This lecture will help you understand:

- Temperature
- Absolute Zero
- Heat
- Quantity of Heat
- The Laws of Thermodynamics
- Entropy
- Specific Heat Capacity
- Thermal Expansion
- Expansion of Water
Temperature

Temperature
• A number that corresponds to the warmth or coldness of an object
• Measured by a thermometer
• A per-particle property
• No upper limit
• Definite limit on lower end
Temperature

Temperature is proportional to the average translational kinetic energy per particle in a substance.

- Gas—how fast the gas particles are bouncing to and fro
- Liquid—how fast particles slide and jiggle past one another
- Solid—how fast particles move as they vibrate and jiggle in place
Temperature

Thermometer

• Measures temperature by expansion or contraction of a liquid (mercury or colored alcohol)

• Reading occurs when the thermometer and the object reach thermal equilibrium (having the same average kinetic energy per particle)

• Infrared thermometers operate by sensing IR radiation
Temperature

Temperature Scale

- Celsius scale named after Anders Celsius (1701–1744)
  - zero °C for freezing point of water to 100°C for boiling point of water
- Fahrenheit scale named after G. D. Fahrenheit (1686–1736)
  - 32°F for freezing point of water to 212°F for boiling point of water
- Kelvin scale named after Lord Kelvin (1824–1907)
  - 273 K for freezing point of water to 373 K for boiling point of water
  - Absolute zero at -273°C
  - Same size degrees as Celsius scale
  - Kelvins, rather than degrees are used
Theory of Temperature

Kinetic Theory of Matter:
Matter is made up of tiny particles (atoms or molecules) that are always in motion.

Thermal Energy:
The total energy (kinetic and potential) of the submicroscopic particles that make up matter.
There is twice as much molecular kinetic energy in 2 liters of boiling water as in 1 liter of boiling water. Which will be the same for both?

A. Temperature.
B. Thermal energy.
C. Both of the above.
D. None of the above.
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Explanation:
Average kinetic energy of molecules is the same, which means temperature is the same for both.
Absolute zero, or zero K, is the lowest limit of temperature at \(-273^\circ\text{C}\). At this temperature, atoms or molecules have lost all available kinetic energy. A substance cannot get any colder.
Absolute Zero

Absolute zero or zero K

• is lowest limit of temperature at -273°C.
• atoms or molecules have lost all available kinetic energy.
• substance at this temperature cannot get any colder.
Absolute Zero

As temperature of a gas changes, volume of a gas changes.

- at 0°C with pressure constant, volume changes by $\frac{1}{273}$ for each degree Celsius

Absolute Zero or Zero K

- lowest limit of temperature
- molecules have lost all available kinetic energy
Thermal Energy

Thermal energy in a sparkler

- Temperature of sparks very high (2000°C)
- Lot of energy per molecule of spark
- Total energy is small due to relatively few molecules per spark
- Low transfer of energy
What Is Heat?

Heat

• defined as a flow of thermal energy due to a temperature difference.
• natural direction of heat flow is from a higher-temperature substance to a lower-temperature substance.
Heat

- 1 liter of water in left pot. 3 liters in right pot.
- both pots absorb the same quantity of heat
- temperature increases three times as much in the pot with the smaller amount of water.

![Diagram of two pots with a thermometer showing different temperature readings]
When the same amount of heat is added to each of the two containers of water, the temperature increase in each will

A. be the same.
B. depend on the amount of water in each.
C. be greater for the container with the most water.
D. be less for the container with the smaller amount of water.
When the same amount of heat is added to each of the two containers of water, the temperature increase in each will

A. be the same.
B. **depend on the amount of water in each.**
C. be greater for the container with the most water.
D. be less for the container with the smaller amount of water.

*Comment:*
Later, we’ll learn that when heat is added to boiling water, temperature won’t increase at all!
Quantity of Heat

Heat is energy in transit, measured in units of energy — joules or calories.

calorie

defined as the amount of heat needed to raise the temperature of 1 gram of water by 1 Celsius degree.

4.18 joules = 1 calorie

so 4.18 joules of heat will change that temperature of 1 gram of water by 1 Celsius degree.
Quantity of Heat

Energy rating of food or fuel

- measured by energy released when they are metabolized

Kilocalorie

- heat unit in labeling food
- One kilocalorie or Calorie (with a capital C) is the heat needed to change the temperature of 1 kilogram of water by 1 degree Celsius.
Quantity of Heat (summarized)

- Heat is energy in transit.
- Heat is measured in joules, calories, or Calories.
- 1 food Calorie equals 1000 calories. To the weight watcher, the peanut contains 10 Calories.
- To the scientist, the peanut releases 10,000 calories. (41,800 joules) of energy when burned or digested.
The quantity of heat needed to raise the temperature of a certain substance a specific amount is 1 Calorie. This is the same amount of energy as

A. 1000 calories.
B. 4.18 joules.
C. Both of these.
D. Neither of these.
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A. 1000 calories.
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You heat a half-cup of tea and its temperature rises by 8°C. How much will the temperature rise if you add the same amount of heat to a full cup of tea?

A. 0°C.
B. 2°C.
C. 4°C.
D. 8°C.
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B. 2°C.
C. 4°C.
D. 8°C.
The Laws of Thermodynamics

Thermodynamics

• movement of heat

First law of thermodynamics

• When heat flows to or from a system, the system gains or loses an amount of heat equal to the amount of heat transferred.

more specifically,

heat added = increase internal energy + external work done by the system

• Energy can neither be created nor destroyed.
The Laws of Thermodynamics

Second law of thermodynamics
• Restates direction of heat flow:
  **Heat never spontaneously flows from a cold substance to a hot substance**

Examples:
  – in summer, heat flows from the hot air outside into the cooler interior of a dwelling
  – in winter, heat flows from the warm inside to the cold exterior

• Heat can flow from cold to hot only when work is done on the system or by adding energy from another source (as in heat pumps and air conditioners, where the direction of heat flow isn’t spontaneous)
The Laws of Thermodynamics

Third Law of Thermodynamics:

No system can reach absolute zero.
When work is done on a system, compressing air in a tire pump for example, the temperature of the system

A. increases.
B. decreases.
C. remains unchanged.
D. is no longer evident.
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A. increases.
B. decreases.
C. remains unchanged.
D. is no longer evident.

Explanation:
In accord with the first law of thermodynamics, work input increases the energy of the system.
When a hot cup is filled with cold water, the direction of heat flow is

A. from the cup to the water.
B. from the water to the cup.
C. random, in no particular direction.
D. nonexistent.
When a hot cup is filled with cold water, the direction of heat flow is

A. from the cup to the water.
B. from the water to the cup.
C. random, in no particular direction.
D. nonexistent.

Explanation:
The second law of thermodynamics tells us that the direction of unassisted heat flow is from hot to cold. (If assisted with energy input, as with an air conditioner for example, then heat can flow from cold to hot.)
Entropy

Entropy

is a measure of the disorder of a system.

Whenever energy freely transforms from one form to another, the direction of transformation is toward a state of greater disorder and, therefore, toward one of greater entropy.

The greater the disorder $\Rightarrow$ the higher the entropy.
Entropy

Second law of thermodynamics — restatement:

Natural systems tend to disperse from concentrated and organized-energy states toward diffuse and disorganized states.

Energy tends to degrade and disperse with time. The total amount of entropy in any system tends to increase with time.
Your garage gets messier each week. In this case, the entropy of your garage is

A. increasing.
B. decreasing.
C. hanging steady.
D. nonexistent.
Your garage gets messier each week. In this case, the entropy of your garage is

A. increasing.
B. decreasing.
C. hanging steady.
D. nonexistent.

*Comment:*
If your garage became more organized each week, then entropy would decrease in proportion to the effort expended.
Specific Heat Capacity

Specific heat capacity

is defined as the quantity of heat required to change the temperature of 1 unit mass of a substance by 1 degree.

- thermal inertia that indicates the resistance of a substance to a change in temperature.
- sometimes simply called specific heat.
Specific Heat Capacity

Substances have their own specific heat capacities.

*Example*: Filling in a hot apple pie has a greater specific heat capacity than the crust. Watery filling has more capacity for storing heat than pie crust.
Specific Heat Capacity

The high specific heat capacity of water

• Has higher capacity for storing energy than almost any other substance

• Involves various ways that energy can be absorbed
  – increase the jiggling motion of molecules, which raises the temperature
  – increase the amount of internal vibration or rotation within the molecules, which becomes potential energy and doesn’t raise temperature
  – then water molecules can absorb energy without increasing translational kinetic energy
Specific Heat Capacity

- Specific heat affects climate
  - for Europeans, in addition to warm jet streams in the atmosphere, current in the Atlantic Ocean carries warm water northeast from the Caribbean regions and retains much of its internal energy long enough to reach the North Atlantic Ocean. Energy released is carried by westerly winds over the European continent.
Which has the higher specific heat, water or land?

A. Water.
B. Land.
C. Both of the above are the same.
D. None of the above.
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A. Water.
B. Land.
C. Both of the above are the same.
D. None of the above.

*Explanation:*
A substance with small temperature changes for large heat changes has a high specific heat capacity. Water takes much longer to heat up in the sunshine than does land. This difference is a major influence on climate.
Thermal Expansion

Thermal expansion

- Due to rise in temperature of a substance; molecules jiggle faster and move farther apart
- Most substances expand when heated, and contract when cooled

Examples:
- railroad tracks closely laid on winter days expand and buckle in hot summer
- warming metal lids on glass jars under hot water loosens the lid by greater expansion of the lid than the jar
Thermal Expansion Application

- The extreme heat of a summer day cause the buckling of these railroad tracks.
- This gap in the roadway of a bridge is called an expansion joint; it allows the bridge to expand and contract.
When stringing telephone lines between poles in the summer, it is advisable to allow the lines to

A. sag.
B. be taut.
C. be close to the ground.
D. allow ample space for birds.
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A. sag.
B. be taut.
C. be close to the ground.
D. allow ample space for birds.

*Explanation:*
Telephone lines are longer in a warm summer and shorter in a cold winter. Hence, they sag more on hot summer days than in winter. If the lines are not strung with enough sag in summer, they might contract too much and snap during the winter—especially when carrying ice.
Ellyn heats a metal ring that has the same inner diameter as the diameter of the metal ball. When the ring is hot, the room-temperature ball

A. fits into the hole as before.
B. no longer fits into the hole.
C. fits into the hole with more room to spare.
D. None of these.
Ellyn heats a metal ring that has the same inner diameter as the diameter of the metal ball. When the ring is hot, the room-temperature ball

A. fits into the hole as before.
B. no longer fits into the hole.
C. **fits into the hole with more room to spare.**
D. None of these.

*Explanation:*
When the ring is heated, ALL parts expand. This means expansion of the inner and outer circumference, inner and outer diameter, width, you name it! The hole expands just as if it were solid metal. How about that!
Expansion of Metal

- Bimetallic strip (brass and iron welded together).
- When the strip is heated, brass expands more than iron.
- When cooled, brass contracts more than iron.
- Due to this behavior, the strip bends as shown.
Expansion of Metal Application

- A thermostat
- When the bimetallic coil expands, the ball of liquid mercury rolls away from the electrical contacts and breaks the electrical circuit.
- When the coil contracts, the circuit is complete.
Expansion of Water

Water expands when it turns to ice. Ice has open-structured crystals resulting from strong bonds at certain angles that increase its volume. This make ice less dense than water.
Expansion of Water

Water between 0°C and 4°C
- does not expand with temperature
- as temperature of 0°C water rises, contraction occurs due to melting of ice crystals in water
- contraction of water continues until 4°C

Water at 4°C
- smallest volume and greatest density

When 0°C water freezes to become ice
- largest volume and lowest density.
Expansion of Water

Volume changes for a 1-gram sample of water.

1. Liquid water below 4°C is bloated with ice crystals.
2. Upon warming, the crystals collapse, resulting in a smaller volume for the liquid water.
3. Above 4°C, liquid water expands as it is heated because of greater molecular motion.
When a sample of 0°C water is heated, it first

A. expands.
B. contracts.
C. remains unchanged.
D. not enough information.
When a sample of 0°C water is heated, it first

A. expands.
B. **contracts**.
C. remains unchanged.
D. not enough information.

*Explanation:*
Ice water contracts due to the melting of microscopic slush crystals. Water continues to contract until it reaches a temperature of 4°C. With further increase in temperature beyond 4°C, water then expands.
When a sample of 4°C water is cooled, it

A. expands.
B. contracts.
C. remains unchanged.
D. not enough information.
When a sample of 4°C water is cooled, it

A. expands.
B. contracts.
C. remains unchanged.
D. not enough information.

*Explanation:*
Parts of the water will crystallize and occupy more space. Interestingly, 4°C water will expand whether heated or cooled!
Water and Ice Application

- As water cools in winter, it becomes more dense and sinks. Sinking continues until the entire pond is at 4°C.
- Then, as water at the surface is cooled further, it floats on top and can freeze.
- Once ice is formed, temperatures lower than 4°C can extend down into the pond.
Water and Ice Application

Cooling of water winter
• becomes more dense and sinks
• continues sinking until entire pond is 4°C

Further cooling of water at the surface
• water floats on top and can freeze

Ice formation
• temperatures lower than 4°C can extend down into pond