Lecture # 9

Temperature
Heat
and First Law of Thermodynamics

Temperature

Thermometers and the Celsius Scale
Thermal Expansion of Solids and Liquids

Heat and First Law of Thermodynamics

Heat and Internal Energy
Specific Heat and Calorimetry
Latent Heat
Energy Transfer Mechanisms

What is Temperature and Heat?

- Temperature is how hot or cold an object feels when we touch it.
- Heat is the exchange of energy between two objects because of differences in their temperatures.

Some important definitions

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

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

Thermal Equilibrium

- When two objects with different initial temperatures *reach thermal equilibrium*, they're *final temperatures will be the same*.

- The law of thermal equilibrium is:

The amount of thermal energy the colder object gains is equal to the amount of thermal energy the hotter object loses.

THERMOMETERS

Thermometers are devices that are used to define and measure temperatures

Some physical properties that change with temperature are

(1) the volume of a liquid,
(2) the length of a solid,
(3) the pressure of a gas at constant volume,
(4) the volume of a gas at constant pressure,
(5) the electric resistance of a conductor,
(6) the colour of an object.

THERMOMETERS

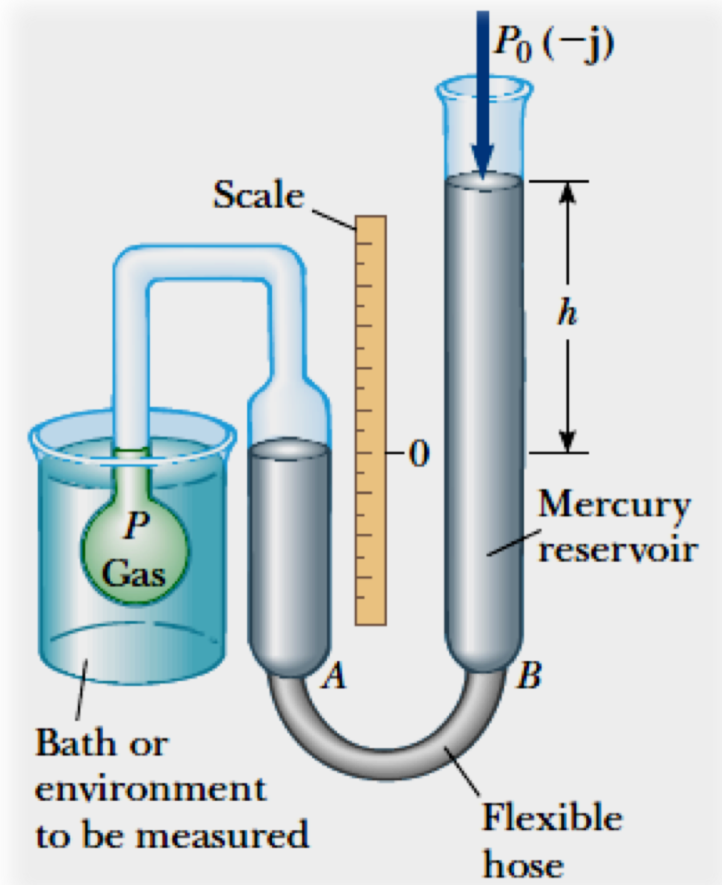
A ***common thermometer*** in everyday use consists of a mass of liquid — usually mercury or alcohol — that expands into a glass capillary tube when heated. **In this case the physical property is the change in volume of a liquid.**

This temperature scale used to be called the ***centigrade scale*** *because there are 100 gradations between the* ice and steam points of water

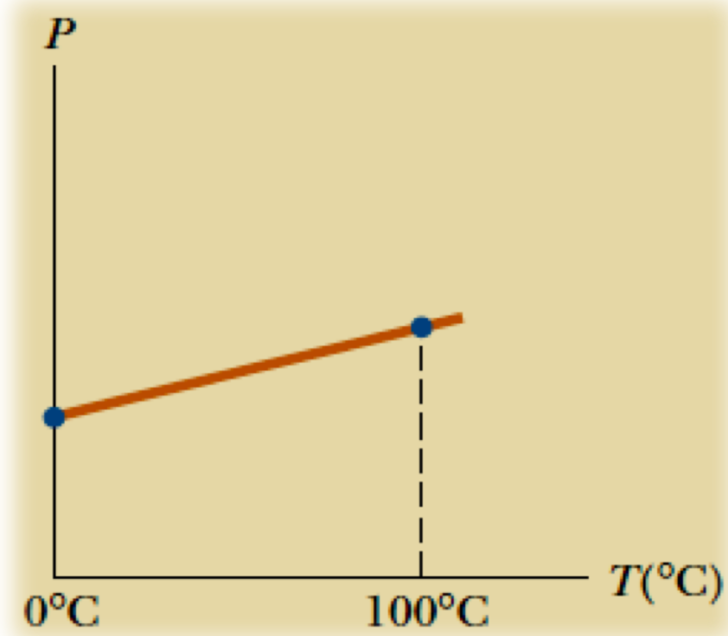
THERMOMETERS

THE CONSTANT-VOLUME GAS THERMOMETER

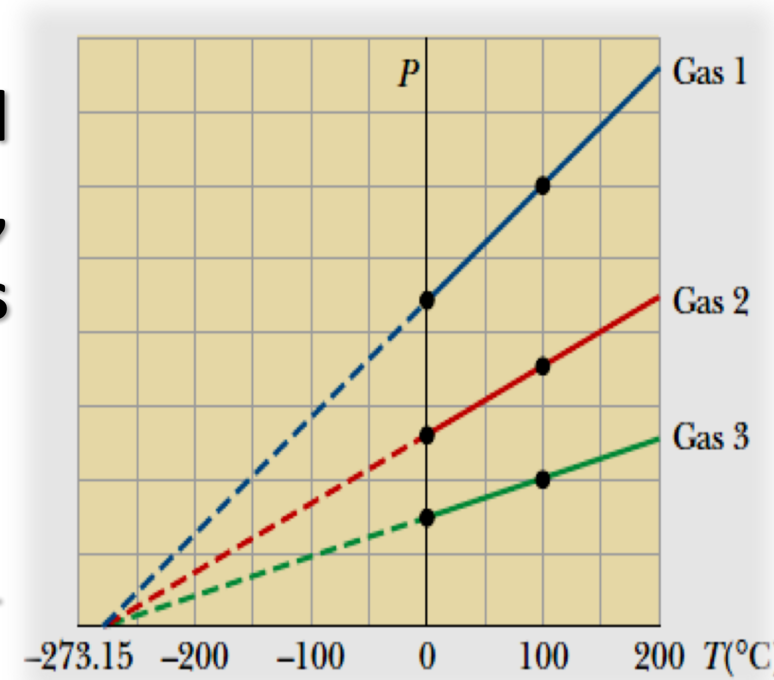
A constant-volume gas thermo- meter measures the pressure of the gas contained in the flask immersed in the bath. The volume of gas in the flask is kept constant by raising or lowering reservoir B *to keep the mercury* level in column *A constant.*



A typical graph of pressure versus temperature taken with a constant-volume gas thermometer. The two dots represent known reference temperatures (the ice and steam points of water).



If you extend the curves toward negative temperatures, you find, in every case, that the pressure is zero when the temperature is -273.15°C . This temperature is often referred to as *absolute zero.*



The three common thermal scales.

K = °C = °F

$T_K = T_C + 273.15$

$T_C = \frac{5}{9}(T_F - 32)$

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

Freezing point of water

Kelvin	Celsius	Fahrenheit
273.15 K	0°C	32°F
373.15 K	100°C	212°F

Boiling point of water at atmospheric pressure

** The SI unit of absolute temperature is the kelvin

Example:

On a day when the temperature reaches 50°F, what is the temperature in degrees Celsius and in kelvins?

$$T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(50 - 32)$$

$$= 10°C$$

$$T = T_C + 273.15 = 10°C + 273.15 = 283\ K$$

A convenient set of weather-related temperature equivalents to keep in mind is that 0°C is (literally) freezing at 32°F, 10°C is cool at 50°F, 20°C is room temperature, 30°C is warm at 86°F, and 40°C is a hot day at 104°F.

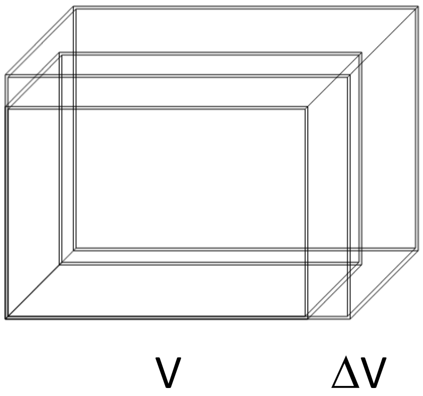
Thermal expansion

- is the tendency of matter to change in length (or volume)in response to a change in temperature.

- This effect is limited in size, and only occurs within limited temperature ranges.

linear Expansion

Volume Expansion



Types of thermal expansion

- ***linear Expansion*** $\Delta L = \alpha \, L_i \, \Delta T$

where α is the linear thermal expansion coefficient.

- ***Volume Expansion*** $\Delta \boldsymbol{V} = \boldsymbol{\beta} \, \boldsymbol{V_i} \, \Delta \boldsymbol{T}$

where β is the volume thermal expansion coefficient.

- The coefficient of linear expansion α is related to the coefficient of volume Expansion β by:

$$\beta = 3 \, \alpha$$

Coefficients of Thermal Expansion at 20 °C

Substance	Linear Coefficient	Volumetric Coefficient
Aluminum	24×10^{-6}	72×10^{-6}
Brass	19×10^{-6}	57×10^{-6}
Copper	17×10^{-6}	51×10^{-6}
Glass(ordinary)	9×10^{-6}	27×10^{-6}
Glass (Pyrex)	3×10^{-6}	9×10^{-6}
Iron/Steel	12×10^{-6}	36×10^{-6}
Lead	29×10^{-6}	87×10^{-6}

Example: Expansion of a Railroad Track

A segment of a steel railroad has a length of 30.000 m when temperature is 0.0 ºC. What is its length when the temperature is 40.0ºC?

Example: Expansion of a Railroad Track

$$\Delta L = \alpha L_i \Delta T = [11 \times 10^{-6} (°C)^{-1}](30.000 \text{ m})(40.0°C)$$
$$= 0.013 \text{ m}$$

If the track is 30.000 m long at 0.0°C, its length at 40.0°C is

30.013 m.

Material	Average Linear Expansion Coefficient $(\alpha)(°C)^{-1}$
Aluminum	24×10^{-6}
Brass and bronze	19×10^{-6}
Copper	17×10^{-6}
Glass (ordinary)	9×10^{-6}
Glass (Pyrex)	3.2×10^{-6}
Lead	29×10^{-6}
Steel	11×10^{-6}
Invar (Ni–Fe alloy)	0.9×10^{-6}
Concrete	12×10^{-6}

Energies- Thermal and Internal

- *Internal Energy* is the sum of the Potential Energy (due to energy stored in bonds and intermolecular forces between particles) and Kinetic energy of the molecules in a system.
- *Internal Energy* is difficult to measure.

- *Thermal energy (or heat) (Q)* is transferred due to a temperature difference.

- **Unit of Heat: joul or The calorie (cal) where** $1 \text{ cal} = 4.186 \text{ J}$
- Note that the “Calorie,” used in describing the energy content of foods, is actually a kilocalorie.)

Thermal Capacity (C)

- Thermal Capacity (Heat Capacity) (**C**) is the energy required to raise the temperature of a substance by 1K .

$$C = \Delta Q / \Delta T$$

- Measured in $J\ K^{-1}$
- Water has a very high capacity.
  - It takes a lot of thermal energy for water's temperature to change
  - This is why the ocean isn't a thousand degrees
  - It's also why it takes some time for a pot of water to begin to boil
- Sand has a low capacity
  - Which is why beach sand gets really hot in the summer

Specific Heat Capacity (c)

- ***Specific Heat (c)*** is the energy required **per unit mass** to raise the temperature of a substance by **1K** .

$$c = \mathbf{C} / m = \Delta Q / m \Delta T$$

- Measured in $J\ kg^{-1}\ K^{-1}$ (in SI)

  or cal / g .°C (in CGS)

- specific heat could measured by calorimeters.

- Why the cheese of pizza is hotter than the bread?

Example:

Using the specific heat capacity of water (4200 J/kg°C), how much energy is needed to increase the temperature of 600 g of water by 80°C in a kettle?

Note: mass = 600 g = 0.6 kg

Energy = mass *specific heat capacity* temperature change

$$\text{energy} = 0.6 \times 4200 \times 80$$

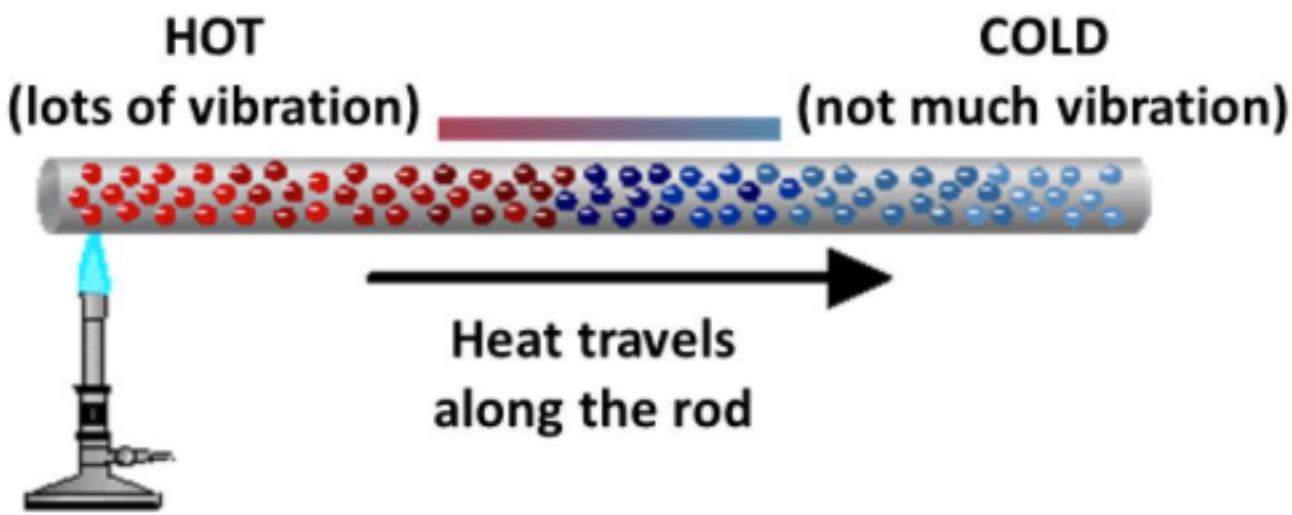
$$= \underline{201\ 600\ \text{J}}$$

Heat energy transfer mechanisms

- ***3 mechanisms***
- Conduction
  - Heat (not the molecules) transfer through material (solid).
- Convection
  - Heat transfer by movement of hot material (fluid)
- Radiation
  - Heat transfer by electromagnetic waves.

1- Thermal Conduction

When you heat a metal strip at one end, the heat travels to the other end.

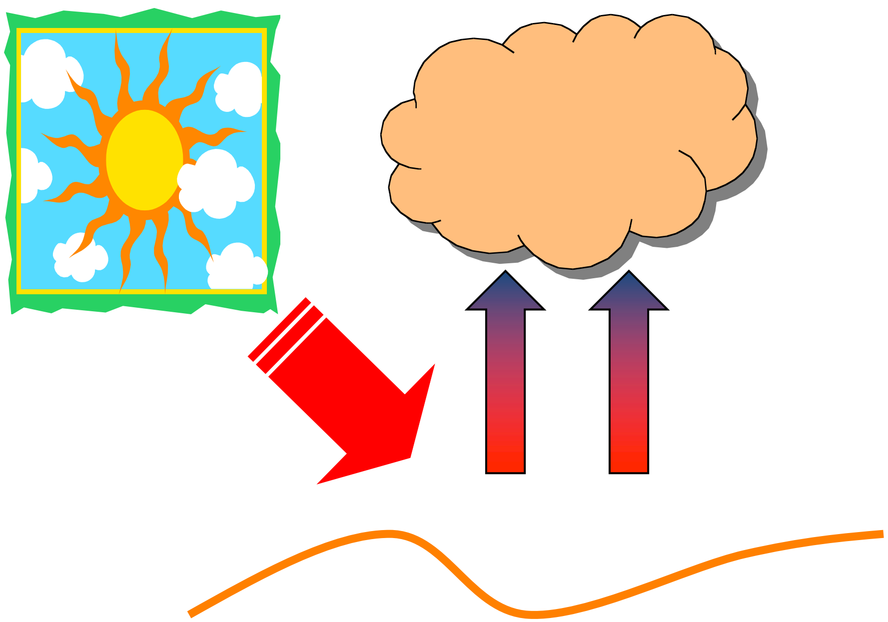


As you heat the metal, the particles vibrate, these vibrations make the adjacent particles vibrate, and so on and so on, the vibrations are passed along the metal and so is the heat.

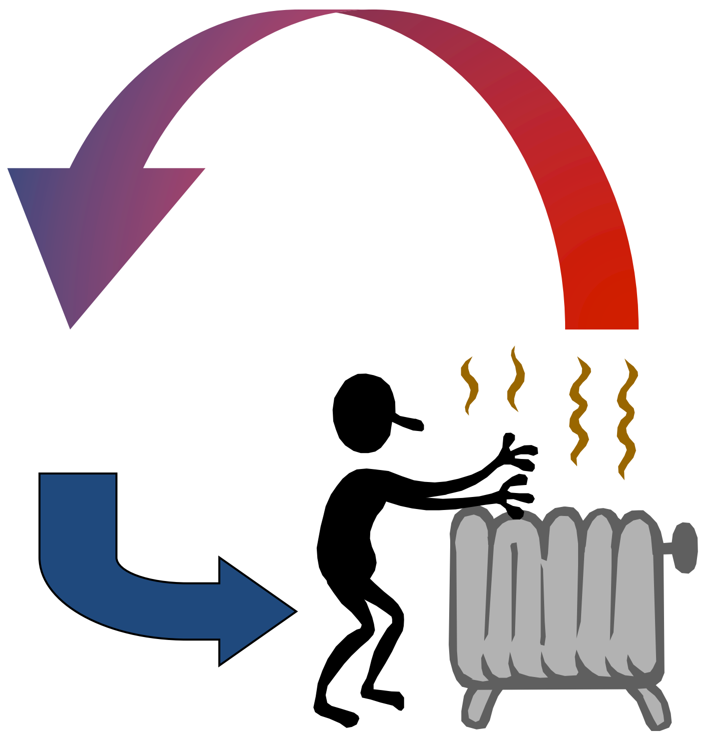
2- Convection of heat

"Hot air rises" (and takes its heat with it!)

-Cumulus clouds



-Radiators

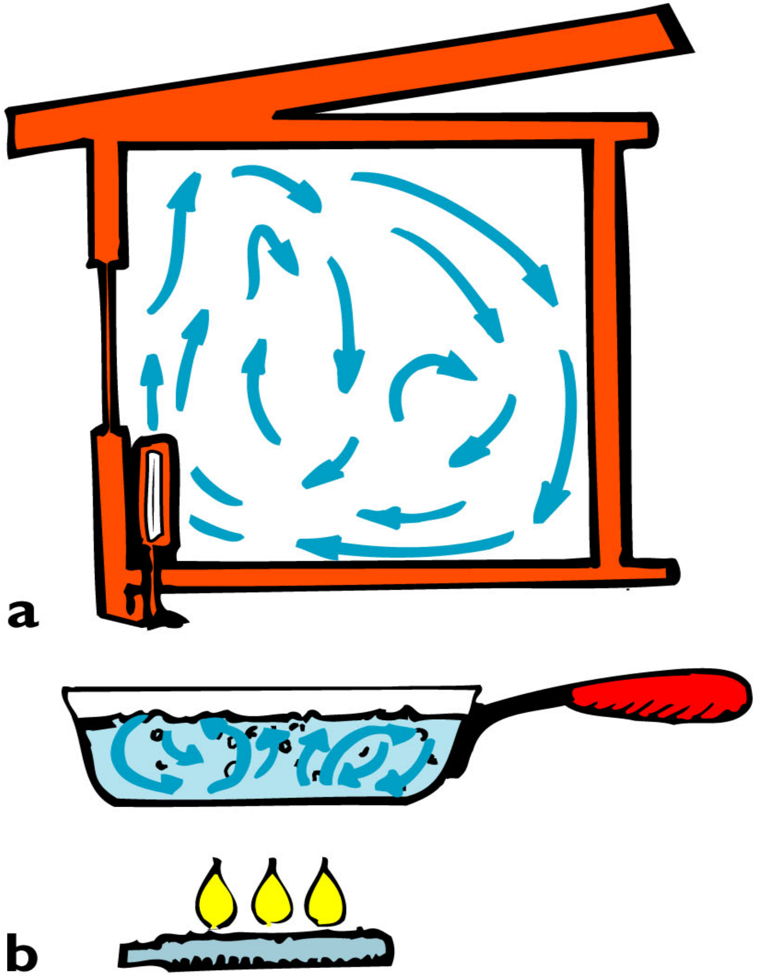


A warm substance transfers energy from one location to another.

Convection, explanation

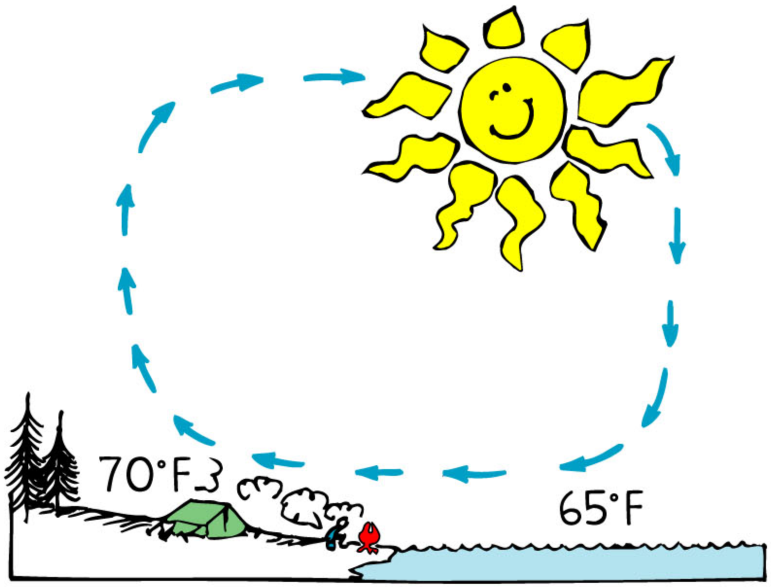
- When the radiator heats the air, it becomes less dense and rises
- Cool air moves in to replace the air that rose
- This generates the air flow
- So radiators don't need a fan to stir the air and to distribute heat throughout a room.
- The rising air cools until its density matches that of the surrounding air.

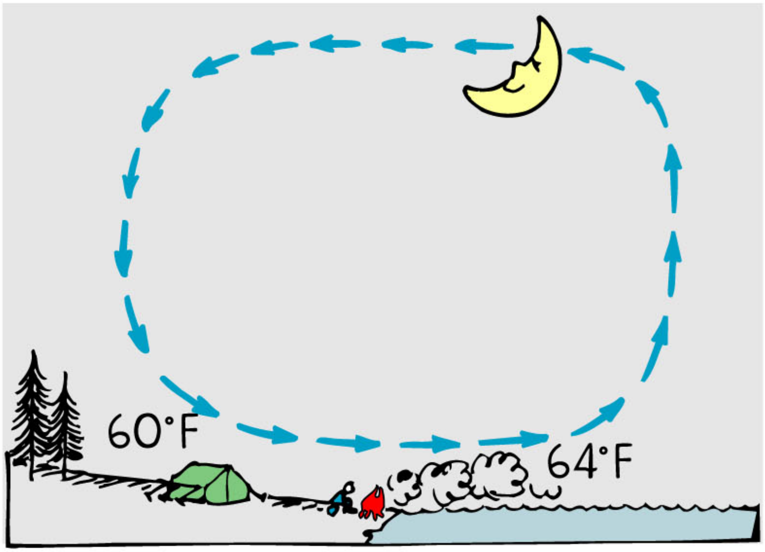
Determine the energy transfer mechanism



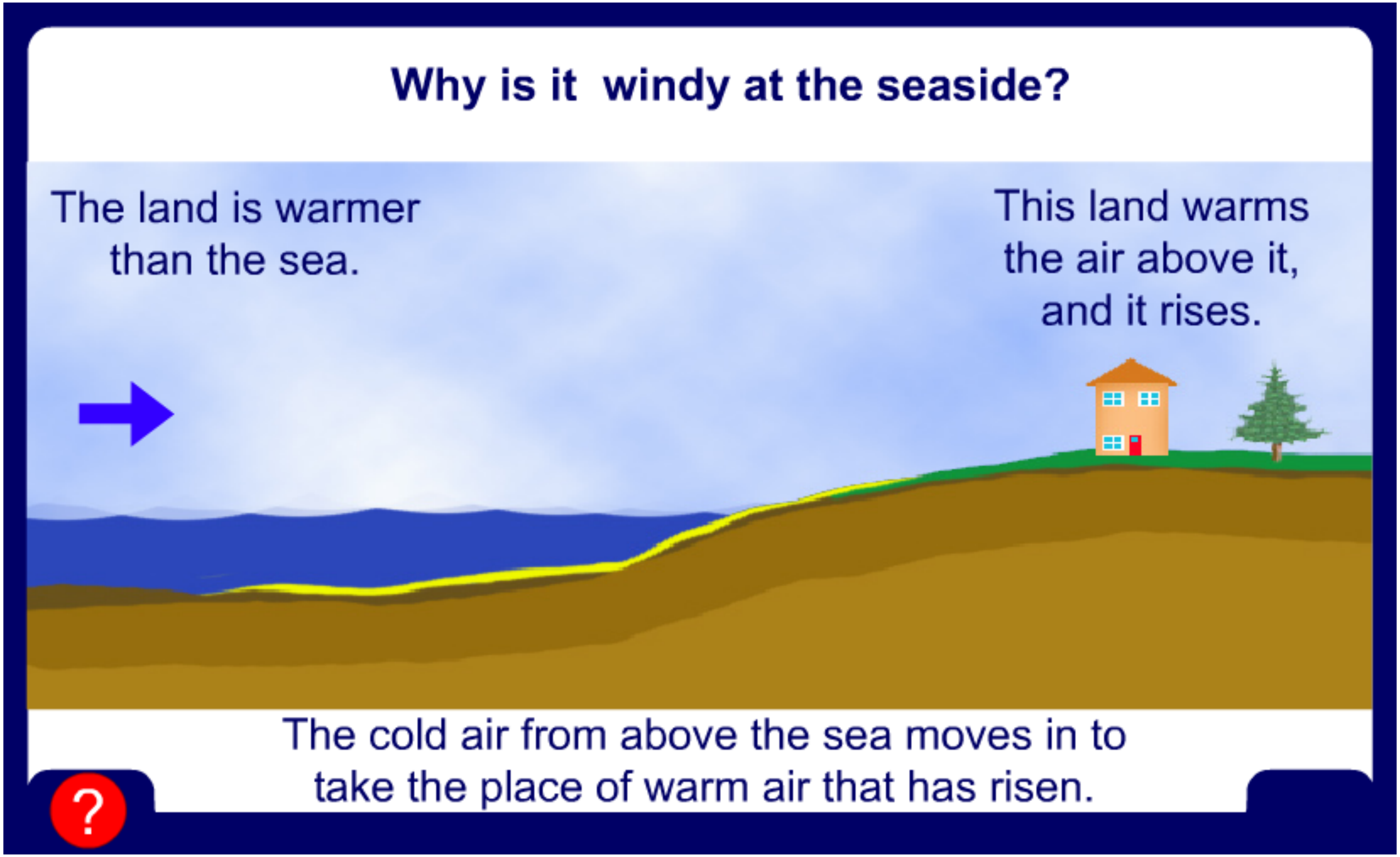
Determine the energy transfer mechanism

- Explains why breezes come from the ocean in the day and from the land at night





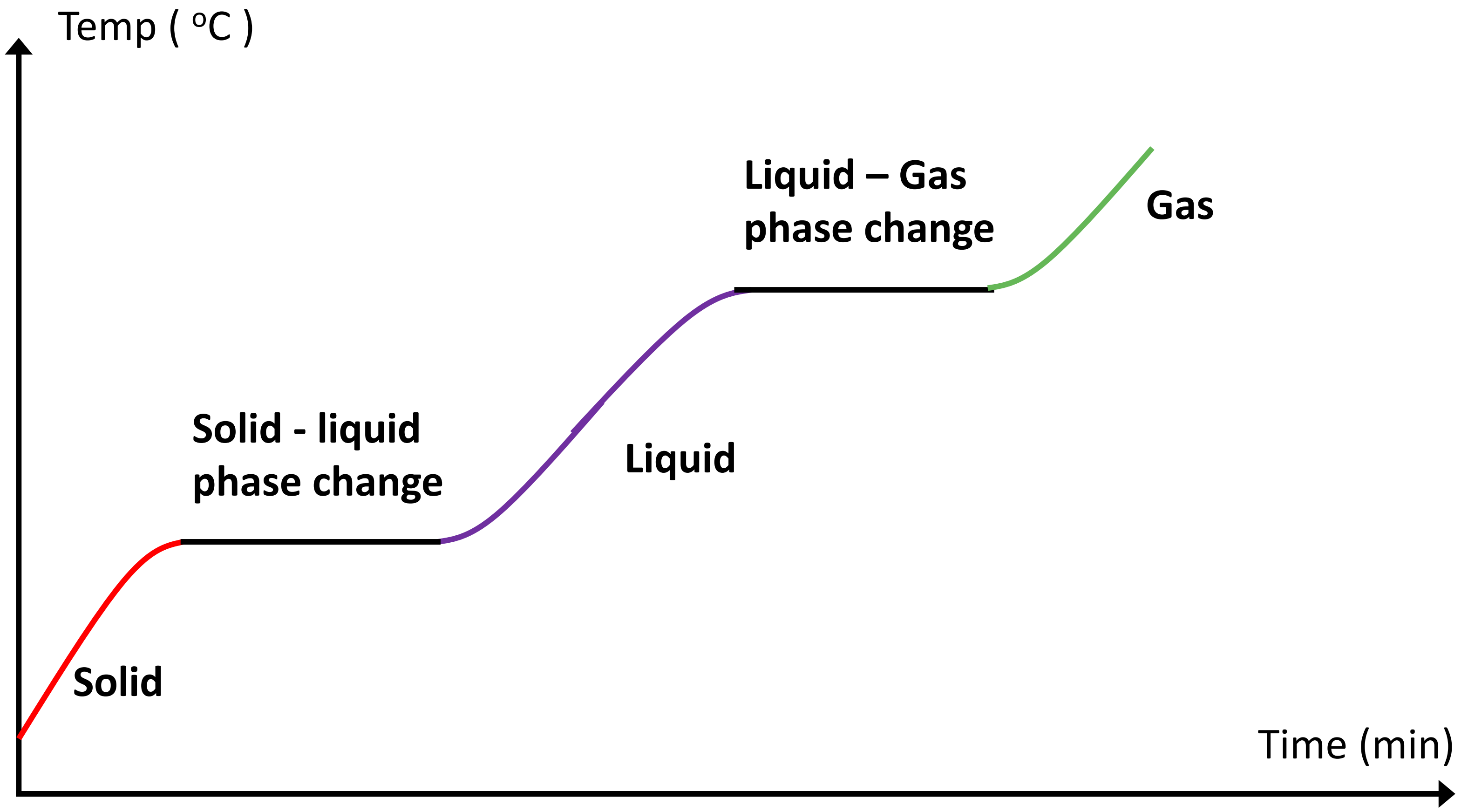
Thermal Convection



3-Radiation

- Thermal Energy Travels as electromagnetic waves (Light, microwaves, radio waves, x-rays)
- Every object above absolute zero is emitting electromagnetic waves (radiation) regardless of temperature.
- Things also absorb radiation.
- Good emitters are also good absorbers.
- When an object is in equilibrium with its surroundings, it radiates and absorbs energy at the same rate, and its temperature remains constant.
- When an object is hotter than its surroundings, it radiates more energy than it absorbs, and its temperature decreases. Whereas an object that is cooler than its surroundings absorbs more energy than it radiates, and its temperature increases.

Heating Curve



***State changes don't occur instantly**

Latent Heat

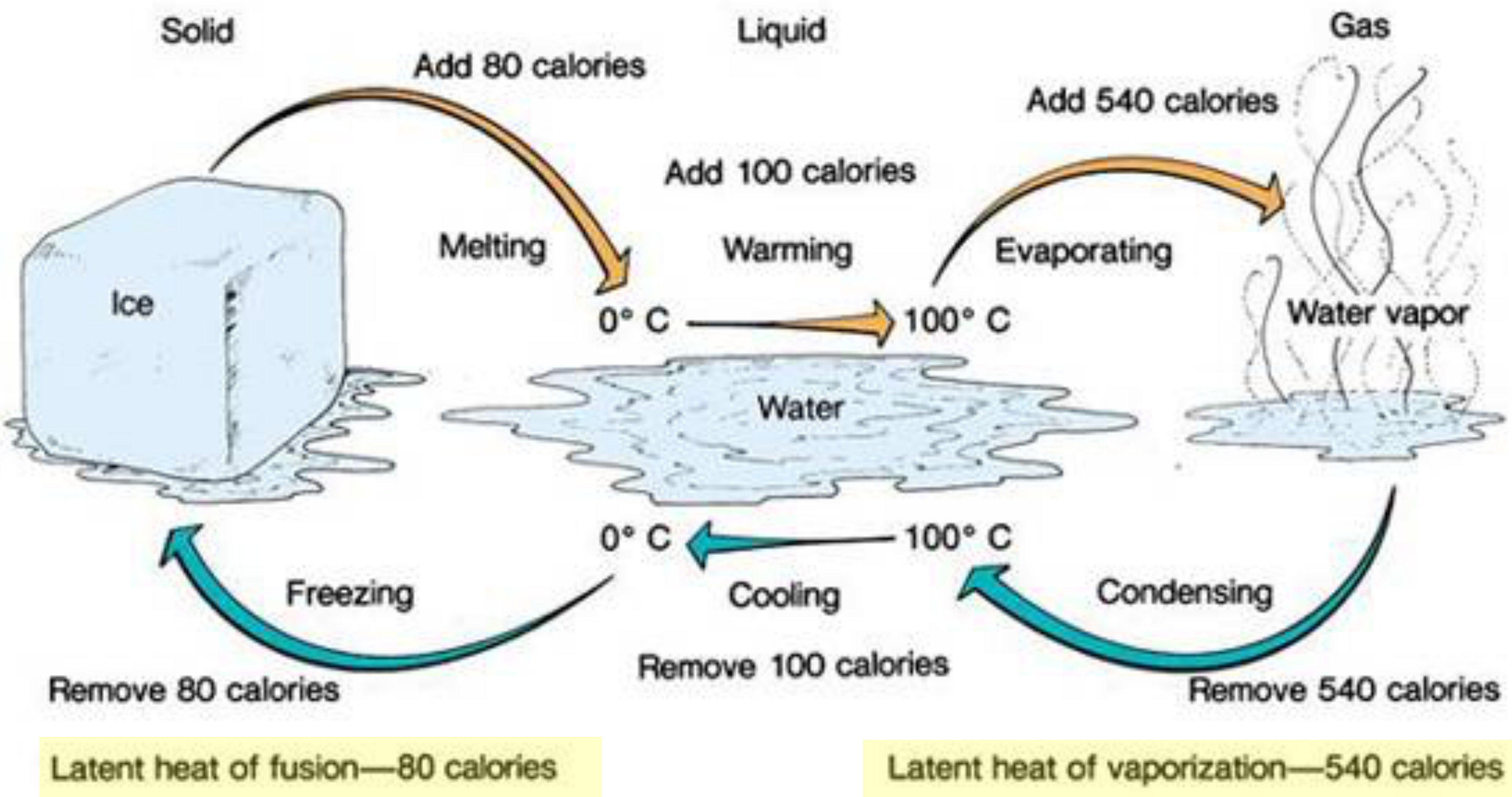
- When a phase (solid, liquid, and gas) change occurs, a lot of energy was absorbed by the substance without its temperature changing.This is due to the latent heat.

- *latent heat* is the amount of heat needed to change the state of matter from one phase to other without a change in temperature.

- *Latent Heat of Fusion* is the amount of heat needed to change the state of matter from **solid** to **liquid** without a change in temperature.

- *Latent Heat of Vaporization* is the amount of heat needed to change the state of matter from **liquid** to **gas** without a change in temperature.

Latent Heat


Solid
Liquid
Gas
Add 80 calories
Add 540 calories
Add 100 calories
Melting
Warming
Evaporating
Ice
0° C
100° C
Water vapor
Water
0° C
100° C
Freezing
Cooling
Condensing
Remove 100 calories
Remove 80 calories
Remove 540 calories
Latent heat of fusion—80 calories
Latent heat of vaporization—540 calories

Homework

- If Celsius thermometer shows the temperature of air 30^0C, find the temperature of air in Fahrenheit thermometer.
- One hundred and fifty joules of heat are added to 75 g of a material whose specific heat is 1.25 J/g C^o. If the material's initial temperature was 43^{o}C, what is its final temperature?
- Suppose you are an astronaut in space, hard at work in your sealed spacesuit. What is the only way that you can transfer excess heat to the environment?
- The table given below shows initial lengths, changes in temperatures and changes in the length of 3 rods. Find whether these rods are made of same matters or not.

Matter	L_i	ΔT	ΔL
A	2L	ΔT	ΔL
B	3L	$2\Delta T$	$3\Delta L$
C	4L	ΔT	ΔL