# CHAPTER 15: HEAT, TEMPERATURE,AND EXPANSION 01/15/19

- What makes something warm or cold? How much motion the molecules have.
- What type of motion? The average translational kinetic energy (moving from one place to another) per molecule.
    - Not the total internal energy
    - Not the total internal kinetic energy
    - Not the rotational or vibrational kinetic energy that doesn't cause molecules to "go anywhere"

**TEMPERATURE**

- Temperature is the quantity that tells us how warm or cold something is. It is the average translational kinetic energy per molecule.
- With few exceptions, when the temperature of an object is raised, its molecules move faster and farther apart on average – the object expands. When the object cools, it contracts.
    - This is how a thermometer works. When the liquid in the glass tube heats up or cools down, it expands or contracts causing it to move further up or lower down in the tube.
- Temperature scales
    - Celsius: 0-100 degrees, water freezing-boiling, geared to math
    - Fahrenheit: 32-212 degrees, freeze-boil, geared to humans
    - Kelvin: 273-373 Kelvins, freeze-boil, geared to nature (absolute zero)
- Most thermometers always display their own temperature (not digital thermometers). When in contact with something we want to measure (e.g. the air), energy flows between them until they are in thermal equilibrium (the same temperature). It is the temperature of the liquid in the thermometer that is being measured on the scale.

**HEAT**

- Heat is the flow of energy due to temperature differences. Objects do not contain heat; heat is energy in transit from a body of higher temperature to one of lower temperature. The direction of spontaneous heat flow is always from hot to cold.
- Temperature and heat are different: the ratio and total amount of energy are different.
    - CHECK QUESTIONS
        - Why are you not injured by sparks from a 2000ºC sparkler?
        - If I drop a hot coal into the Atlantic Ocean, does heat flow from the coal to the ocean or from the ocean to the coal? Why? Which has more kinetic energy? Which has higher average kinetic energy (temperature)?
- Temperature is somewhat similar to liquid pressure. The direction of heat flow is from high to low temp (liquid flow is from high to low pressure). The total amount of heat flow depends on how much total internal energy is available (amount of liquid flow depends on how much liquid is available).

## SPECIFIC HEAT CAPACITY

- CHECK QUESTION: Some foods hold their temperature more than others. Can you give examples of some that hold their temperature well and not so well?
- Some materials are easier to heat and cool than others.
- Specific heat capacity of a substance is defined as the quantity of heat required to change the temperature of a unit mass of the substance by 1 degree.
    - Something that absorbs a lot of heat for a given temperature change has high specific heat capacity.
        - It takes 8 times more energy to raise 1 g of water 1 degree than it does to raise 1 g of iron 1 degree.
- Specific heat capacity is also the capacity for storing internal energy.
    - Water takes more energy to heat than the land next to it and it cools much slower than the land as well. That's why areas surrounded by water do not have extreme temperature fluctuations. The stability of the water's temperature moderates the climate.
    - West coast – East coast difference

## THERMAL EXPANSION

- Most substances expand when heated and contract when cooled due to the molecule moving faster and farther apart.
- Usually the change in size is a very small fraction of the size of the object, but it can be noticeable.
    - Steel expands 1 part in 100,000 for every 1ºC change.
    - DEMO: ring and hoop
    - Telephone wires sag
    - Metal lid on a glass jar
    - Joints in roadways, bridges.
    - Tooth fillings,
    - Railroad tracks.
- Different substances expand at different rates. Put two different metals with different expansion rates together and you have a bimetallic strip.
    - DEMO: bimetallic strip
    - CHECK QUESTION: what will happen to the strip and why?
        - This is how a thermostat works.

## EXPANSION OF WATER

- CHECK QUESTION: What is the temperature at the bottom of Lake Michigan right now? Lake Tahoe on Jan 1, 1901? Etc.: 4ºC.
- Ice cold water contracts when the temperature is increased until it reaches 4ºC, at which point it will expand with further temperature increases. Its greatest density is at 4ºC.
    - FIG: 15.21
- This happens because microscopic ice crystals are present in ice cold water, and ice crystals have a lot of open space – lower density. As the water is heated from 0ºC to 4ºC, the ice crystals start to collapse and become more dense water. But

the liquid water is expanding during that time as well. By 4ºC, the small number of ice crystals is overwhelmed by the expansion of the liquid, and water starts expanding rather than contracting.

    - FIG: 15.18, 15.19

- Go through cooling of a pond from 10ºC to 0ºC

## CHAPTER 16: HEAT TRANSFER 01/15/19

Heat transfers from warmer things to cooler things in three ways:

- Conduction
- Convection
- Radiation

**CONDUCTION**

- CHECK QUESTION: Why do pots and pans have wooden or plastic handles?
- DEMO: heat nail in a flame
    - How does heat transfer from one end of the nail to the other?
- The fire causes atoms at the heated end to move more rapidly, causing the atoms and free electrons to collide with their neighbors, which bump into their neighbors until increased motion has been transferred to atoms in the entire object. This heating by electron and atomic collisions is called ***conduction***.
- How well a solid conducts heat depends on the atomic and electron binding. Materials with "loose" outer electrons that are free to move conduct well.
    - Metals have the loosest electrons and are excellent heat and electricity *conductors*.
    - Wood, paper, cork, glass, Styrofoam have tight electrons and are poor conductors, or good *insulators*.
        - DEMO: flame on paper wrapped around metal bar
        - Wood pot handles are safe to hold briefly even when hot.
        - Most liquids and gases are poor conductors (snow, fiberglass insulation, thermal underwear)

**CONVECTION**

- Heat transfer by the actual motion of fluids is called ***convection***. Liquids and gases transmit heat mainly by convection, which involves the overall motion of mass from one place to another.
- In convection, a volume of fluid gets heated up and expands becoming less dense. The less dense mass of fluid is buoyed up, and denser, cooler fluid moves in to take its place. i.e. warm air (water) rises, and cool air (water) sinks.
    - DEMO: ice and water in a test tube.
    - As the warm air rises, it expands more because the atmospheric pressure is less at higher altitudes. As the air expands it cools.
        - DEMO: blowing on your hand with open mouth and pursed lips
        - Ping-pong ball explanation: average speed of atoms decreases
- Uneven heating of the Earth's surface results in convection currents, or winds.
    - Seashore winds: sea breeze during the day, land breeze at night

**RADIATION**

- How does heat from the sun warm us? It is not through conduction because air is a poor conductor. Convection occurs from the atmosphere being heated by the Earth, not the sun. Neither conduction nor convection can occur in space (no mass). The heat energy is transmitted by the ***radiation*** of electromagnetic waves.

- DEMO: hand in front of a light bulb
- Electromagnetic waves include radio, microwave, infrared, visible light, ultraviolet, X-rays, and gamma-rays, listed in order from longest to shortest wavelength.
- The shorter the wavelength, the higher the frequency, or rate of vibration.
  - DEMO: waves on a spring

- Emission of radiation; all substances at any temperature emit radiation. The peak frequency of the radiation is directly proportional to the absolute temperature (Kelvin scale) of the emitter: $f \alpha T$.
  - The sun has a relatively high temperature and emits relatively high frequency radiation (most of it visible light). The Earth is much cooler and emits much lower frequency radiation (infrared), which we can't see.
  - Earth's interior is heated by radioactivity (uranium, etc.). This heat is conducted to the surface (which is also warmed by absorbing the sun's radiation) and then radiated into the atmosphere and space.
  - Infrared radiation is called heat radiation because our skin happens to absorb infrared waves very well. Coals, light bulbs, the sun all emit infrared and we feel their warmth.
- Absorption of radiation: things that emit radiation don't run out of energy because they also absorb radiation. Good emitters are good absorbers, poor emitters are poor absorbers.
  - DEMO: black vs. silver containers of hot/cold water
- Reflection of radiation: good absorbers don't reflect radiation well – they look dark or black.
  - Good reflectors are poor absorbers (and emitters). Clean snow does not melt quickly in sunlight. Light colored buildings are cool in summer and warm in winter.
- Greenhouse effect: The atmosphere is transparent to high frequency (e.g. visible light) radiation. This radiation is absorbed by the Earth, which heats up. The Earth reradiates at lower frequency (infrared) because it is cooler than the sun. Gases such as water vapor and carbon dioxide absorb infrared radiation very well and reradiate it back to Earth. So this energy doesn't escape back to space, and the Earth warms up. Without the Greenhouse effect, the Earth would be -18ºC! The concern is whether too much excess carbon dioxide and other greenhouse gases are causing the Earth to warm up too much.
  - FIG: 16.21

**THERMOS BOTTLE:** FIG: 16.27

- How does a thermos bottle (or vacuum bottle) inhibit heat transfer?
  - Conduction is inhibited because there is no conduction through the vacuum, and conduction through the glass walls and plastic stopper is slow since both are poor conductors.
  - Convection is inhibited because it can not take place in a vacuum, and the stopper prevents convection through the top.
  - Radiation is inhibited because the silvered inner walls are good reflectors and thus poor absorbers and emitters of radiation.

## CHAPTER 19: VIBRATIONS AND WAVES 01/16/19

A ***vibration*** is a wiggle in time.
A ***wave*** is a wiggle in space and time. A wave extends from one place to another.
DEMO: chalk line vibrations and waves

**VIBRATION OF A PENDULUM**

- DEMO: pendulum
- Time for one to-and-fro swing, or vibration, is called the **period,** *T*.

**WAVE DESCRIPTION**

- Frequency, *f*: how frequently a wave vibration occurs. How many vibrations occur in a given time (e.g. per second). Frequency is measured in units called hertz (Hz), which is one vibration per second.
    - Frequency = 1/Period
- Amplitude: the distance from the midpoint of the wave (or vibration) to the crest or trough. The maximum displacement from equilibrium.
- Wavelength, $\lambda$: the distance from crest to crest (or trough to trough, or between any successive identical parts of the wave).

**WAVE SPEED**

- What is transported from one place to another by a wave is a disturbance in the medium, not the material of the medium itself. In other words, energy is transported by the wave. The speed at which the disturbance travels is related to the frequency and wavelength of the wave.
    - DEMO: wave machine
    - Wave speed = frequency × wavelength = $f\,\lambda = f\,/\,T$
    - Example: freight car question, pg. 363
    - Example: water waves, Problem 36
    - Example: FM wavelengths, Problem 5

**TRANSVERSE AND LONGITUDINAL WAVES**

- DEMO: waves on a spring
    - Transverse: disturbance moves at right angles, or transverse, to the wave speed direction.
    - Longitudinal: disturbance (compression and rarefaction) moves in same direction as the wave speed direction.

**INTERFERENCE**

- Two or more material objects cannot share the same space at the same time. Two or more waves can exist in the same time and place. The waves overlap to form an **interference** pattern, within which wave effects can be increased, decreased, or neutralized.
    - FIG: 19.10
    - The separate displacements of each wave add at each point. This is called the *superposition principle*.

- *Constructive interference*: when crests overlap crests, producing a wave of increased amplitude.
- *Destructive interference*: when crests overlap troughs, producing a wave of decreased amplitude (possibly zero amplitude, or cancellation).

- **Standing waves**: Two waves of equal frequency and wavelength passing through each other in opposite directions (such as a wave reflecting upon itself) that create stable regions of constructive and destructive interference.
  - Nodes: stationary regions of minimal or zero displacement.
  - Antinodes: regions of maximum displacement, halfway between nodes.
  - Standing waves produced in strings of musical instruments, in the air of an organ pipe, flute, etc.
  - DEMO: standing transverse waves in a spring
  - DEMO: standing longitudinal waves on a longitudinal wave machine

**DOPPLER EFFECT**

- The change in frequency of a wave due to the motion of the source is called the Doppler Effect.
  - An observer in front of the source's motion sees waves coming more often than if the source was stationary, and thus measures a higher frequency. This is because each successive wave has a shorter distance to travel to the observer, and thus gets there in a shorter amount of time since the wave speed in the medium doesn't change.
  - An observer behind the source's motion sees waves coming less often than if the source was stationary, and thus measures a lower frequency. This is because each successive wave has a longer distance to travel to the observer, and thus gets there in a longer amount of time since the wave speed in the medium doesn't change.
  - FIG: 19.15, 19.16
- This is what happens when you hear the pitch of a car horn or train whistle change as it passes you. The pitch is higher (higher frequency) as it approaches, and then lower pitch (lower frequency) when it recedes from you.

**SHOCK WAVE**

- When a source of waves outruns the waves it produces, a wave pattern is produced behind the source that overlaps at the expanding edges, which are a region of large constructive interference. In water, the edges are V-shaped and called a **bow wave**. Example: the wake of a speed boat.
  - FIG: 19.18, 19.19
- A supersonic aircraft makes a similar 3-dimensional shock wave, produced by overlapping spheres that form a cone. The shell of this cone is a region of constructive interference with highly compressed air that sweeps behind the aircraft. When the cone reaches a listener, they hear a loud, sharp crack called a **sonic boom**.
  - FIG: 19.24, 19.25

# CHAPTER 20: SOUND 01/16/19

**ORIGIN OF SOUND**

- Sound is produced by vibrations and is a form of energy.
    - DEMO: tuning fork in water
    - Usually the original vibration stimulates the vibration of something else.
        - Piano string stimulates the vibration of sounding board.
        - Vocal cords stimulate vibration of air in the throat.
- Sound is transmitted in the form of longitudinal waves.
- Frequency corresponds to pitch (e.g. high pitched sounds have high frequency vibrations).
- Young person's hearing range is about 20-20,000 hertz
    - DEMO: sound generator

**NATURE OF SOUND**

- Longitudinal sound waves in air are composed of alternating zones of compressed and rarefied air traveling at the same speed.
    - FIG: 20.2
- Sound must have a material medium to be transmitted through.
    - Actual material must be compressed and rarefied.
    - The material must be elastic (i.e. .have the ability to change shape in response to a force, and then return to its initial shape once the force is removed). It can be solid, liquid, or gas (e.g. steel, water, air).
    - Sound is generally fastest in solids, then liquids, and slowest in gases.
        - 15 times faster in steel than in air, 4 times faster in water than air.
    - Inelastic materials do not transmit sound (e.g. putty).
    - A vacuum cannot transmit sound.
- Speed of sound in air depends on wind, temperature, and humidity. It does not depend on frequency or loudness.
    - Speed is 330 m/s in 0ºC dry air.
    - Speed is faster in more humid air, faster in warmer air.
    - To estimate distance in kilometers to lightning, divide the number of seconds for the sound delay by three.

**REFLECTION OF SOUND**

- Sound reflects from a smooth surface just like light – the angle of incidence equals the angle of reflection.
    - Reflection of sound is called an *echo*. Multiple reflections are called *reverberations*.
- The fraction of sound energy carried by the reflected sound wave is greater if the surface is rigid and smooth, less if soft and irregular. Sound energy not carried by the reflected wave is absorbed by the surface.
- Echoes, shower reverberations, concert hall acoustics, ultrasound, bats, dolphins

**FORCED VIBRATIONS**

- Forced vibration is setting up vibrations in one object with vibrations from another. Sound can be made louder by forcing vibrations in a larger object that can set more air in motion with its own vibrations (but the sound will not last as long due to conservation of energy!).
    - Sounding boards of instruments
    - DEMO: tuning fork on a table

**NATURAL FREQUENCY**

- Every object produces its own special sound when it is made to vibrate. This is because different objects vibrate differently. Every object when disturbed vibrates at its own special set of frequencies which produces its special sound.
    - An object's special set of vibration frequencies are called its *natural frequencies*, which depend on the object's elasticity, size, and shape.

**RESONANCE**

- When the frequency of forced vibrations matches an object's natural frequency, a dramatic increase in amplitude occurs. This is called *resonance*.
    - DEMO: tuning forks
    - DEMO: swings (pendulum bob)
    - Troops marching across a bridge (Manchester, 1831)
    - VIDEO: Tacoma Narrows Bridge (1940)

**INTERFERENCE**

- Like any waves, two or more sound waves can exhibit interference.
    - FIG: 20.17
    - DEMO: two speakers
    - Waves producing constructive interference are *in phase*.
    - Waves producing destructive interference are *out of phase*.
- Concert hall acoustics
- Anti-noise technology: noisy devices can be equipped with microphones and electronics that can receive the noisy sound, generate a mirror-image sound wave pattern and send it out through speakers to interfere with the original sound. The mirror-image (opposite) wave cancels the original noise.

**BEATS**

- When two tones (sound waves) of slightly different frequency are sounded together, the combined sound has a fluctuation in loudness due to alternating constructive and destructive interference.
    - Vibrations are momentarily in phase, then out of phase, then in phase, etc.
    - The periodic variation in loudness (amplitude) is called *beats*.
- The frequency of beats is equal to the difference between the two individual tone frequencies. The combined sound has a frequency equal to the average of the two individual frequencies. (e.g. 256 Hz and 258 Hz tones sounded together produce a 257 Hz sound which beats at 2 Hz).
    - DEMO: tuning forks