❶ Electrolyte solutions
- ❶ Blood cell: highest ionic & H_2O
- ❶ Inner layer of the skin
- ❶ Nerves
- ❶ Muscle fibers
- ❶ Cell membranes

Low conductance materials:

few free e^{-}

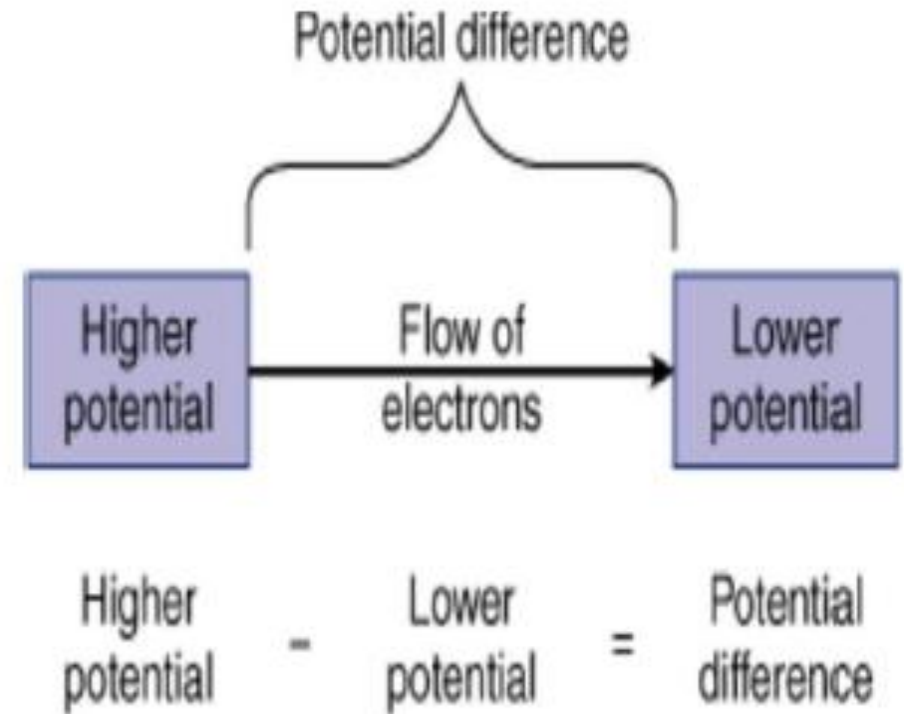
- ❶ Air, Wood, Glass, Rubber
- ❶ Bone
- ❶ Cartilage
- ❶ Tendons
- ❶ Ligaments
- ❶ Outer layer of Skin has keratinized epithelium (little H_2O) acts as insulator

Human body: The greater is the percentage of H_2O in the tissues, the better is the conductance of **electricity**.

Electrical Stimulation Related Terms

Voltage (electrical potential difference): **is** the differences of electrical energy between two points that produce electrical force capable of moving charged particles through conductors

Volt (V) **is** a unit of force required to move a current of 1A in 1s against a resistance of 1Ω.



Higher voltages result in deeper penetration

- High Volt: ≥ 150 V
- Low Volt: ≤ 150 V

Electrical current

Most practical applications of electricity deal with electric currents.

- The electric charges move through some region of space.

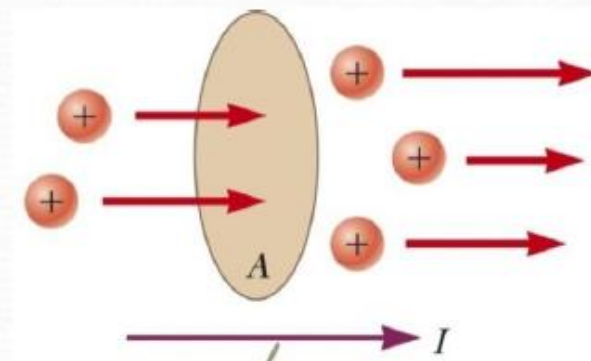
Electric current is the rate of flow of charge through some region of space.

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

The **symbol** for electric current is I .

$$I_{avg} = \frac{\Delta Q}{\Delta t}$$

In an ordinary conductor, the **direction of current flow** is opposite the direction of the flow of electrons.



The direction of the current is the direction in which positive charges flow when free to do so.

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.

Electrical Stimulation Related Terms

Intensity (Magnitude) of Current

- It is the rate of an (e^-) flow through a conductor from cathode (-) to anode (+), per second.
- Measured in **Ampere** or (mA= 1/1,000 ampere) or (μ A; 1/1,000,000 ampere)
 $1 \text{ amp} = 6.25 \times 10^{18} e^- / \text{sec}$

Resistance: is a quantitative degree of opposition to the flow of electron.

It is **directly proportional** to **length** and **inversely proportional** to **cross section area** of a **conductor.**

Ohm: (Ω) unit to measure resistance to current flow;

1 ohm = the amount of resistance needed to develop **0.24 calories** of heat when **1 Am** of current is applied for **1 second**

Electrical Stimulation Related Terms

Ohm's law current is directly proportion to voltage & inversely proportional to resistance”

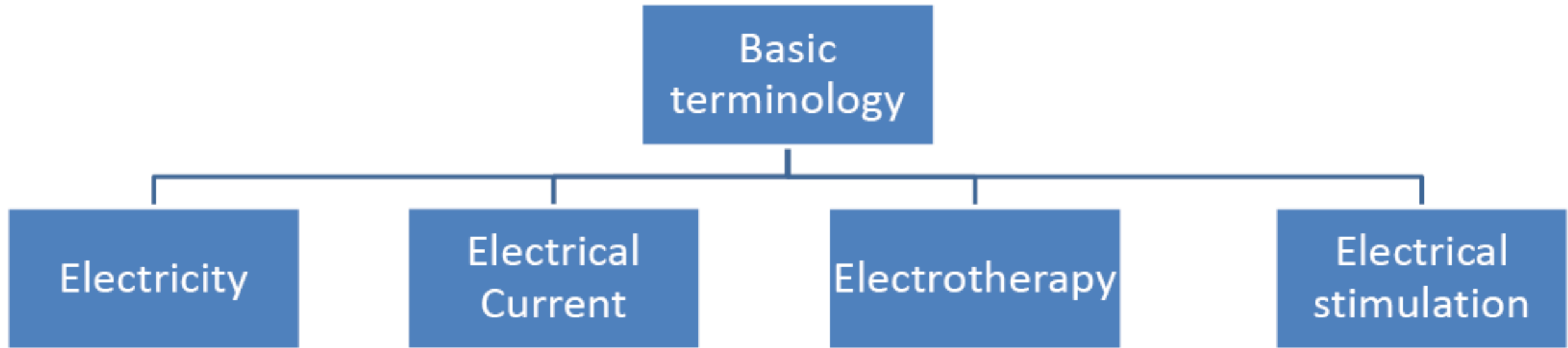
$$I = V/R$$

I=current flow, V=Potential differences, R=Resistance

Check the concept

- (a) If you had a 100 V electrical stimulator applied to a muscle that was providing 20,000 Ω resistance, how much current would flow through the muscle?
- (b) What would the current how be if you decreased skin/muscle resistance to 10,000 Ω ?
- Ohm's law tells us there are two ways of increasing current in a circuit. What are they?

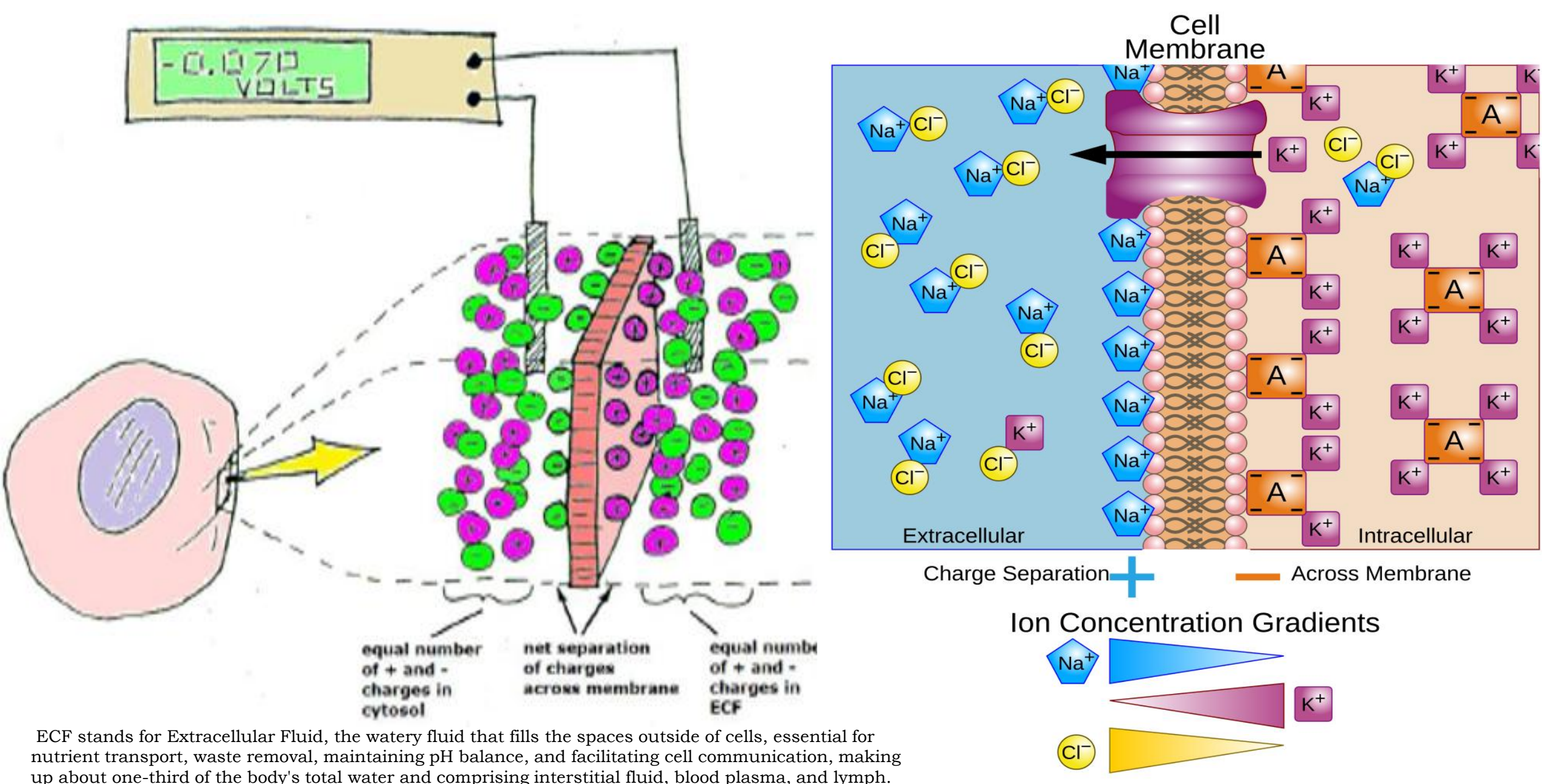
Electrical Stimulation Related Terms



- A form of energy that exhibits magnetic, chemical, mechanical, and thermal effects; formed from the interaction of positive (+) & negative (-) charges
- A flow of charged particles **electron (e⁻)/ions** from higher to lower concentration.
- Application of electrical energy for therapeutic purposes
- Application of therapeutic electrical current devices to stimulate **excitable tissues**, with the aim of producing **physiological reaction** for **therapeutic benefits**.

Electrical Circuits in the Human Body

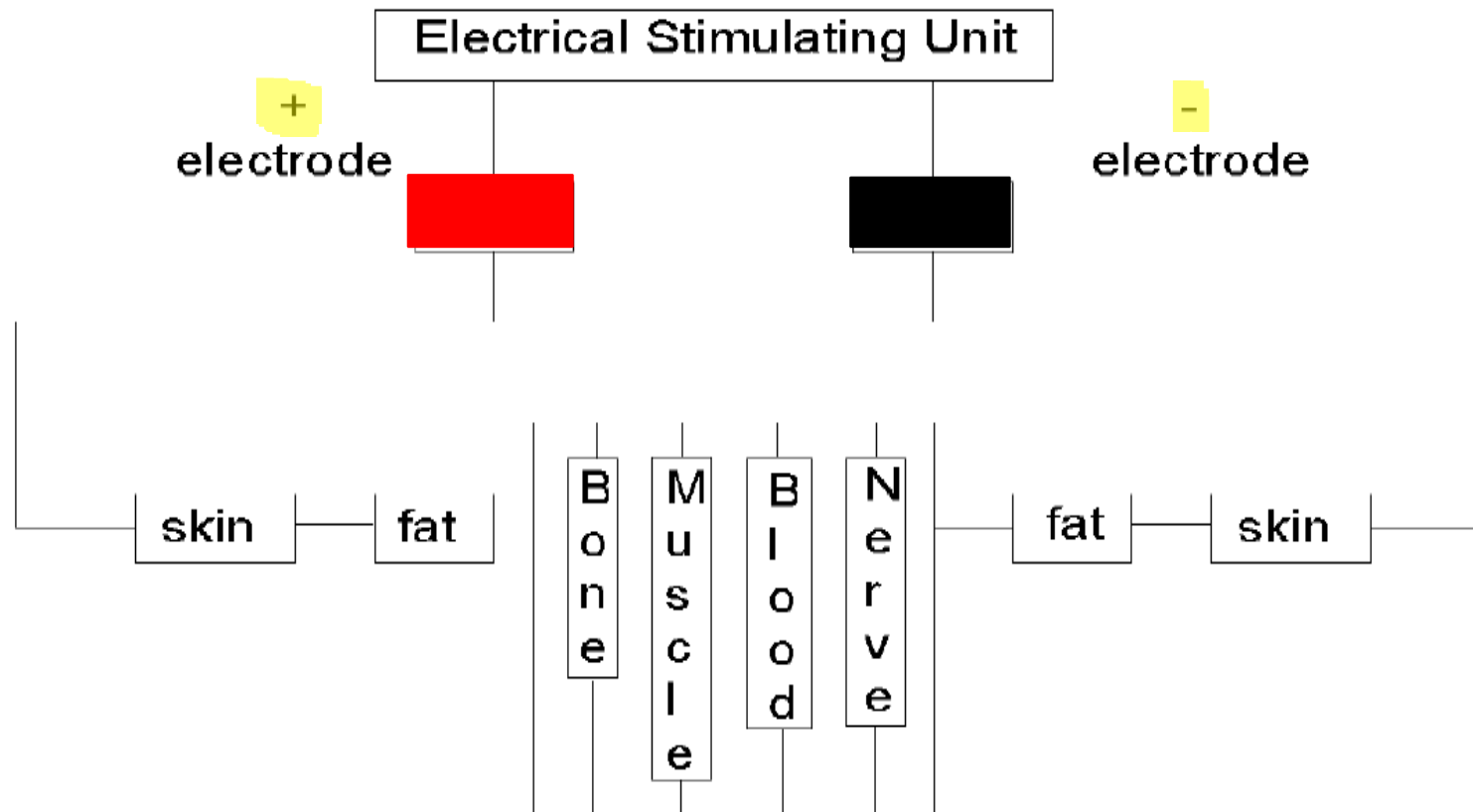
- Electricity plays an important role in medicine .
- There are two aspects of electricity and magnetism in medicine :
 - 1. electrical and magnetic effects generated inside the body ,
 - 2. applications of electricity and magnetism to the surface of the body.
- The electricity generated inside the body **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 .



ECF stands for Extracellular Fluid, the watery fluid that fills the spaces outside of cells, essential for nutrient transport, waste removal, maintaining pH balance, and facilitating cell communication, making up about one-third of the body's total water and comprising interstitial fluid, blood plasma, and lymph.

Key: Blue pentagons – sodium ions; Purple squares – potassium ions; Yellow circles – chloride ions; Orange rectangles – membrane-impermeable anions (these arise from a variety of sources including proteins). The large purple structure with an arrow represents a transmembrane potassium channel and the direction of net potassium movement.

Electrical Circuits in the Human Body



Current enters the body **through** a **SERIES** circuit (**skin & fat**).

Once the current enters the tissues, it takes many different **PARALLEL** paths

in Human body; the greater is the percentage of **H₂O** in the tissues, the better is the conductance of **electricity** & lower resistance.

Parameters of electrical Current stimulation

- 1) Types of currents: **Alternating current (AC)** vs. **Direct current (DC)**
- 2) Frequency
- 3) Intensity of current
- 4) Time dependent parameter (Pulse attributes)
- 5) Tissue impedance
- 6) Current density
- 7) Electrodes considerations, which are:
 - a) **Polarity**
 - b) **Types and size**
 - c) **Placement**
 - d) **Configurations**
 - e) **Orientation**

Parameters of electrical Current stimulation

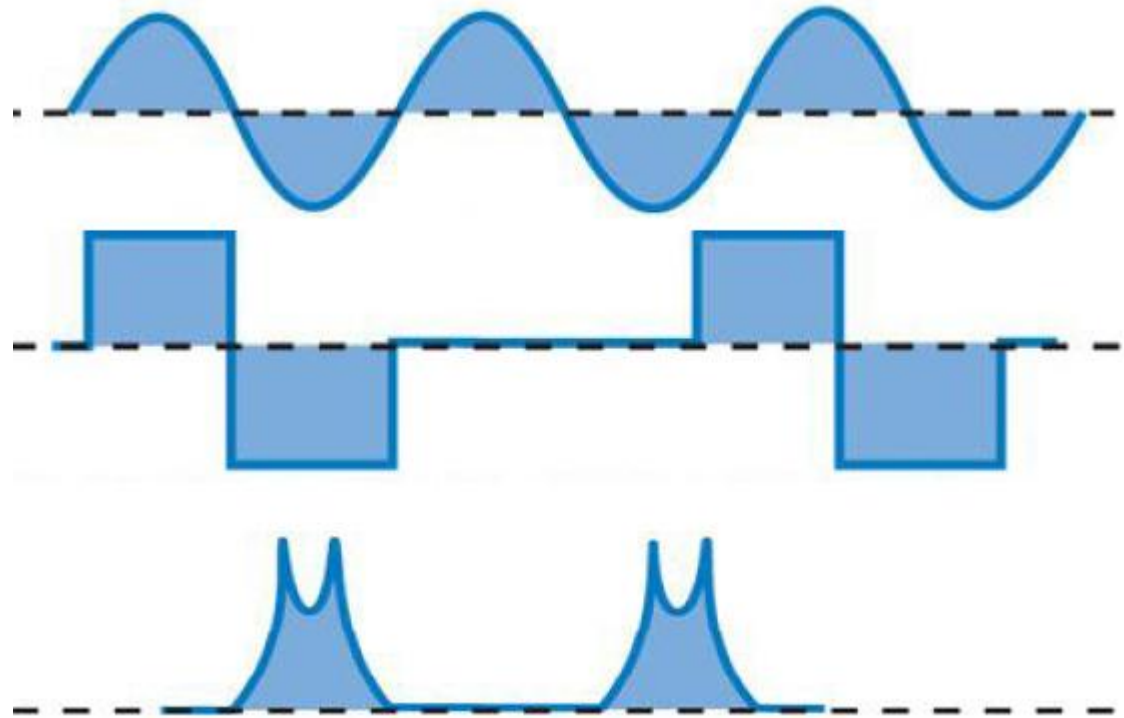
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Waveforms related parameters

Waveform is a graphic representation of “**shape**, **direction**, **amplitude**, **duration** and **frequency**” of the electrical current.

1-Waveforms Shape:

- ① Sine wave
- ① Rectangular wave
- ① Square wave
- ① Triangular wave
- ① Saw tooth wave
- ① Trapezoid wave



All types of current may take on any of the waveform

Direct current (DC)**Alternating Current (AC)****Pulsed current () PC**

Def.	is continuous unidirectional flow of e-'s toward (+) pole	The e- flow in alternating directions in both sides of isoelectric line from (-) pole to (+)pole.	Interrupted electron flow The simplest form of interruption is to turn the switch on and off
Shape	Monophasic	Biphasic	Monophasic or biphasic
Types	Traditional "galvanic current" Modulated Interrupted direct current or "interrupted galvanic"	Current can be symmetrical, asymmetrical e.g. TENS,	Groups of pulses are interrupted for short periods of time (inter-pulse intervals) & repeat. Russian current Interferential current
Uses	Iontophoresis Stimulate contraction of denervated muscle;	Pain relief Neuromuscular stimulation.	Pain relief Neuromuscular stimulation Wound healing

Iontophoresis is the process of passing a weak electrical current through the skin, and it has a variety of uses in medicine.

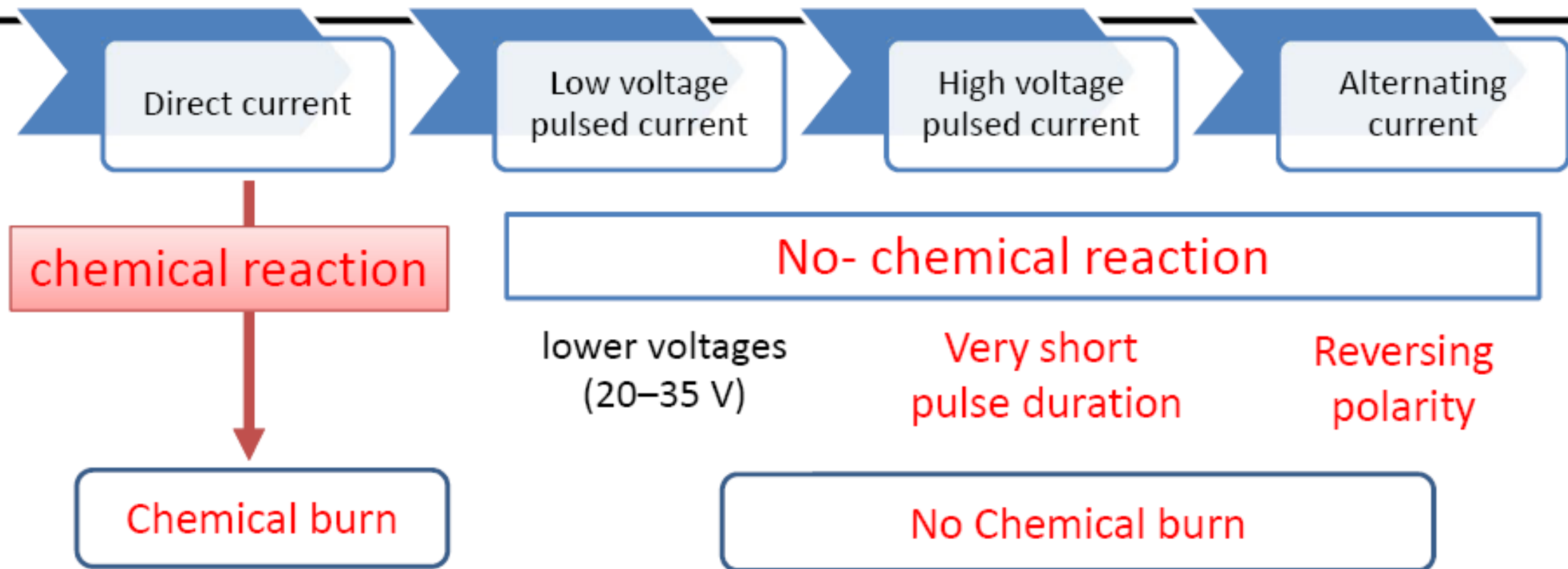
denervated muscles lack a nerve supply, hence their muscular functionality is lost.

Neuromuscular Stimulation or **NMES** uses a device that sends electrical impulses to nerves. This input causes muscles to contract.

Wound healing refers to a living organism's replacement of destroyed or damaged tissue by newly produced tissue.

Nerve **doesn't know** the difference between different current types (e.g. AC and DC, PC)

The **biggest difference** between **direct current** and **alternating current** is the ability of **direct current** (e.g. **continuous unidirectional, long pulse duration current**) to produce **chemical reaction**.



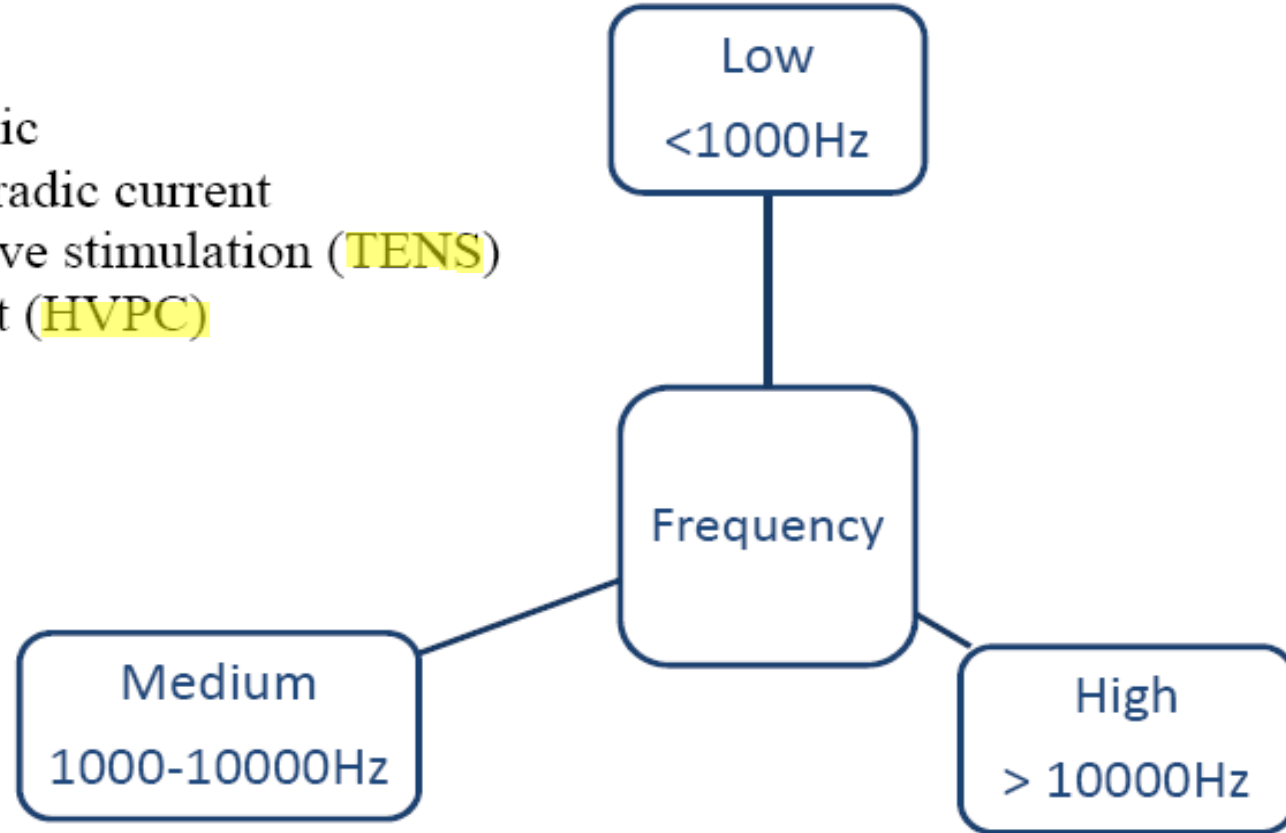
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Frequency

Frequency : is the number of cycles completed each second by the waveform (i.e., it is a cycles/sec).

Direct current (**DC**)/ Galvanic
Interrupted direct current/faradic current
Transcutaneous electrical nerve stimulation (**TENS**)
High Voltage Pulsed Current (**HVPC**)
Didynamic Current



Interferential current
Russian current

Diathermy is a therapeutic treatment that uses electric currents to generate heat in layers below the skin surface.

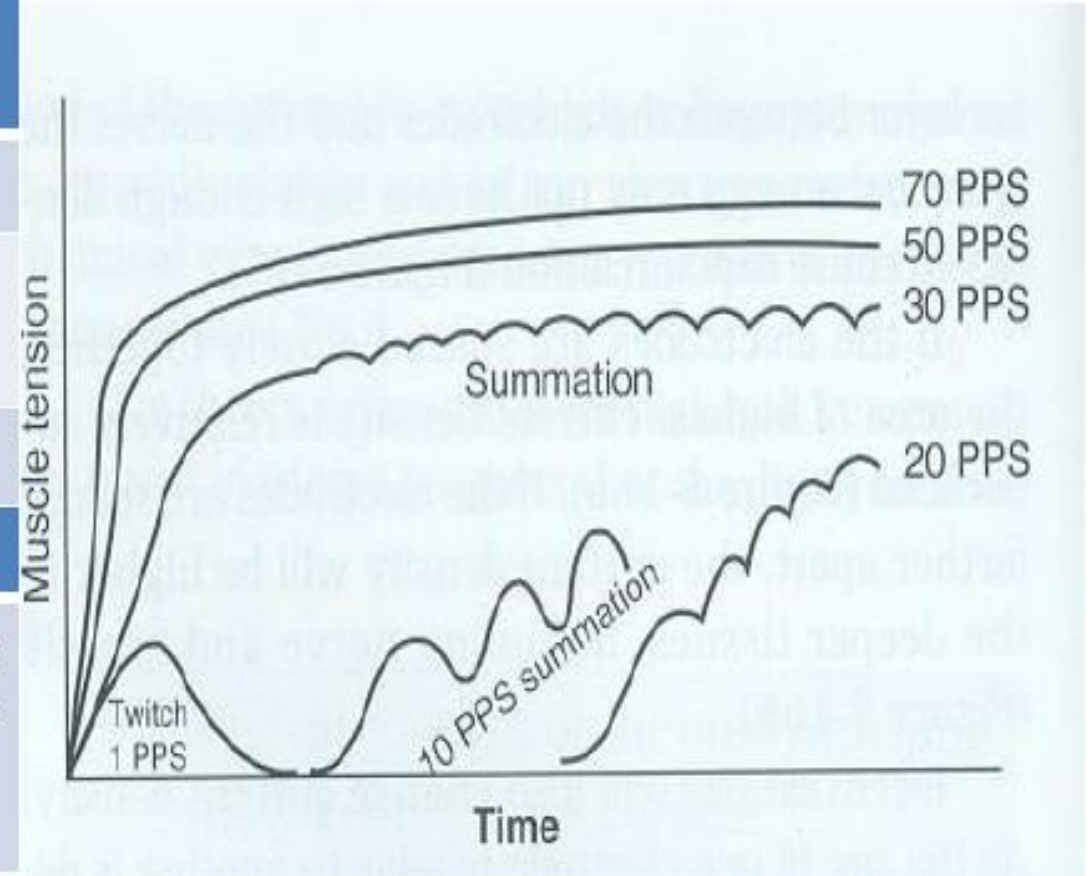
Short wave diathermy(**SWD**)
Ultrasound (**US**)

Frequency **determines** types of muscles contraction and degree of mechanical adaption

Frequency range	Muscle contraction types
< 20Hz	Individual twitch
20-35Hz	Individual twitches become less distinguishable summation
≥50	Tetanic muscle contraction

Mechanical adaption

Increase amount between pulse (inter-pulse duration allows muscles fibers to recovery form fatigue



Effects of frequency on the pain modulation (sensory level)

1. Spinal pain modulation > 60-120Hz
2. Supra-spinal pain modulation ≤ 20Hz

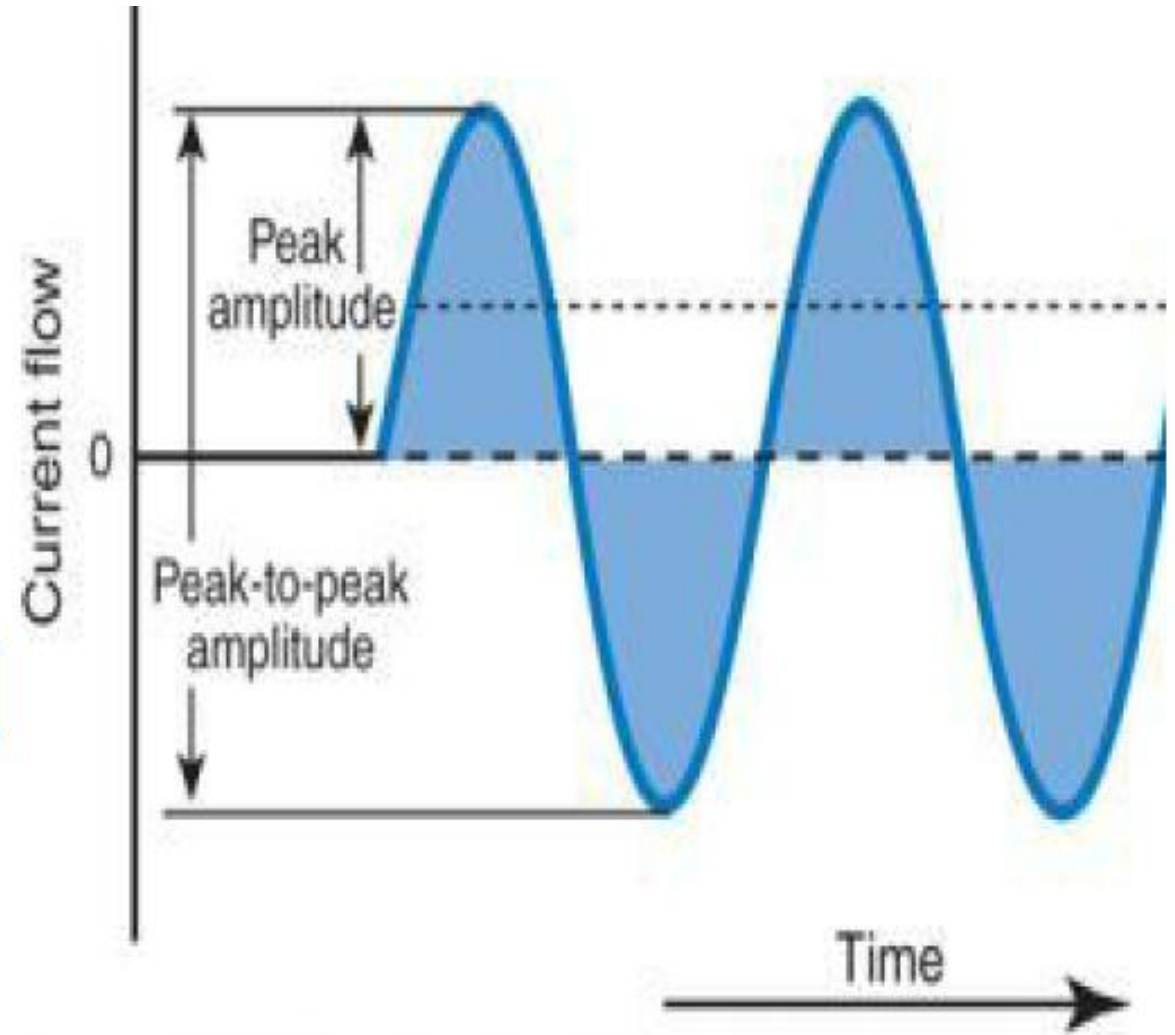
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Current Intensity = Amplitude

Peak current amplitude:
is the maximum (highest) amplitude from zero value of the same phase .

Peak-to-peak amplitude:
is the amplitude measured from the peak (maximum) of one phase to the peak (maximum) of next phase.



Current Intensity = Amplitude

Increase intensity will increase:

- ❖ Strength of stimulus sensory (e.g. contraction).
- ❖ Depth of penetration of current to deeper tissue (nerve & muscles)

Nerves always depolarize in the following orders:

- 1) Sensory nerves
- 2) Pain nerves
- 3) Muscle fiber

This happen based on the:

Cross-sectional diameter : Large-diameter nerves depolarize first

Location of the nerve: Superficial nerves depolarize first.

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Time dependent parameters

Pulse: is an individual waveform, that contains one or more phases, and it is measured in microseconds or milliseconds.

Pulse named by number of phases such as:

1. Monophasic

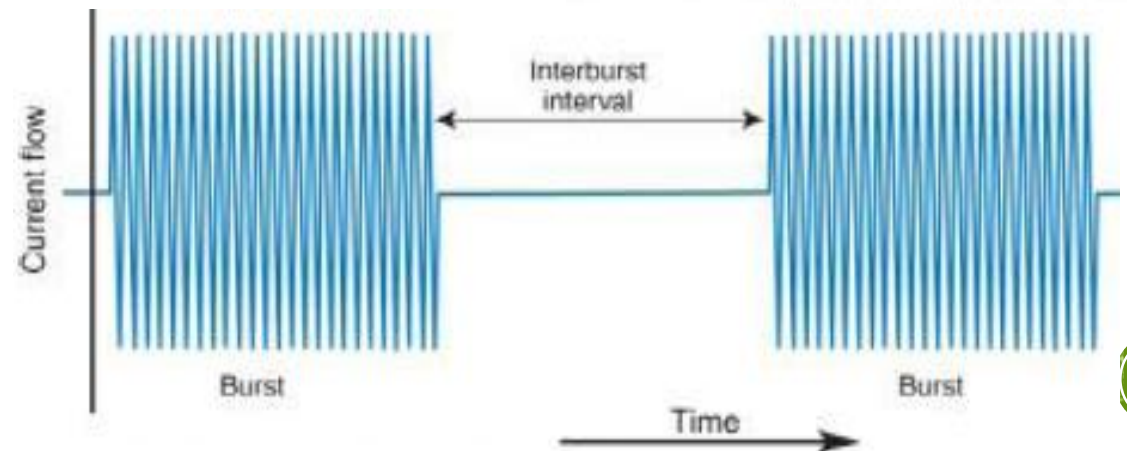
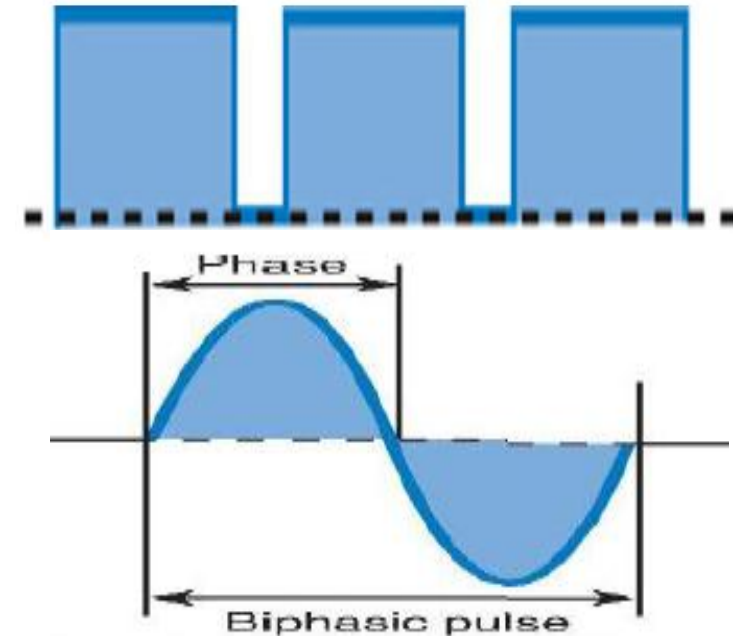
- One phase
- Current flows in one direction only.

2. Biphasic

- Two phases
- Current flows in both directions.

3. Polyphasic (pulsatile)

- Many phases



Time dependent parameters

Pulse duration (PD) = pulse width

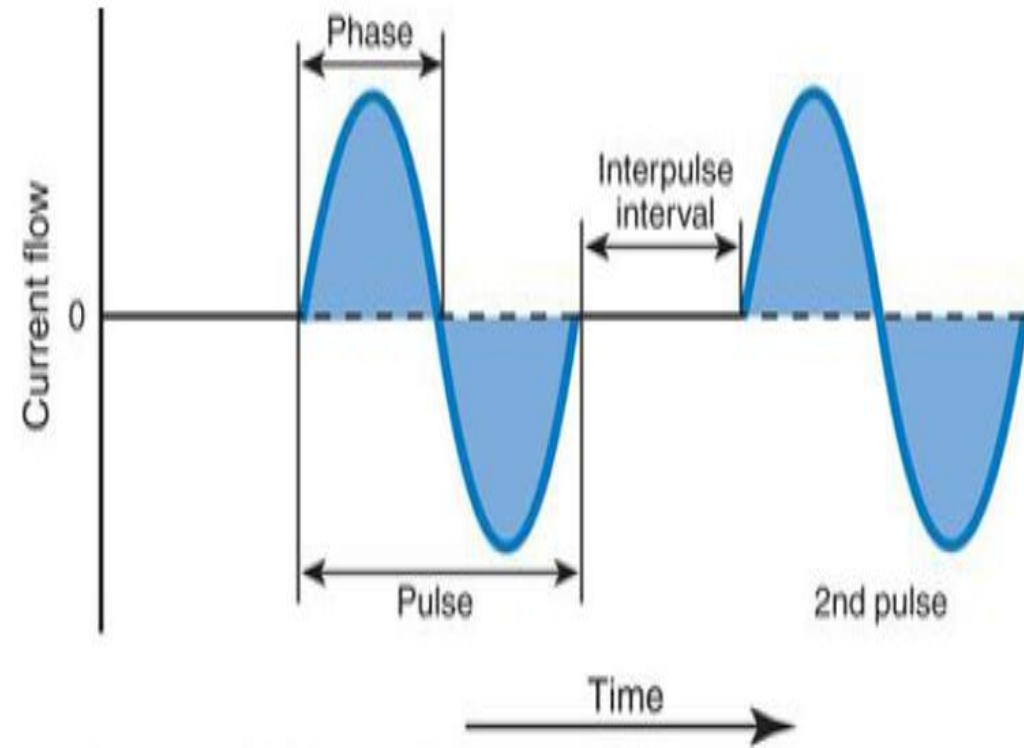
pulse width: is a duration of one phase of pulse.

pulse width: is a length of time current flow in one direction before return to zero.

pulse width: is the length of the time from beginning of first phase of the pulse to the end of last phase of the pulse at which the electrical flow is “on”.

Inter-pulse interval (IPI): is the time where electrical flow is “off”.

Pulse Period = pulse duration (PD) + inter-pulse interval (IPI)



Parameters of electrical Current stimulation

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Tissue impedance

Higher conductance materials:

free flow of e^- s

- ❶ Silver, Copper,
- ❶ Electrolyte solutions
- ❶ Blood cell: highest ionic & H_2O
- ❶ Inner layer of the skin
- ❶ Nerves
- ❶ Muscle fibers
- ❶ Cell membranes

Low conductance materials:

few free e^- s

- ❶ Air, Wood, Glass, Rubber
- ❶ Bone
- ❶ Cartilage
- ❶ Tendons
- ❶ Ligaments
- ❶ Outer layer of Skin has keratinized epithelium (little H_2O) acts as insulator

Human body: The greater is the percentage of H_2O in the tissues, the better is the conductance of **electricity**.

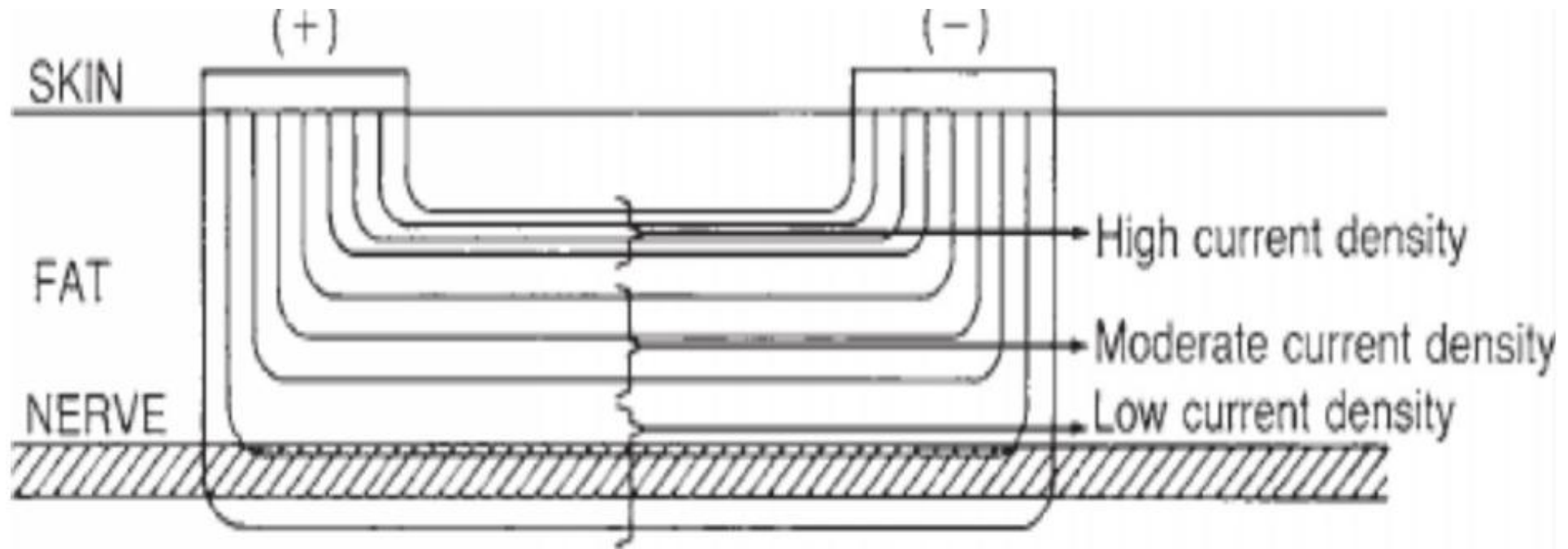
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Current Density (CD)

Current Density (CD): is the amount of current per unit area.

- CD is the **highest** where electrodes **contact the skin** and **decreased** as the electricity penetrates into **deeper tissues**.
- Increases **CD** will **increase** perception of stimulus.
- **CD** is equal under same sized and proper distance of electrodes (at least 2 inches) .



Current Density (CD)

- A **placed closely** electrodes produces **high CD** in **superficial tissues**.
- A **short spaced** electrodes produces **high CD** in the **deeper tissue** (nerve & muscle).
- Large electrode (**dispersive electrode**), the CD is **less**.
- Small electrode (**active electrode**) closed relatively to treatment area (nerve and muscle), the CD is **greater**.

Parameters of electrical Current stimulation

- 1) Types of currents: **Alternating current (AC)** vs. **Direct current (DC)**
- 2) Frequency
- 3) Intensity of current
- 4) Time dependent parameter (Pulse attributes)
- 5) Tissue impedance
- 6) Current density
- 7) **Electrodes considerations**, which are:
 - a) Polarity
 - b) Types and size
 - c) Placement
 - d) Configurations
 - e) Orientation

Electrodes

Electrodes: are devices attached to the terminals of electrical stimulator through which current enters and leaves the body.

Electrodes come in a variety of **sizes**, **shapes**, and **materials**.

Electrodes named according to their function.

Metal-sponge electrodes



durable , reusable,
inexpensive, inflexible

Carbone electrodes



Relatively inexpensive, fairly
durable, gel or water required,
may cause skin irritation

Self adhesive electrodes



expensive, less durable,
flexible, skin irritation
Contamination

Electrodes Locations/orientation

1. On/or around the painful area.
2. Over specific **dermatome** corresponding to the painful area.
3. Over specific **myotomes** corresponding to the painful area .
4. Spinal cord segment.
5. Course of peripheral nerve.
6. Over trigger point.
7. Acupuncture point.

Note that Muscle fibers are **4-times** more **conductive** when the current flows with the **direction of the fibers** than when it flows **across** them.

Polarity

▶ Positive Pole (anode)

- Lowest Concentration of Electrons
- Connected to the positive terminal
- Color code is red
- Attracts (-) Ions
- Acidic Reaction
- Hardening of Tissues
- Decreased Nerve irritability
- Used in later stage of tissue healing to enhance epithelial migration across the wound bed

▶ Negative Pole (cathode)

- ❖ Greatest Concentration of Electrons
- ❖ Connected to the negative terminal
- ❖ Color code is black
- ❖ Attracts (+) Ions
- ❖ Alkaline Reaction
- ❖ Softening of Tissues
- ❖ Increased Nerve Irritability
- ❖ Used in the early inflammatory stage of tissue (3-7days)
- ❖ Used in infected wound

Electrical Stimulation Related Terms

Practical tips to decrease skin Resistance

1. Decrease distance between electrodes (length)
2. Increase the size of electrodes (cross section area)
3. Minimize air-electrode interface
4. Use electrodes jelly or moisten the electrodes
5. Pre-warming the skin by moisten heat (i.e. hot packs)

N.B. Preheating the treatment area may increase the comfort of the patient but also increases resistance and need for higher output intensities

Effect of Electrical stimulation

Musculoskeletal System

- ✦ Muscle excitation result in contraction, so increase muscles strength/endurance
- ✦ Increase muscle blood flow.
- ✦ Increased Muscle fiber hypertrophy (both type I and type II fibers)
- ✦ Increased proportion of type I muscle fibers.
- ✦ Attenuation of the decrease in ATPase, e.g. immobilization



Wound Healing

- ✦ Increase capillary permeability and blood flow
- ✦ Increase macrophage, leucocytes and activities.
- ✦ Increase fibroblast & osteoblast activity.
- ✦ Induce bactericidal effects.
- ✦ Reduction of edema.



Pain Perception

- ✦ Modulation of pain perception through central and peripheral mechanisms

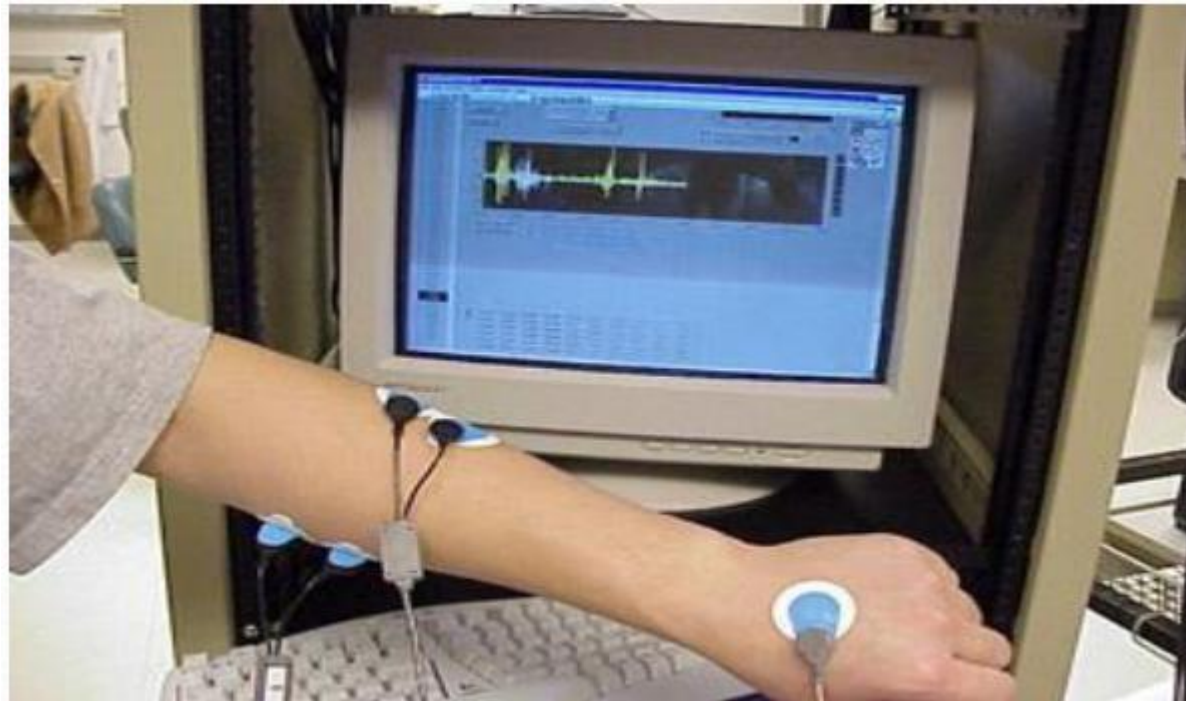


Electromyography

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.



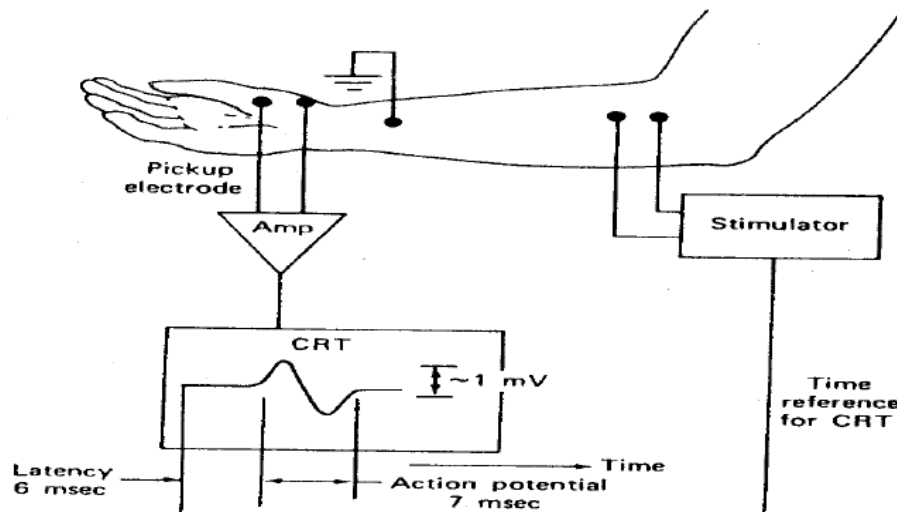
Electromyography

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,

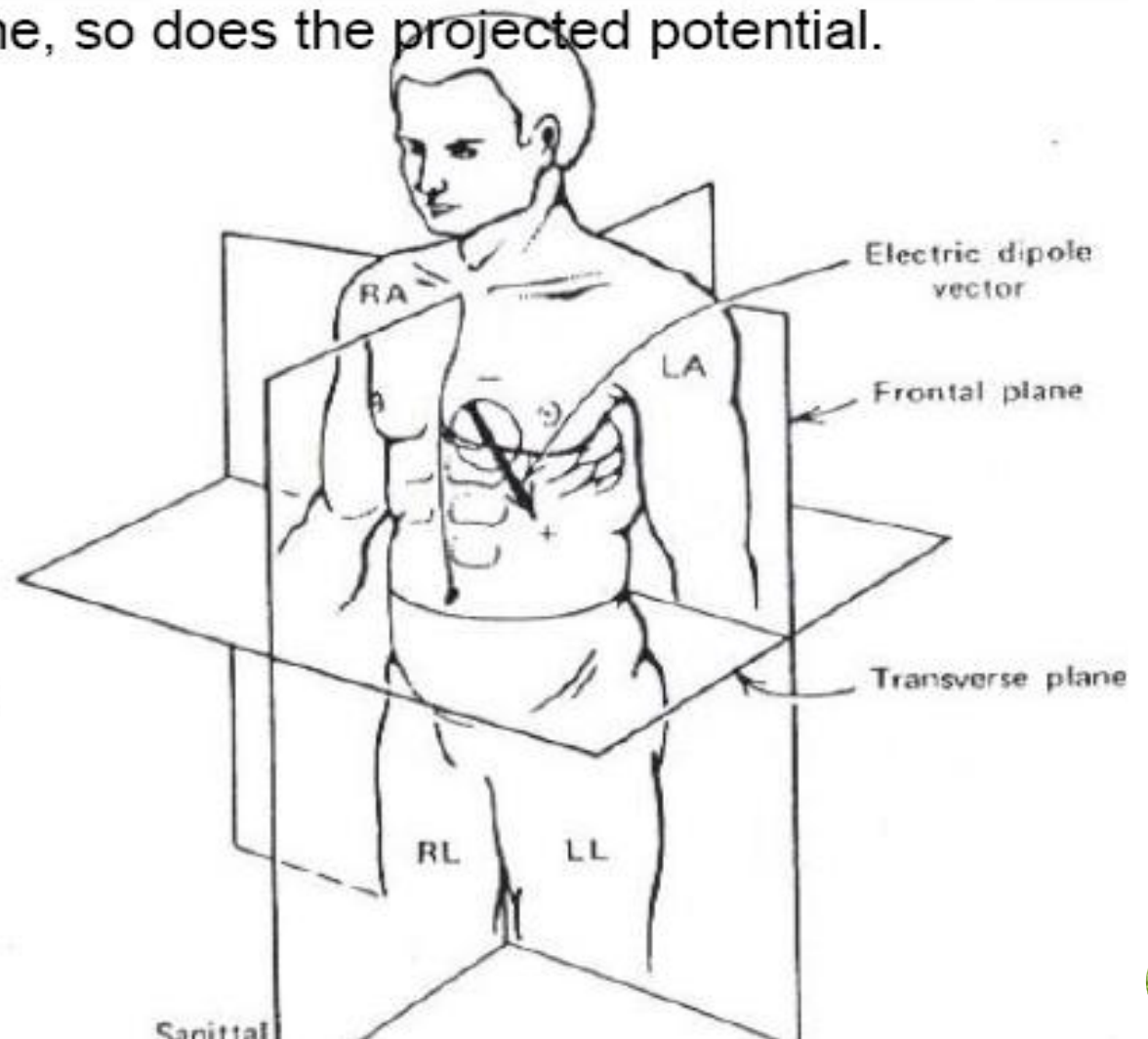


An **electric dipole** is produced when equal positive and negative charges are separated from each other. It can be represented by a vector.

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** and **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.

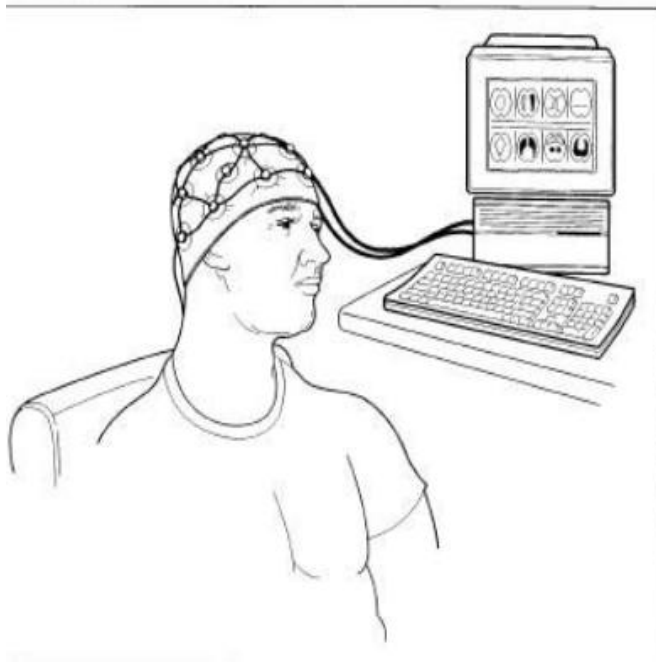


Electroencephalograph (EEG)

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

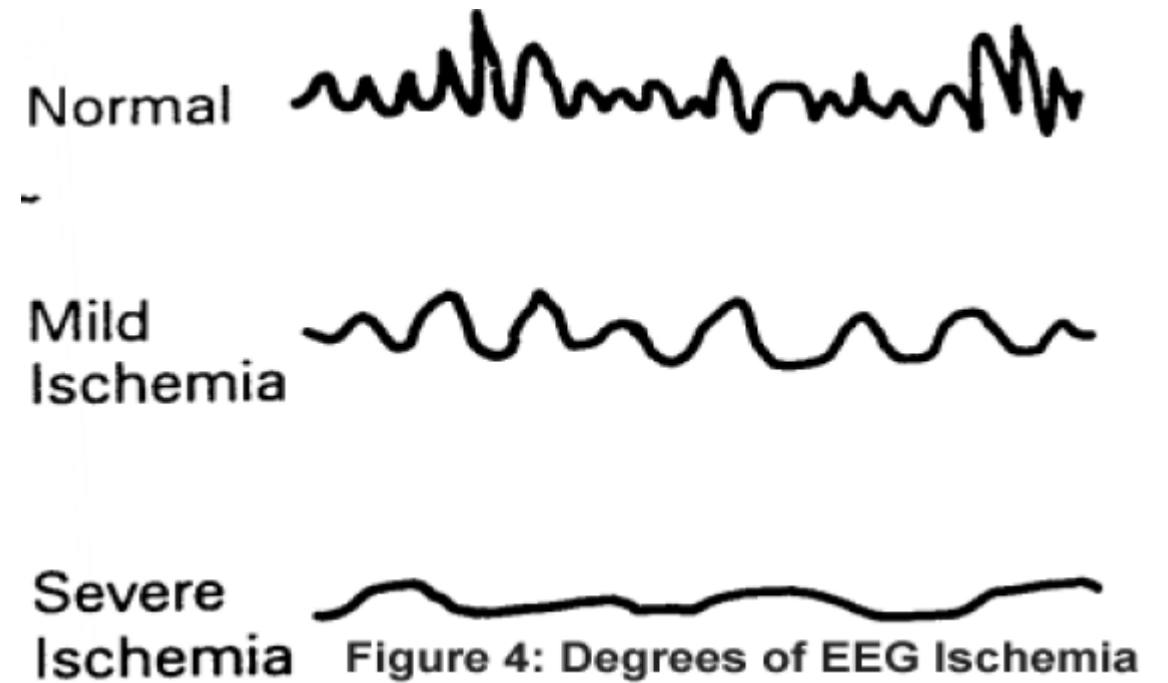


Electroencephalograph (EEG)

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

Ischemia is a serious condition where a lack of blood flow deprives tissues and organs (like the heart, brain, or limbs) of essential oxygen and nutrients, often due to narrowed or blocked arteries (atherosclerosis or clots). It can cause symptoms like chest pain (**angina**), shortness of breath, or neurological issues, and if untreated, can lead to permanent damage, tissue death, heart attacks, or strokes, requiring prompt medical attention.



Beta (13-30 Hz)

Alpha (8-13 Hz)

Theta (4-8 Hz)

Delta (< 4 Hz)

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 than 5 k Ω , between 2-5 k Ω , 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.

QUESTION



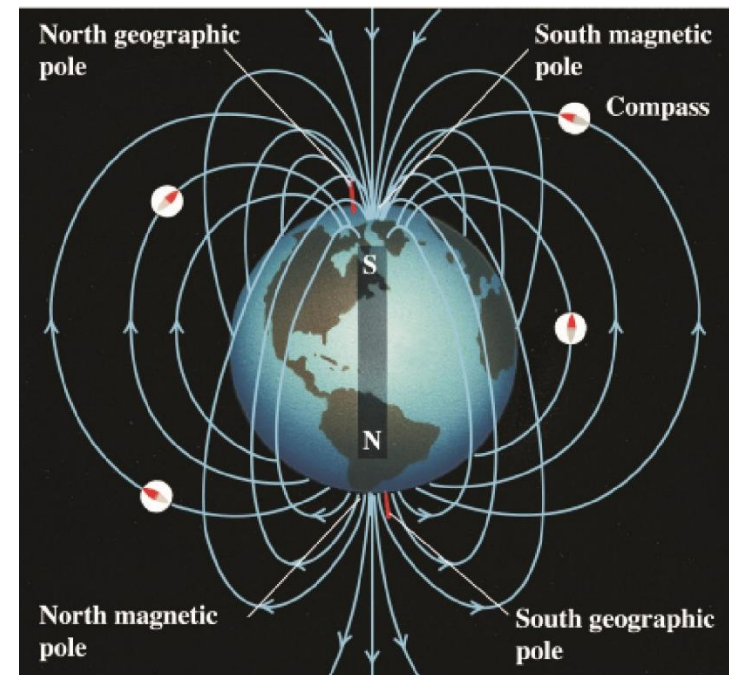
Medical Physics

Lec.7: Magnetism

Dr. AQEEL SALIM

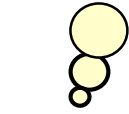
Dr. AQEEL SALIM

Magnetic Objects





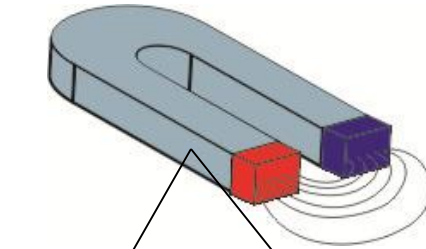
Magnetic Devices



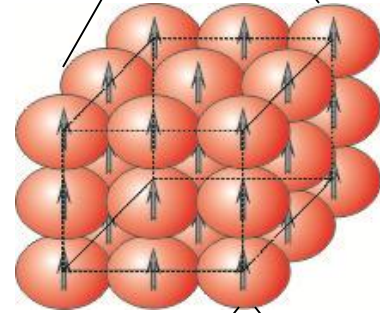
What is Magnetism?

- **Magnetism** has been around as long as there has been an Earth with an iron magnetic core.
- Thousands of years ago the Chinese built compasses for navigation in the shape of a spoon with rounded bottoms on which they balanced.
- Certain natural rocks are **ferromagnetic** – having been magnetized by cooling of the Earth's core.

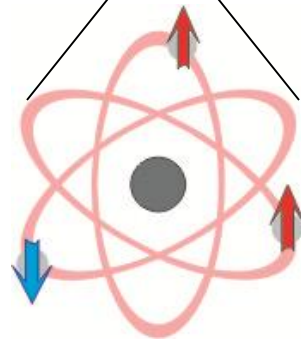
The inside of magnets: origin of magnetism



A magnet



consists of
aligned magnetic atoms

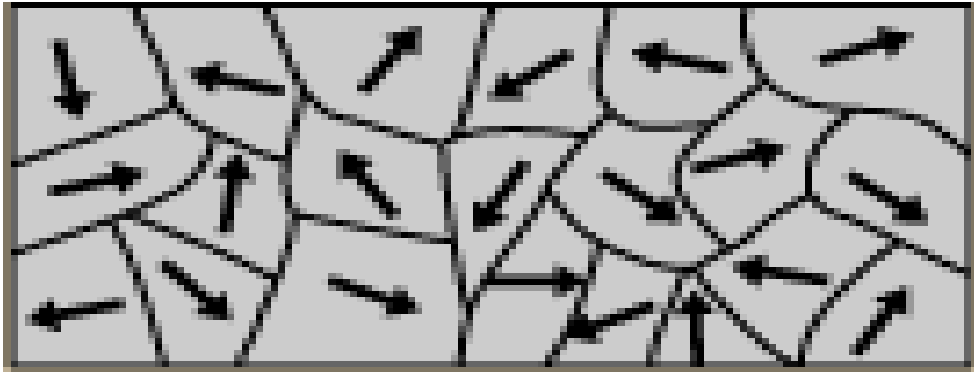


magnetic atoms have
unpaired electron spins

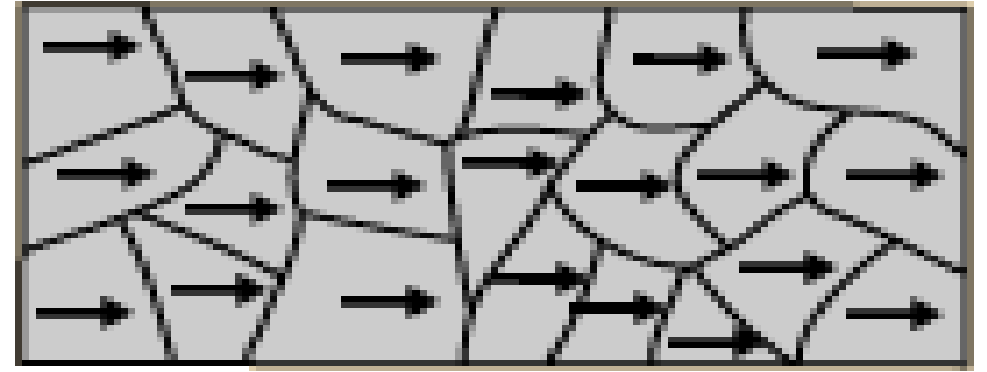
magnet = arrangement of atoms with aligned spins

Magnetic Domains

- Microscopic groups of atoms with aligned magnetic poles



not magnetized



magnetized

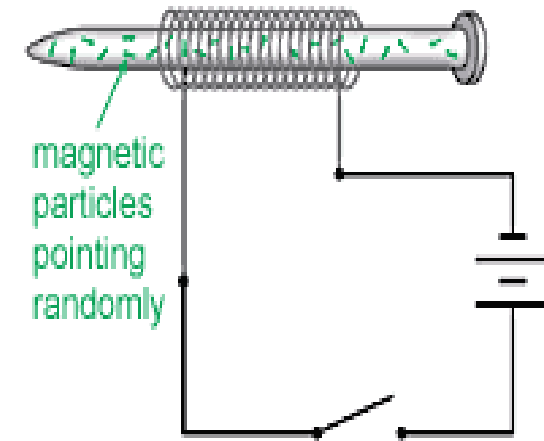
Permanent magnets

- **Permanent magnets** are Material that keeps its magnetic properties, even when it is not close to other magnets
- **Permanent magnets** are Made by placing a magnetic material in a strong magnetic field, which causes the domains to remain aligned.
- The domains of **temporary magnets** are only aligned when the material is influenced by a magnetic field. (ex. Refrigerator, white board)

- **Electromagnet** – temporary magnet that is created by electric current flowing in a wire, usually in the form of a wire coiled around a piece of iron

- **Strength of an electromagnet depends on three factors:**

1. amount of current in the wire
2. amount of iron or steel in the core
3. number of turns in the coil



Magnetic field is present only when current is flowing in the wire coil

Electromagnetic Field Types

According current and its changes over time:

- Static field
- Alternating field (dynamic)
- Pulse field (dynamic)

According frequency:

- Low-frequency magnetic field
- High-frequency magnetic field

According distribution of the magnetic field in surroundings

- **homogeneous field** – has the same size and direction at all points
- **inhomogeneous field** – has different size and direction in the considered space

Magnetic Therapy

- ✓ **Magnetic therapy** is a type of physical therapy during which the body is exposed to a low frequency magnetic field.
- ✓ Cells in the body contain ions that can be affected by magnetic forces.
- ✓ When the tissue is exposed to pulsed magnetic fields, weak electrical current is induced activating all cells that are exposed to it.

Magnetic Therapy Characteristics

1. **Magnetic therapy** is not addictive and has no known side-effects.
2. **The patient** does not experience any negative sensations during treatment.
3. **Magnetic field pulses** penetrate evenly across body tissue so the patient does not need to take off any clothes. It can also penetrate through plaster casts.

Magnetic Therapy effect on tissue:

- ✓ it expands blood vessels in the affected area and improves the circulation of blood (visodilating effect).
- ✓ Relieves stress in the musculoskeletal system (myorelaxation effect).
- ✓ Strengthens the immune system (regenerating and detox effect).
- ✓ Harmonizes a vegetative nervous system.

What conditions can be treated with magnetotherapy?

Magnetotherapy can be helpful in treating a variety of conditions, including:

- 1. Muscle injuries:** It can help reduce pain and inflammation in injured muscles, speeding recovery.
- 2. Bone injuries:** This procedure can help stimulate healing in fractured or injured bones.
- 3. Arthritis:** It is able to help reduce pain and inflammation in joints affected by arthritis.

What conditions can be treated with magnetotherapy?

4. **Chronic pain:** It can be useful in the treatment of back pain, neuralgia and headache.
5. **Sports injuries:** It is able to help reduce inflammation and speed up recovery after sports injuries.
6. **Circulation problems:** This therapy can improve blood circulation in the body, which can help treat conditions such as peripheral vascular disease.

What conditions can be treated with magnetotherapy?

7. **Chronic pain:** It can be useful in the treatment of chronic pain, including back pain, neuralgia and headache.
8. **Sports injuries:** It is able to help reduce inflammation and speed up recovery after sports injuries.
9. **Depression and anxiety:** Transcranial magnetic therapy is able to help treat depression and anxiety by stimulating certain areas of the brain.

Magnetotherapy Equipment's

1. Diameter of 50 to 60 cm – for spine, hip joints, pelvis, sometimes shoulders with C/Th region of the spine
2. Diameter of 30 cm – thighs, knees
3. Diameter of 20 cm – knees, lower legs, ankles, feet, elbows, forearms, hands







QUESTION



Medical Physics

Lec.7: Magnetism

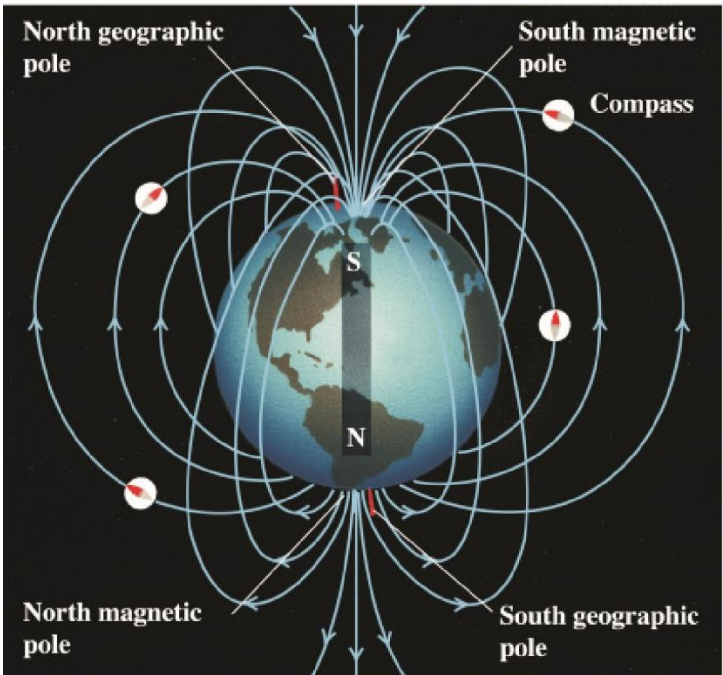
Dr. AQEEL SALIM

Dr. AQEEL SALIM

What is Magnetism?

- **Magnetism** = the phenomenon of physical attraction for iron observed in magnets, inseparably associated with moving electricity and characterized by fields of force.
- **Magnetic force** *increases as magnets move closer together.*

Magnetic Objects





Magnetic Devices



Overview of Talk

- **A historical perspective** ... the spin on magnetism ...
- **Magnetism today**... the hi-tech society
- **A Glimpse of the Future**.....ultra-small, ultra-fast

A historical perspective

The term "magnetism"

Legend:

Shepherd by the name of **Magnés** found that his iron tipped cane was attracted to rocks

More probable:

Name comes from city of **Magnesia** (modern Turkey) surrounded by magnetic rock deposits

first described "magnetism" as the attraction of iron by "lode**stone**"

- lodestone is the naturally occurring mineral magnetite Fe_3O_4



Thales of Miletus
(Greek, ~ **634 - 546 BC**)



What is Magnetic Fields?

- **Magnetism** has been around as long as there has been an Earth with an iron magnetic core.
- Thousands of years ago the Chinese built compasses for navigation in the shape of a spoon with rounded bottoms on which they balanced.
- Certain natural rocks are **ferromagnetic** – having been magnetized by cooling of the Earth's core.

What is Magnetic Fields lines?

Similarities to electric lines

- A line drawn tangent to a field line is the direction of the field at that point.
- The density of field lines still represent the strength of the field.

Differences

- The magnetic field lines do not terminate on anything. They form complete loops. There is no magnetic charge on which top end as there was in the electric case. This means if you cut a bar magnet in half you get two smaller bar magnets ad infinitum all the way down to the atomic level – Magnetic atoms have an atomic dipole – not a monopole as is the case for electric charge.
- They are not perpendicular to the surface of the ferromagnetic material.

$$\phi_B = \text{Magnetic flux} = \int \mathbf{B} \cdot d\mathbf{A}$$

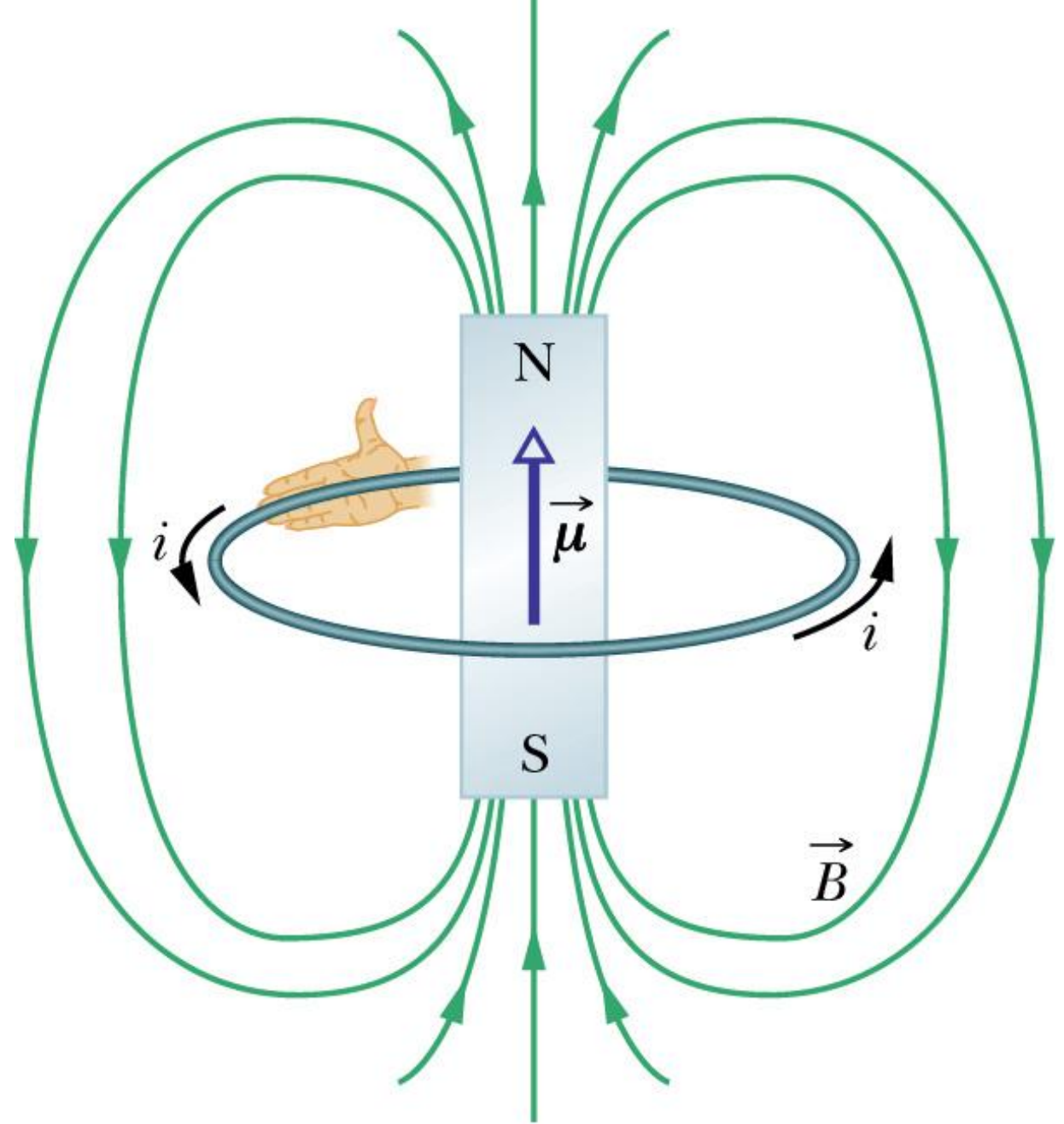
$$\phi_E = \text{Electric flux} = \int \mathbf{E} \cdot d\mathbf{A}$$

Magnetic field lines do not stop at surface.

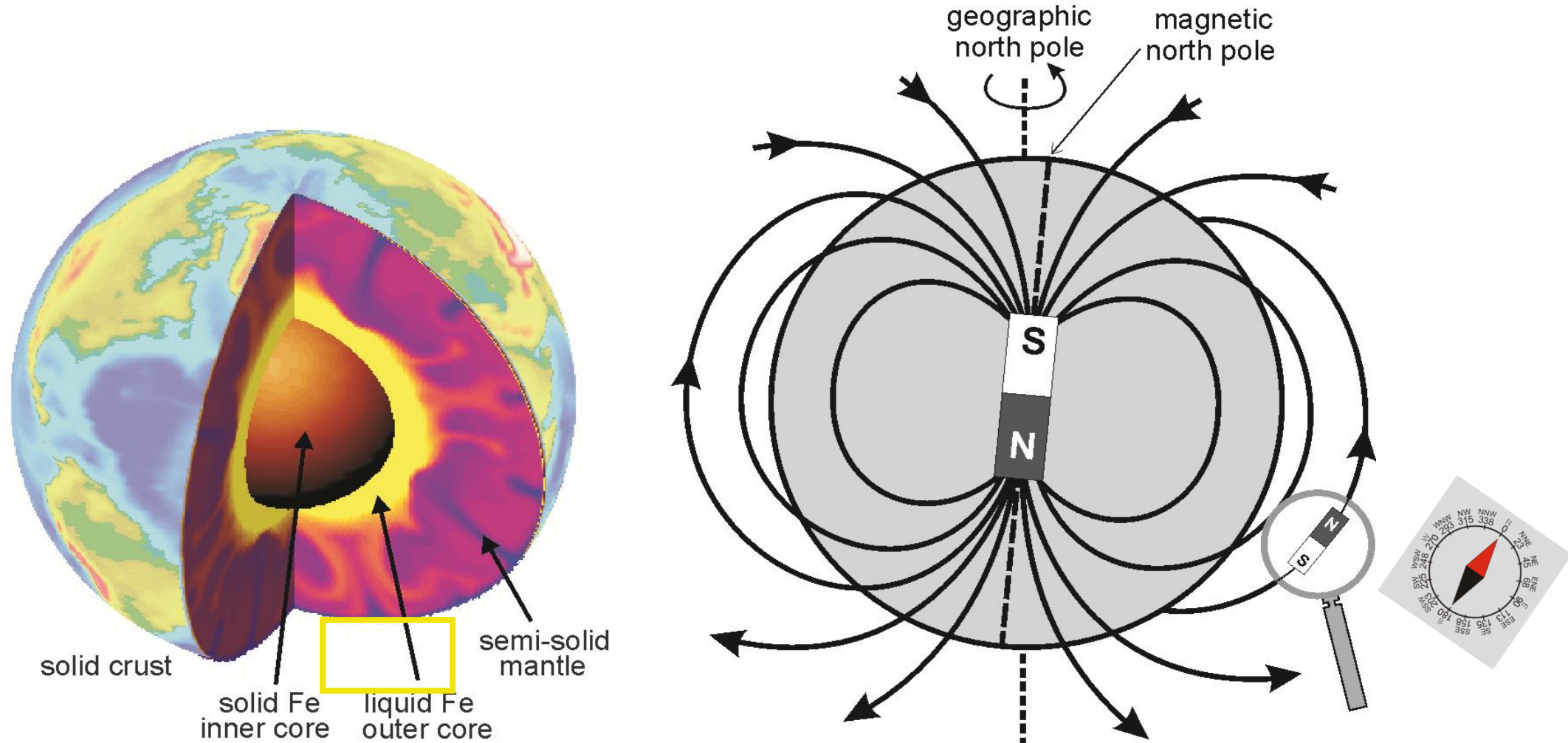
They are continuous.

They make complete loops.

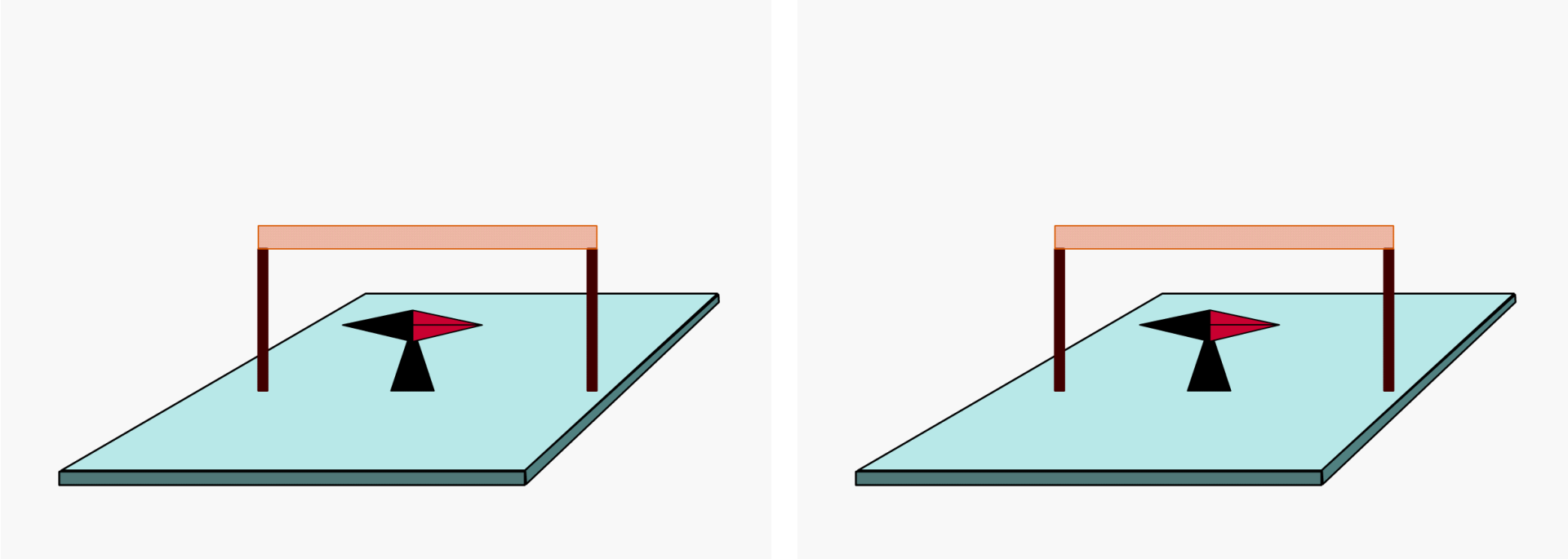
Field lines for a bar magnet are the same as for a current loop



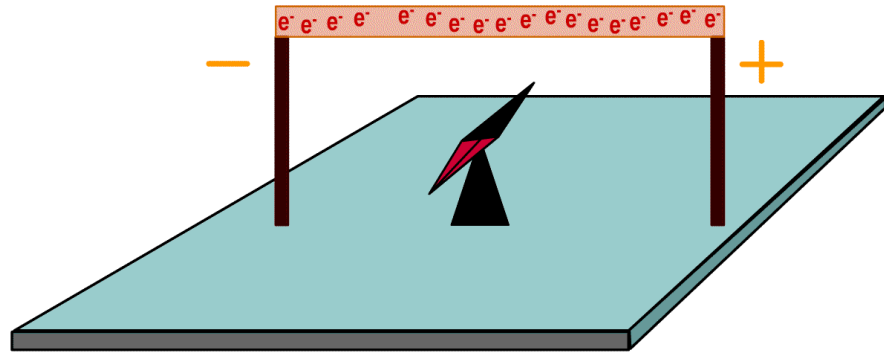
The Earth and its Magnetic Field



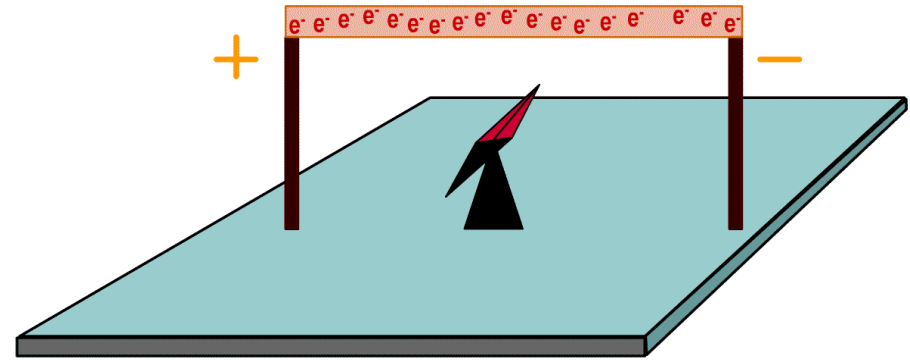
Earth field mostly from electric currents in the liquid iron outer core
Field changes direction about every 500,000 years

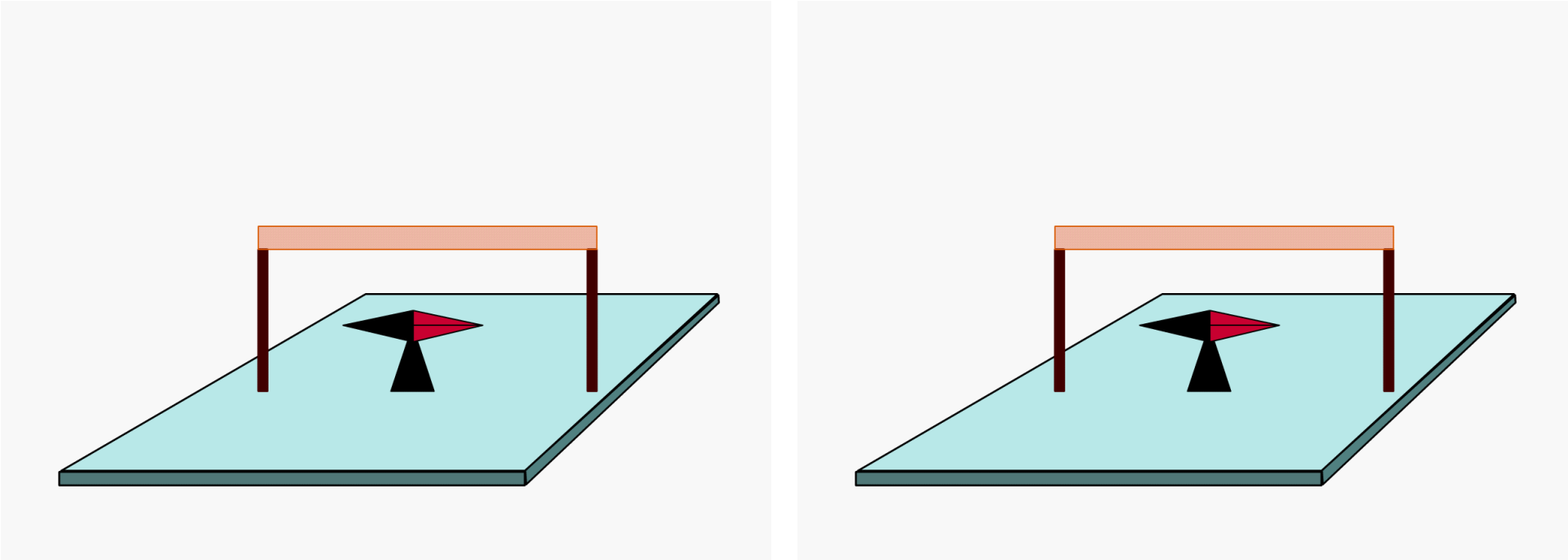


ELECTRIC CURRENT

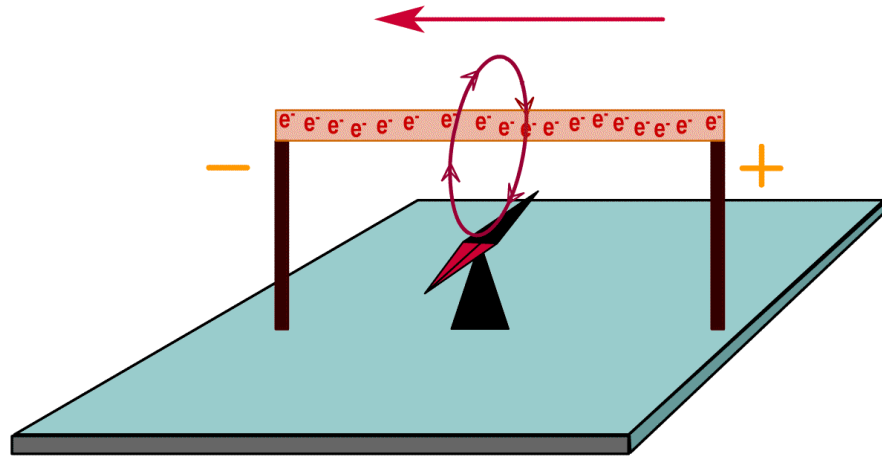


ELECTRIC CURRENT

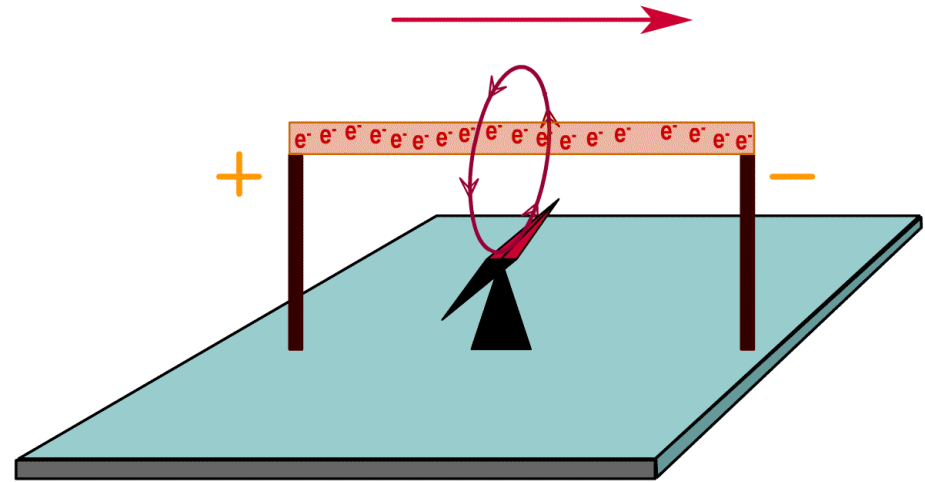




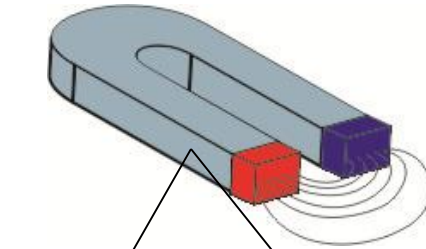
ELECTRIC CURRENT



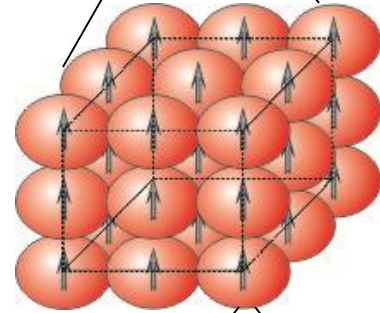
ELECTRIC CURRENT



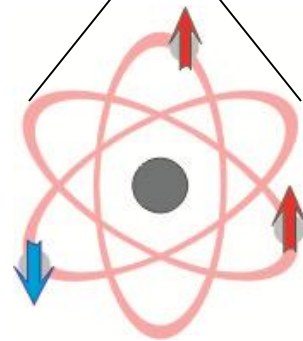
The inside of magnets: origin of magnetism



A magnet



consists of
aligned magnetic atoms

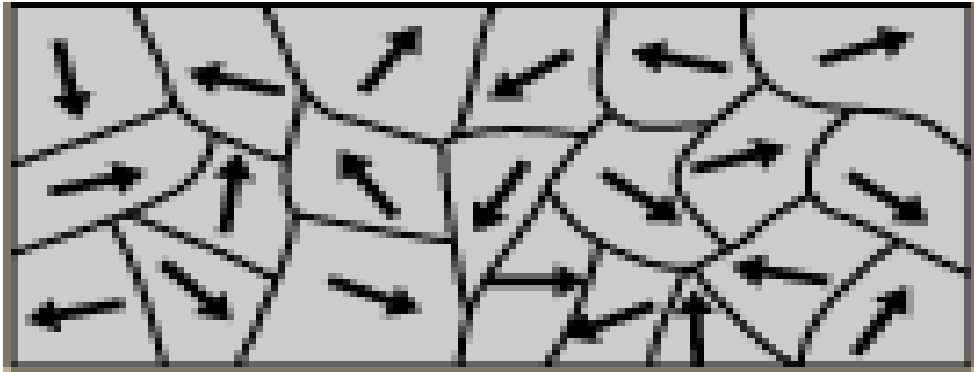


magnetic atoms have
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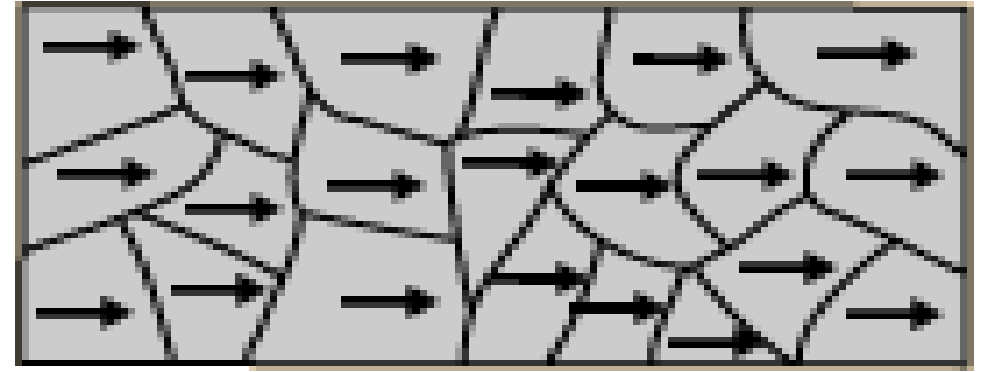
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Magnetic Domains

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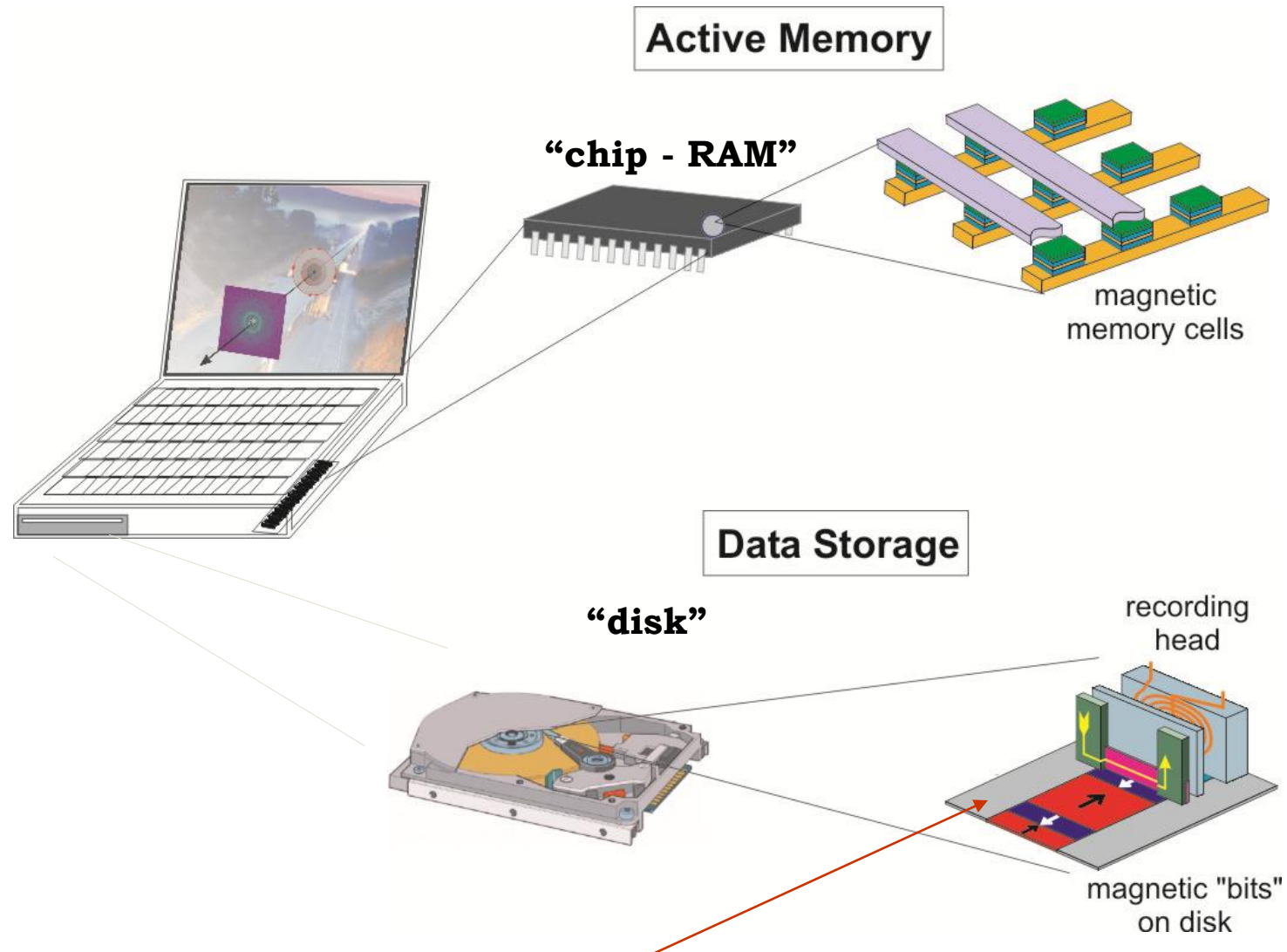
magnetized

Magnetism today.....

the high-tech society...

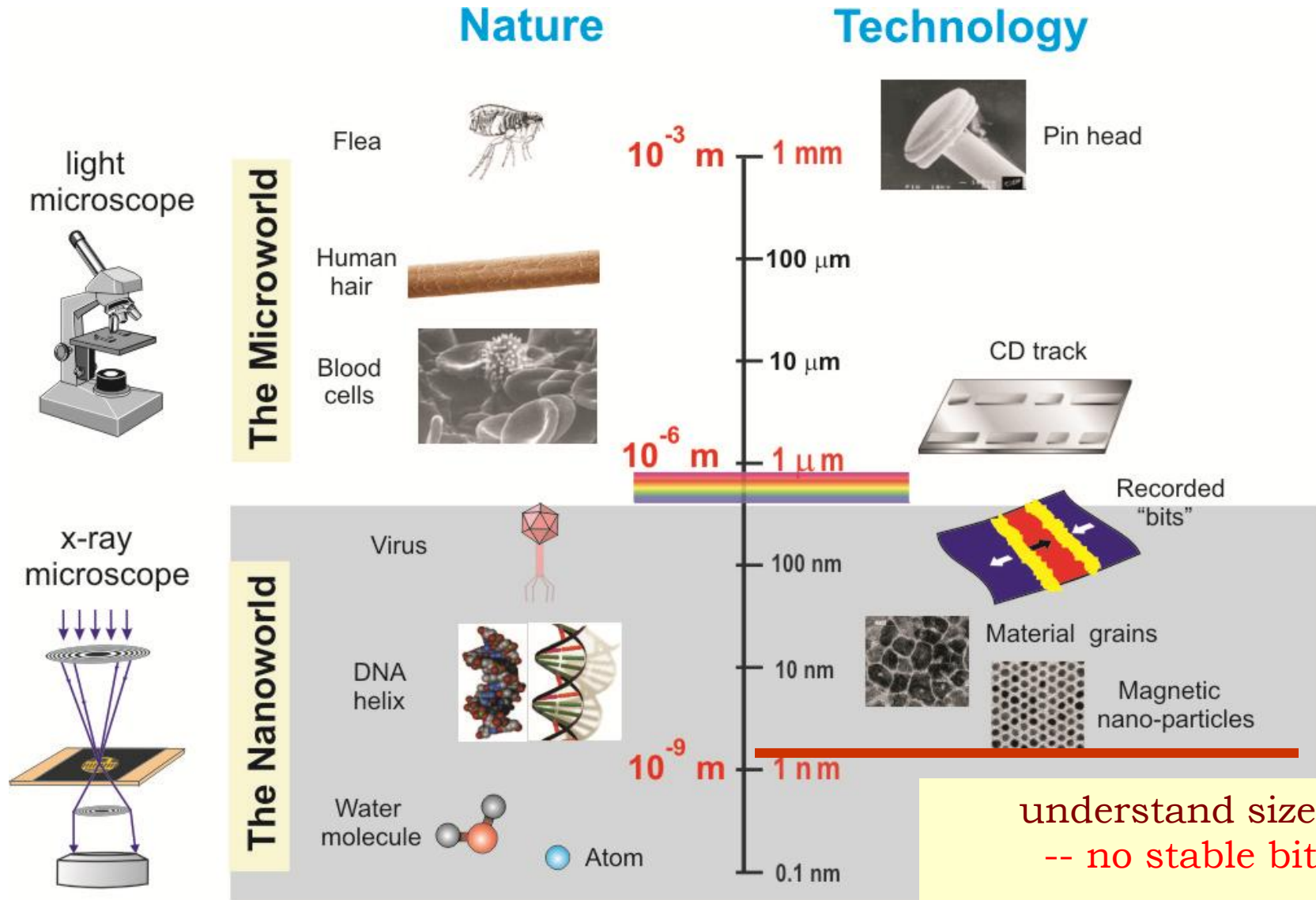
.....beyond electricity and wireless

The spin on electronics: magnetic devices in computers



“0” and “1” bits = small magnetic areas with opposite magnetization direction

The invisible ultra-small world



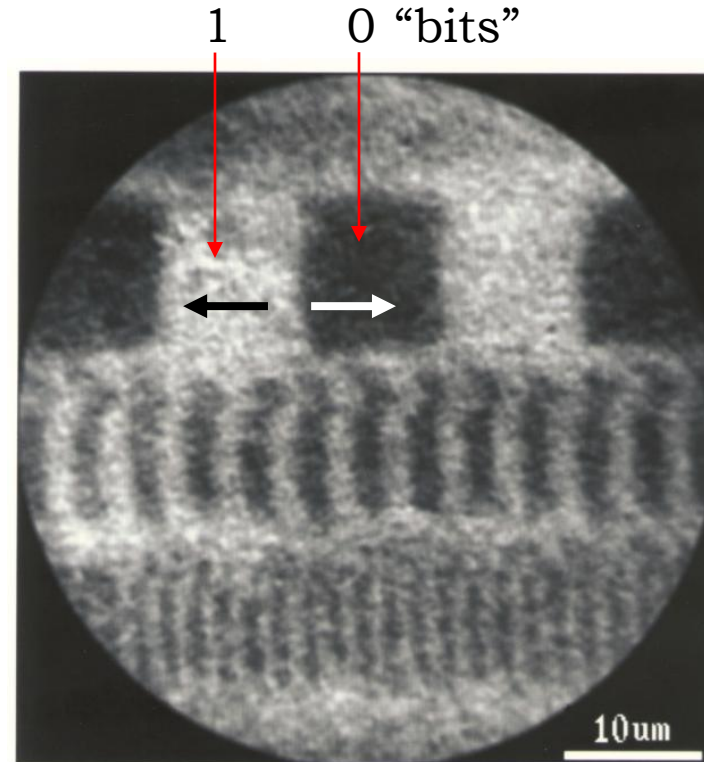
X-ray images ... then and now

X-rays have come a long way.....



1895
W. Röntgen, Würzburg

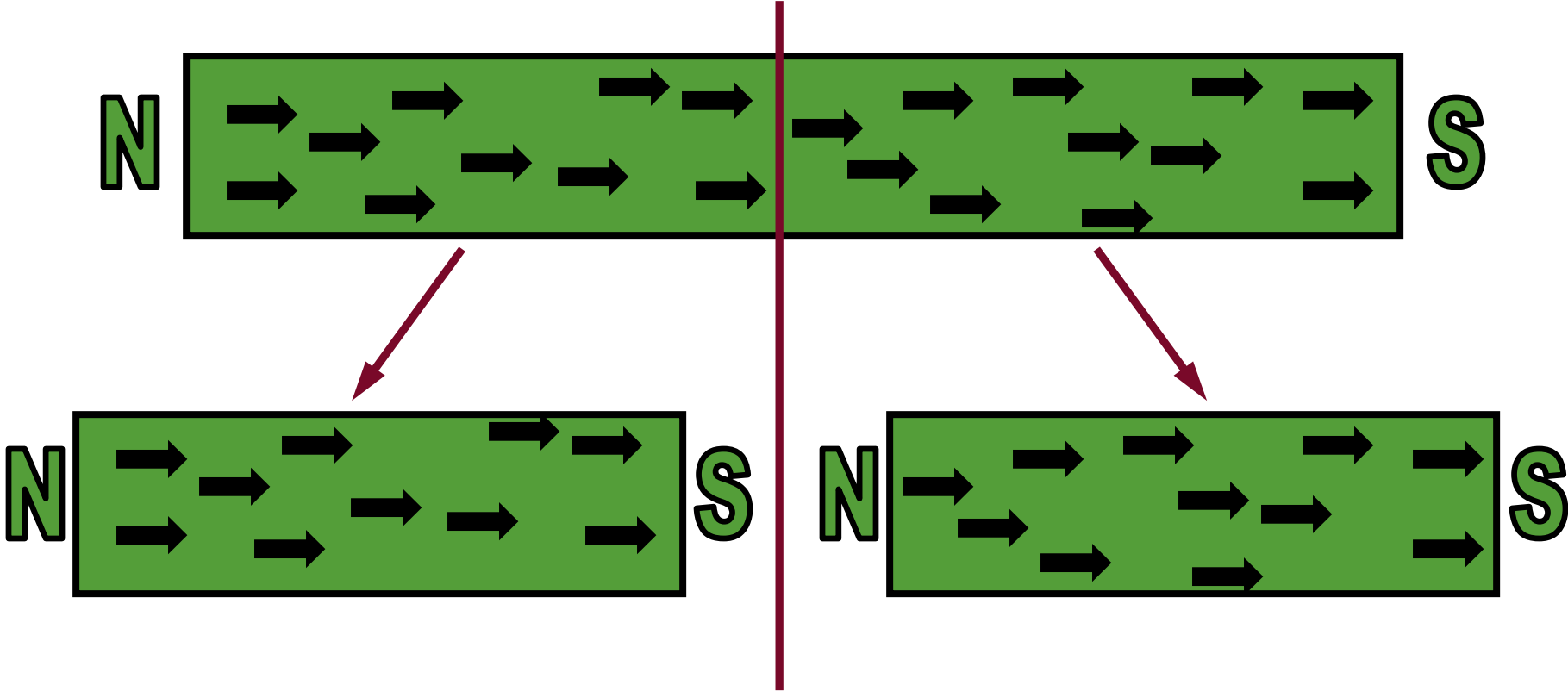
10,000 times
smaller
→



1993
SSRL/SLAC



What happens when you cut a magnet in half?

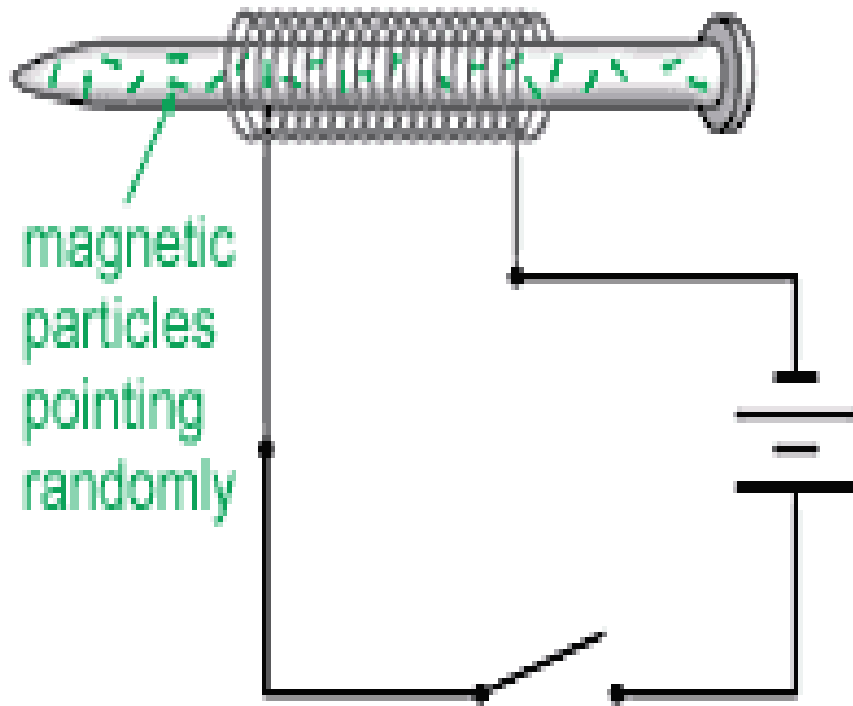


Permanent magnets

- Permanent magnets are Material that keeps its magnetic properties, even when it is not close to other magnets
- Permanent magnets are Made by placing a magnetic material in a strong magnetic field, which causes the domains to remain aligned.

- The domains of **temporary magnets** are only aligned when the material is influenced by a magnetic field. **(ex. Refrigerator, white board)**

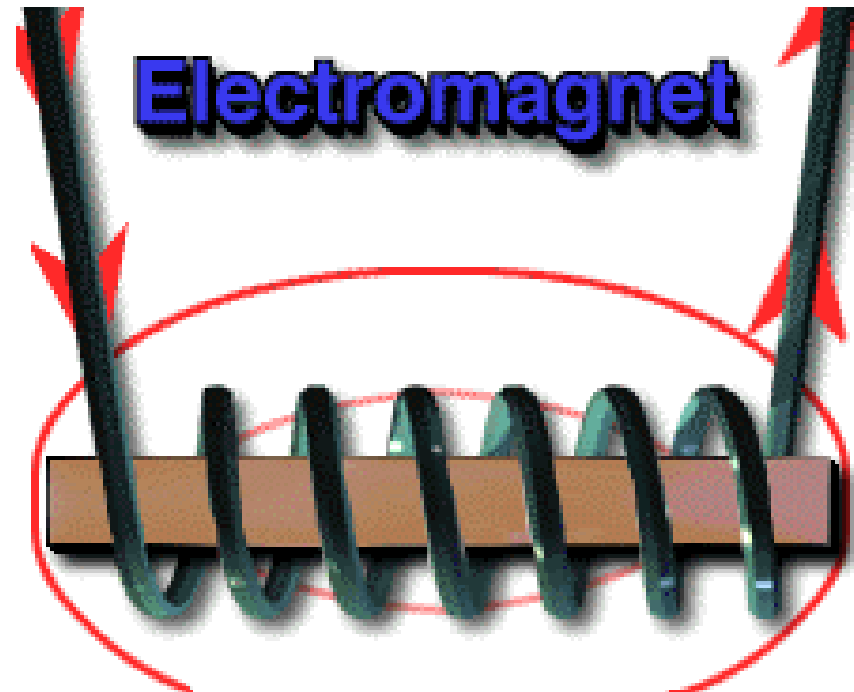
- **Electromagnet** – temporary magnet that is created by electric current flowing in a wire, usually in the form of a wire coiled around a piece of iron



Magnetic field is present only when current is flowing in the wire coil

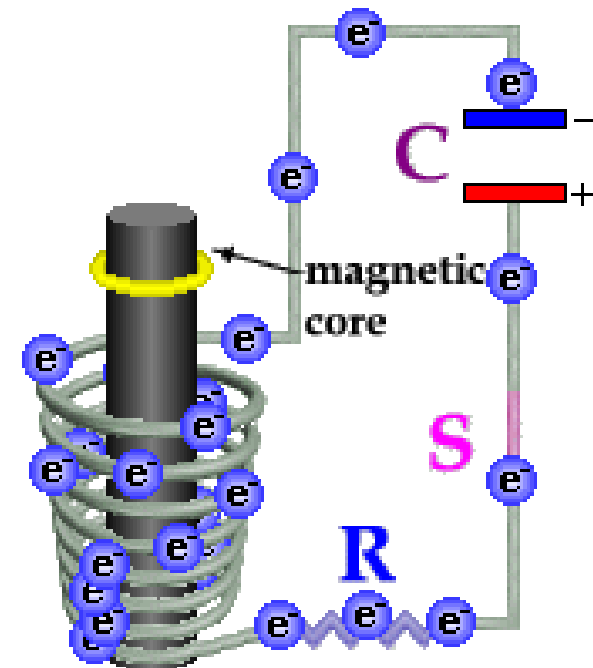
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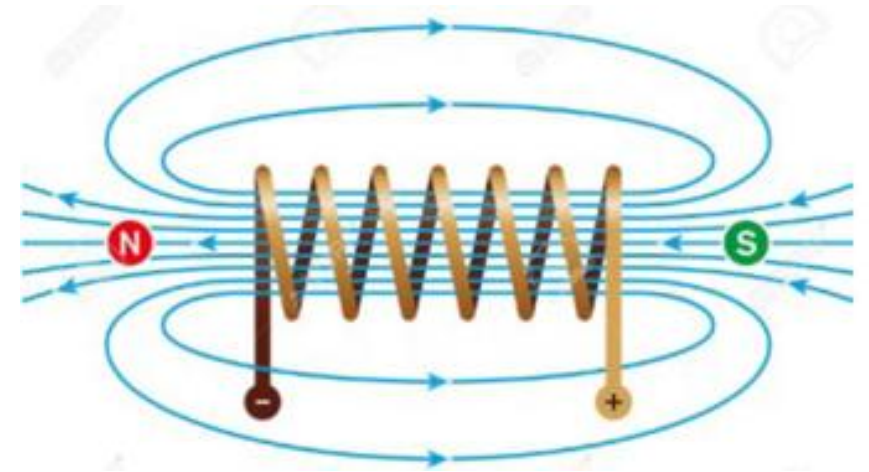
Producing Electric Current

- **Electromagnetic induction** – the production of an electric current by moving a loop of wire through a magnetic field or moving a magnet through a wire loop (which changes the magnetic field near the conductor; no battery!)



Theory of electromagnetic field– movement of electrical charge generate induced magnetic field

- Magnetic field is generated around each conductor through which the electric current flows
- Physical properties depend on this electrical current
- This phenomenon is called electromagnetic induction
- Induction of magnetic field of the earth – approximately 10^{-5} T (Tesla)



According current and its changes over time:

- **Static field** - unchanging intensity and direction of the field over time, this kind of field is generated around permanent magnets and around conducts flown by direct current
- **Alternating field (dynamic)** – alternating of polarity, values of intensity is changing regularly from 0 to positive maximum and through 0 to negative maximum and back to 0; this kind of field is generated around conducts flown by alternating current
- **Pulse field (dynamic)** – jump changes values of intensity; this kind of field is generated around conducts flown by electrical impulses;

According frequency:

- Low-frequency magnetic field
- High-frequency magnetic field

According distribution of the magnetic field in surroundings

- **homogeneous field** – has the same size and direction at all points
- **inhomogeneous field** – has different size and direction in the considered space

Magnetic Therapy

- ✓ **Magnetic therapy** is a type of physical therapy during which the body is exposed to a low frequency magnetic field.
- ✓ Cells and colloidal systems in the body contain ions that can be affected by magnetic forces. When the tissue is exposed to pulsed magnetic fields, weak electrical current is induced activating all cells that are exposed to it.

Magnetic Therapy

- ✓ As a result of sickness, the surface potential of the cells varies when compared to healthy cells.
- ✓ Tissue treated with the help of an magnetic field with suitably selected biotropic parameters, **results in** the increased activity of the cell's surface, further increasing its membrane potential, eventually resulting in the balancing of the intracellular potential.

Magnetic Therapy

- ✓ **Magnetic therapy** is not addictive and has no known side-effects.
- ✓ **The patient** does not experience any negative sensations during treatment.
- ✓ **Magnetic field pulses** penetrate evenly across body tissue so the patient does not need to take off any clothes. It can also penetrate through plaster casts.

Effects of pulsed electromagnetic fields on tissue:

- ✓ Within a couple minutes, **it expands** blood vessels in the affected area and improves the circulation of blood (visodilating effect).
- ✓ **Relieves** stress in the musculoskeletal system (myorelaxation effect).
- ✓ **Strengthens** the immune system (regenerating and detox effect).
- ✓ **Harmonizes** a vegetative nervous system.

Magnetic Therapy

- ✓ **Metal implants** are not an obstruction either as in modern usage, they are no longer ferromagnetic in nature.
- ✓ **Magnetic therapy** is prescribed by a rehabilitation physician on an individual basis and only after an exact diagnosis and possible contraindications are determined first.

How does magnetotherapy work?

- ✓ **Magnetotherapy** works by using magnetic fields to stimulate healing in the body. These can penetrate the soft tissue of the body and reach the bones, making them a useful tool for treating muscle and bone injuries.
- ✓ **When the therapy is applied**, magnetic fields penetrate the body and stimulate the flow of blood and oxygen to the affected area.

Effects of pulsed electromagnetic fields on tissue:

- ✓ By improving the permeability of the cellular membrane, it affects cell metabolism and allows for quicker absorption of swelling. It helps in healing bone fractures as well as open wounds of the skin and subcutaneous tissue.
- ✓ A **pulsed magnetic field** reduces the transmission of painful sensations from the nerve endings to the central nervous systems, further reducing pain.

Subcellular level:

- **electron interactions**- transfer of electrons between molecules, which accelerates or slows some chemical reactions
- **magnetomechanical effect**- changes in the orientation of some molecules, especially DNA and RNA, changes in the permeability of membrane systems
- **magnetolectric effect**- based on the induction of electrical potentials in the living organism - changes in nerve impulses propagation, changes in the intensity of metabolism

Cellular level:

- decrease of osmotic resistance of erythrocytes
- Calcium channel activation
- increase phagocytosis

Tissue level:

- increasing oxygen consumption
- increasing blood supply through tissues
- stimulation of the adrenal gland
- activation of the vagus nerve
- activation of the immune system
- acceleration of healing proces (e.g. fractures)
- suppressing of some micro-organisms (not enough valid data!)

What conditions can be treated with magnetotherapy?

- ✓ **Magnetotherapy** can be helpful in treating a variety of conditions, including:
 - ✓ – **Muscle injuries**: It can help reduce pain and inflammation in injured muscles, speeding recovery.
 - ✓ – **Bone injuries**: This procedure can help stimulate healing in fractured or injured bones.
 - ✓ – **Arthritis**: It is able to help reduce pain and inflammation in joints affected by arthritis.

What conditions can be treated with magnetotherapy?

- ✓ – **Chronic pain**: It can be useful in the treatment of back pain, neuralgia and headache.
- ✓ – **Sports injuries**: It is able to help reduce inflammation and speed up recovery after sports injuries.
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What conditions can be treated with magnetotherapy?

- ✓ – **Depression and anxiety**: Transcranial magnetic therapy is able to help treat depression and anxiety by stimulating certain areas of the brain.
- ✓ It is important to note that **magnetic therapy** is not a cure for these conditions, but it can be an effective tool for reducing symptoms and improving patients' quality of life.

specific magnetic gradient and effect–different applicator

- The **magnetic gradient** is determined by the density of the magnetic induction's isolines of each applicator
- Using multiple applicators at the same time, the effect does not increase

Types of applicators:

1. Flat magnetic therapy applicators
2. Solenoid-type magnetic therapy applicators
3. ring magnetic therapy applicators
4. Other types of applicators – depends on the manufacturer

various shapes of flat applicators

- square or rectangular
- „double blanket“
- „triple blanket“
- to local applications
- all-segment applications – spine, upper limbs
- older types - forbidden to lie on the applicator
- newer types - allowed to lie on the applicator
- double sides:
 - north side (+) – analgetic and inhibition effect
 - South side (-) – stimulating and facilitating effect



Diameter of 50 to 60 cm –

- for spine, hip joints, pelvis, sometimes shoulders with
- C/Th region of the spine
- Diameter of 30 cm – thighs, knees
- Diameter of 20 cm – knees, lower legs, ankles, feet, elbows, forearms, hands





Diameter of 40 cm –
area of C/Th spine,
shoulder, spine segment

- **Diameter of 30 cm** –
narrow area on limbs
(knee joint gap, lower
part of cervical spine)





QUESTION