# Introduction to Energy and Building Science Fundamentals

Course No. ENRG 52

# Outline

## A. Introduction to fundamentals of lighting

- Lighting terminology
- Physics and principles of lighting
- Units of measurement
- Vision and colors
- Ambient, directional and task lighting
- Over- and under-illuminance

## B. Lighting systems

- Components
- Types of lamps
- Ballasts
- Lamp comparison matrix
- Types of lighting luminaires and intensities
- Energy efficiency measures (EEMs)

## C. Lighting controls

- Basic concepts of effectiveness of lighting control
- Types and appropriate applications of lighting controls
- Lighting control equations
- Energy efficiency measures (EEMs)

## D. Additional EEMs

- De-lamping
- Scotopic lighting
- Task and ambient light levels
- Circadian rhythms

## E. Lighting measurements

- Tools
- Data loggers and applications

## F. Lighting calculations

- Equation and method of calculating lumens (zonal cavity formula)
- Equation and method of calculating energy savings
- Method of calculating skylight energy savings

## G. Lighting standards, codes and regulations

- Underwriters' Laboratory (UL)
- Uniform Building Code (UBC)
- Americans with Disabilities Act (ADA)
- Title 24 applications

## H. O&M measures to assure optimal performance

# B. Concepts and principles of energy

1. First law of thermodynamics
2. Second law of thermodynamics
3. Energy, Work, and Power

# B. Concepts and principles of energy

1. First law of thermodynamics
2. Second law of thermodynamics
3. Energy, Work, and Power

# Concepts and Principles of Energy:

- Energy exists in many form (heat, light, chemical or electrical energy).
- Energy is the ability to bring about change or to **do work.**
- **Thermodynamics** is the study of energy.

# First Law of Thermodynamics

- Energy cannot be created or destroyed
- It can **only** be transformed from one form to another
- The total amount of energy and matter in the Universe remains constant – it merely changes from one form to another.

- Energy can only be transformed
  - That means that within a system, the system is either doing something, or something is being done to the system
  - Energy is being transferred to it or away from it
  - a change in internal energy is equal to heat added to the system, minus the work done by the system
  - [insert equation]
  - If you think about it, if you are doing work, you're transferring the energy to someone else (-W)
  - If my energy is going up, if the delta is increasing, then work is being done to me (+W)
  - Change in internal energy is equal to the change in heat minus the change in the work done
  - Change in internal energy is equal to the heat added plus the work done to the system

# B. Concepts and principles of energy

1. First law of thermodynamics
2. Second law of thermodynamics
3. Energy, Work, and Power

# Second Law of Thermodynamics

- The **Second Law of Thermodynamics** states that "in all energy exchanges, if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state."
  - It is impossible for a process to have as its sole result the transfer of heat from a cooler body to a hotter one.
- This is also commonly referred to as **entropy.**
  - A watch you have to wind, will run until the potential energy in the spring is converted, and not again until energy is reapplied to the spring to rewind it.
  - A car that has run out of gas will not run again until you walk 10 miles to a gas station and refuel the car.
  - Once the potential energy locked in carbohydrates is converted into kinetic energy (energy in use or motion), the organism will get no more until energy is input again. In the process of energy transfer, some energy will dissipate as heat. Entropy is a measure of disorder: cells are NOT disordered and so have low entropy. The flow of energy maintains order and life. Entropy wins when organisms cease to take in energy and die.

- Heat always flows from hot to cold objects **never** cold to hot
  - So if you take a warm can of soda, and put it a bucket of ice, the cold does not go from the ice to the can. The heat goes from the can to ice – and actually warms up the ice – there by making the cans colder.

- We can extend the second law of thermodynamics and talk about the transfer of energy:
  - When energy is converted, some energy is lost as heat
- Basically, the extension of
  - Work in = work out + heat
    - Putting fuel into a generator  will create electricity as well as heat created by the generator (and that heat is actually waste because that heat can’t be used for anything)
  - Work in > work out
    - The **work in** is always going to be greater than the work out because of the heat loss / waste

# $2^{nd}$ Law of Thermodynamics and Entropy

- Entropy is the measure of the amount of **disorder** in a system
  - Take water is frozen in a nice, compact, ice cube. The ice cube has a lot of structure and a lot of order; all the molecules are being held together by precise bonds, etc.
  - When you let the ice cube melt, it's going to gain entropy; its starting to gain energy; the molecules are moving around, it's starting to lose that order and starting gain disorder and pretty soon the ice cube will become water
  - The water has even more motion, energy, disorder
  - If we let that continue, it will begin to evaporate and it's going to turn into water vapor and  the water vapor is going to become all the molecules in the air – and now you have a lot of energy and a lot of disorder and high entropy

# B. Concepts and principles of energy

1. First law of thermodynamics
2. Second law of thermodynamics
3. Energy, Work, and Power

# Energy, Work, and Power

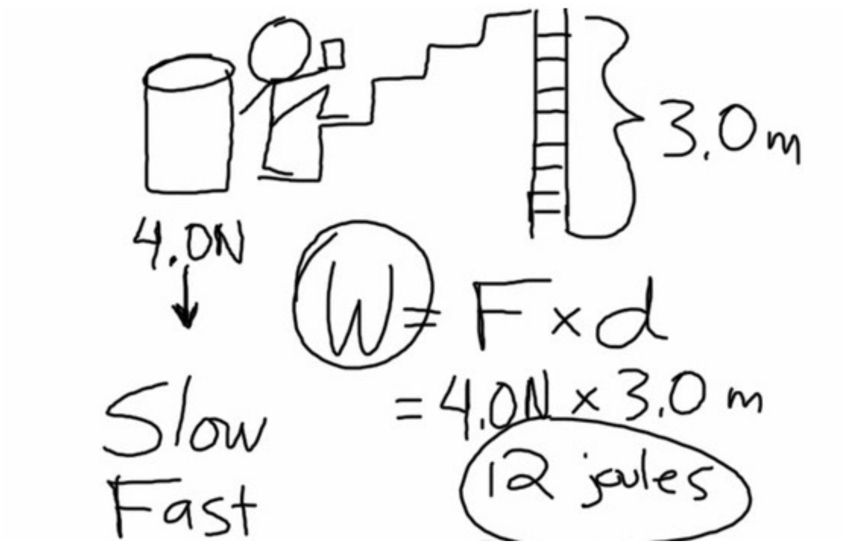
- Energy is the **ability** to do work
- **Work** in scientific terms is simply force (*times) distance
  - Any thing that can apply **force** over a given **distance** is said to have energy
  - Work is measured in joules
- **Power** is defined as an amount of work done over a given amount of time (P = Work/Time)

# Power

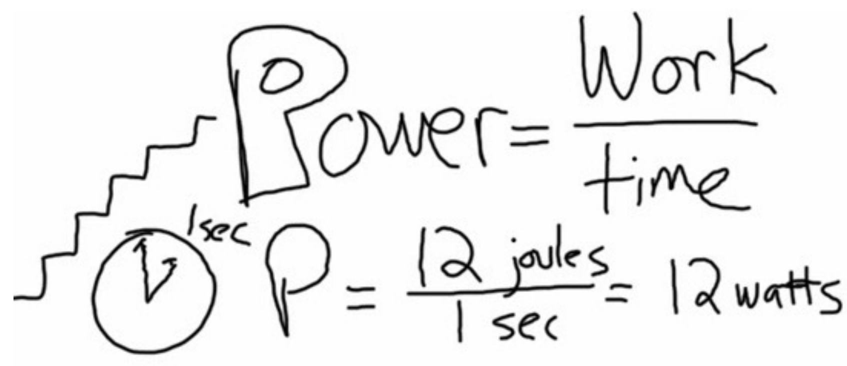
- Power, which is measured in watts, helps us understand how fast or slow the work is done
- In conventional terms, we use Horse Power to measure power: the conversion rate is 1 HP = 746 watts
- If we move the can in 1 second, that .004 hp machine.

# Work and Power

**Measuring Work**




**Measuring Power**



# B. Heat Transfer

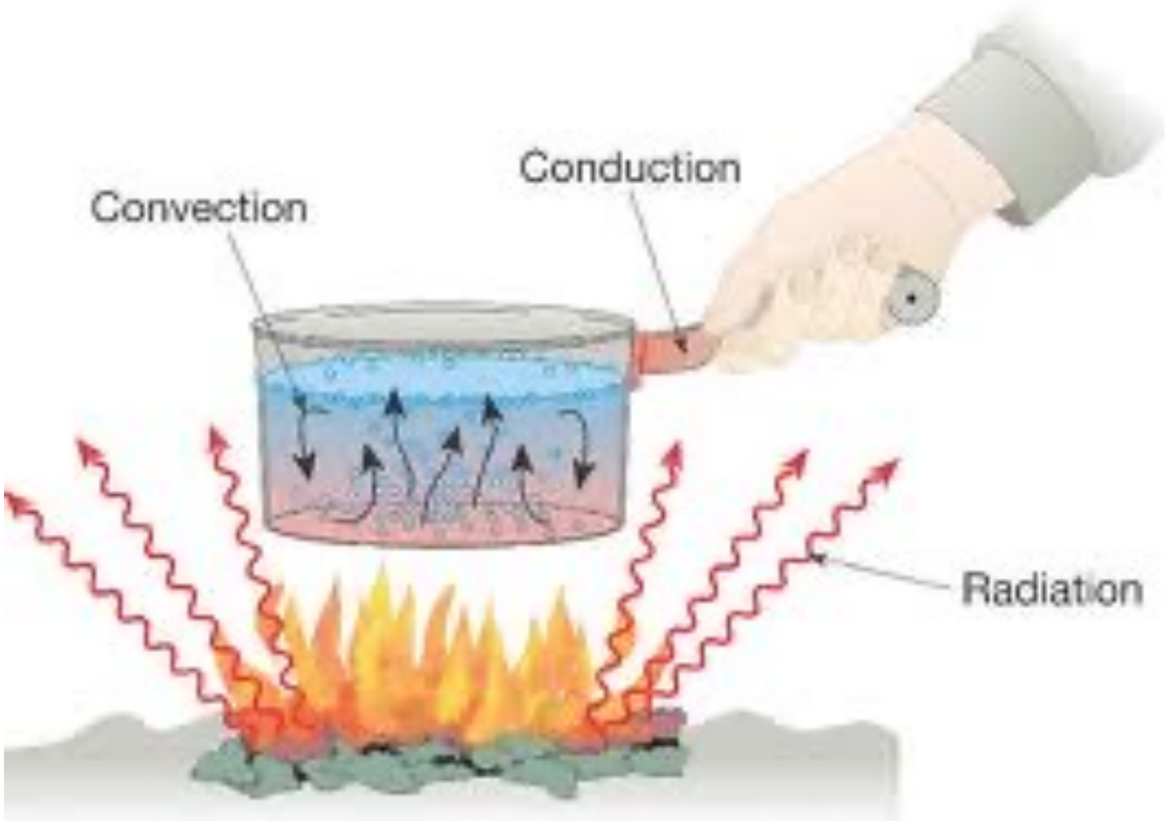
1. Methods of heat transfer
2. Radiant Energy

# C. Heat Transfer

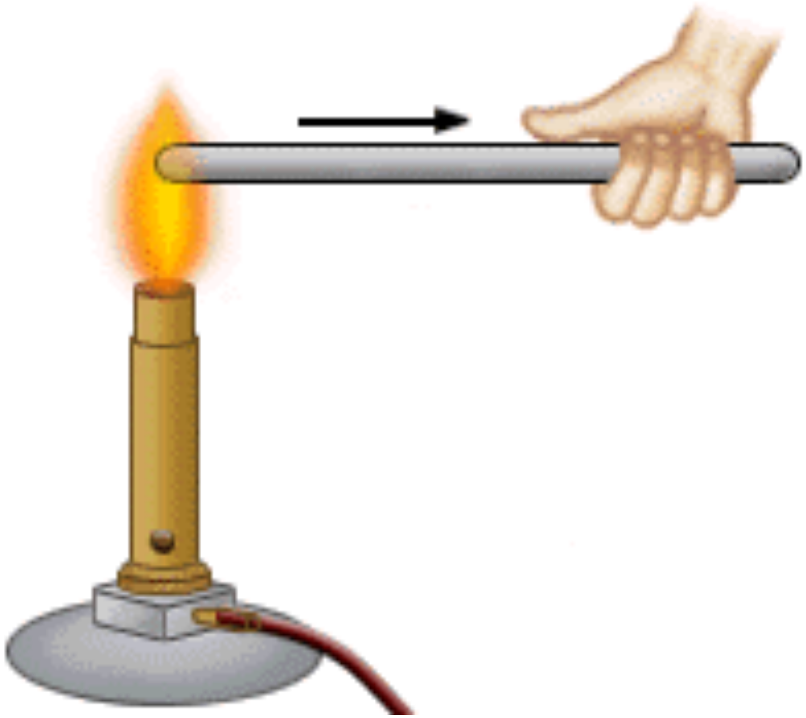
1. Methods of heat transfer
2. Radiant Energy

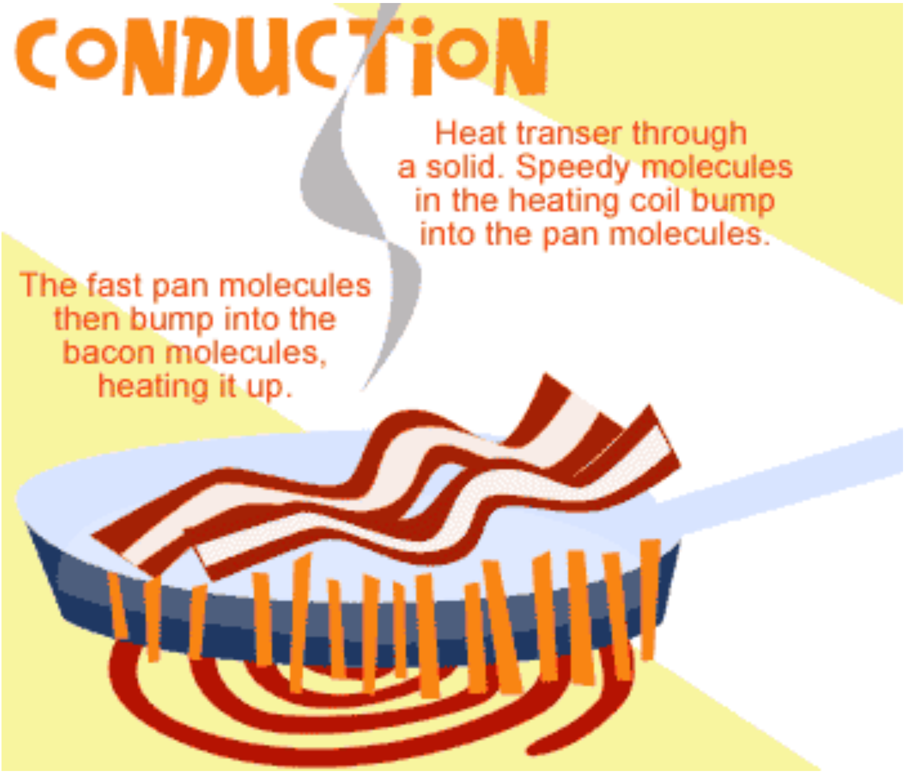
# Heat Transfer

- There are three ways that heat can travel:
  - Conduction
  - Convection
  - Radiation



# Conduction

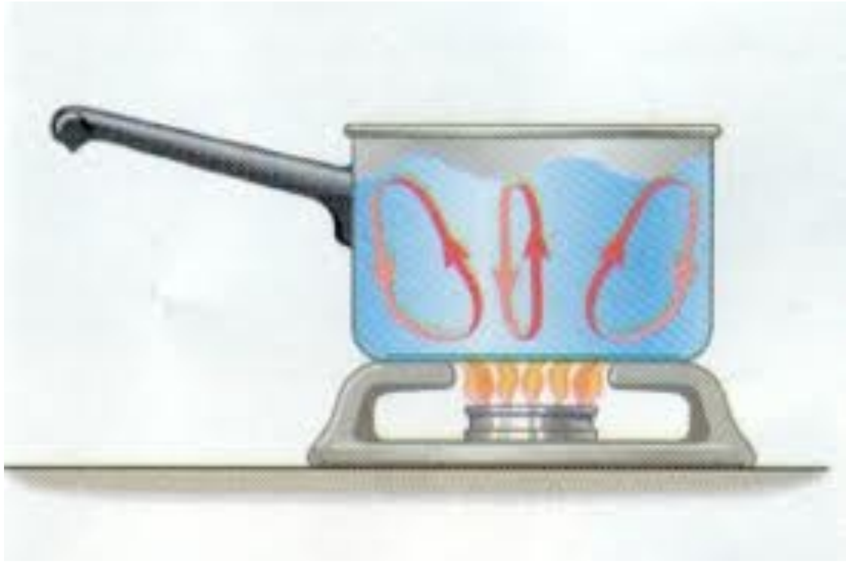


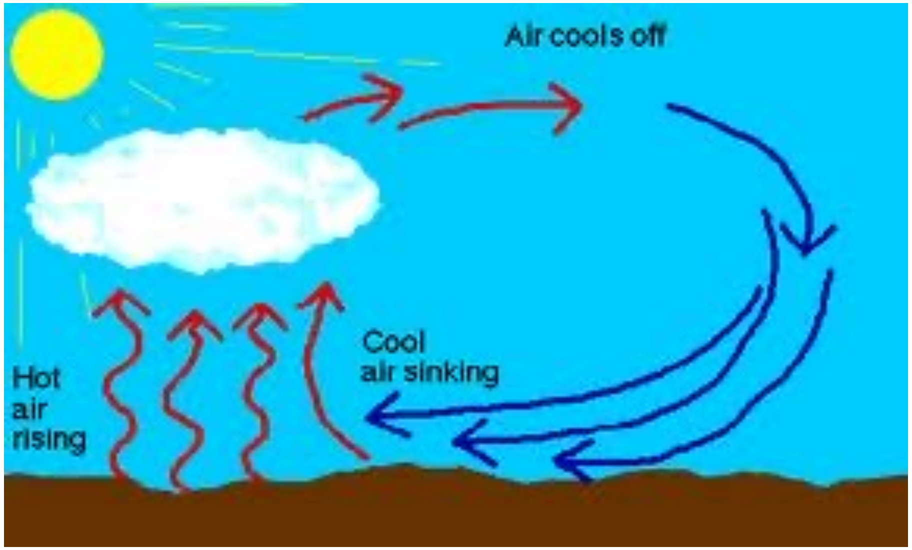

CONDUCTION
Heat transer through a solid. Speedy molecules in the heating coil bump into the pan molecules.
The fast pan molecules then bump into the bacon molecules, heating it up.

# Conduction

- The process by which heat is directly transmitted through a substance
- Heat is transferred from the warmer part of an object to the cooler part of the same object
- Not all substances conduct heat at the same speed
  - Metals and stone are considered good conductors since they can speedily transfer heat, wood, paper, and air are poor heat conductors

# Convection





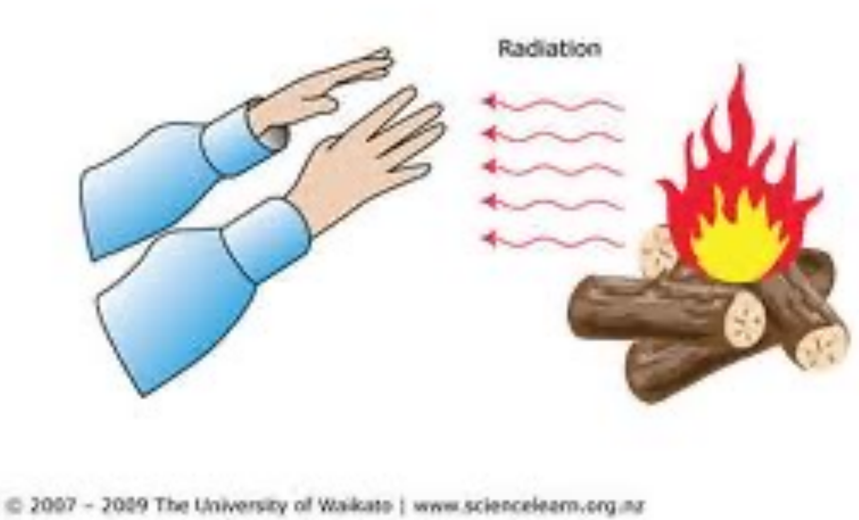
# Convection

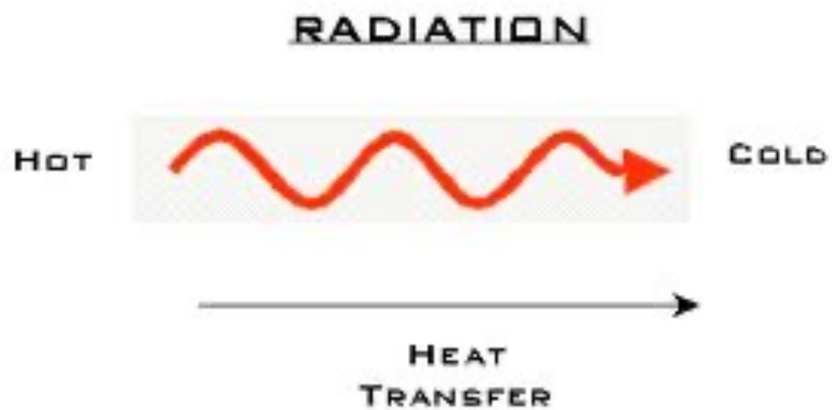
- Convection is the transfer of thermal energy by the motion of fluid.
  - As a fluid is heated by atoms and molecules of the fluid moves faster, spread out, and become less dense.
  - The heated, less dense fluid will rise via a buoyant force from the surrounding cooler, more dense fluid.
  - The heated fluid continues to rise until it has cooled (by transferring its thermal energy to the rest of the fluid) becomes more dense than the surrounding fluid, and fall back down to the heat source, at which point a convection cycle will begin.

# C. Heat Transfer

1. Methods of heat transfer
2. Radiant Energy

# Radiation


Radiation
© 2007 – 2009 The University of Waikato | www.sciencelearn.org.nz


RADIATION
HOT
COLD
HEAT
TRANSFER

# Radiation

- Transfer of energy across a system by means of electromagnetic waves that are caused solely by a temperature difference.
- Heat is transferred in the form of waves without need for a medium for heat to move through

# Radiant Energy Waves

- Reflectivity (p): is the fraction reflected by the surface
- Transmission (t): is the fraction transmitted by the surface
- **Absorption** (a): is the fraction absorbed by a surface:

$$a + p + t = 1$$

# Heat Transfer Summary

| | Definition | Example on the Sun | Example on the Earth |
|---|---|---|---|
| Convection | Currents are created when there are differences in temperature and density within a fluid | Convective currents swirl around until they pass through the photosphere | Cooling yourself by using a fan |
| Conduction | The transfer of heat by direct contact between two materials with different temperatures | NA **(Remember that the Sun has no solid surfaces — it is a "ball of gas.")** | Heat loss through an exterior house wall |
| Radiation | The movement of heat waves | The way energy from the Sun's core moves to the Sun's surface | Cooking food in a solar oven |

# D. Units Conversion

1. kWh to BTU/hr
2. Tons to pounds
3. Therms to BTUs
4. Foot-candle to kW

# kWh to BTu

**kWh to Btu**

- kWh to BTU/hr

- 1 kWh = 3412.14 BTU
  - The **energy** of 1 kWh is  equal to 3412.1416… BTU.

- Example: Convert 5 kWh to BTU:
  - If 1 kWh = 3,412.1463…
  - Then 5 kWh = 3,412.14 *5
  - 17,060.708 BTU

# D. Units Conversion

1. kWh to BTU/hr
2. Tons to pounds
3. Therms to BTUs
4. Foot-candle to kW

# Tons to Pounds

- Conversion of Tons to Pounds
  - 1 ton is equal to 2,000 lbs

# D. Units Conversion

1. kWh to BTU/hr
2. Tons to pounds
3. Therms to BTUs
4. Foot-candle to kW

# Therm to BTU

- Therm to BTUs
  - 1 therm is equal to 100,000 BTU

# D. Units Conversion

1. kWh to BTU/hr
2. Tons to pounds
3. Therms to BTUs
4. Foot-candle to kW

# Foot-candle to kW

- Foot-candle to kW
  - First we convert Foot-candle to lumen:
    - 1 foot candle is equal to 10.76 lumens
  - Convert lumens to watts
    - 1 lumen is equal to 0.001496 watts
  - 50 foot candles * 10.76 lumens = 538 lumens
  - 538 lumens * 0.001496 = 0.804848 watts
- Formula:
  - (*foot candles*) * (10.76 lumens) * (0.001496 watts) = foot-candles converted to watts

# E. Change of state (phase change)

1. Phase changes
2. Solids phase change
3. Vapors phase change
4. Dependence of boiling temperature on pressure
5. Molecular (kinetic) theory of liquids and gases
6. Superheated, Saturated, and Sub-cooled Conditions
7. Sensible and Latent Heat

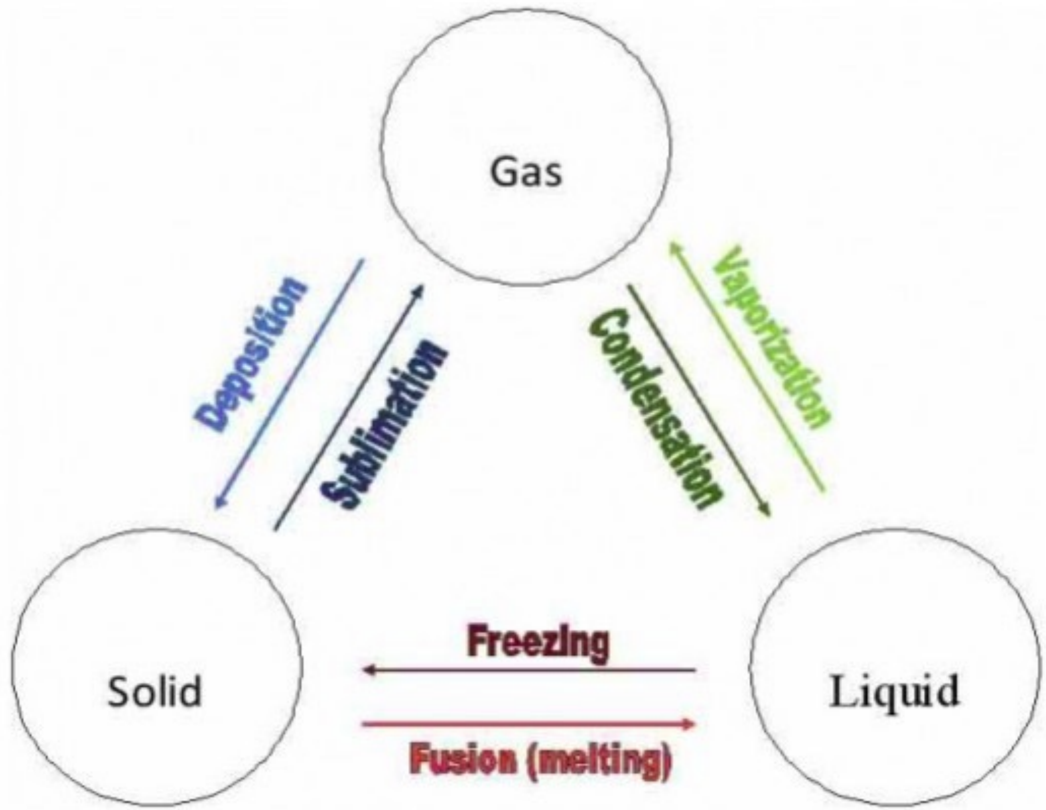
# Phase Changes

- States of matter are also referred to as *phases*.
- Matter can exist in four phases: Solid, Liquid, Gas, and Plasma
- **Phase Change**: the reversible physical change that occurs when a substance changes from one state of matter to another

# Energy and Change of State

- The *energy* of a substance is related to the *motion* of its particles.
- If energy is ADDED to a substance its particles move *faster.*
- If energy is REMOVED, its particles move *slower*.

# Phase Change Graphic

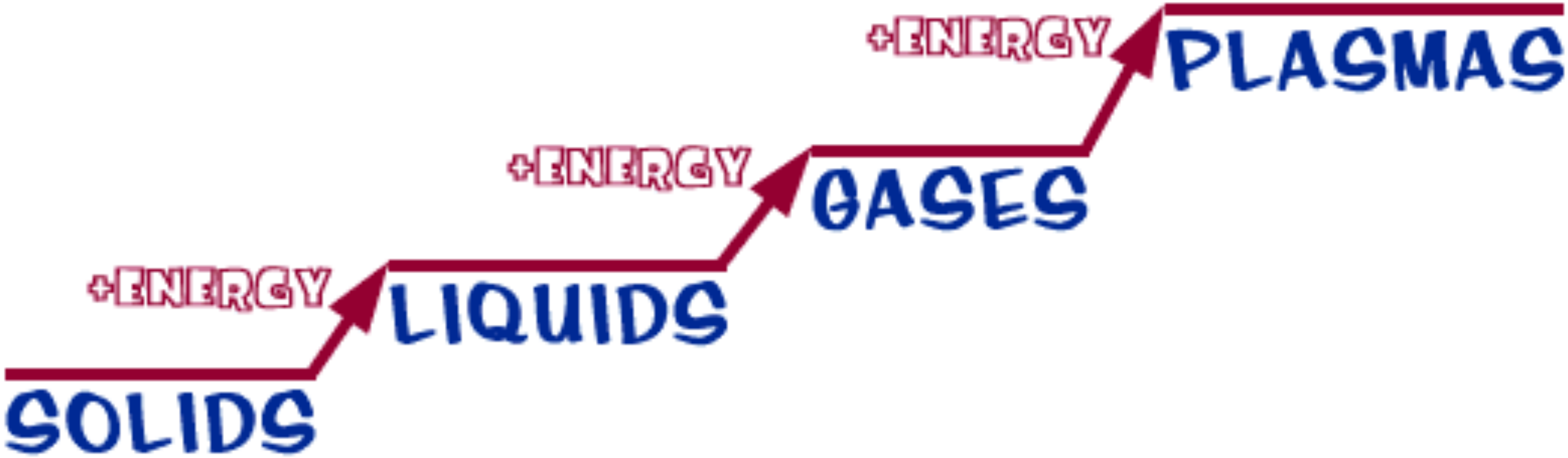


# Matter

- **Solids:** matter that has a definite shape and definite volume
- **Liquids**: Matter that has a definite volume, but no definite shape; liquids take on the shape of their container
  - Viscosity: the resistance of a liquid to flow easily
- **Gas:** Matter that has neither definite shape nor definite volume; gas fills available space in a container regardless of the size or shape of the containers
- **Plasma:** Matter that exists in a very high energy state, very rare on earth; matter in the plasma state is very high energy and therefore dangerous to humans

# Phase Changes

- Substances can be made to change by adding or taking away energy



# E. Change of state (phase change)

1. Phase changes
2. Solids and Liquid phase changes
3. Vapors phase change
4. Dependence of boiling temperature on pressure
5. Endothermic vs Exothermic
6. Molecular (kinetic) theory of liquids and gases
7. Superheated, Saturated, and Sub-cooled Conditions
8. Sensible and Latent Heat

# Phase Changes

| Description of Phase Change | Term for Phase Change | Heat Movement During Phase Change |
|---|---|---|
| Solid to liquid | Melting | Heat goes into the solid as it melts. |
| Liquid to solid | Freezing | Heat leaves the liquid as it freezes. |

# Solid – Liquid Phase Changes

- **Melting:** the change of a solid liquid

- **Melting Point:** the temperature at which a solid changes to liquid

# Liquid to Solid Phase Changes

- **Freezing:** the phase change from liquid to a solid

- **Freezing Point:** temperature at which a substance changes from liquid to solid

# E. Change of state (phase change)

1. Phase changes
2. Solids and Liquid phase changes
3. Gas and Vapors phase change
4. Dependence of boiling temperature on pressure
5. Endothermic vs Exothermic
6. Molecular (kinetic) theory of liquids and gases
7. Superheated, Saturated, and Sub-cooled Conditions
8. Sensible and Latent Heat

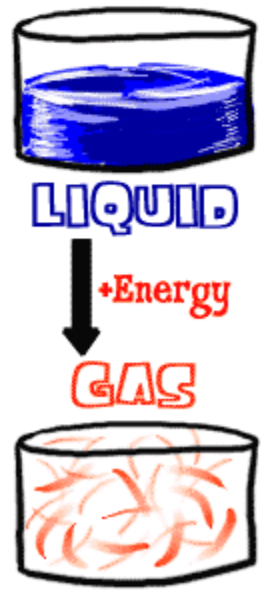
# Liquid to Gas Phase Changes

| Description of Phase Change | Term for Phase Change | Heat Movement During Phase Change |
|---|---|---|
| Liquid to gas | Vaporization, which includes boiling and evaporation | Heat goes into the liquid as it vaporizes. |
| Gas to liquid | Condensation | Heat leaves the gas as it condenses. |

# Liquid – Gas Phase Changes

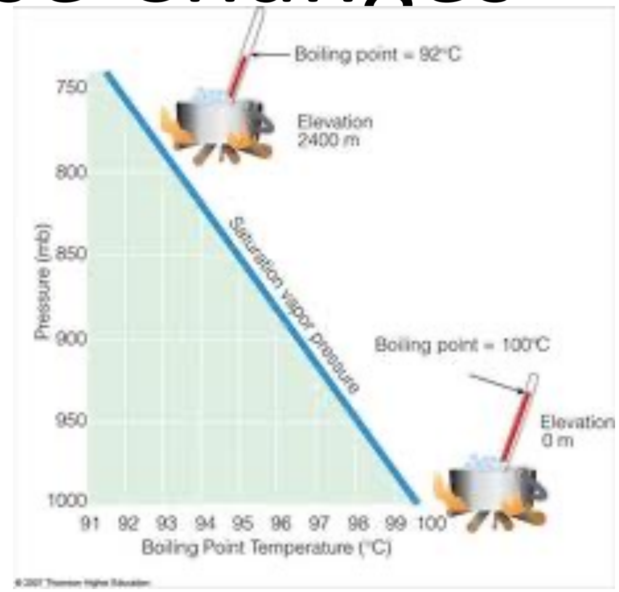
- **Vaporization:** change from liquid to gas

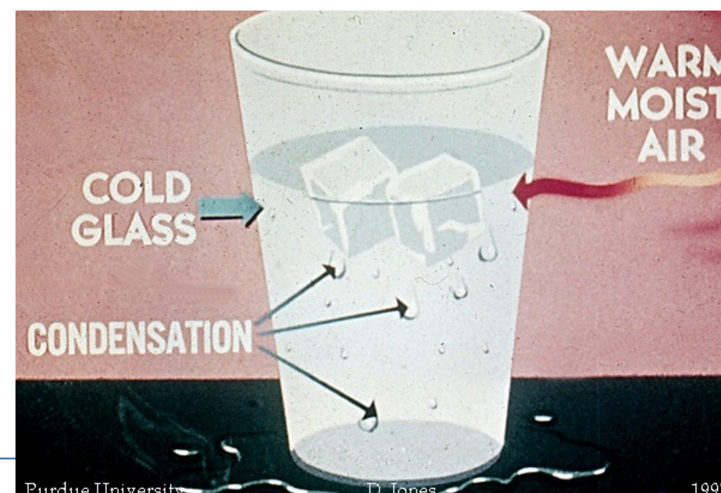
- **Evaporation:** when vaporization takes place at the surface



# Liquid – Gas Phase Changes

- **<u>Boiling</u>** - particles inside liquid changing to gas
- **<u>Boiling Point</u>** - temperature at which liquid becomes gas
- **<u>Condensation</u> -** when a substance goes from gas to liquid



# Solid Gas Phase Changes

| Description of Phase Change | Term for Phase Change | Heat Movement During Phase Change |
|---|---|---|
| Solid to Gas | Sublimation | Heat goes into the solid as it sublimates. |
| Gas to solid | Deposition | Heat leaves the gas as it deposits. |

# Solid – Gas Phases Changes

- Sublimation: a solid's surface particles escape directly into the gas phase and to not go through the liquid phase
  - For example: Dry Ice

# E. Change of state (phase change)

1. Phase changes
2. Solids and Liquid phase changes
3. Vapors phase change
4. Dependence of boiling temperature on pressure
5. Endothermic vs Exothermic
6. Molecular (kinetic) theory of liquids and gases
7. Superheated, Saturated, and Sub-cooled Conditions
8. Sensible and Latent Heat

# Temperature

- The temperature of a substance is a measure of the speed of its particles and therefore is a measure of its energy.
  - Steam has a higher temperature than liquid water, so particles in steam have more energy.
- Solid to Liquid - the particles in the liquid have **more energy** than particles in the solid
- Steam to a liquid - the particles in the liquid have **less energy** than the particles in the gas
- Liquid to a solid - the particles in the solid have **less energy** than the particles in the liquid

# E. Change of state (phase change)

1. Phase changes
2. Solids and Liquid phase changes
3. Vapors phase change
4. Dependence of boiling temperature on pressure
5. Endothermic vs Exothermic
6. Molecular (kinetic) theory of liquids and gases
7. Superheated, Saturated, and Sub-cooled Conditions
8. Sensible and Latent Heat

# Endothermic vs. Exothermic

- If energy is being added then the molecules are absorbing energy. This is called an ENDOTHERMIC PROCESS.

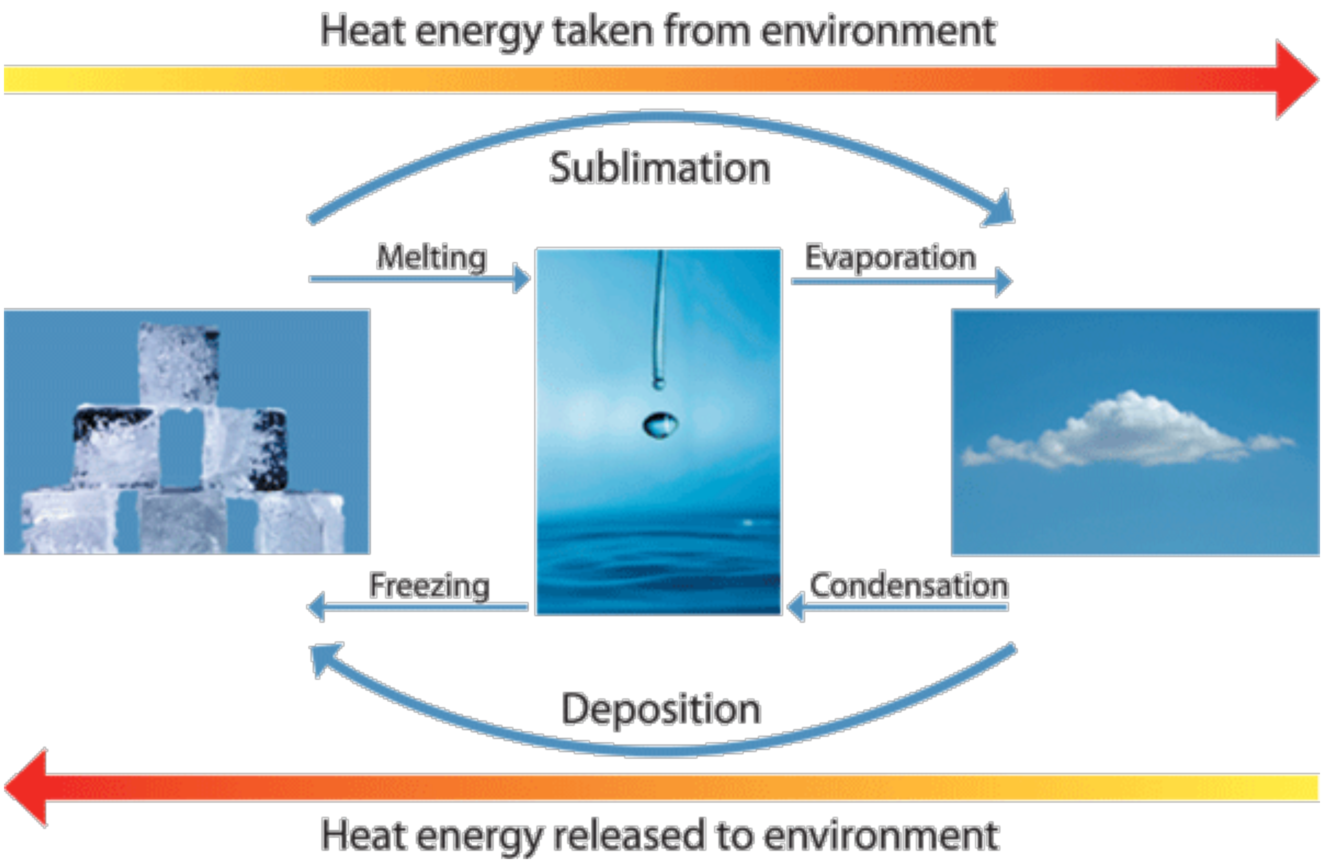
- If energy is being taken away then the molecules are losing energy. This is an EXOTHERMIC PROCESS.

# Which phase changes are Endothermic and which are Exothermic?

- Liquid to a solid - freezing
- Gas to a liquid -condensation
- Solid to a liquid - melting
- Solid to a gas – sublimation
- Liquid to a gas - vaporization

# Endothermic

Figure 7




# Exothermic

# E. Change of state (phase change)

1. Phase changes
2. Solids and Liquid phase changes
3. Vapors phase change
4. Dependence of boiling temperature on pressure
5. Endothermic vs Exothermic
6. Molecular (kinetic) theory of liquids and gases
7. Superheated, Saturated, and Sub-cooled Conditions
8. Sensible and Latent Heat

# Kinetic Molecular Theory Postulates

- All matter (solid, liquid, and gas) is made up of tiny particles called atoms, or atoms that are joined to form molecules.
- These particles are in constant motion and Molecular motion is random.
- Particles in motion possess kinetic energy and their motion increase as they gain energy.
- There is an exchange (transfer) of energy between particles (atoms and molecules) during a collision between them.
- Particles (molecules) in gases do not exert large forces on each other, unless they are in collision with each other.
- Collisions between these particles are perfectly elastic.
- Molecular motion is greatest in gases, less in liquids, and least in solids.
- Solids retain a fixed volume and shape - particles are tightly packed, usually in a regular pattern.
- Liquids assume the shape of the container which it occupies but maintain their volume - particles close together with no regular arrangement.
- Gases assumes the shape and volume of its container and will expand to fill a container of any size - particles are very well far apart with no regular arrangement.

# Average Kinetic Energy = Temperature

- Temperature is a measurement of the average kinetic energy of the particles within a substance. Meaning that temperature measures movement of particles.

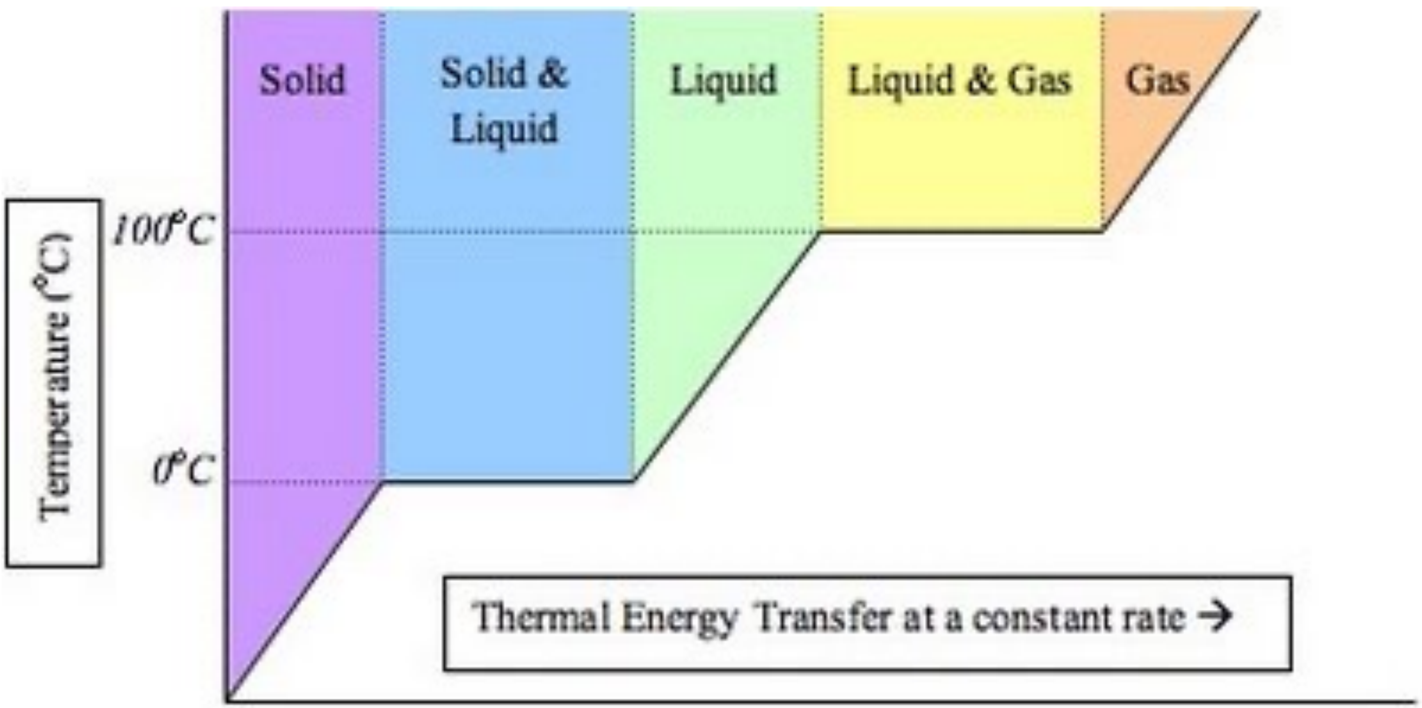
- Temperature is proportional to the average kinetic energy of the molecules of a substance. That means if you double the Kelvin temperature of a substance, you double the average kinetic energy of its molecules.

- When the average kinetic energy of the molecules goes up (a rise in temperature), the average speed of the molecules increases. A change in average kinetic energy is not directly proportional to a change in average speed.

# Kinetic Molecular Theory of Matter

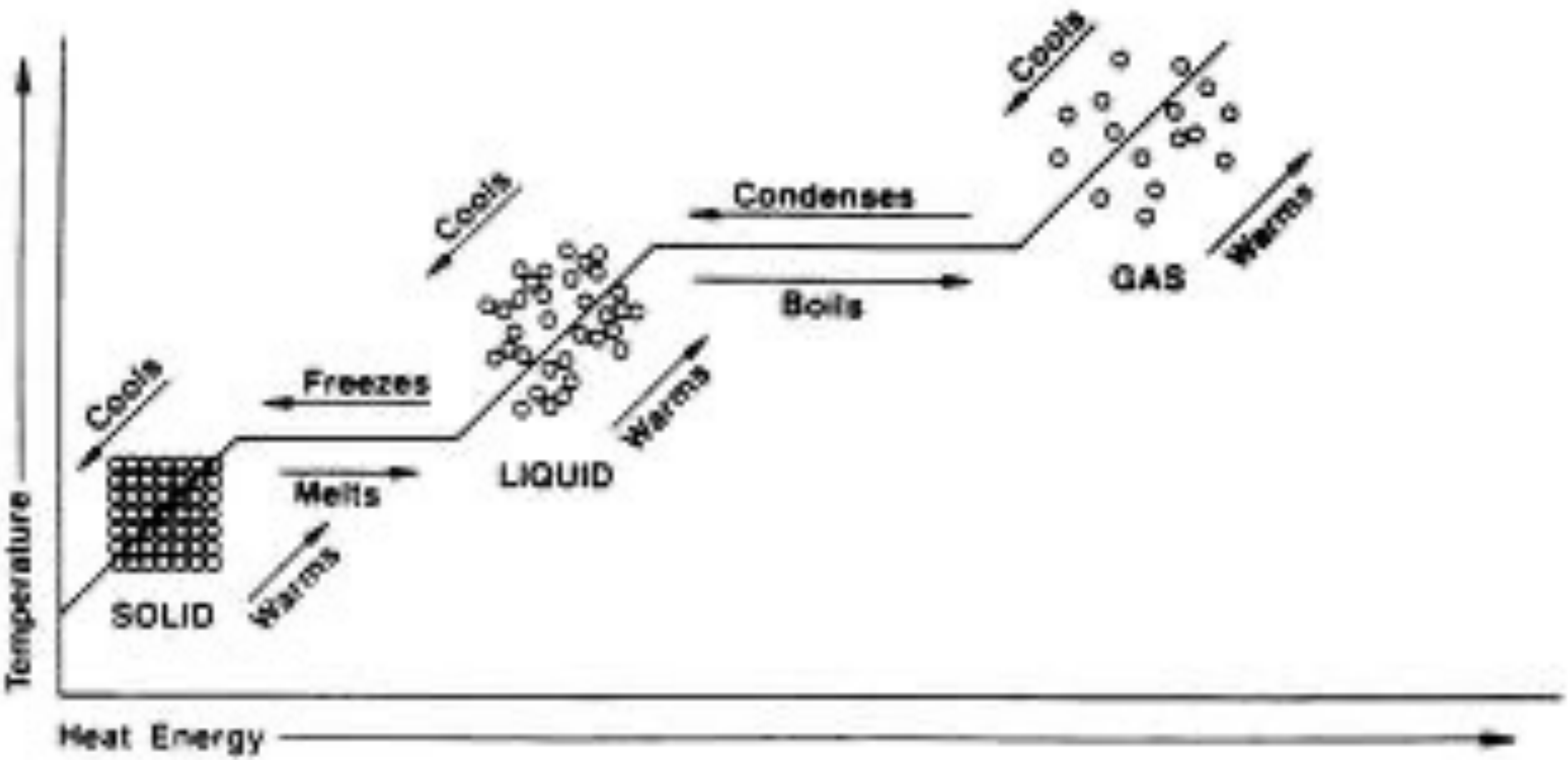
- The Kinetic Molecular Theory of Matter is a concept that basically states that atoms and molecules possess an energy of motion (kinetic energy) that we perceive as temperature.
- In other words, atoms and molecules are constantly in motion , and we measure the energy of these movements as the temperature of that substance.
- This means if there is an increase in temperature, the atoms and molecules will gain more energy (kinetic energy) and move even faster.

# Using Temperature to Indicate Phase Change




- Whenever there is a plateau there is a phase change.
- This means that there is two phases of the substance at the same time.

# Water Phase Change Graph



# E. Change of state (phase change)

1. Phase changes
2. Solids and Liquid phase changes
3. Vapors phase change
4. Dependence of boiling temperature on pressure
5. Endothermic vs Exothermic
6. Molecular (kinetic) theory of liquids and gases
7. Superheated, Saturated, and Sub-cooled Conditions
8. Sensible and Latent Heat

# Superheated, Saturated, and Sub-cooled Conditions

- Superheat is any temperature of a gas above the boiling point for that liquid.
- Saturation is simply the term used to describe the point where a change of state in a substance is taking place.
- Sub-cooling only applied to solids and liquids. It is any temperature of a liquid or solid below its saturation temperature.

# Examples of Superheated, Saturated, and Sub-cooled Conditions

- **Superheated:** water boils at 212°F. As the water boils it changes states and as long as the water is boiling the temp remains the same. After all the water has turned into vapor, adding heat will increase the temperature of the stream above 212°F. Any increase in temperature above its boiling point is called "superheat." Steam at 213°F is superheated by 1 degree.
- **Saturation** is used to describe the point where a change of state is taking place. For water, that would be at 212°F.
- **Sub-cooling** is any temperature of a liquid or solid below its saturation temperature. Water at 211°F has been sub-cooled by 1 degree. Coffee that is 180°F has been sub-cooled by 32 degrees.

# E. Change of state (phase change)

1. Phase changes
2. Solids and Liquid phase changes
3. Vapors phase change
4. Dependence of boiling temperature on pressure
5. Endothermic vs Exothermic
6. Molecular (kinetic) theory of liquids and gases
7. Superheated, Saturated, and Sub-cooled Conditions
8. Sensible and Latent Heat

# Sensible Heat and Latent Heat

- Sensible Heat is heat that can be measured by a thermometer.
  - Since both Superheat and Sub-cooling are changes in temperature, they are both sensible heat processes.
- Latent Heat is the heat that is added to a liquid that causes it to change from liquid to gas without a change in temperature.
  - For example, as long as water is boiling and not completely changed to gas, the temperature remains at 212$^{\circ}$F. That is called "latent" heat – even though we add heat to keep the water boiling, the heat does not register as an increase on the thermostat during the boiling process.

# BEST Center Curricula, Resources & Recordings

Academic Programs
Georgia Piedmont Technical College - Building Automation Systems
Milwaukee Area Technical College - Sustainable Facilities Operations
Laney College - Commercial HVAC Systems
City College San Francisco - Commercial Building Energy Analysis & Audits

Professional Development Materials, Presentations & Videos
National Institutes
Building Automation Systems Instructor Workshops
Webinars (e.g., BEST Talks)

Faculty Profile Videos
Reports & Case Studies
Marketing Resources



BEST
Building Efficiency for a Sustainable Tomorrow

National Science Foundation