Temperature and Heat

Temperature

Thermal Expansion

The 1st Law of Thermodynamics

Heat Transfer

Specific Heat Capacity

Phase Transition

Heat Engines and the 2nd Law of Thermodynamics

Temperature and Energy (Heat)

Temperature and Heat are used interchangeably however they mean 2 different things.

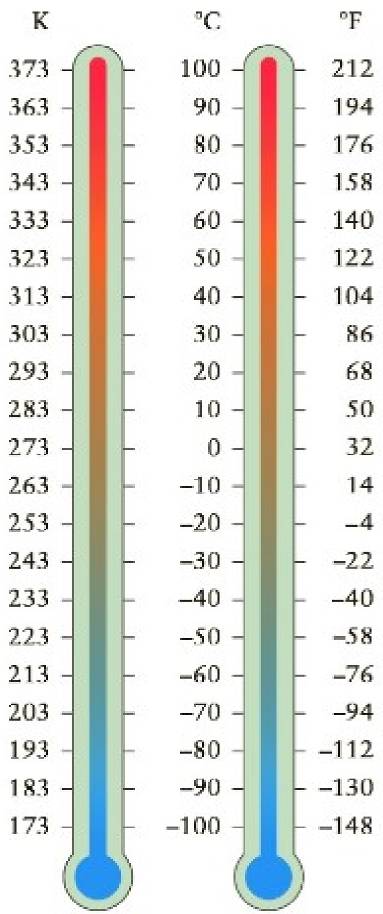
Heat is energy and it is an additive quantity. The units of Energy is Joules.

The combined Temperature of two bodies is not additive, it is an equilibrium state.

The units of Temperature are Celsius, Fahrenheit and **Kelvin**.

Heat is calculated.

Temperature is measured.



Principle: The Kelvin scale temperature of matter is proportional to the average kinetic energy of the constituent particles.

Units: Temp: C, F, K, Heat: Joules, Calories, N-m.

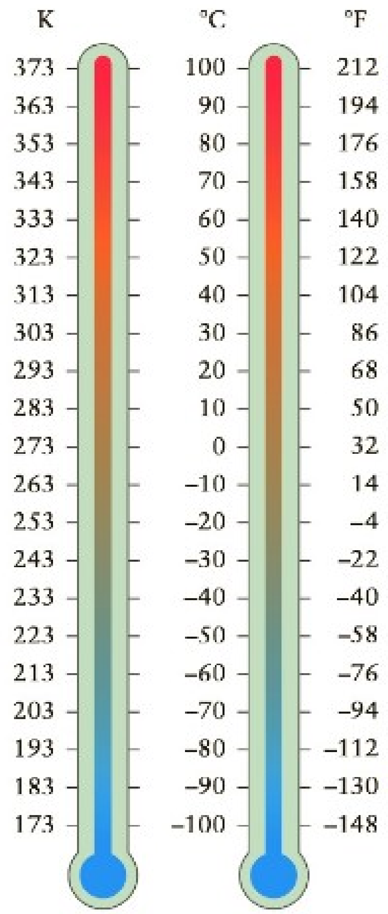
Temperature - heat

a) Given the thermometers pictures, plot these scales into a sheet

b) The C graph take any 2 points to make a plot (i.e to plot 30C, go right 3 boxes and up 3 box, Label the first graph C

c) The F graph take any 2 point to make a plot (i.e. plot 212F, go right 10 boxes and go up 21 boxes), Label 2nd Graph F

d) On each graph what would be the temperature (units)

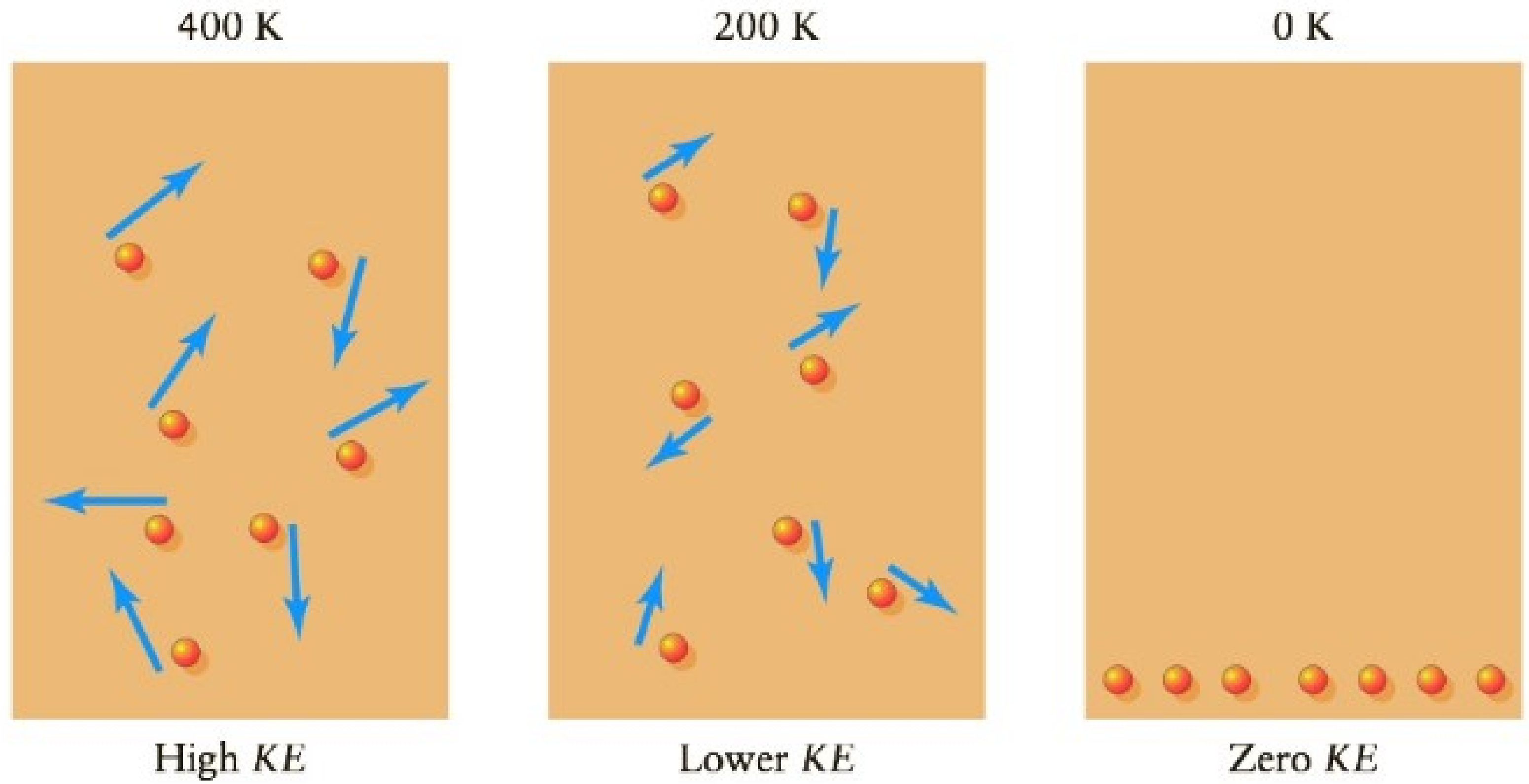


Temperature and Energy

Temperature is dependent on the KE of atoms in Kelvin Scale.

A around 2 K, some conductors become SUPERCONDUCTORS, no more resistance VIR.

An illustration of what happens at Zero K



Units: Temp: C, F, K, Heat: Joules.

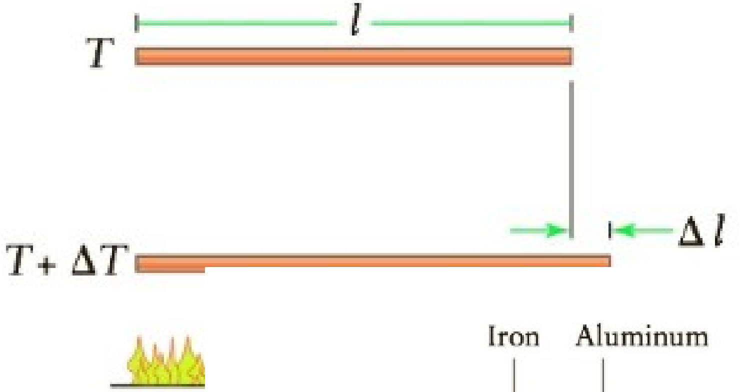
Thermal Expansion

In many instances as temperature increases, pressure increase (reminder: pressure = F/A).

Solid Linear Expansion: depends on 1) Length, 2) ΔT, 3) Material

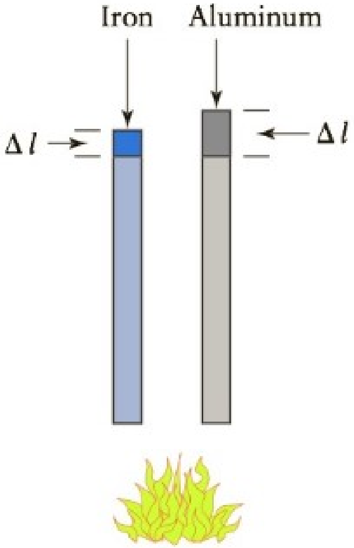
We call alpha α the coefficient of linear expansion (it is the slope!)

$$\Delta l = \alpha * l_0 * \Delta T$$



What are the units of $\alpha, \Delta l, \Delta T$?

Solid	α ($\times 10^{-6}$/°C)
Aluminum	25
Brass or bronze	19
Brick	9
Copper	17
Glass (plate)	9
Glass (Pyrex)	3
Ice	51
Iron or steel	12
Lead	29
Quartz (fused)	0.4
Silver	19

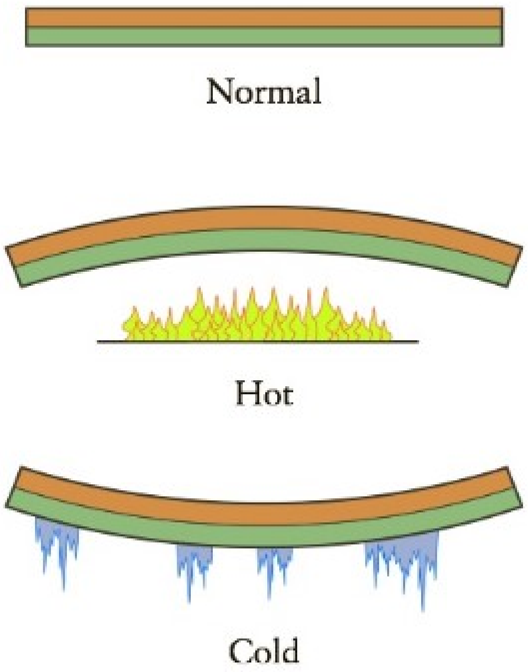


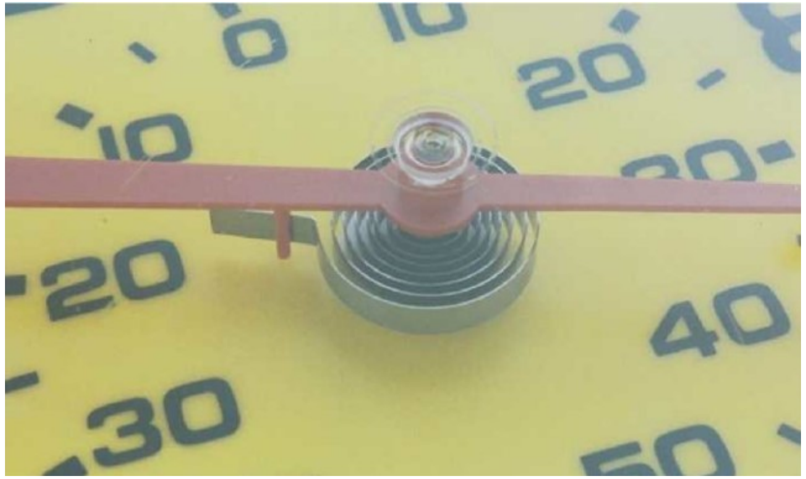
Units: Thermal Expansion: α 1/C

Thermal Expansion

Bimetallic Strips used everyday and everywhere.

Very reliable technology, very sensitive and much easier to read than standing thermometers.





$$\Delta l = \alpha \, l \, \Delta T$$

Units: Thermal Expansion: α 1/C

Thermal Expansion - Solids

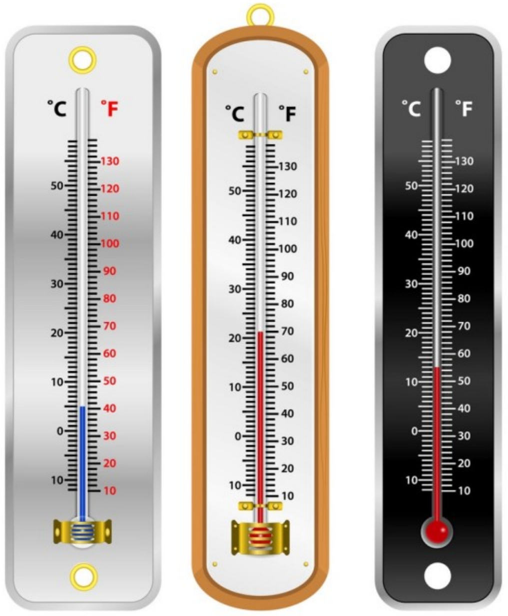
An iron railroad rail is 700 ft long when the temperature is 30C.
What is the length of the road when the temperature is -10 C.

Thermal Expansion - Solids

A machinist wishes to insert a ring with a diameter of 4.997 mm into a steel rod with a diameter of 5 mm. By how much would the machinist have to lower the temperature of the rod to make it fit into the ring?

Liquids

Liquid thermometers (Mercury, Ethanol, Isopropanol)



We call alpha α the coefficient of linear expansion (it is the slope!)

Convert from C → to F

$$°F = \left(\frac{9}{5} * °C\right) + 32$$

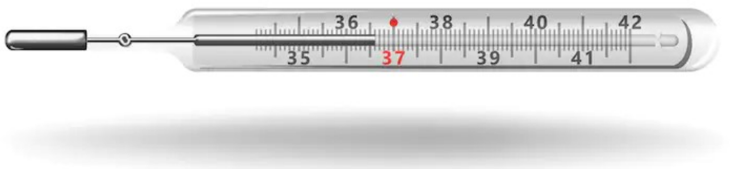
Convert from F → to C

$$°C = (°F - 32) * \frac{5}{9}$$

Convert from C → to K

$$°K = °C + 273.15$$

Special case to convert from F to Kelvin 2 steps,



Convert from F → to C, then C to K

$$°K = \left((°F - 32) * \frac{5}{9}\right) + 273.15$$

Liquids

Common Temperatures to memorize, they will be in the exam.

°C	°F	
- 40	- 40	Where Celsius equals Fahrenheit (good to double check formulas)
0	32	The freezing point of water. (Water, Ice, Vapor Co-exist)
21	70	A typical room temperature.
35	95	Hypothermia Starts
37	98.6	Body temperature.
38	99	Fever Starts, depends oral, rectal or Armpit
100	212	Boiling point of water at sea level.

Thermal Expansion - Solids

Your jet is arriving in London, and the pilot informs you that the temperature is 30C. Should you put on your jacket?

Convert the following to C (212, 98)

Convert the following to F (0, -40)

Liquid - H2O weird behavior

Try it at home, fill up a bottle of water to the top, cover it a day later check it out.

Try a can of coke –

Extreme care must be take handling medical solutions in freezers – thermal expansion is real.

Above 4C (39F) water expands when heated

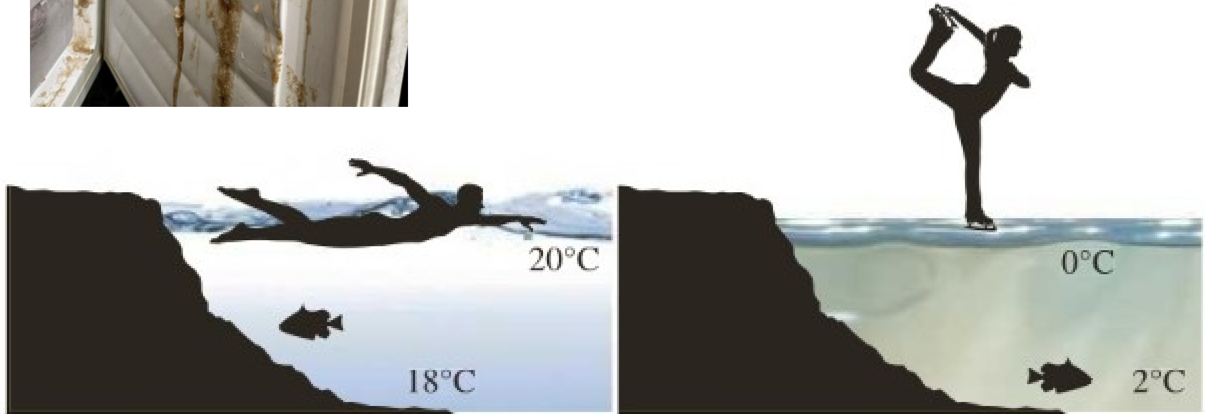
Between 0C (32F) – 4C (39F) water is weird

It expands when Cooled

It contracts when Heated

i.e. water at 2C occupies more volume than at 3C

Think about skating on a lake, Ice on top water on the bottom



Gases: Ideal Gas Laws (Jacques Charles 1746)

The volume expansion of gases is larger than Solids or Liquids.

The amount of expansion does not depend on the gas.

Law: **Ideal Gas Law** In a gas with a density that's low enough that interactions between molecules can be ignored the pressure, volume, and temperature of the gas are related using the equation shown.
The constant depends on the quantity of gas present but not its specific type.

$$pV \approx T\ (constant)$$

Typically we use

$pV = T$ or $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} = Constatnt$

Often in refrigeration system, the volume is fixed, as such an increase in pressure produces an increase in temperature. The tires of your car during summer are subject to an increase in temperature, pressure and limited volume – you better check your tires pressure.

For this law to work, the units of Temperature must be in Kelvin.

Practice – Ideal Gas Law

A volume of $8\ 10^{-3}\ m^3$ of an ideal gas enclosed in a thin, elastic membrane in a room at sea level where the air temperature is 18C.

If the temperature of the room is increased by 10C, what is the new volume of the gas?

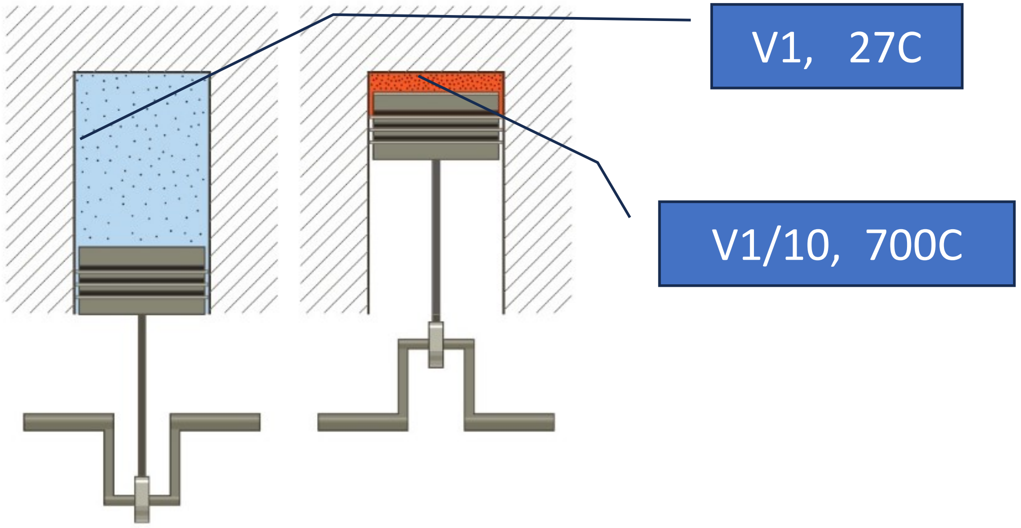
Practice – Ideal Gas Law

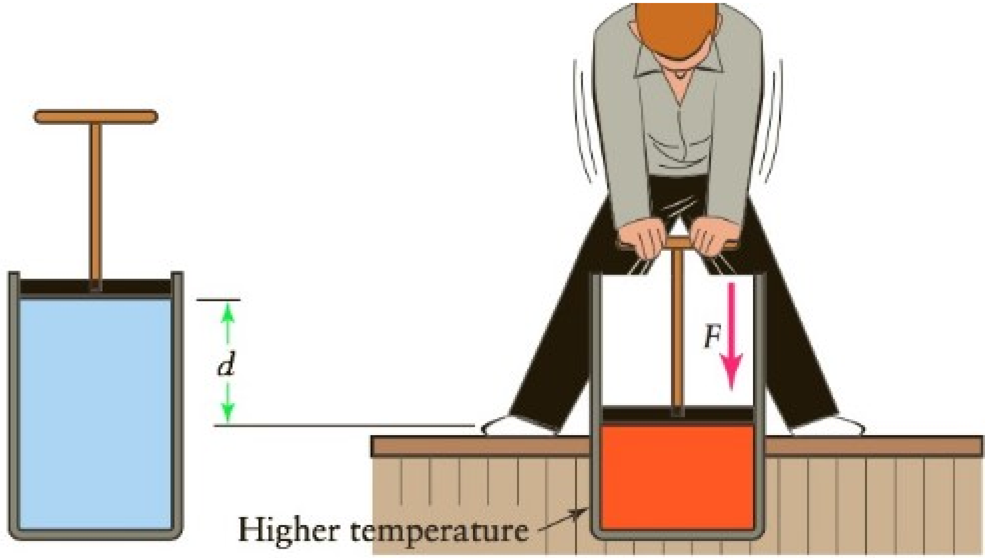
An amount of an ideal gas at 16C and a pressure of 1.75 10^{-5} Pa occupies a volume of 2.75 m^3. If the volume is increased to 4.20 m^3 and the temperature is raised to 26.4C, what will be the new pressure of the gas?

First Law of Thermodynamics

2 ways to increase the temperature of matter.

1. Exposing to / near something hotter (Stove, Heater, Sun, Drier, Fire…)
2. By doing work on it (Friction, Gas Compression, stirring a pot…)





Temp Increase = Gain in Kinetic Energy. Lets spice it up, be active and hot!

Temp Decrease = Loss in Kinetic Energy.

Q is the symbol for heat and units Joules (Heat = Energy)

Gas (Only KE), Liquid & Solids (Both KE+PE)

Units: Heat Q : J (Joules), Calories

First Law of Thermodynamics

For Solids and Liquids both are important, Kinetic and Potential Energy.

Definition: **Heat** the form of energy that is transferred between 2 substances because they have **different temperatures**.

Definition: Internal Energy U The sum of the KEs & PEs of the atoms in a substance.

Units for Heat: J (Joules), Calories (cardio), BTUs appliance, N-m

First Law of Thermodynamics

Law: The First Law of Thermodynamics, The **change** in internal energy of a substance equals the work done on it plus the heat transferred to it.

$$\Delta U = Work + Q$$

We introduce U Internal Energy (KE+PE) / U in Joules

See Picture:

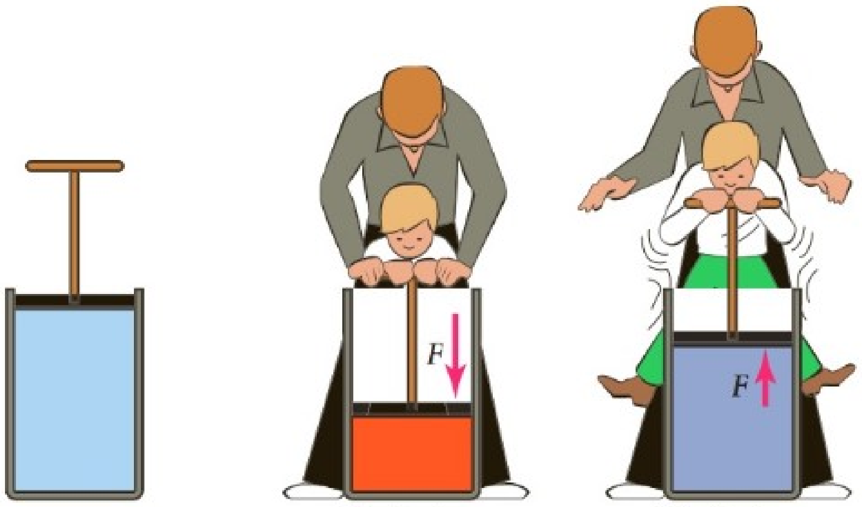
- Work could be (+) or (-) / Heat could be (+) or (-)

Work (+) if done "ON" a substance

Work (-) if "substance does" the work

Heat Q (+) when heat flows "Into" substance (Temp Increase)

Heat Q (-) when heat flows "Out of" substance (Temp Decrease)



Work done on the gas

Work done by the gas

Define your system or follow instructions.

How do we quantize Work and Heat?

Units for Heat: J (Joules), Calories (cardio), BTUs appliance, N-m

First Law of Thermodynamics – Organizing Thoughts

First Law of Thermodynamics

$$\Delta U = Work + Q$$

Internal Energy U = (KE+PE).

$$\Delta U = \Delta(KE + PE)$$

Solids & Liquids: atoms have both (KE+PE)

Gases atoms have only (KE)

Work: discussed in prior chapter, i.e. Force x Distance along force.

Heat: Q, discussed later, calculated by temp difference increase or decrease.

$$Q = C * m * \Delta T$$

Work done "ON" or Heat transferred "TO"

Work & Heat are energy in transition, whereas KE & PE are stored Energy

First Law of Thermodynamics is a Law of Conservation

Units for Heat: J (Joules), Calories (cardio), BTUs appliance, N-m

Practice - Pressure

Air in a balloon does 50 J of work while absorbing 70 J of heat.

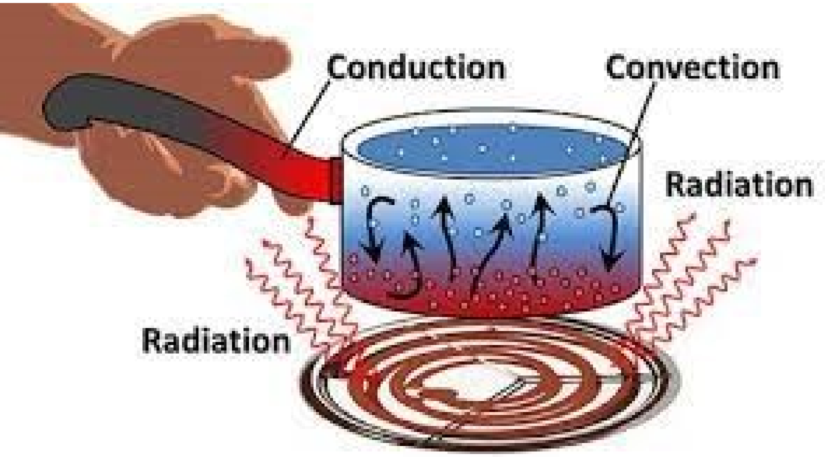
What is its change in internal energy?

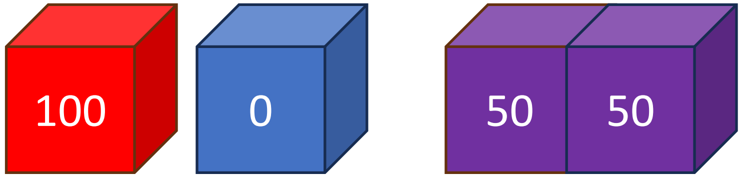
Heat Transfer – Temperature Change

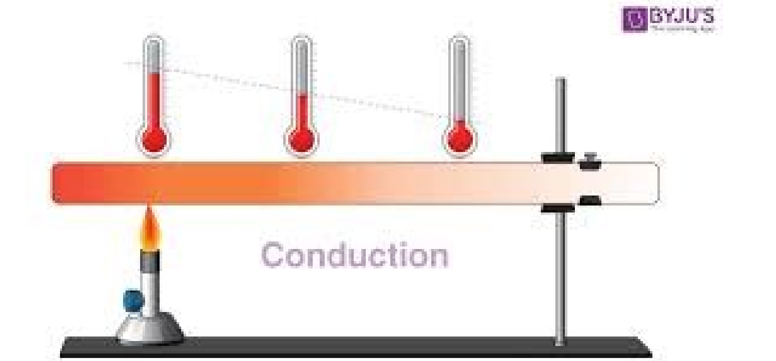
Heat Transfer occurs whenever there is a temperature change. As soon as there is a temperature difference there will be a temperature potential (kind of force). Heat Transfer Modes (There is a lot of overlap between modes)

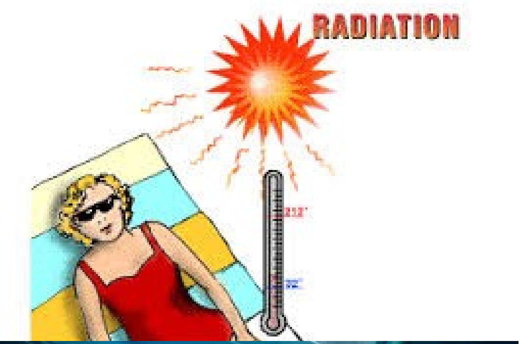
Definitions:

- **Conduction**: The transfer of heat of objects in direct contact
- **Convection**: The transfer of heat by buoyant mixing in fluids fluid
- **Radiation**: The transfer of heat by way electromagnetic waves









Heat Transfer – Temperature Change

Two objects @ the same temp are in thermal equilibrium – No Heat Transfer

Whenever there is two objects at 2 different there will be Heat Transfer

Conduction:

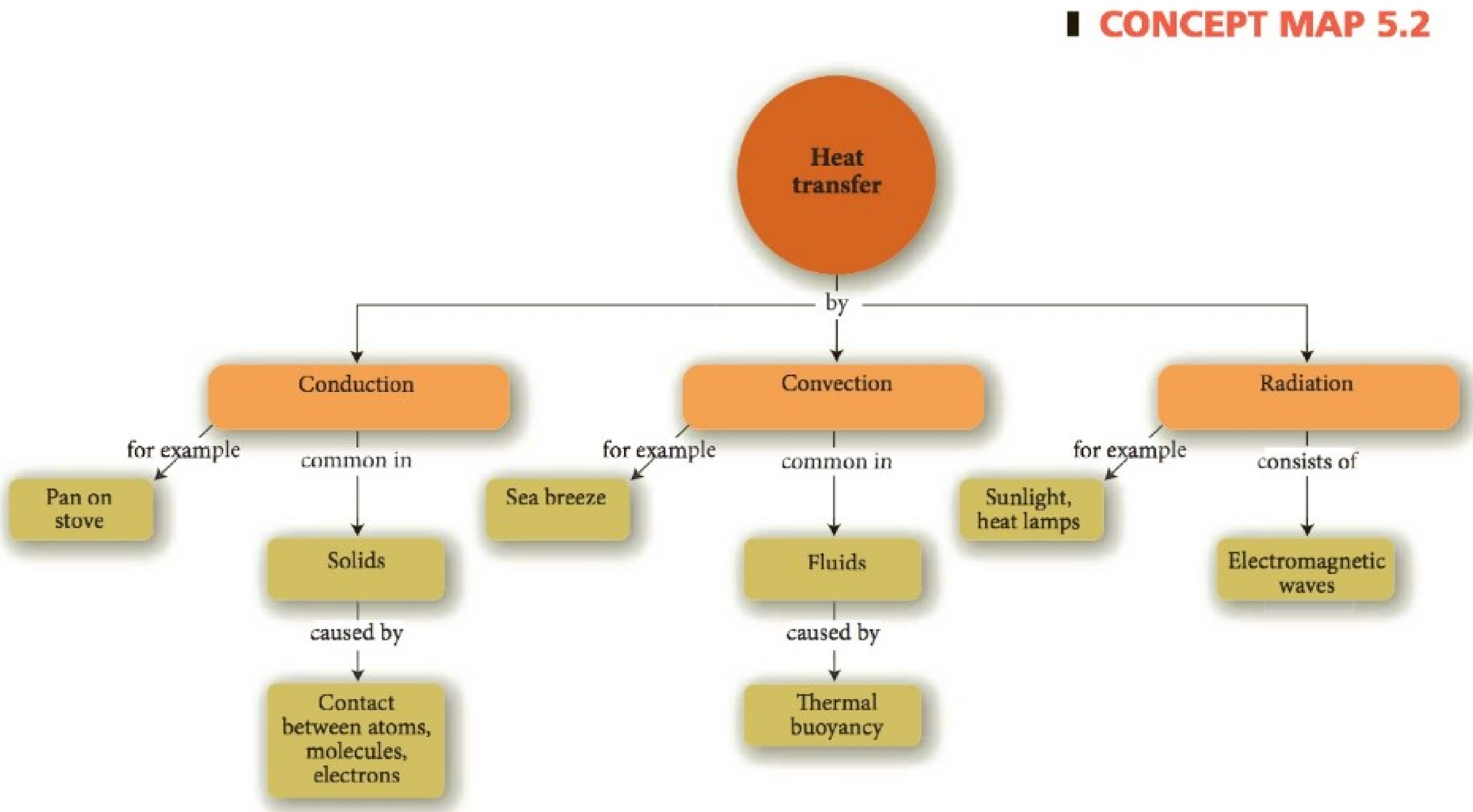
- Thermal Conductors (i.e. copper, steel, diamond – very compact dense)
- Thermal Insulators (i.e. Wool, Styrofoam, fiber glass – lots of space and air, special case Vacuum – no air just emptiness, Vacuum no atomic interaction so no KE & no PE)

Radiation: Can be transferred even through Vacuum

Radiation in the medical field is it safe?

They use the non-ionizing radiation – Go Figure!

Heat Transfer



Heat Transfer - Specific Heat Capacity

Curiosity Kills the cat!

How much energy it takes increase the temp by …?

Is it easier to cool a mosquito or an elephant?

Mostly common depends on the ***temperature difference***, the quantity ***mass,*** and the substance ***material***.

For instance it takes more energy to increase the temperature of water by 1 degree than say copper or mercury – this number is called ***specific heat capacity noted as capital C***.

Remember Heat KE & PE.

1 calories is the energy required to increase 1 kg of H_2O by 1 C.

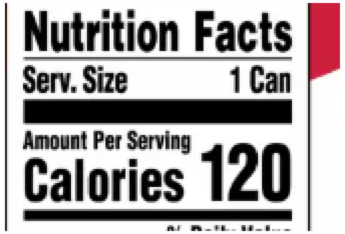
1 calorie = 4.184 J

Note: C for H_2O is high (it is great at absorbing & releasing heat – H_2O is unique, useful, & weird)

Could Q be negative?

$$Q = C * m * \Delta T$$

Substance	
Solids	
Aluminum	890
Concrete	670
Copper	390
Ice	2,000
Iron and steel	460
Lead	130
Silver	230
Liquids	
Gasoline	2,100
Mercury	140
Seawater	3,900
Water (pure)	4,180



Practice - Heat

A bottle containing 3 kg of water at a temperature of 20C is placed in a refrigerator where the temperature is kept at 3C.

How much heat is transferred from the water to cool it to 3C?

Practice - Heat

Compute the amount of heat needed to raise the temperature of 1 kg of water from its freezing point to its boiling point.

Practice - Heat

A 1,200 kg car going 25 m/s is brought to a stop using its brakes. Approximately 20 kg of iron in the brakes & wheels absorbs the heat produced by the friction.

(a) What was the car's original kinetic energy?

(b) After the car has stopped, what is the change in temperature of the brakes & wheels?

Practice – Heat & Energy

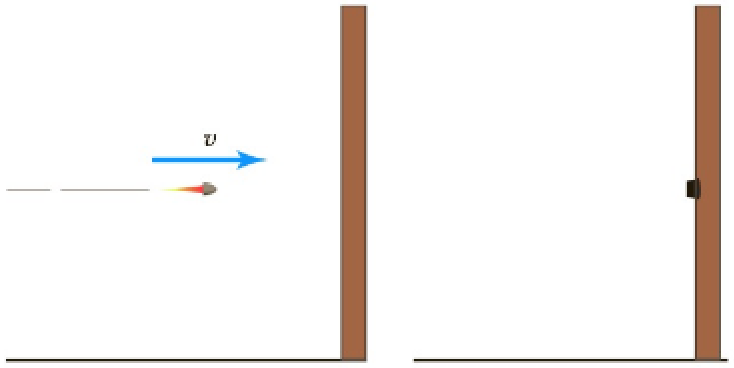
Water flowing over the Lower Falls in Yellowstone National Park drops 94 m.

If all of the water's energy goes to heat it, what is its temperature increase?

Practice - Pressure

A 0.02 kg lead bullet traveling 200 m/s strikes an armor plate and comes to a stop.

If all of the bullet's energy is converted to heat, what is its temperature change?



Practice – Heat & Internal Energy

A 10 kg lead brick is dropped from the top of a 629 m-tall television transmitting tower in North Dakota and falls to the ground.

Assuming all of its energy goes to heat it, what is its temperature increase?

Phase Transition – Change of State

What are the states of matter we studied in chapter 4?

What causes matter to change state? – Pull up your notes

Lets start with some experiments and observations - water.

Note: from left to right and from bottom to up

-Ice to (mix water ice) -100 to 0 C Q= 2.1kJ/kg

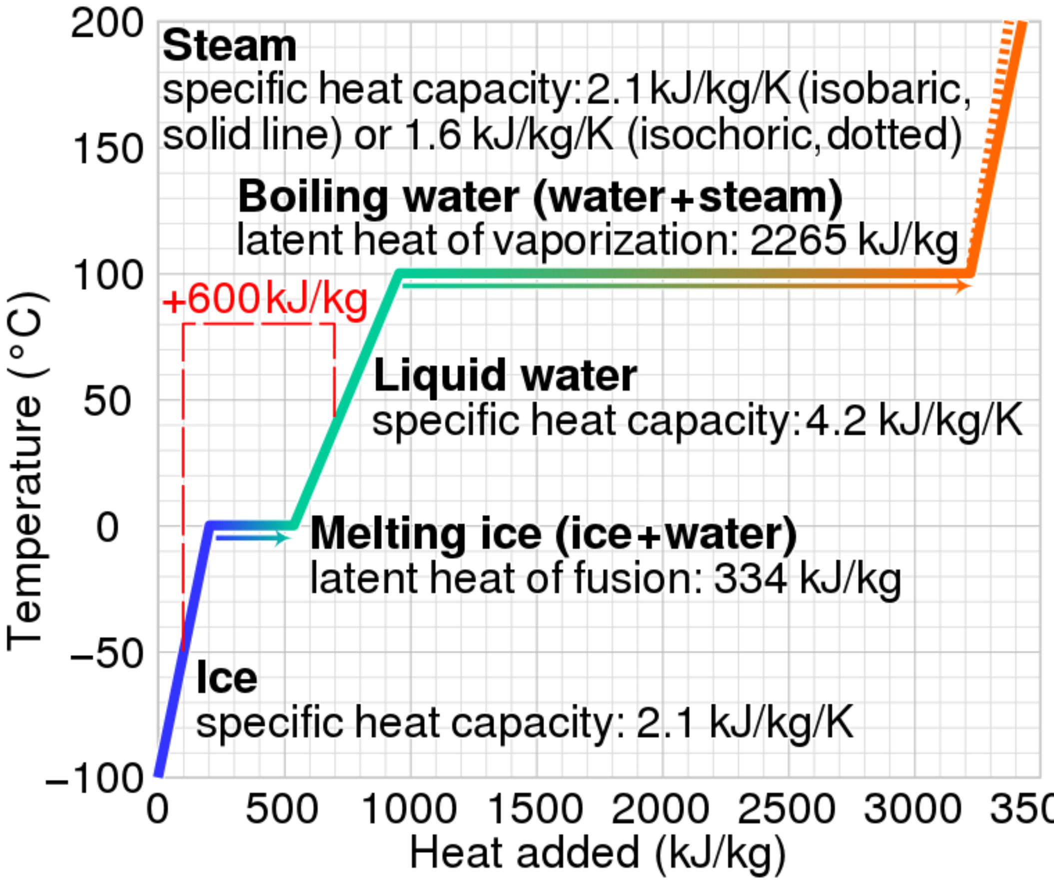
-Melting ice and water 0C to 0C 334kJ/kg

-Liquid water 0C to 100C 4.2 kJ/kg

-Boiling water 100 to 100C 2265kJ/kg

-Steam 100 to 200C 2.1kJ/kg

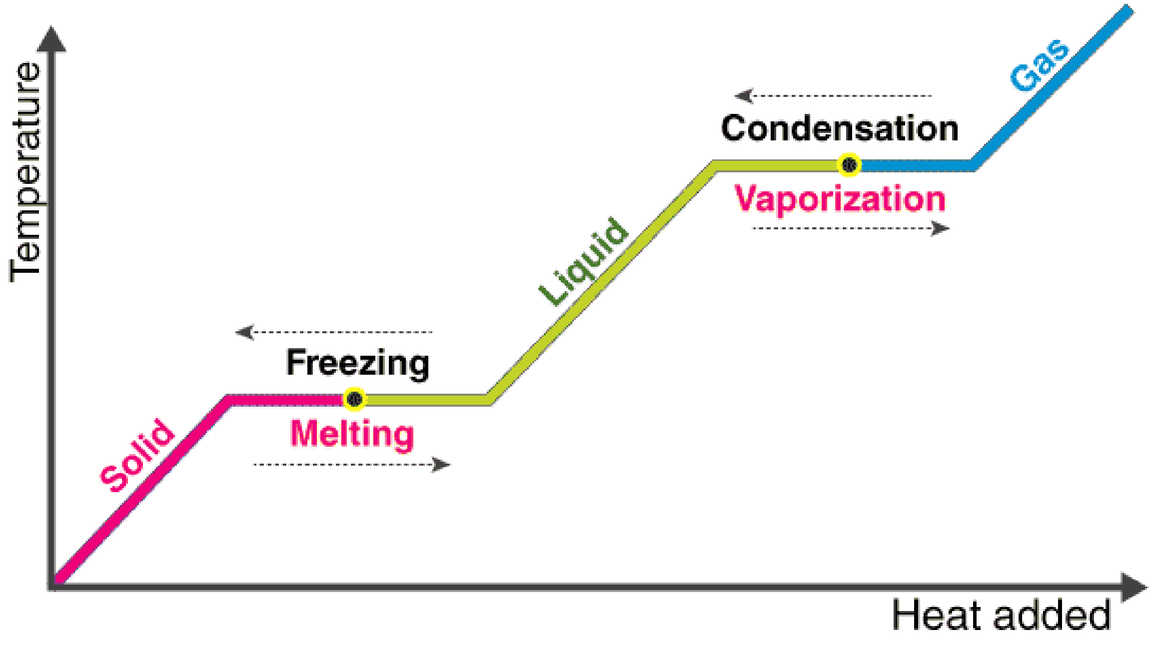
- Phase transfer takes much more energy than temperature increase – called Latent Heat.
- During phase transfer no temperature increase –called Sensible Heat



Phase Transition – Change of State

Heat	Temperature Change	Phase Change	KE	PE
Sensible Heat	YES	NO	YES	NO
Latent Heat	NO	YES	NO	YES

Name	Phase Involved	Effect
Melting	Solid to Liquid	Increase U
Boiling / Vaporization	Liquid to Gas	Increase U
Condensation	Gas to Liquid	Decrease U
Freezing	Liquid to Solid	Decrease U
Sublimation, Solid to Gas will not be discussed in this chapter		



Humidity – Water Vapor

Water Vaporizes / Boils at 100C (212F)
Today the temperature is xx and humidity is xx so how did water vaporized?

It is the average Kinetic Energy – average is the sum of very high & very low KE.

Very high KE water molecules escape and float in the air.

Definitions: Humidity is the mass of water vapor in the air **per** unit volume – the density of water vapor in the air – Mass/ Volume = Density!

Humidity ranges from 0.001 kg/m^3 (cold day in a dry climate) to 0.03 kg/ m^3 (hot, humid day). These densities are much less than the normal density of the air, 1.29 kg/ m^3. Humidity is a small component of the air—less than 5%.

At any given temperature, there is a maximum possible humidity called Saturation Density. Once that maximum is reached, inter-molecular forces overcome KE and water molecule bound again and form droplets

Humidity – Water Vapor

Definitions: Relative Humidity is the humidity expressed as a percentage of saturation density

$$Relative\ Humidity = \frac{humidity}{saturation\ density} * 100\%$$

62% RH means 62% of the max amount of vapor is present or we are 38% near saturation.

Why dew forms on plant during morning (after night)? What happens at night?

When vapor is cooled and humidity stays constant, condensation occurs. The temperature at which this occurs is called the dew point.

Summary

- **Temperature** is the basis of our sense of hot and cold. Physically, the temperature of a substance is proportional to the average kinetic energy of its atoms and molecules.
- Three different temperature scales are in common use today—the **Fahrenheit, Celsius,** and **Kelvin** scales. The Kelvin temperature scale uses the lowest possible temperature, **absolute zero,** as its zero point.
- In most cases, matter expands when its temperature is raised. The amount of expansion depends on the substance and the temperature change. This property is exploited in mercury and alcohol thermometers and in bimetallic strips.
- The **internal energy** of a substance is the total potential and kinetic energies of its atoms and molecules. It can be increased by doing work on the substance and by transferring **heat** to it.
- The **first law of thermodynamics** states that the change in internal energy of a substance equals the work done on it plus the heat transferred to it.
- Heat can be transferred from one place to another in three ways. **Conduction** is the transfer of heat via contact between atoms or molecules. **Convection** is the transfer of heat via buoyant mixing in a fluid. **Radiation** is the transfer of heat via electromagnetic radiation. In some situations, all three processes occur at the same time.
- Except during phase transitions, the temperature of matter increases whenever its internal energy increases. The specific heat capacity is a characteristic of each substance that relates the mass and temperature increase to the heat transferred.
- During phase transitions, the potential energies of the atoms and molecules change while their average kinetic energy remains constant. So the internal energy increases while the temperature stays the same.
- **Evaporation** is a liquid-to-gas phase transition that occurs below the boiling temperature. It is responsible for the water vapor present in the air. **Humidity** and **relative humidity** are two measures of the water-vapor content in air.
- **Heat engines** are devices that use heat from a hot source to do work. They release heat at a cooler temperature in the process. The maximum efficiency of a theoretically "perfect" heat engine is determined by the temperatures of the hot and cold reservoirs.
- **Heat movers** use an energy input to remove heat from a cool substance and transfer it to a warmer substance.
- **Entropy** is a measure of the disorder in a system. Heat engines do not "consume" energy, but they do increase entropy, thus reducing the quality or ease of the use of the energy. Increases in the entropy (disorder) of the universe result from all natural processes.

Equations

Equation	Comments
$\Delta l = \alpha \, l \Delta T$	Thermal expansion of a rod
$pV = (\text{constant}) \; T$	Pressure, volume, and temperature of a fixed amount of a gas (ideal gas law)
$\Delta U = \text{work} + Q$	First law of thermodynamics
$Q = C\, m\, \Delta T$	Heat needed to raise the temperature of a substance by ΔT
$\text{relative humidity} = \dfrac{\text{humidity}}{\text{saturation density}} \times 100\%$	Definition of relative humidity