

CHAPTER FOUR

HEAT AND THERMODYNAMICS

Outline

- ▶ Thermodynamics
- ▶ Temperature and Heat
- ▶ Heat Transfer Mechanisms
- ▶ thermal equilibrium
- ▶ Zeroth law of Thermodynamics
- ▶ Temperature Scales
- ▶ Thermal Expansion
- ▶ The Concept of Heat, Work and Internal Energy
- ▶ Specific Heat and Latent Heat
- ▶ The First Law of Thermodynamics

- ▶ What is Thermodynamics?
- ▶ What is temperature?
- ▶ What is heat?
- ▶ How are the two concepts related?
- ▶ Do the temperature objects transfers equal heat?

Thermodynamics

- ▶ One of the principal branches of physics and engineering .
- ▶ science that govern energy conversions processes (heat to work and vice versa)
- ▶ In winter, when we rub our palms together, we feel warmer; here work done in rubbing produces 'heat'.
- ▶ Conversely, in a steam engine, the 'heat' of the steam is used to do useful work in moving the pistons, which in turn rotate the wheels of the train.
- ▶ consider macroscopic systems, or systems with a large number of degrees of freedom. large scale" properties of the systems.
- ▶ it deals with quantities (like T , P and V)
- ▶ One of the central concepts of thermodynamics is temperature.

■ Heat pumps



■ Mechanical devices



The language of Thermodynamics

- ▶ System is any part of the universe chosen for study
- ▶ Surrounding is The rest of the universe in the neighbourhood of the system.
- ▶ System and surroundings are separated by some kind of **boundary** wall.
- ▶ $\text{Universe} = \text{System} + \text{Surrounding}$

Types of systems

(a) Open systems:-

- ▶ Allows exchange of both heat and matter through the boundary. E.g. digestive system.



(b) Closed systems

- ▶ Allows only exchange of heat with surrounding but not matter. E.g. refrigerator

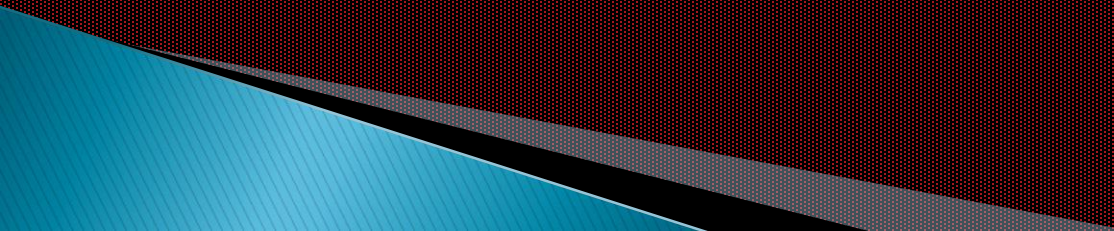


Isolated System:-

- ▶ No heat or matter exchange occurs with surrounding.
- ▶ E.g. Vacuum flask.



Temperature

- ▶ A measure of how warm or cold an object is with respect to some standard.
 - ▶ Related to the random thermal motion of the molecules in a substance.
 - ▶ Measure of average translational kinetic energy of molecules.
 - ▶ Does not depend on the total number of molecules in a substance
- 

Heat

- ▶ The energy transferred between objects due to a temperature difference
- ▶ Energy in transit (similar to work)
- ▶ is a measure of the total energy of motion of all of its molecules
- ▶ Heat always flows from hotter to colder objects
- ▶ Transferring an amount of heat to an object may raise its temperature.
- ▶ is a function of the number of molecules in a substance,
- ▶ Heat and temperature are not same

Consider a person heated containers of equal volumes of olive oil and water to 165° F (74° C) in a sous vide water bath, then placed a raw egg into each one. What did he observed?

- ▶ The water turned the egg white cloudy very quickly. because it takes more energy to heat water to 165° F than it does olive oil. Water has more heat capacity than olive oil.



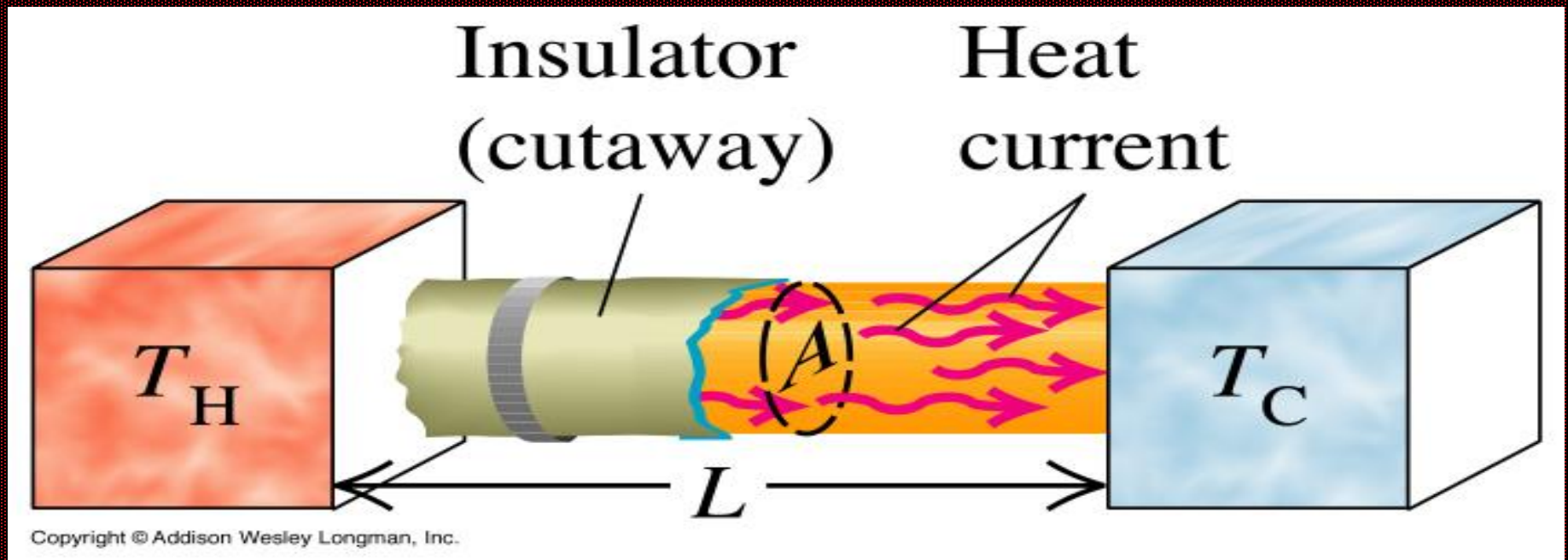
Heat Transfer Mechanisms

- ▶ When two bodies are at different temperatures, thermal energy transfers from the one with higher temperature to the one with lower temperature.
- ▶ Heat energy can be transferred from one body to another in three different ways.



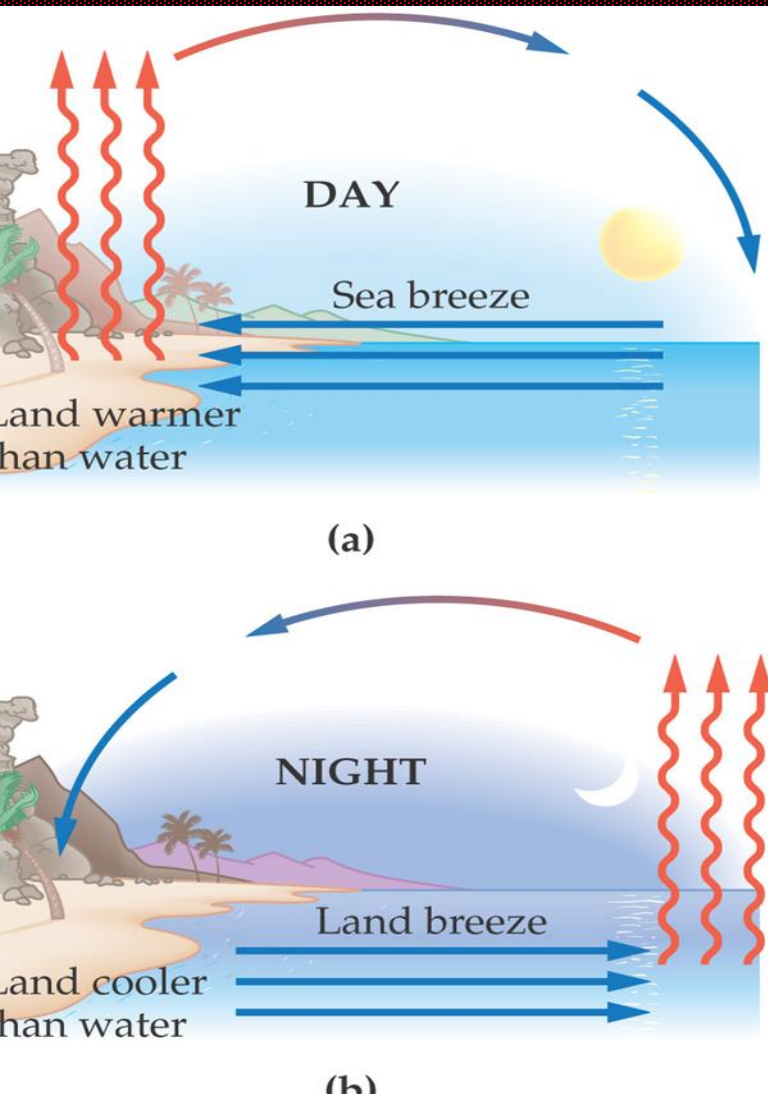
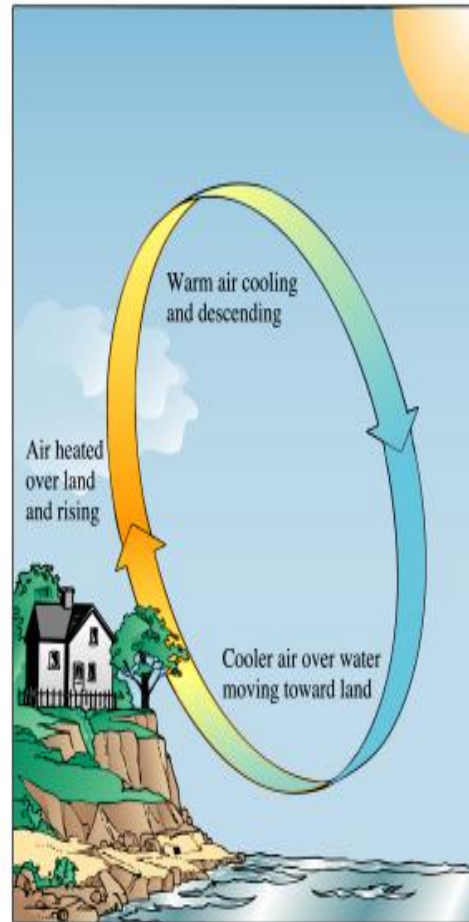
Conduction.

- ▶ is the transfer of heat through solids or stationary fluids.

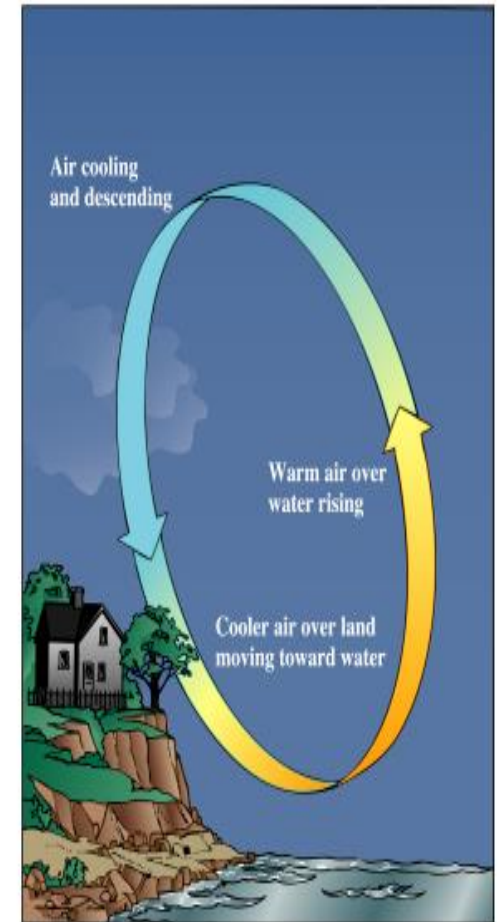


Convection

- uses the movement of fluids to transfer heat.



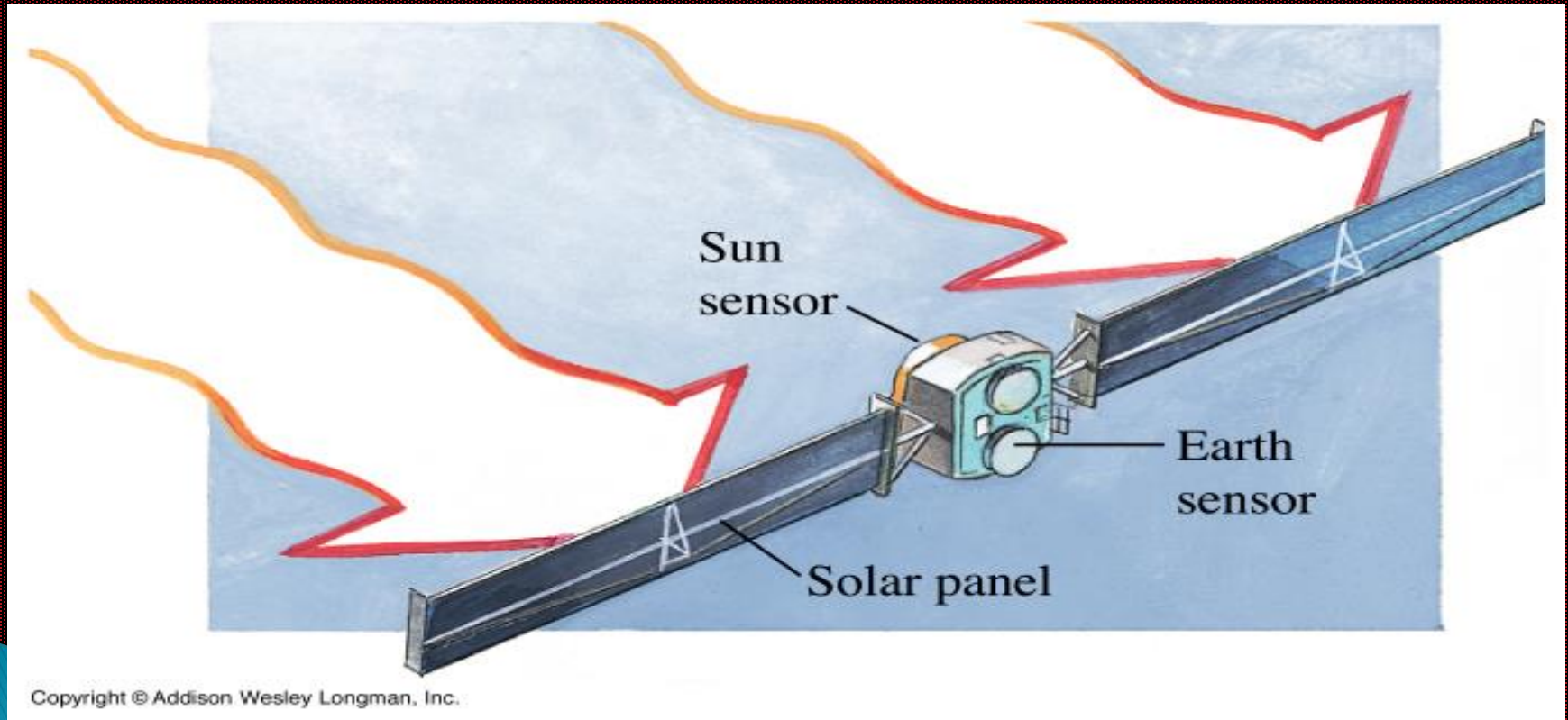
(a)



(b)

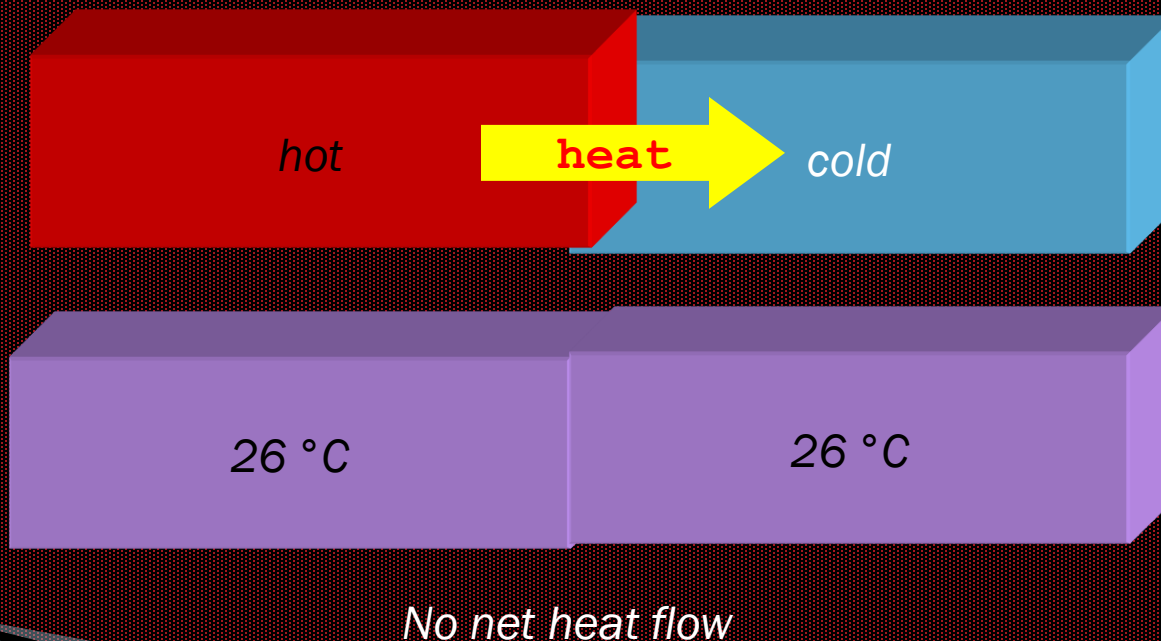
Radiation

- ▶ does not require a medium for transferring heat;
- ▶ this mode uses the electromagnetic radiation emitted by an object for exchanging heat.



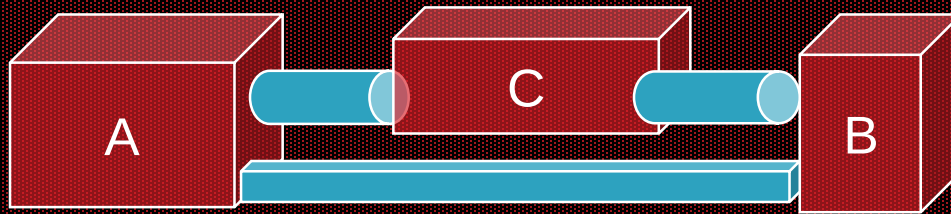
thermal equilibrium

- Two bodies are said to be at thermal equilibrium if they are at the same temperature. This means there is no net exchange of thermal energy between the two bodies.



Zeroth law of Thermodynamics

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

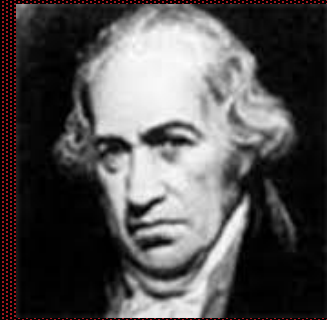


Temperature Scales

- ▶ There are three common temperature scales – Celsius (Centigrade), Kelvin, Fahrenheit
- ▶ Celsius scale, °C (1742)
- ▶ metric temp. scale
- ▶ Water freezes at 0° Celsius.
- ▶ Water boils at 100° Celsius.



Fahrenheit scale, °F (1724)



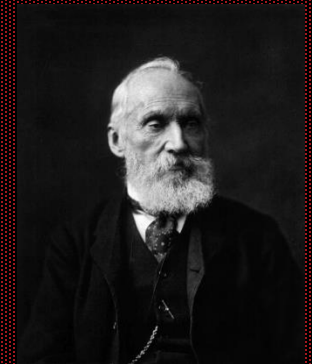
- ▶ customary (English) temp. scale,
- ▶ First modern thermometer (Hg)
- ▶ Water freezes at 32° Fahrenheit .
- ▶ Water boils at 212° Fahrenheit .
- ▶ In other words, **five** steps on the **Celsius** scale is equivalent to **nine** steps on the **Fahrenheit** scale,
- ▶ Since these scales are linear, and they're offset by 32 °F, we get the conversion

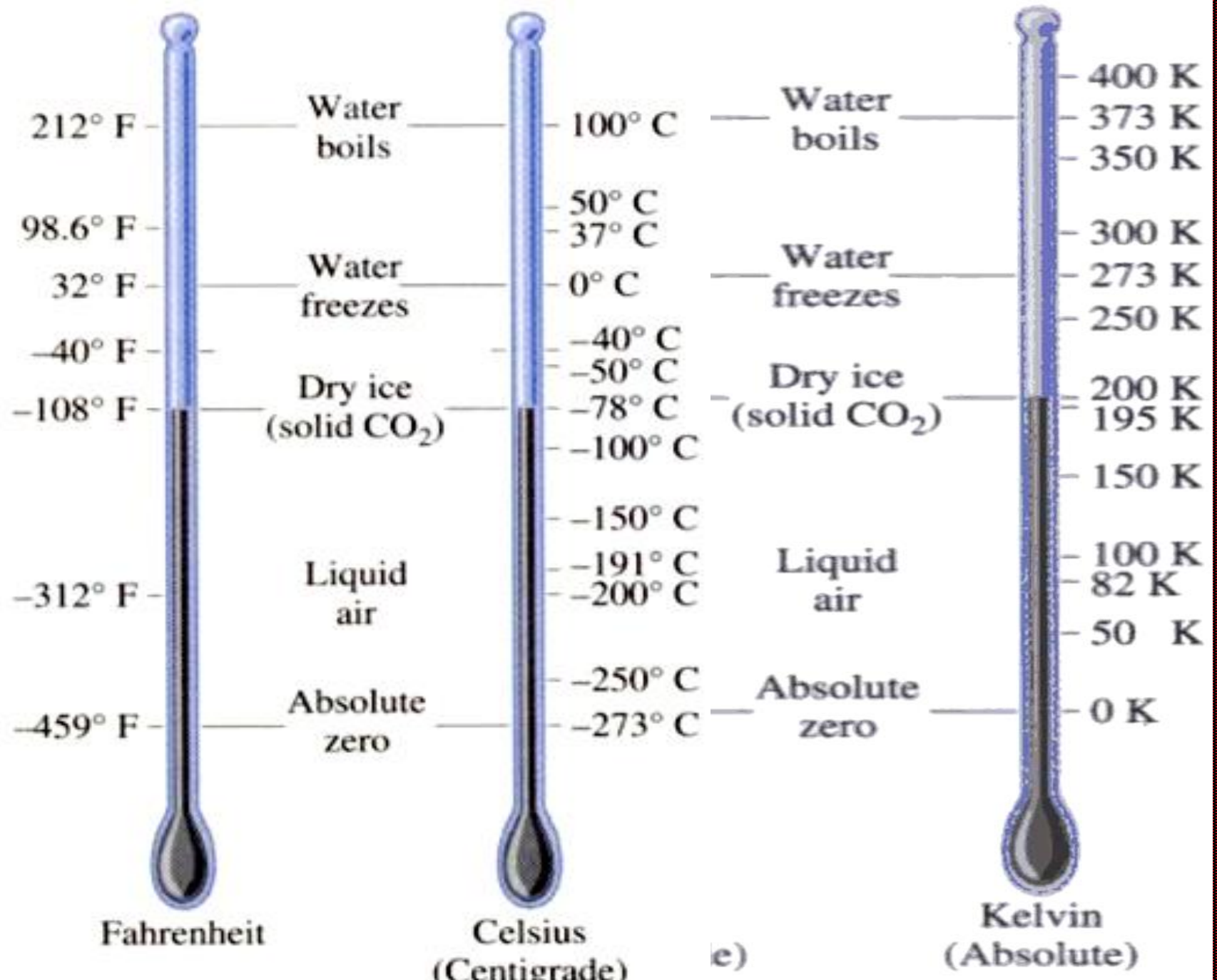
$$T_F = \frac{9}{5}T_C + 32^\circ$$

Kelvin, K (1848)

- ▶ metric absolute zero temp. scale
- ▶ ‘triple point’ of water 273.16 K
- ▶ Absolute thermodynamics temperature scale
- ▶ One step on the Kelvin scale is the same as one step on the Celsius scale. These scales are off by 273.15 K we get the conversion

$$T_K = T_C + 273.15$$





Thermal Expansion

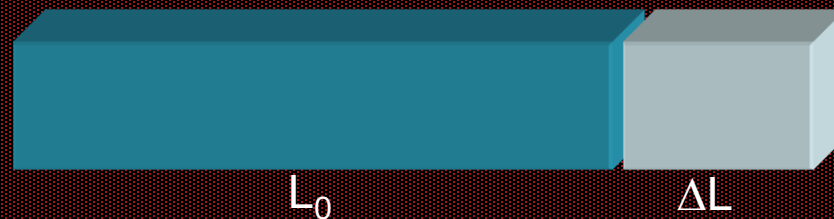
- ▶ For $\alpha > 0$:
- ▶ If $\Delta T > 0$: $\Delta L > 0$  material expands
- ▶ If $\Delta T < 0$: $\Delta L < 0$  material compresses
- ▶ The exception to this rule is water. As water is cooled from 4°C to 0°C , it expands which explains why ice floats (it is less dense than water).
- ▶ Why does a lake freeze from the top and not the bottom?

Thermal Expansion - Linear

- ▶ objects expand along linear dimensions such as length, width, height, diameter, etc.
- ▶ The amount of expansion depends on the **original length**, the **type of material**, and the **change in temperature**.

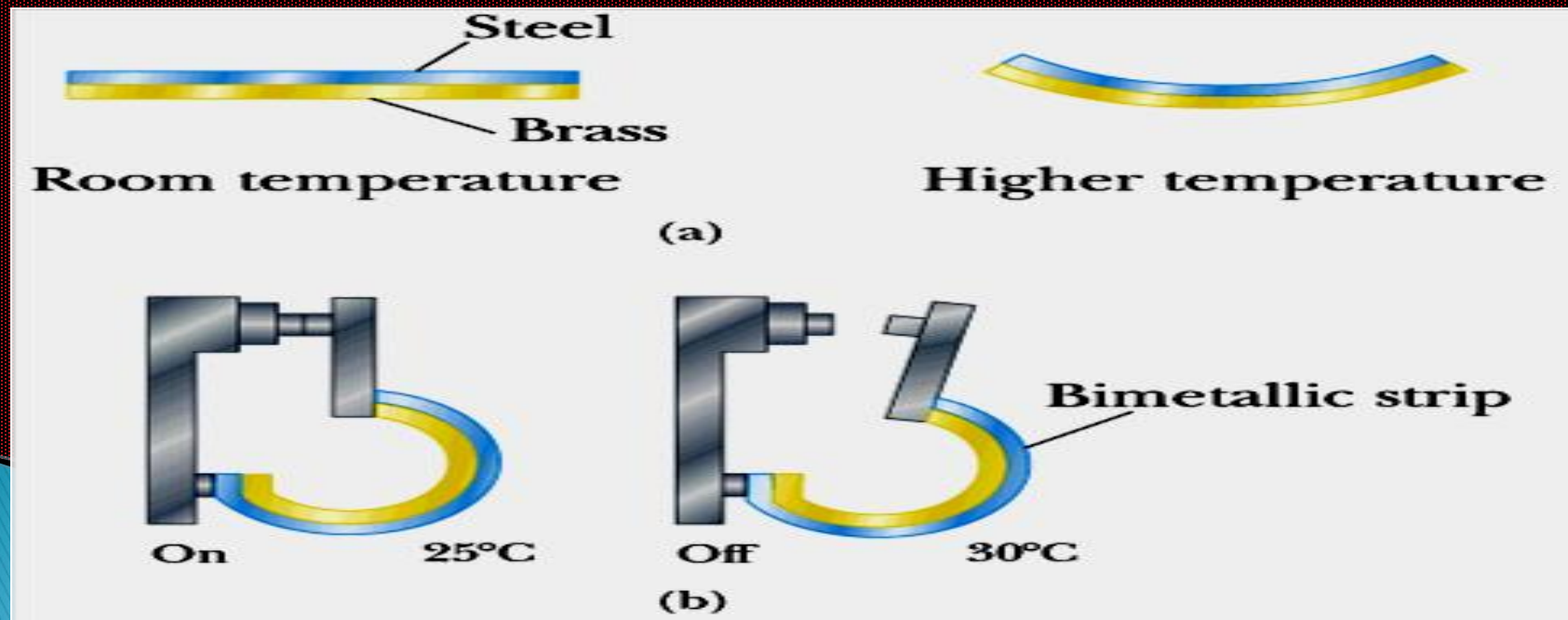
$$\Delta L = L_0 \alpha \Delta T$$

$$L_F = L_0 + \Delta L$$



Common Practical application is A bimetallic strip

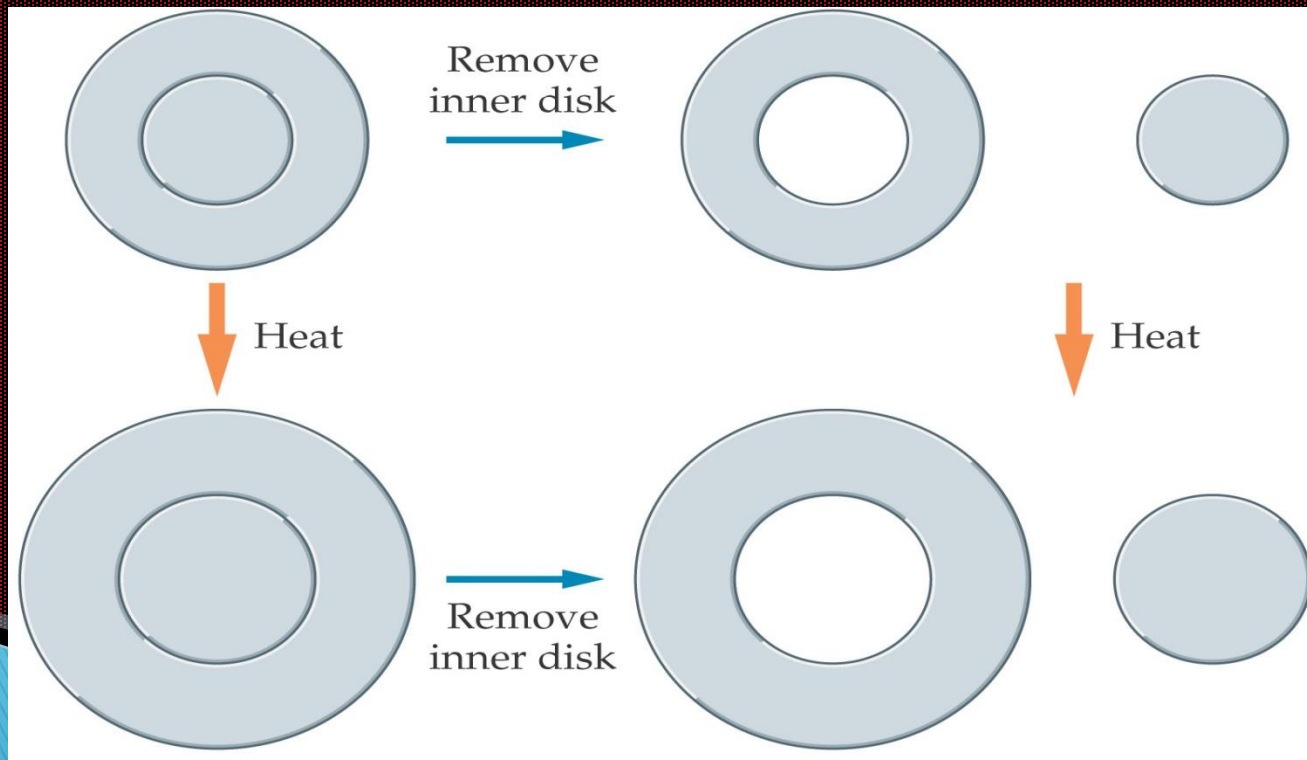
- ▶ Bimetallic strips are used to build a thermometer or a thermostat
- ▶ When the temperature changes, the strip bends, making or breaking an electrical circuit, which causes the furnace to turn on or shut off.



Thermal Expansion -area

- ▶ The expansion of an area of a flat substance is derived from the linear expansion in both directions:

$$\Delta A \approx 2\alpha A \Delta T$$

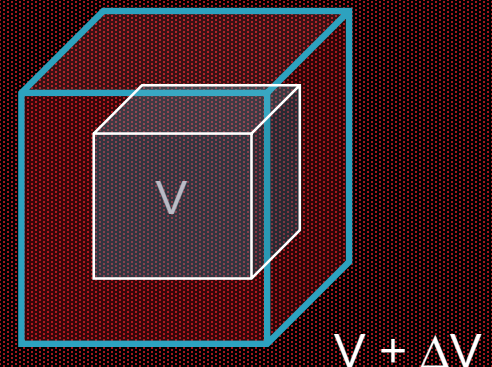


Thermal Expansion – volume

- ▶ The change in volume of a solid is also derived from the linear expansion:

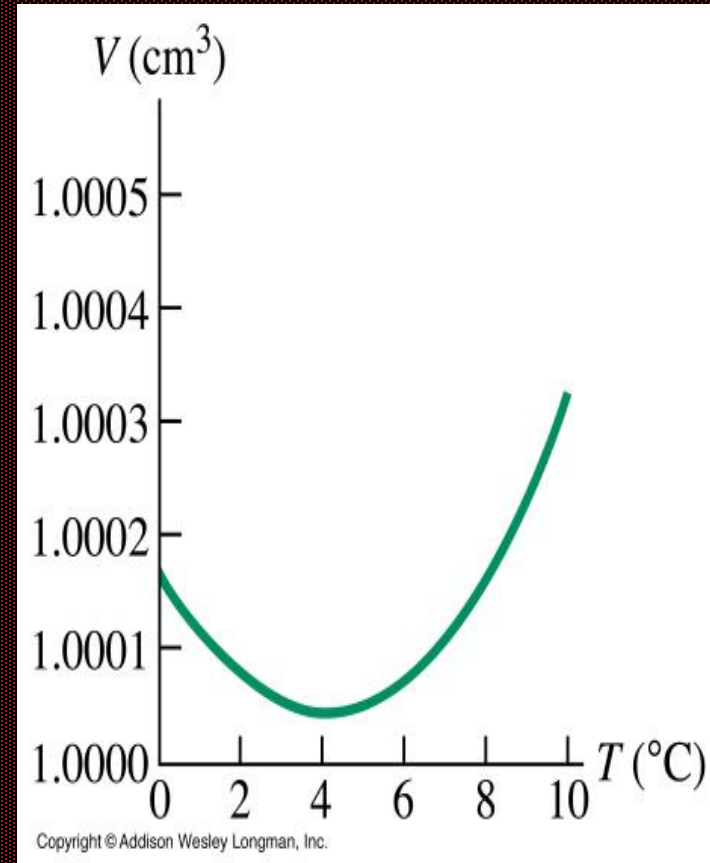
$$\Delta V \approx 3\alpha V \Delta T$$

- ▶ For liquids and gases, only the coefficient of volume expansion is defined:
- ▶ $\Delta V = V_0 \gamma \Delta T$ $V_F = V_0 + \Delta V$



Thermal Expansion of Water:

- ▶ What are unusual behavior of water?
- ▶ How it is important for life existence?
- ▶ Anomalous Expansion Between 0 - 4°C
- ▶ Water also expands when it is heated, except when it is close to freezing; it actually expands when cooling from 4° C to 0° C.
- ▶ This is why ice floats and frozen bottles burst.



Examples

1. The main span of San Francisco's Golden Gate Bridge is 1275 m long at its coldest. The bridge is exposed to temperatures ranging from -15°C to 40°C . What is its change in length between these temperatures? Assume that the bridge is made entirely of steel.
2. A square hole 8.00 cm along each side is cut in a sheet of copper. (a) Calculate the change in the area of this hole resulting when the temperature of the sheet is increased by 50.0 K. (b) Does this change represent an increase or a decrease in the area enclosed by the hole?
3. The average coefficient of volume expansion for carbon tetrachloride is $5.81 \times 10^{-4} (^{\circ}\text{C}^{-1})$. If a 50.0-gal steel container is filled completely with carbon tetrachloride when the temperature is 10.0°C , how much will spill over when the temperature rises to 30.0°C ?

The Concept of Heat, Work and Internal Energy

- ▶ Work: transfer of energy that makes use of the uniform motion of atoms in the surroundings.
- ▶ is the only energy which is transferred to the system *through* external macroscopic forces.

$$\Delta W = - P \Delta V$$

- ▶ Mechanical work is *positive* when it is performed **on** the system.

Heat:

- ▶ a spontaneous transfer of energy that makes use of random motion of atoms in the surroundings.
- ▶ The two ways in which energy can be transferred into or out of a system – **heat** and **work**
- ▶ **An object does not possess heat and work!!**
- ▶ Q is positive if ΔT is positive; that is, if heat is added to a system.
- ▶ Q is negative if ΔT is negative; that is, if heat is removed from a system.

Internal energy:

- ▶ is all the energy of a system that is associated with its microscopic constituents.
- ▶ Internal energy includes kinetic energy of random translational, rotational, and vibrational motion of molecules, potential energy of molecules and between molecules.
- ▶ But for ideal gas it is only related to kinetic energy (temperature)

Specific Heat and Latent Heat

- ▶ As heat is added to a substance it will either be absorbed to raise the temperature OR to change the state of matter.
- ▶ It can NEVER do both at the same time!
- ▶ Temperature will NOT change during a phase change!

Specific Heat -Temperature Change

- ▶ The Amount of heat energy needed to raise the temperature of 1kg object by one degree Celsius

$$Q = mc\Delta T$$

- ▶ For gases, heat may be added by keeping volume or pressure as constant

$$Q_v = nC_v\Delta T$$

$$Q_p = nC_p\Delta T$$

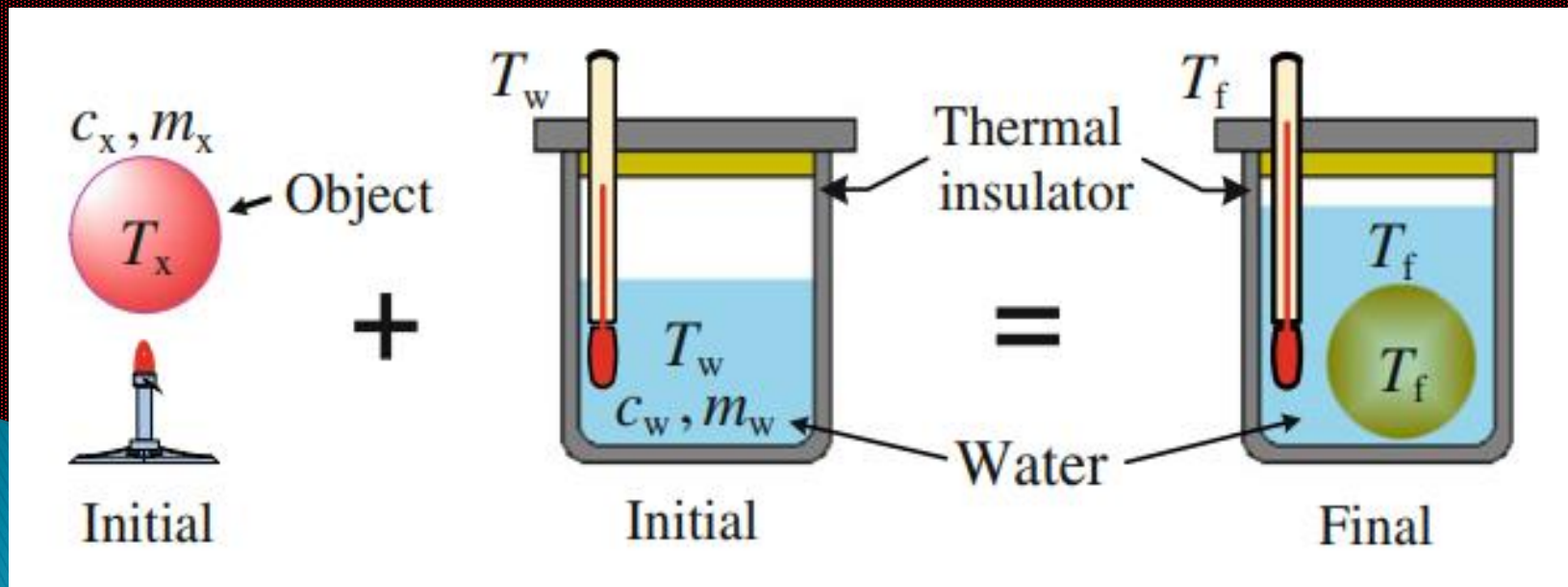
$$C_p > C_v$$

Measuring Specific Heat

- ▶ if T_f is the final temperature after reaching equilibrium, then $T_w < T_f < T_x$.
- ▶ Heat gained by the water to be $Q = m_w c_w (T_f - T_w)$,
- ▶ heat energy lost by the object to be $-Q = m_x c_x (T_f - T_x)$.

$$Q = m_w c_w (T_f - T_w) = -m_x c_x (T_f - T_x)$$

Assuming that the entire system does not lose or gain any heat from its surrounding,



Latent Heat-Phase Change

- The amount of heat energy per unit mass, L , that must be transferred when a substance completely undergoes a phase change *without changing temperature* is called the **latent heat**

$$Q = \pm m L$$

- **Latent Heat of Fusion (L_f)**: is the heat absorbed or released when matter melts, changing phase from solid to liquid form at constant temperature
- **Latent Heat of Vaporization (L_v)**: is the heat absorbed or released when matter vaporizes, changing phase from liquid to gas phase at constant temperature

- ▶ **Melting or Freezing Point** – the temperature at which a substance melts or freezes. Water: 0°C
- ▶ **Boiling or Condensation Point** – the temperature at which a substance vaporizes or condenses. Water: 100°C For other substances, refer.

The First Law of Thermodynamics

- ▶ How to increase U of a system?
- ▶ The total increase in the thermal energy of a system is the sum of the work done on it and the heat added to it.

$$\Delta U = W + Q$$

- ▶ W - is positive for work done on a system
- ▶ - is negative for work done by the system
- ▶ Q - is positive for heat enters to the system
- ▶ - is negative for heat leaves from the system

Different Processes and 1st law

- ▶ **Isobaric**-pressure of the system remains constant.

$$\Delta U = Q - P \Delta V$$

- ▶ **Isochoric**- volume of the system remains constant. Such system can do no work

$$W = 0, \Delta U = Q$$

- ▶ All the heat entering the system goes into increasing the internal energy
- ▶ Thus, if heat is absorbed by a system the internal energy of the system increases.

Adiabatic – no transfer of heat

$$\Delta U = W = -P \Delta V$$

- ▶ Using either insulating boundary or rapid compression and expansion
- When a gas is compressed adiabatically, both W and ΔU are positive; work is done on the gas
- When the gas expands adiabatically, ΔU is negative; work is done by the gas

Isothermal – Temperature remains constant

$$\Delta U = 0 \quad 0 = Q + W, \quad Q = -W = P\Delta V$$

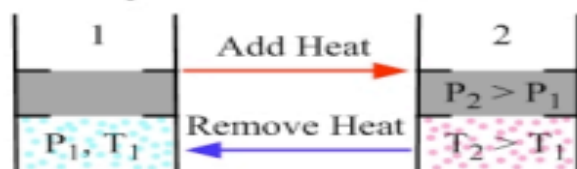
- ▶ If the process is quasi-static(slow) it's nearly isothermal.

$$W = -nRT \ln\left(\frac{V_f}{V_i}\right)$$

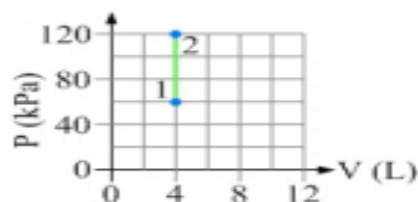
Summary of Thermodynamic Processes

Isochoric (Constant Volume)

Special condition: $W = 0$



Physical system: A container of fixed volume to which heat can be added or removed.



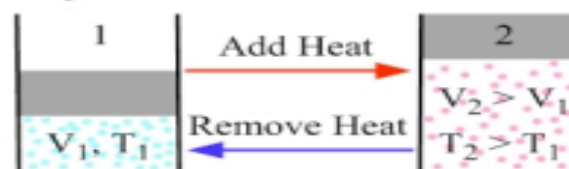
First Law:
 $Q = \Delta E_{\text{int}}$

Ideal Gas Law:

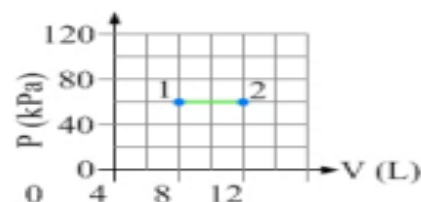
$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Isobaric (Constant Pressure)

Special condition: $W = P \Delta V$



Physical system: A cylinder sealed by a piston that can move up or down without friction.



First Law:

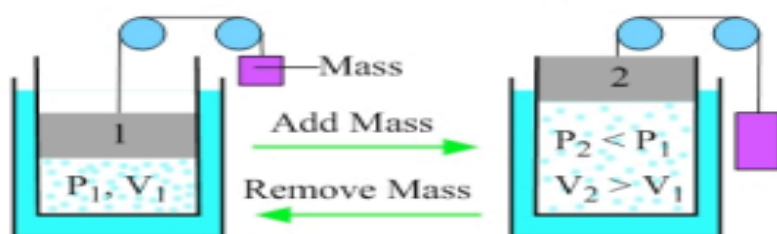
$$Q = P \Delta V + \Delta E_{\text{int}}$$

Ideal Gas Law:

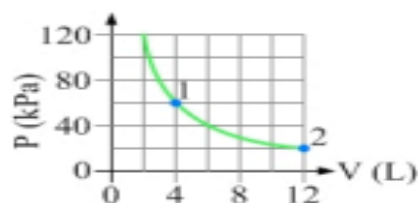
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Isothermal (Constant Temperature)

Special condition: $\Delta E_{\text{int}} = 0$



Physical system: A cylinder in a bath of constant temperature, to which changes are made slowly.



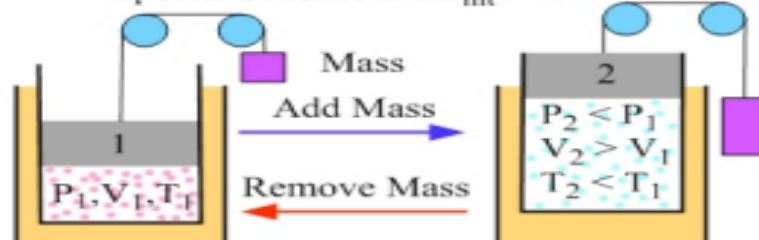
First Law:
 $Q = W$

Ideal Gas Law:

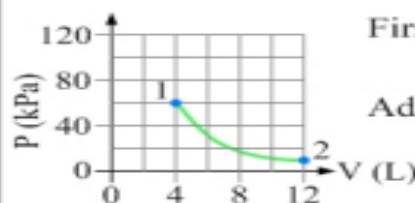
$$P_1 V_1 = P_2 V_2$$

Adiabatic (Zero Heat)

Special condition: $\Delta E_{\text{int}} = -W$



Physical system: A cylinder that is well insulated, and/or in which changes are made quickly.



First Law: $W = -\Delta E_{\text{int}}$

Adiabatic Equations: $\gamma = \frac{C_p}{C_v}$

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

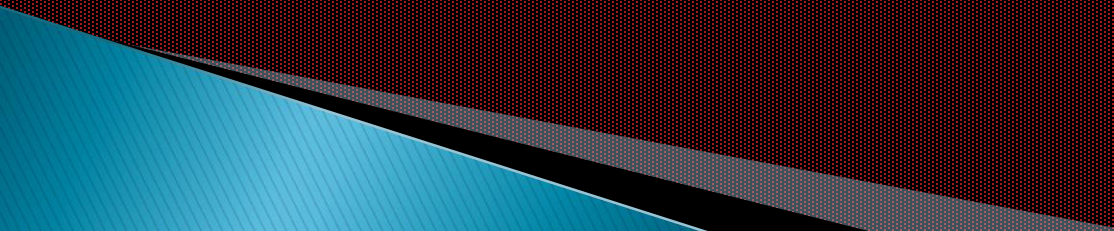
Thermodynamic Sign Conventions for Heat and Work

- ▶ Heat added to system $Q > 0$
- ▶ Heat removed from system $Q < 0$
- ▶ Work done by system $W < 0$
- ▶ Work done on system $W > 0$

Any questions?

End of chapter FOUR

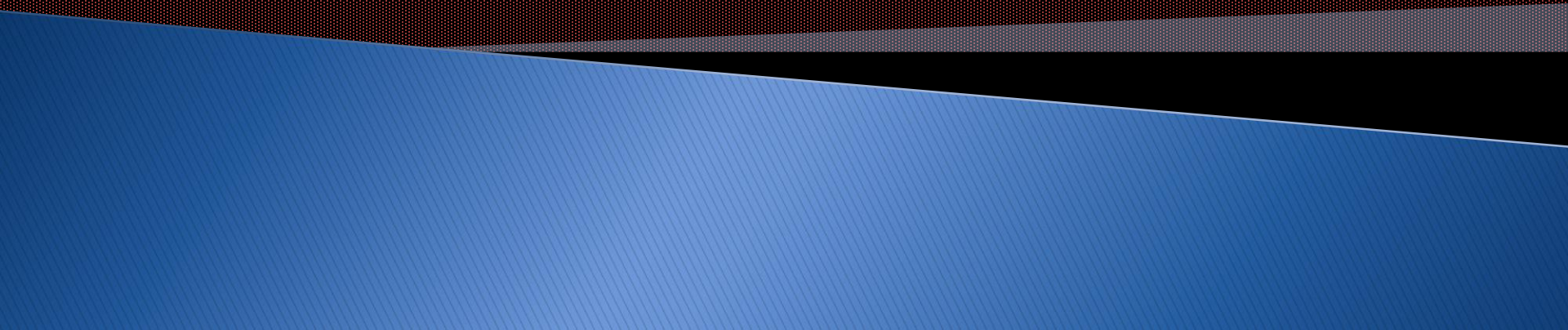
THANK YOU!



CHAPTER FIVE

OSCILLATIONS, WAVES AND

OPTICS



Periodic Motion

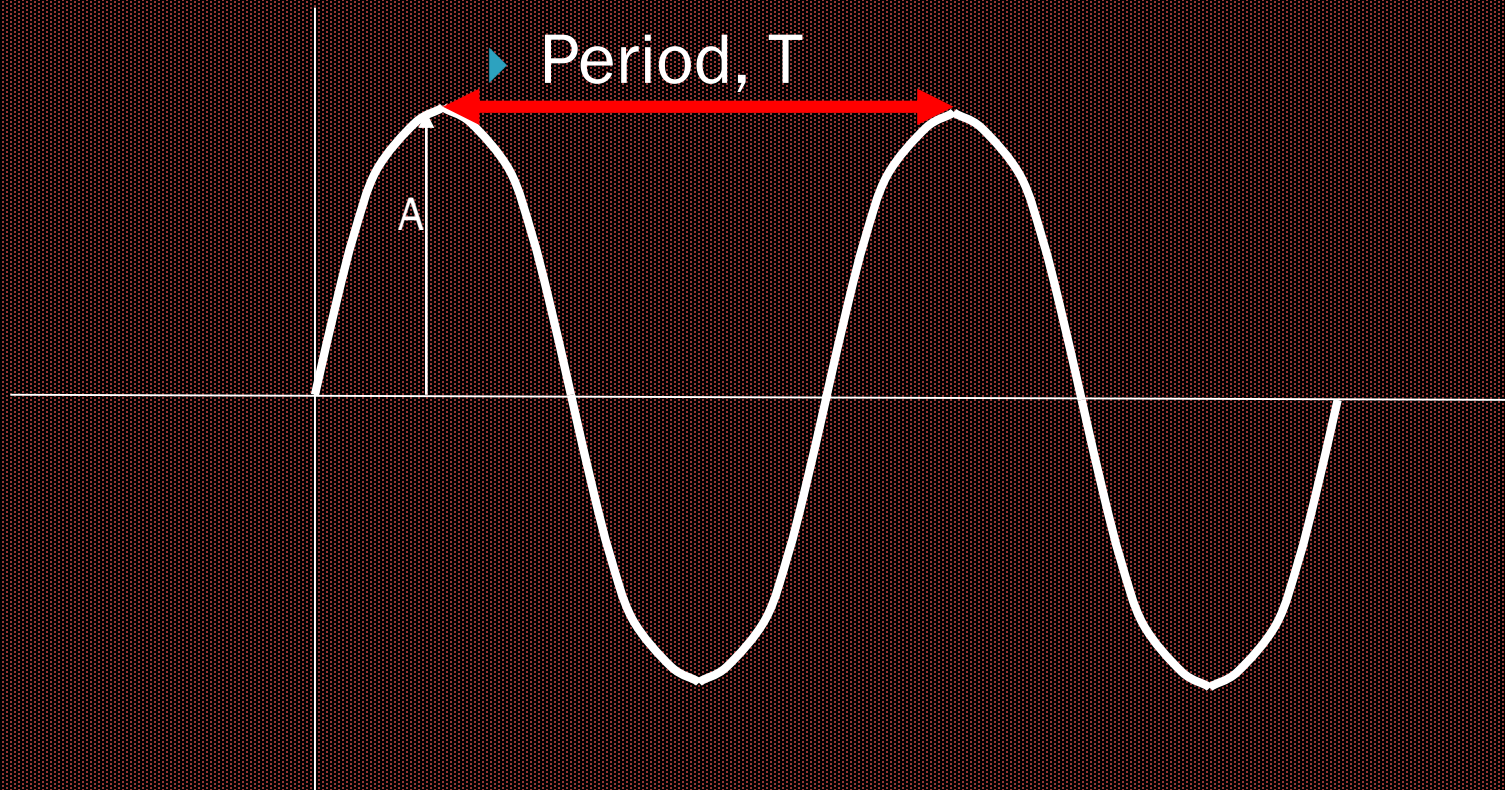
- ▶ Periodic motion is any motion that repeats on a regular time basis
- ▶ Example
 - ✓ Rotation of a bicycle wheel
 - ✓ Rising of the sun and Change of the seasons
 - ✓ The tides and Bird songs

Oscillatory Motion

- ▶ Is periodic
- ▶ The particle oscillates back and forth about a equilibrium position.
- ▶ the force always acts in a direction to restore the system to its equilibrium position.
- ▶ Such a force is called a “restoring force”
- ▶ Oscillators are the basic building blocks of waves.

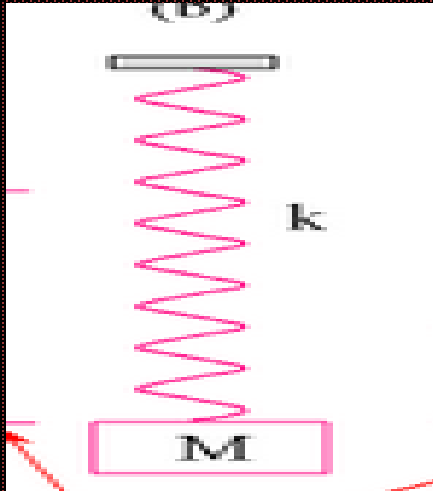
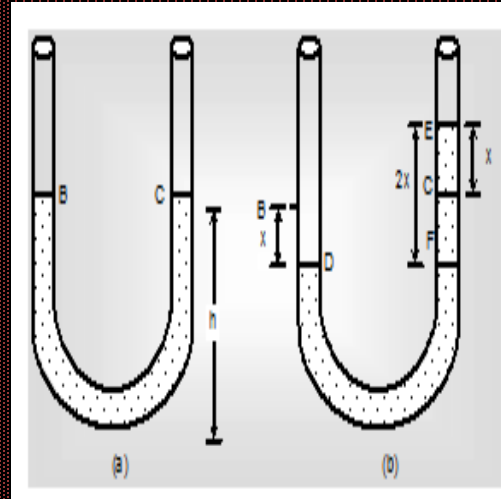
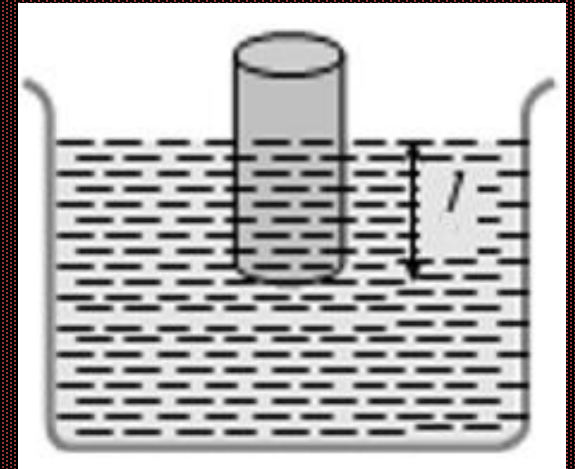
Common Terminologies

- ▶ **Period (T(s))**: the time necessary for one complete cycle (a complete repetition of the motion).
- ▶ **Frequency(Hz or cycle/s)**: the number of cycles per unit time.
- ▶ **Equilibrium (0)**: the spot the mass would come to rest when not disturbed ($F_{net} = 0.$)
- ▶ **Displacement: (s or x)**: distance from equilibrium.
- ▶ **Amplitude**: the magnitude of the maximum displacement from equilibrium position.



Types of oscillatory motion:

- ▶ **Linear** oscillation and **circular** oscillation.



Oscillatory systems are of two types,
mechanical and non- mechanical systems

MECHANICAL

- ▶ two things are specially responsible i.e
Inertia & Restoring force.

NON- MECHANICAL

- ▶ The body itself doesn't change its
position but its physical property varies
periodically.

Simple Harmonic Motion

- ▶ A special kind of periodic motion
- ▶ SHM - if the force is always directed toward the equilibrium position
- ▶ The net force is proportional and opposite to displacement
- ▶ An oscillating system which can be described in terms of **sine** and **cosine** functions

$$T = \frac{2\pi}{\omega}$$

- **Example**
- ▶ The motion of a spring-mass system
- ▶ The motion of simple pendulum (for small displacement)

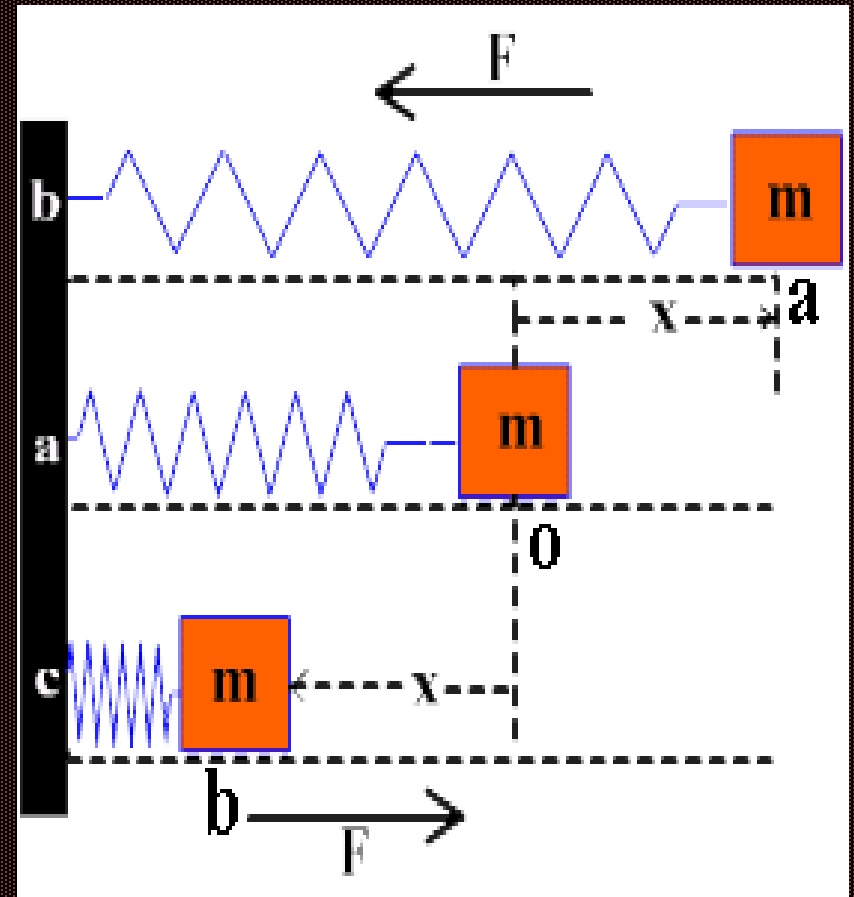
Spring-mass system

- obeys Hooke's Law

$$F = -kx$$

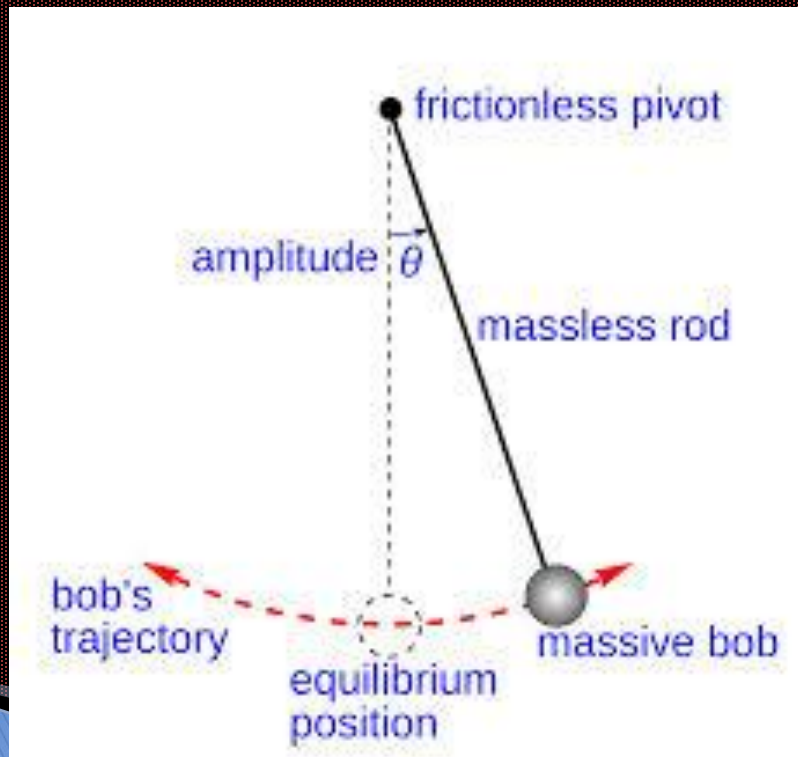
$$a(x) = -\omega^2 x$$

$$T = 2\pi \sqrt{\frac{m}{k}}$$



Simple Pendulum

- ▶ In general, the motion of a pendulum is not SHM
However, for small angles ($< 10^\circ$), it becomes SHM
 $\sin \theta \approx \theta$ $F_t = -mg \sin \theta = -mg \theta$
- ▶ obeys Hooke's Law



$$T = 2\pi \sqrt{\frac{L}{g}}$$

- ▶ This shows that the period is independent of the amplitude A and the mass m
- ❖ The period depends on:
 - the **length** of the **pendulum**, L
 - and the **freefall acceleration**, g
- ▶ **VERY IMPORTANT:** frequency and period of oscillations DO NOT depend on the amplitude

Discuss, in pairs

- ▶ Where is the mass moving fastest, slowest?
- ▶ Where is the mass's acceleration maximum, zero?
- ▶ What forces act on the mass? When is the unbalanced force at a maximum value, zero?

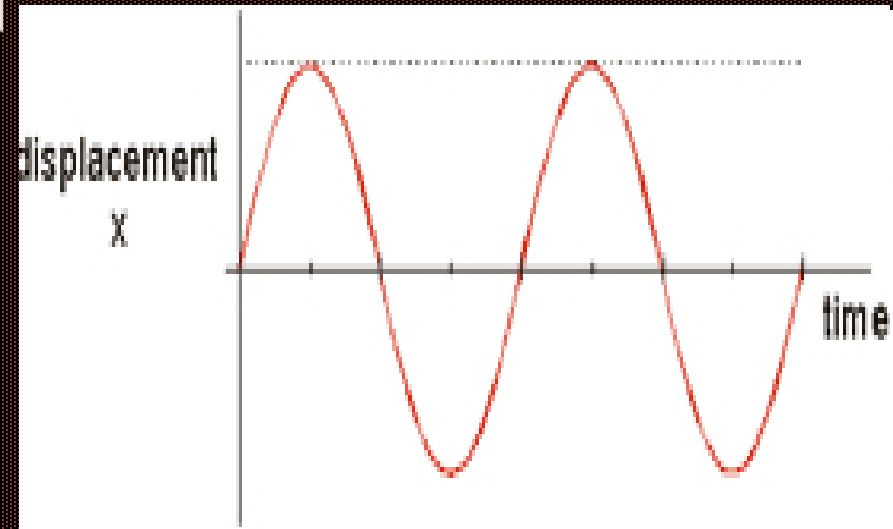
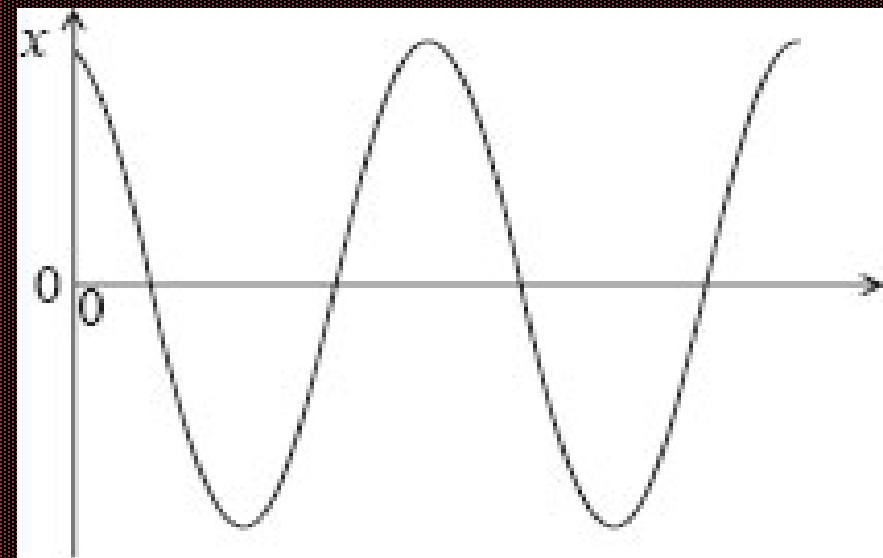
Displacement in SHM

- ▶ Motion starts from equilibrium
- ▶ Displacement against time

$$x(t) = A \sin(\omega t)$$

- ▶ Motion starts from the limit of the oscillation
- ▶ Displacement against time

$$x(t) = A \cos(\omega t)$$



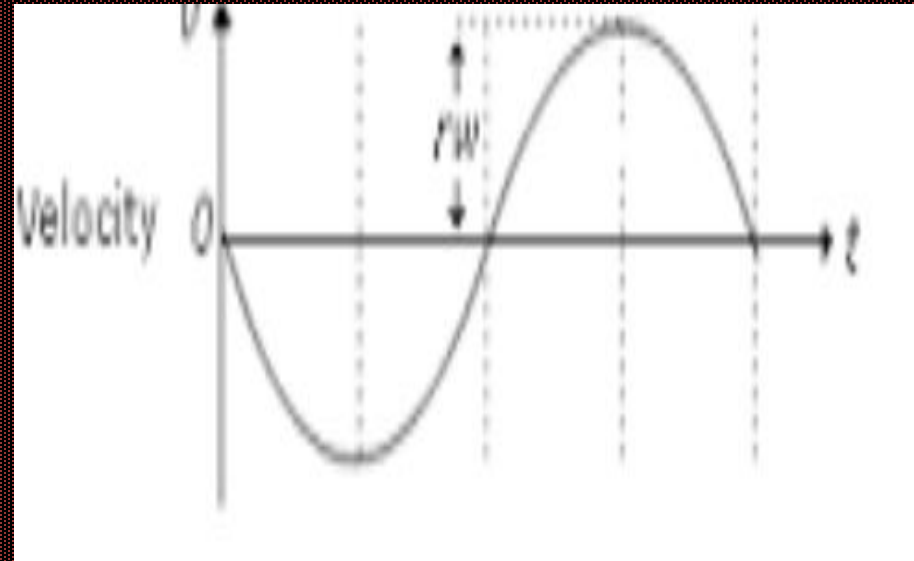
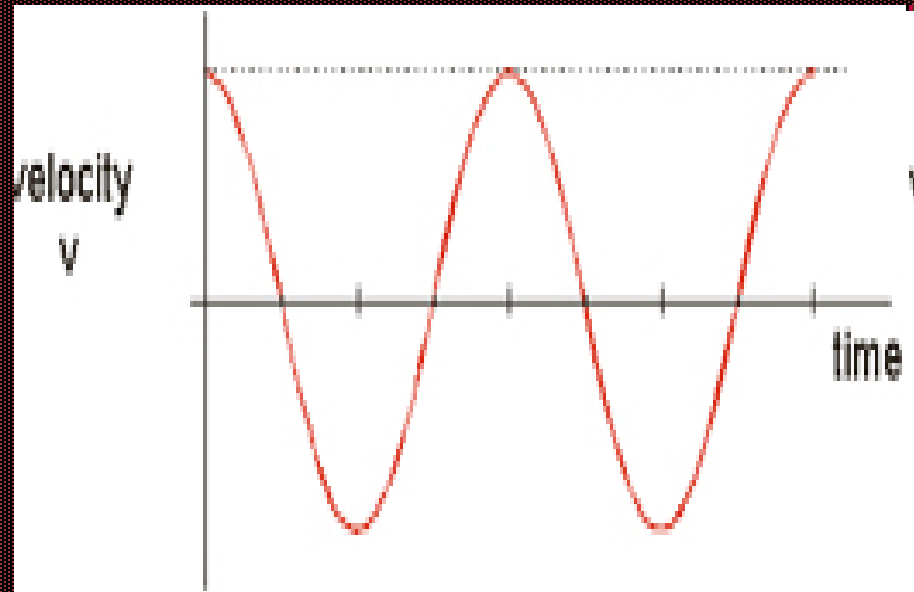
Velocity in SHM

- ▶ Motion starts from equilibrium
- ▶ *Maximum velocity* occurs at equilibrium position
- ▶ Velocity against time

$$V(t) = \omega A \cos(\omega t)$$

- ▶ Motion starts from the limit of the oscillation
- ▶ Displacement against time

$$V(t) = -\omega A \sin(\omega t)$$



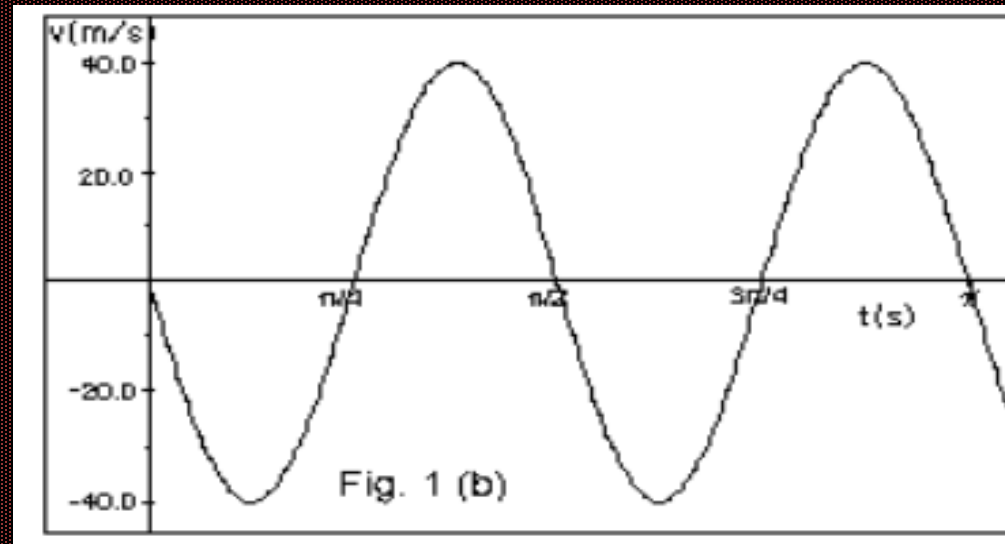
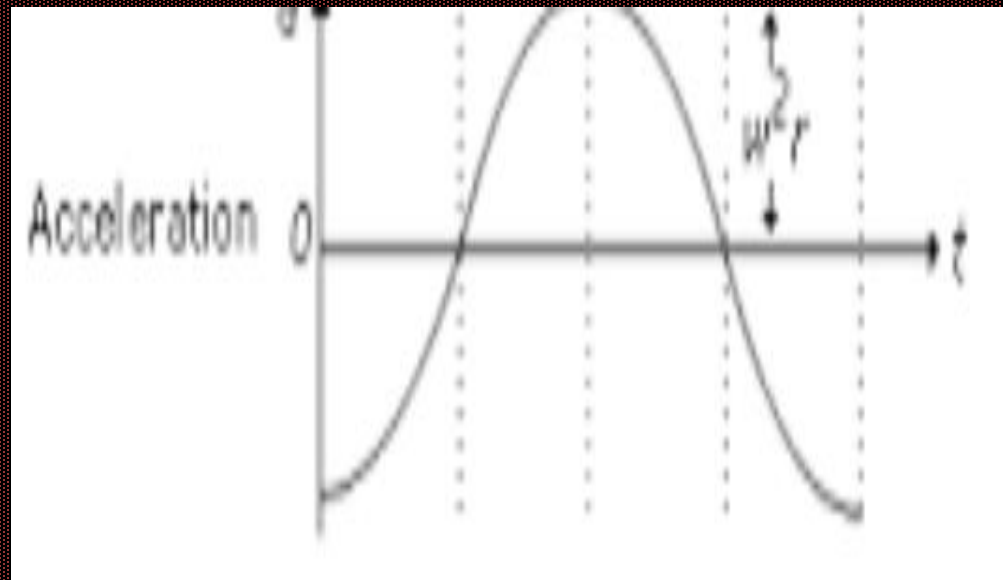
Acceleration in a SHM

- ▶ Motion starts from equilibrium
- ▶ *Maximum acceleration* is observed at $x = \pm A$;
- ▶ Displacement against time

$$a(t) = -\omega^2 A \sin \omega t$$

- ▶ Motion starts from the limit of the oscillation
- ▶ Displacement against time

$$a(t) = -\omega^2 A \cos(\omega t)$$



Velocity and Displacement

$$V = \pm \omega \sqrt{A^2 - X^2}$$

- ▶ The particle has $\pm V$ at a single point in the path
- ▶ Maximum when the object passes the equilibrium

Energy of the SHM

- ▶ In free oscillation the total energy is constant

$$E = PE + KE$$

- ▶ The kinetic energy can be found by

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

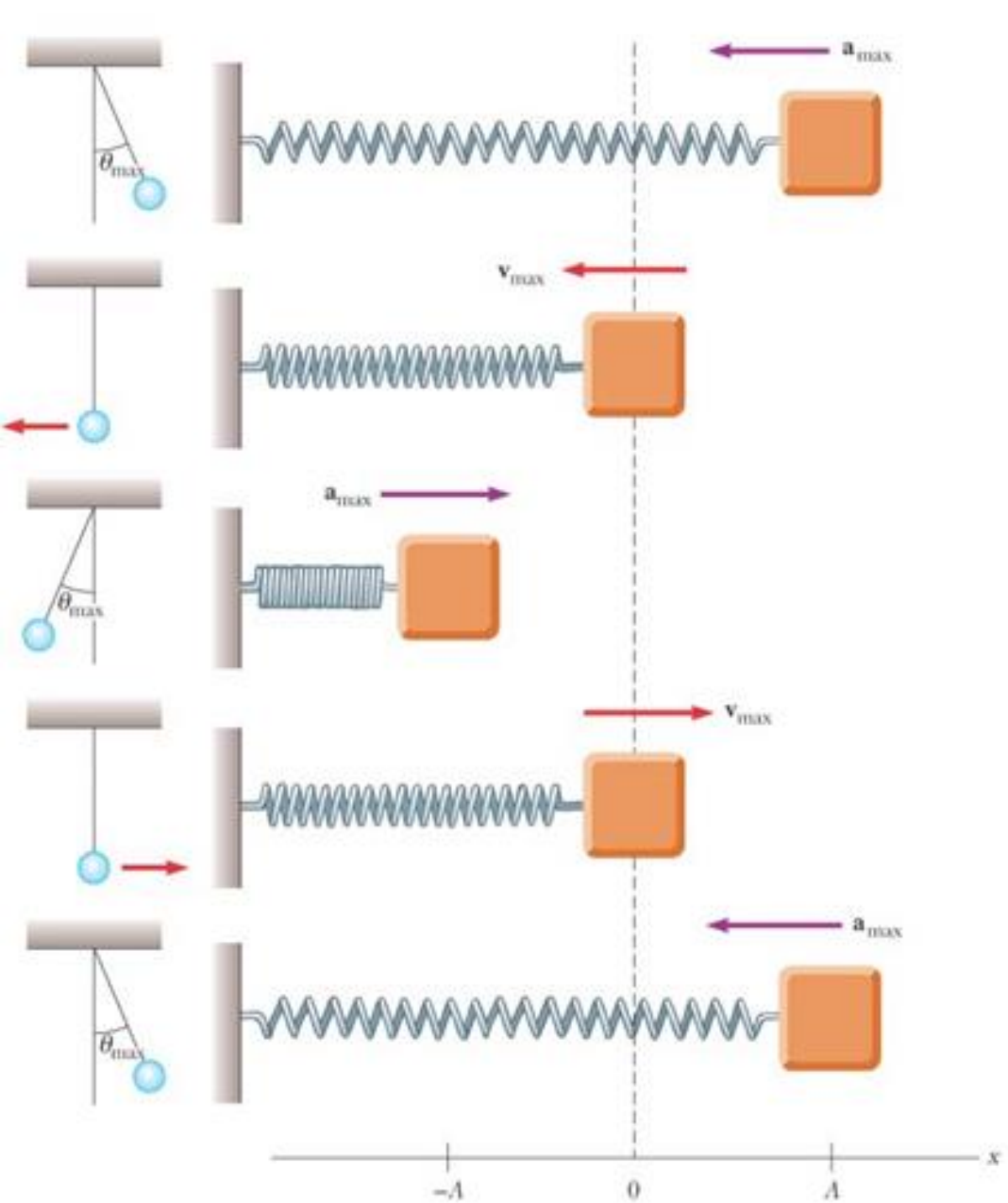
$K_{\max} = \frac{1}{2} kA^2$ - object passes the equilibrium position

- ▶ The elastic potential energy can be found

$$U = \frac{1}{2} kx^2$$

$U_{\max} = \frac{1}{2} kA^2$ - object is at the limit of oscillation

- ▶ The total energy is $K + U = \frac{1}{2} kA^2$



t	x	v	a	K	U
0	A	0	$-\omega^2 A$	0	$\frac{1}{2} k A^2$
$T/4$	0	$-\omega A$	0	$\frac{1}{2} k A^2$	0
$T/2$	$-A$	0	$\omega^2 A$	0	$\frac{1}{2} k A^2$
$3T/4$	0	ωA	0	$\frac{1}{2} k A^2$	0
T	A	0	$-\omega^2 A$	0	$\frac{1}{2} k A^2$

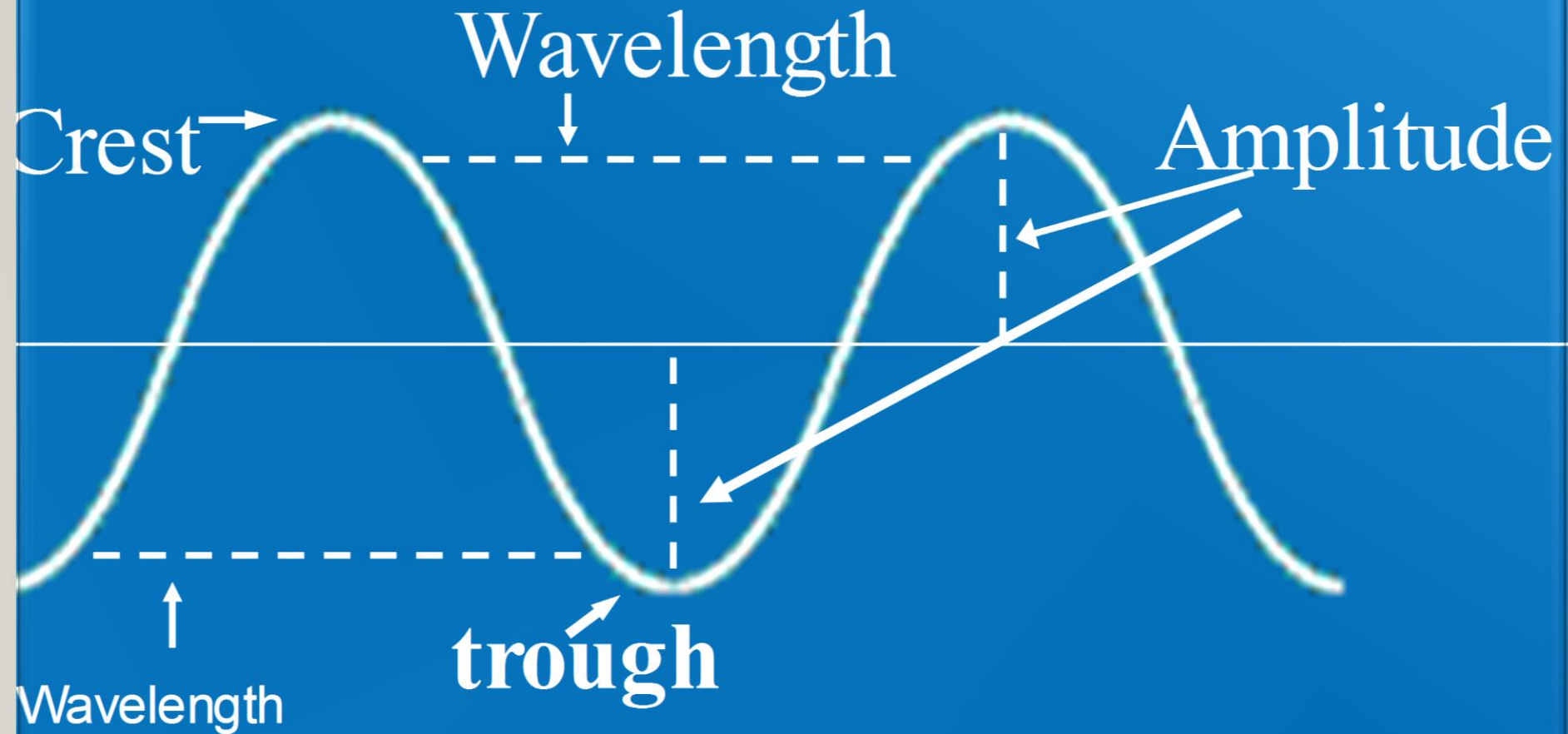
Wave and Its Characteristics

- ▶ What do Waves transfer?
- ▶ What are the two main types of waves?
- ▶ Which type of wave requires a medium?
- ▶ What are the colors of Visible Light?
Which color is the HIGHEST energy wave?

Waves

- ▶ rhythmic disturbances that carry energy through matter or space
- ▶ carry energy and momentum but no material or substance is transferred outward from the source
- ▶ Information can be sent via matter or waves.

Wave Diagram



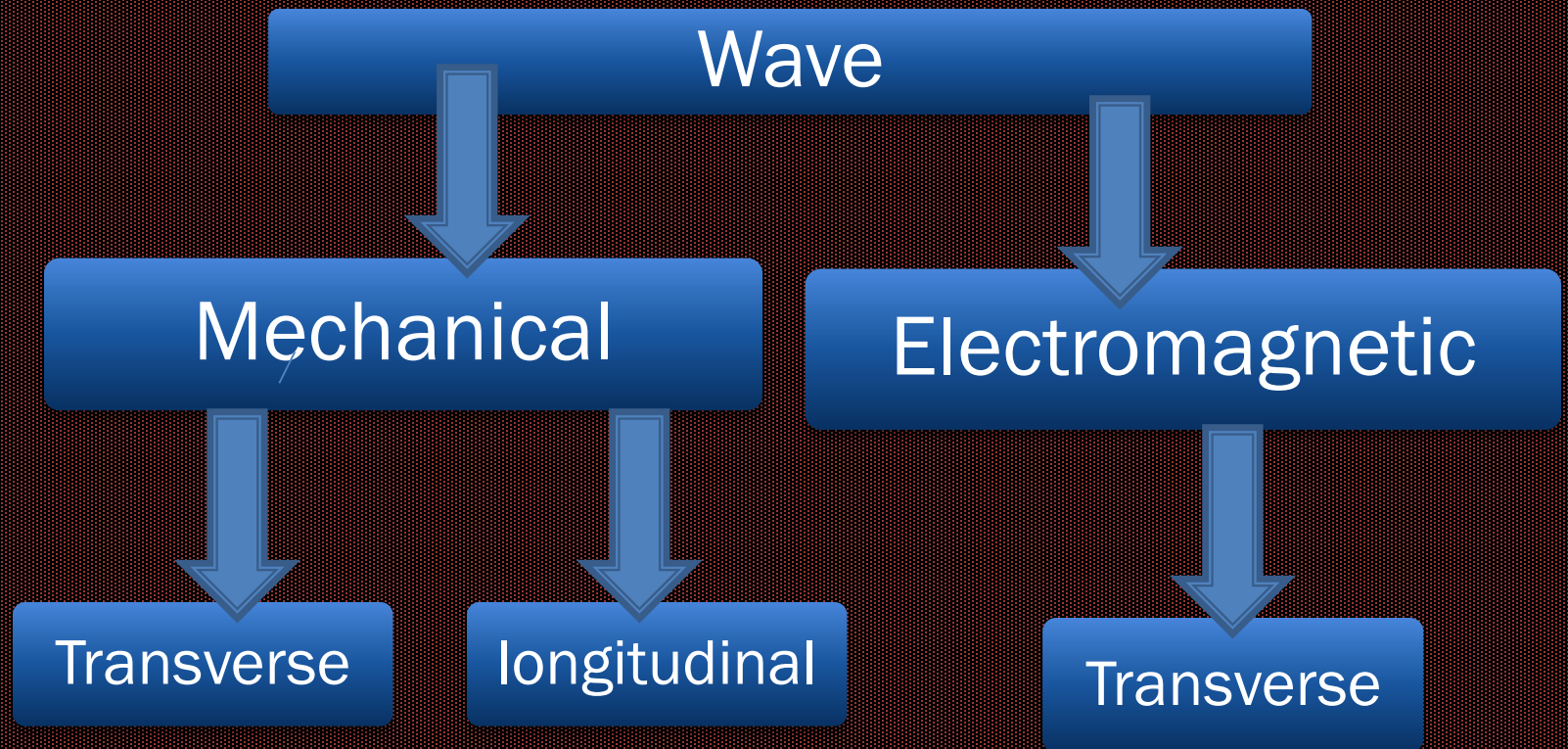
- ▶ Crest; Highest point of a transverse wave
- ▶ Trough; lowest point of a transverse wave
- ▶ Amplitude; The maximum vertical distance that particles vibrate from their normal position when a wave passes
- ▶ measures the intensity of wave. (Loudness, brightness)
- ▶ Wavelength; The distance between any two successive identical parts of a wave
- ▶ Frequency; the number of full wavelengths that pass a point in a particular period of time (rate). Determines energy and color (Red is the easiest to see, violet is the hottest (most energetic))

Wave Speed

- ▶ the speed at which a wave passes through a medium.
- ▶ Waves travel at different speeds in different media phases (s, l, g).
- ▶ These waves travel fastest in solids and the slowest in gases(why?)
- ▶ $V=f\lambda$
- ▶ For mechanical wave in a material medium

$$V = \sqrt{\frac{\text{elastic property}}{\text{inertial property}}}$$

TYPES OF WAVES



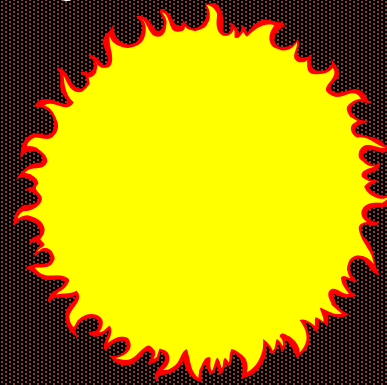
▶ Mechanical Waves

- ▶ Must travel through a material medium
- ▶ Cannot travel through a vacuum
- ▶ Examples: sound, ocean waves

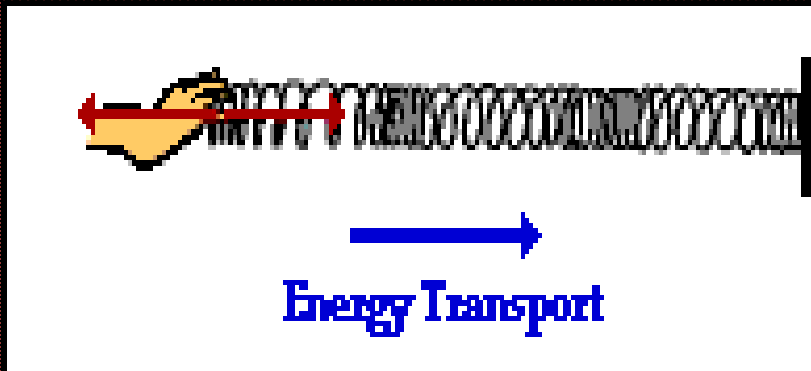


Electromagnetic Waves

- ✓ Does not require a material medium
- ✓ Can be transferred through a vacuum
- ✓ Examples: light, UV rays, Visible light

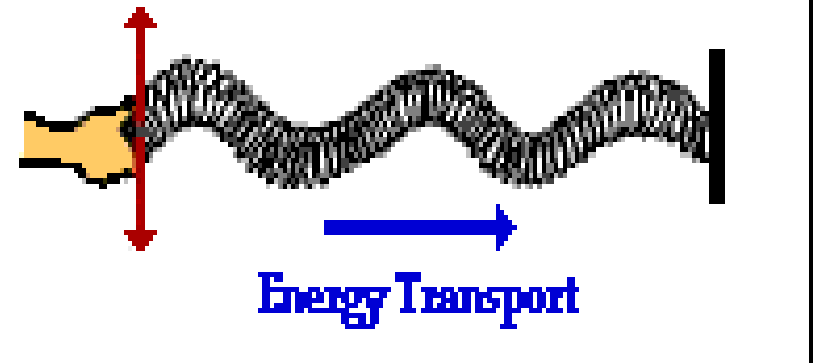


▶ Longitudinal



- ✓ medium moves in the same direction as the wave's motion
- ✓ Examples: sound waves, springs, slinky

Transverse



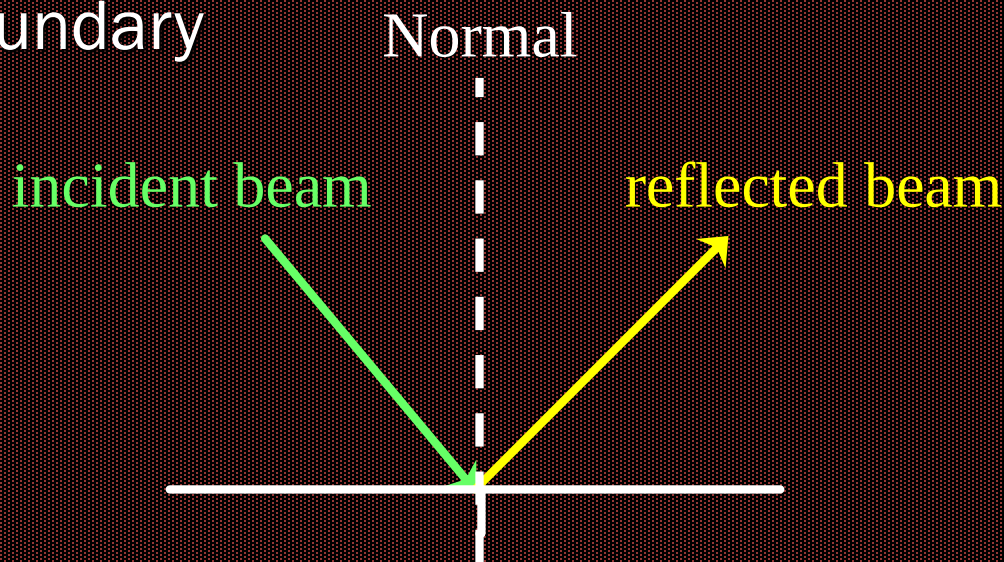
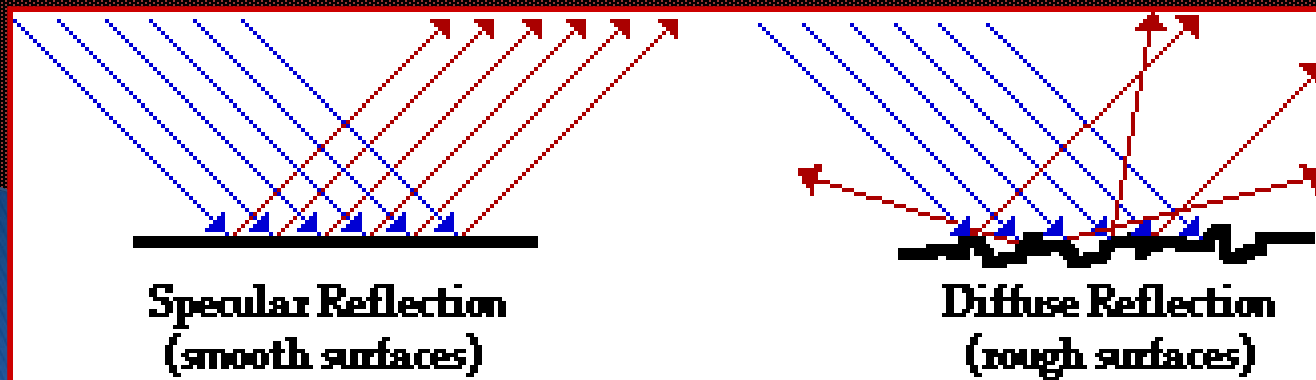
- ✓ medium vibrates perpendicular to the direction of wave motion
- ✓ Examples: electromagnetic waves

Wave Behavior

- Reflection
- Refraction
- Diffraction
- Interference
- Doppler effect

Reflection

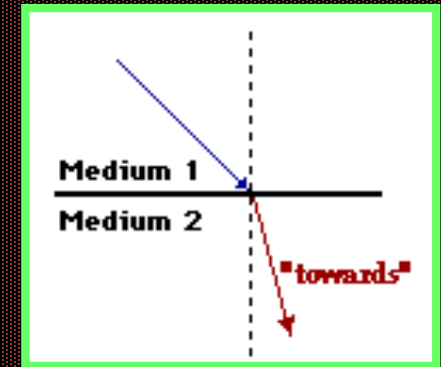
- ▶ The bouncing back of a wave as it meets a surface or boundary



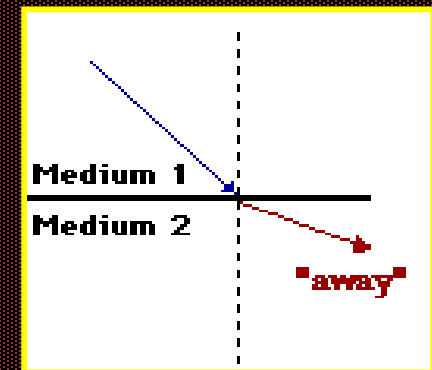
Refraction

- ◆ bending of waves when passing from one medium to another
- ◆ caused by a change in speed
 - **slower (more dense)** $\Rightarrow$ light bends toward the normal
 - **faster (less dense)** $\Rightarrow$ light bends away from the normal

SLOWER



FASTER



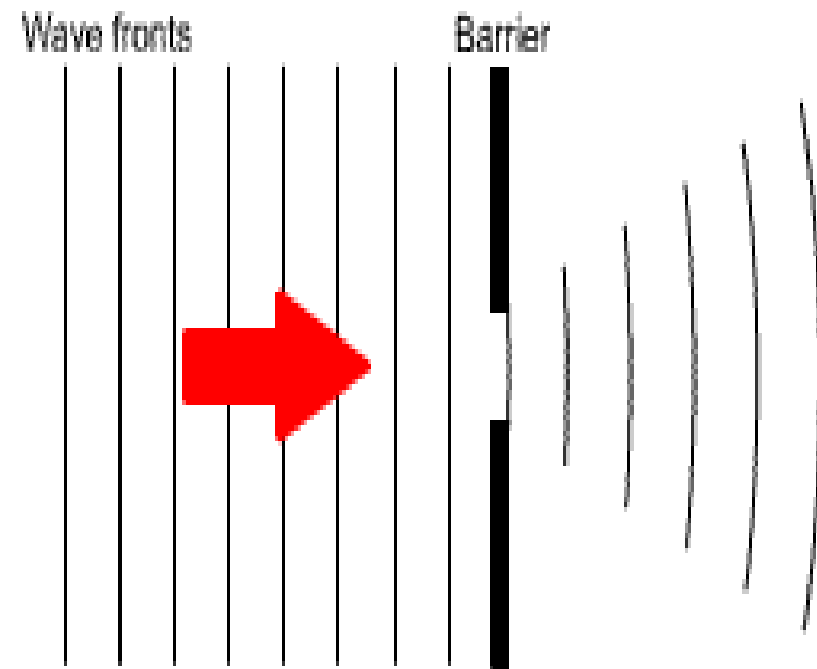
Refraction depends
on...

- ✓ speed of light in the
medium
- ✓ wavelength of the
light - shorter
wavelengths (blue)
bend more



Diffraction

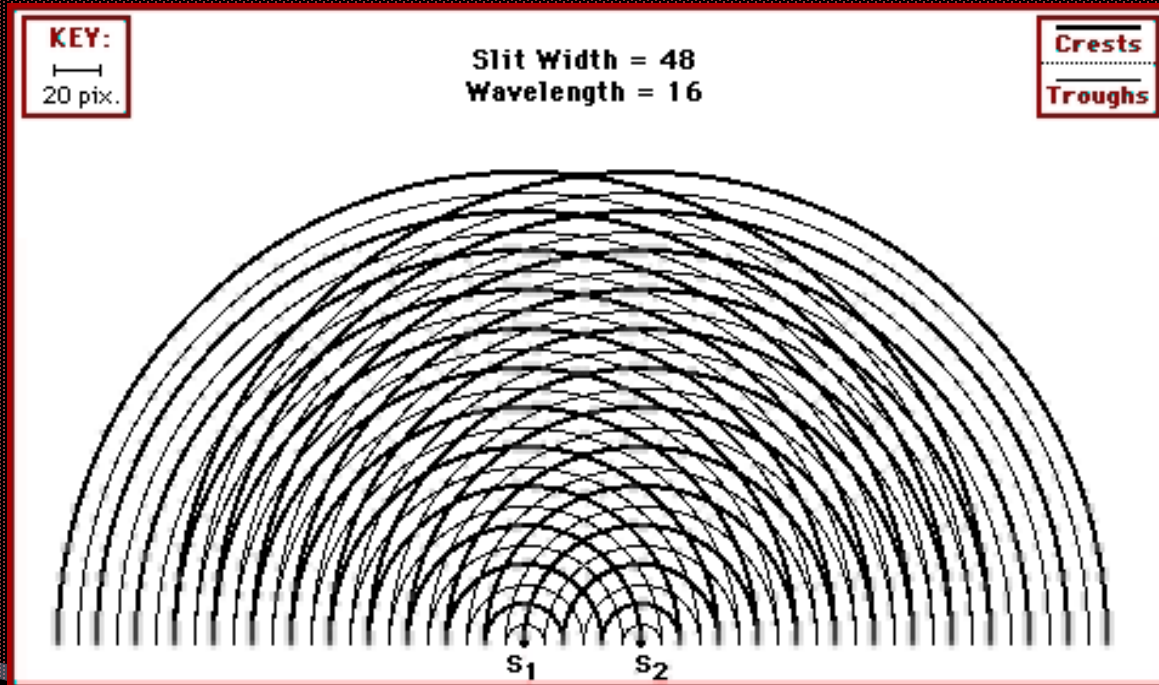
- ▶ is the spreading of waves around a slit or an obstacle.
- ▶ This effect is only significantly noticeable if the slit width is approximately the same size as the wavelength of the waves.
- ▶ longer wavelengths (red) spread more



A simple demonstration of diffraction

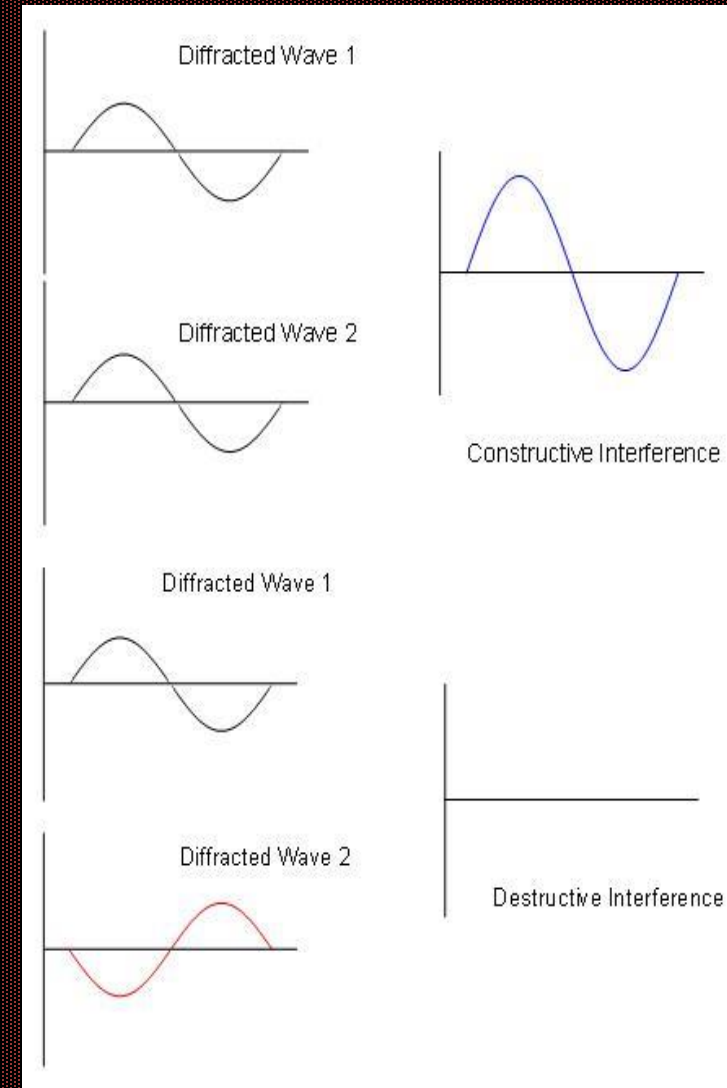
Interference

- ▶ The combination of two or more waves that exist in the same place at the same time.
- ▶ Once waves pass, they return to original shape



Two types of Interference

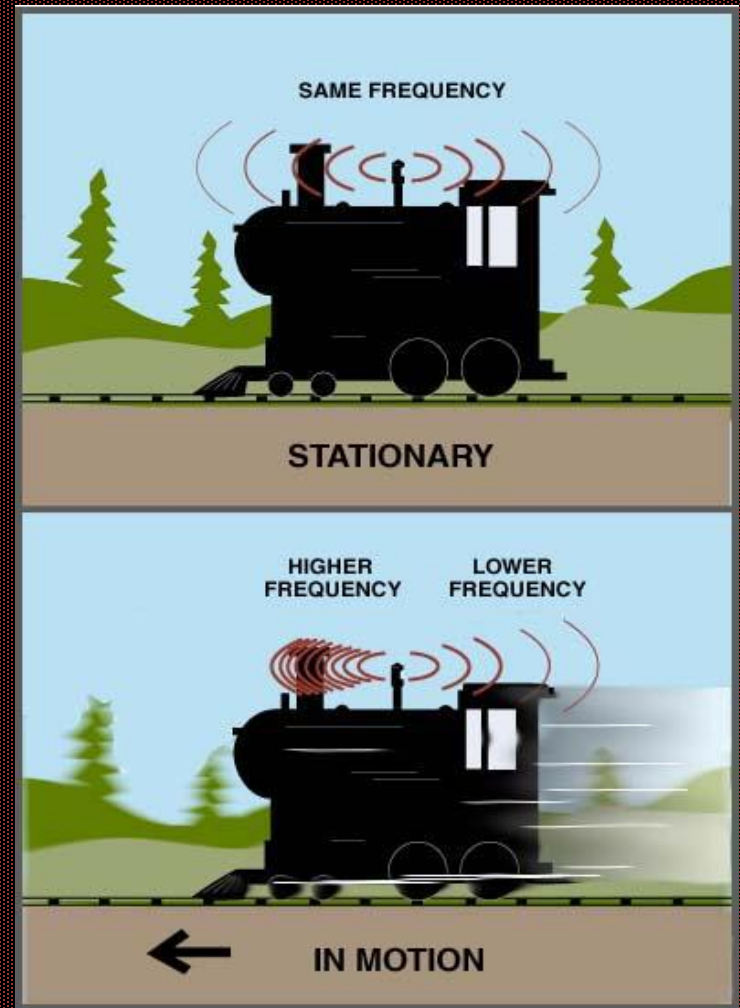
- ▶ **constructive** $\Rightarrow$ **brighter light**
- ▶ **destructive** $\Rightarrow$ **dimmer light**
- ▶ Both are caused by two or more waves interacting, but...
- ▶ **Constructive interference** combines the energies of the two waves into a greater amplitude
- ▶ **Destructive interference** reduces the energies of the two waves into a smaller amplitude.



- ▶ When light waves interfere with each other, colorful displays are produced.
- ▶ When two waves with different frequencies interfere with each other, beats are produced

Doppler Effect

- ▶ Frequency shift
- The Doppler effect is the apparent change in frequency of a wave due to the motion of the source or the observer.
- The observed frequency is higher when the source and observer are getting closer.
- The observed frequency is lower when the source and observer are getting farther away.



The Doppler Effect

- ▶ When the source and observer are approaching each other.

$f_o = f_s \frac{v+v_o}{v-v_s}$ The observed frequency of wave is increased

- ▶ when they are receding from each other.

$f_o = f_s \frac{v-v_o}{v+v_s}$ The observed frequency of wave is decreased

Generally

- ▶ $f_o = f_s \frac{v \pm v_o}{v \mp v_s}$

Applications of Doppler effect

- ▶ police microwave speed units
- ▶ measuring the speed of a tennis ball
- ▶ measuring the speed of blood flowing through an artery
- ▶ monitoring the heart-beat of a developing fetus
- ▶ sonar: ships & submarines to detect submerged objects
- ▶ detecting distance planets
- ▶ observing the motion of oscillating stars

Resonance

- ▶ It is the phenomenon occurs When the frequency of the driving force is equal to the natural frequency
- ▶ Causes dramatic increase in amplitude
- ▶ This dramatic increase in the amplitude is called resonance
- ▶ At resonance, the applied force is in phase with the velocity
- ✓ So, the power transferred to the oscillator is maximum
- ✓ Energy transferred easily

- ▶ Desirable resonance:-
tuning the radio, tuning
musical instruments, etc

Undesirable resonance :
safety of buildings, bridges,
airplanes etc.

The Tacoma Narrows Bridge
suffered spectacular
structural
failure after absorbing too
much resonant



Image Formation by Thin Lenses and Mirrors

optics.

- ▶ The overall study of how light behaves
- ▶ The branch of optics that focuses on the creation of images is called geometric optics, because it is based on relationships between angles and lines that describe light rays.

Basic optical devices

Prism



Mirror



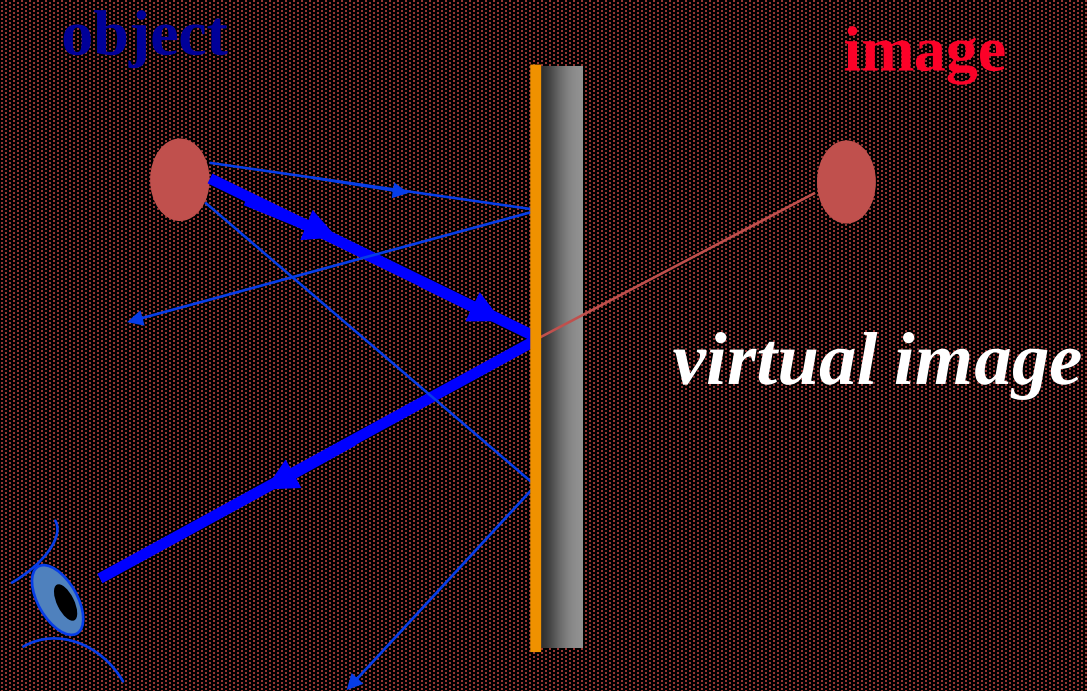
Converging lens



Diverging lens



Images Formed by Plane Mirrors

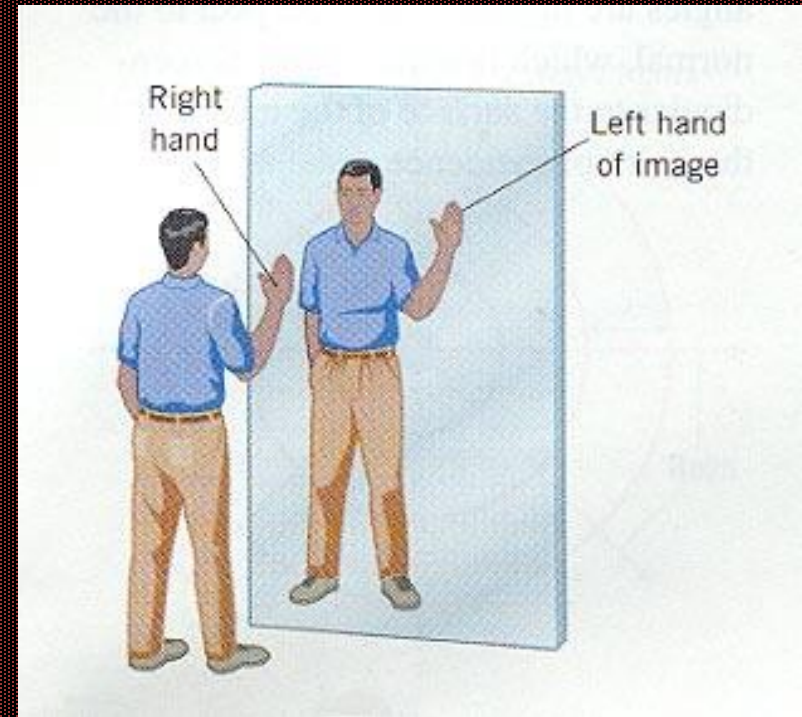


- ▶ (the ray reaching your eye doesn't really come from the image). But.... the brain thinks the ray came from the image
- ▶ If light energy doesn't flow from the image, the image is "virtual".

Properties of the Image Formed by a plane Mirror

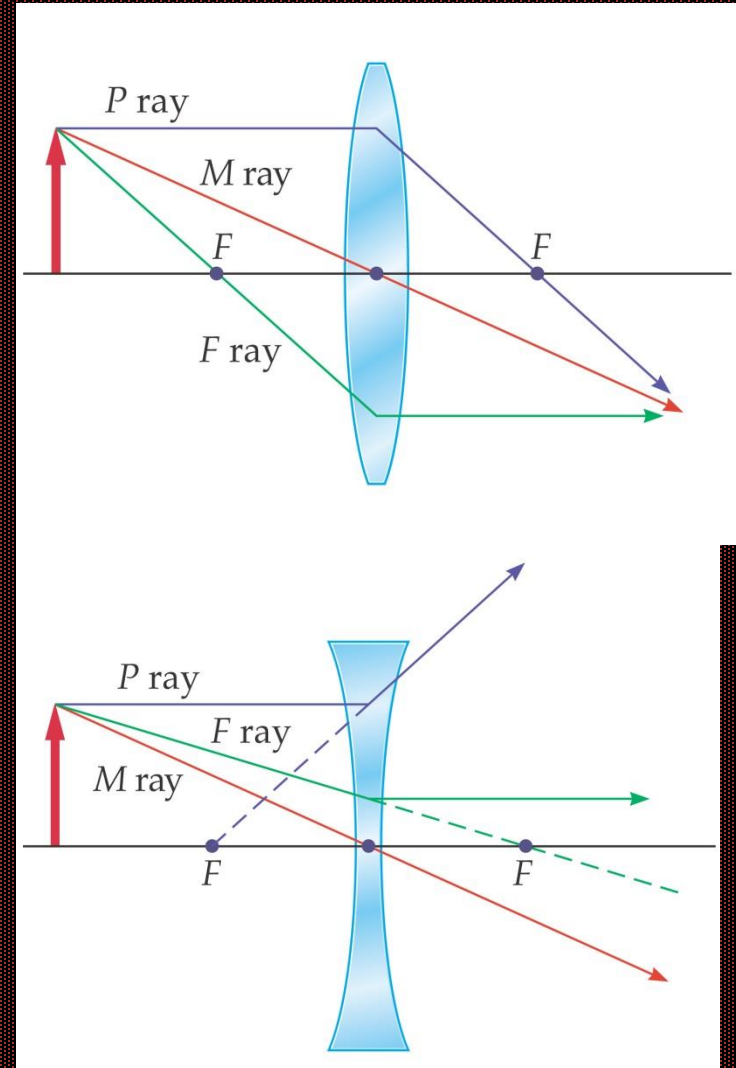
- ▶ The image is as far behind the mirror as the object is in front.
- ▶ $S_o = S_i$
- ▶ The image is unmagnified.
- ▶ The image is virtual.
- ▶ The image is upright. It has the same orientation as the object.
- ▶ There is a front-back reversal in the image.

AMBULANCE



Images formed by Lenses

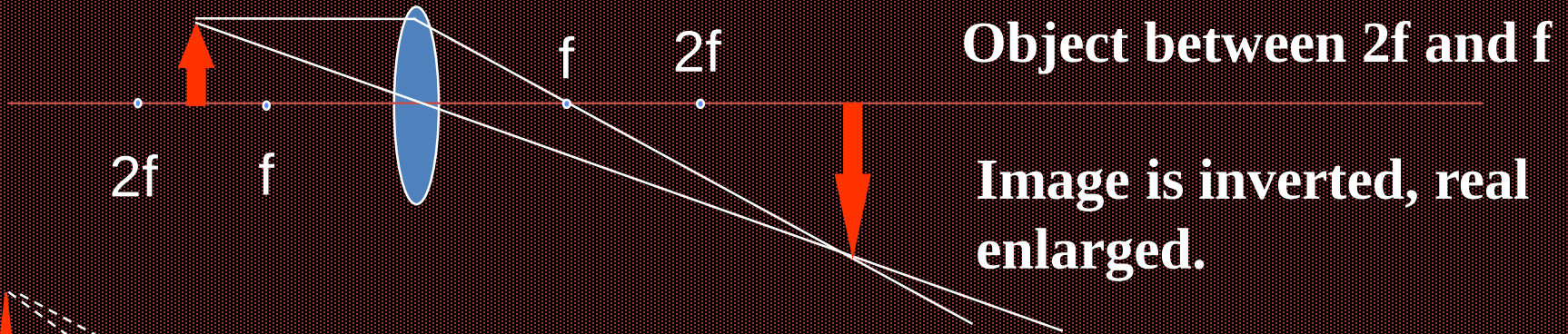
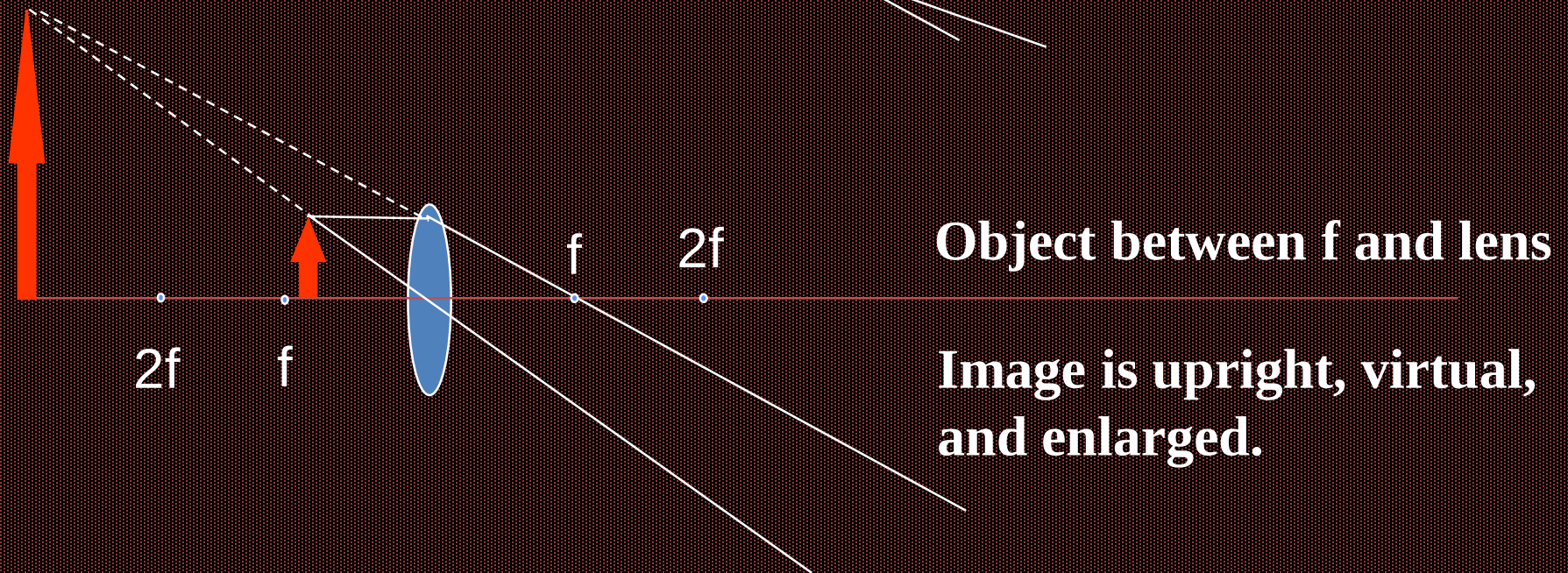
- ▶ The three basic light rays used in ray tracing:
 1. A ray which leaves the object parallel to the axis, is refracted to pass through the focal point (P).
 2. A ray which passes through the lens's center is un deflected (M).
 3. A ray passing through the focal point (as shown) is refracted to end up parallel to the axis (F).



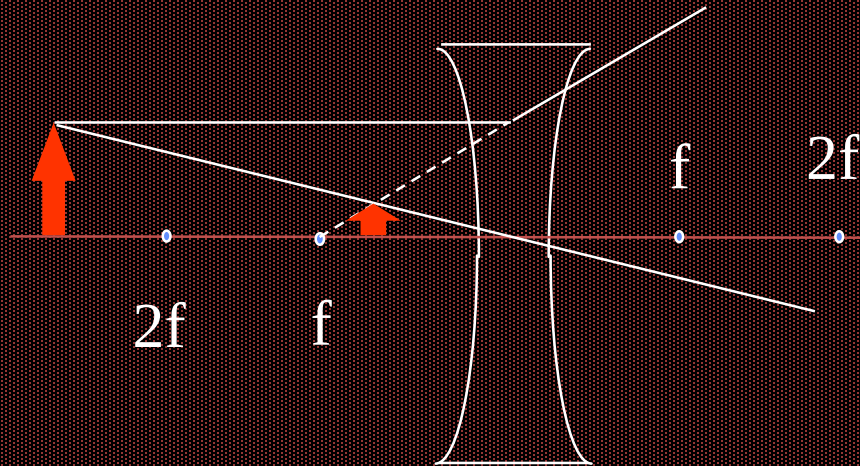
Lenses

- ▶ Lenses are commonly used to form images by refraction
 - All is a result of Snell's law and can be derived from that.
 - Lenses are used in optical instruments
 - Cameras
 - Telescopes
 - Microscopes

Images Formed by a Convex (Converging) Lens

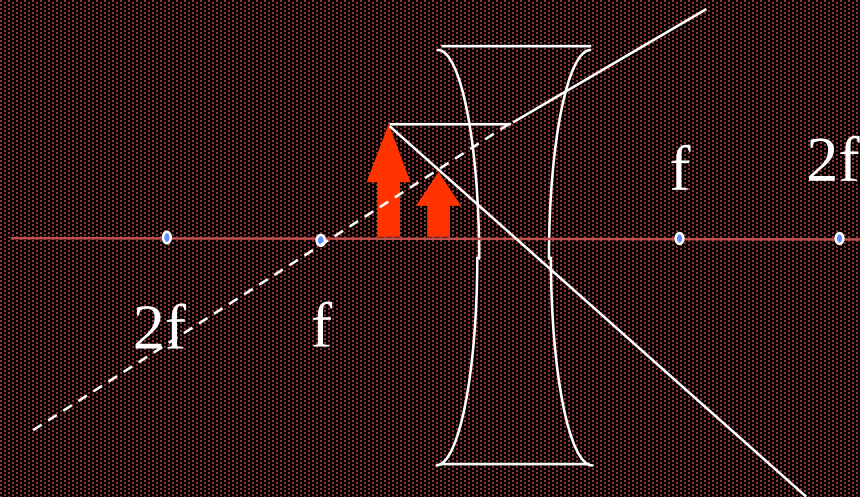


Images Formed by a Concave Lens(Diverging)



Object beyond $2f$.

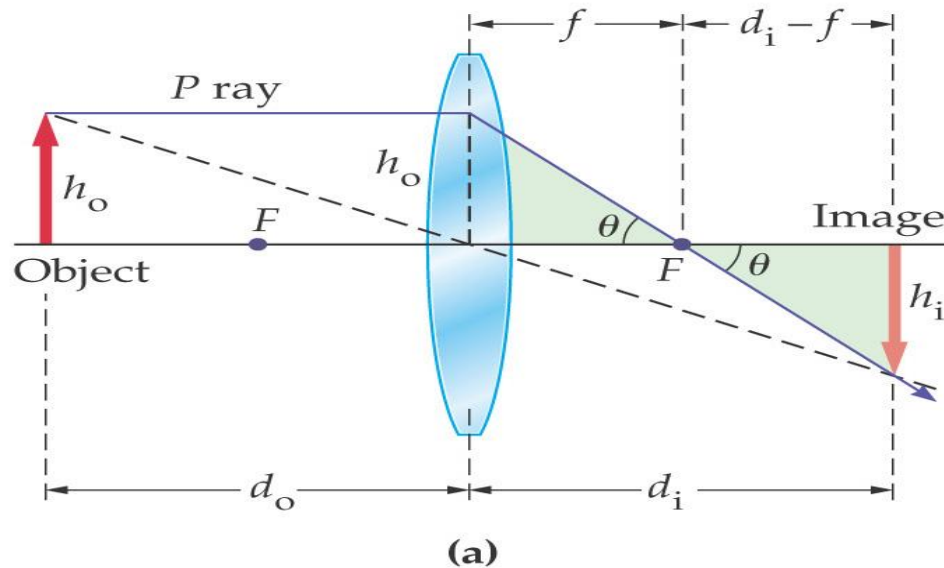
**Image is upright,
virtual, reduced.**



**Object between
 f and lens.**

**Image is upright,
virtual, reduced.**

The Thin Lens Equation



$$\frac{h_o}{f} = \frac{-h_i}{d_i - f}$$

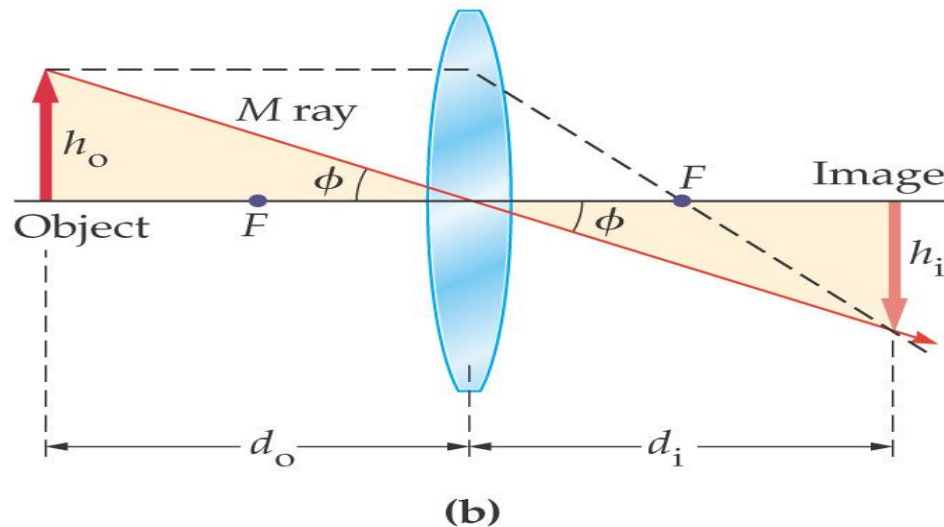
$$\frac{h_o}{d_o} = \frac{-h_i}{d_i}$$

Thin Lens Equation

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

Magnification

$$m = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$$



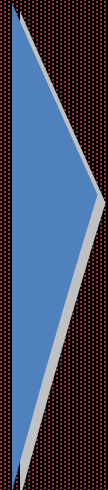
Sign Conventions

Converging or convex lens

- focal length is positive
- image distance is positive when on the other side of the lens (with respect to object)
- height upright is positive, inverted is negative

Diverging or concave lens

- focal length is negative
- image distance is always negative
(on the same side of the lens as the object)
- height upright is positive, inverted is negative



The End!!

