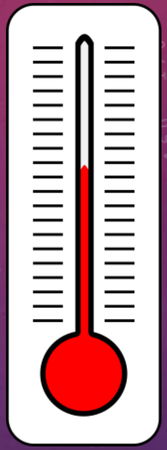
HEAT AND TEMPERATURE

PES 1000 – PHYSICS IN EVERYDAY LIFE

HOW DO WE MEASURE TEMPERATURE?

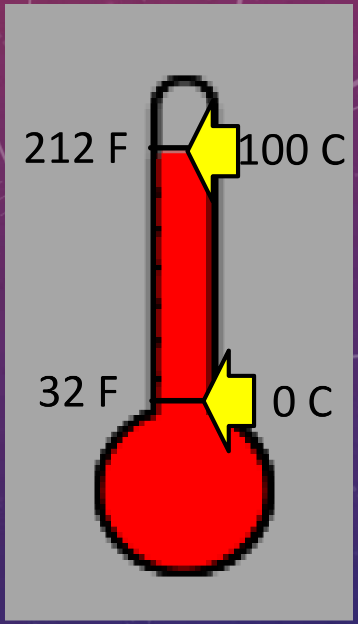
- Thermal expansion – The fluid in a thermometer's bulb heats up and expands, increasing the volume until it flows up the tube of the thermometer.
- Color change – Some materials change color based on their temperature. Examples are forehead thermometers and mood rings.
- Heat transfer – Touching an object can cause a transfer of heat to or from the object to our hand. We sense the object as hot or cold.
- Radiation – If an object is so hot that it is glowing, we can gauge the temperature based on its color (red hot, white hot, etc.)
- Voltage changes – Heat can cause a change in the electrical properties of a material. The voltage difference between two points is a measure of the temperature difference. (Thermocouples use this principle.)





TEMPERATURE SCALES

- Water can be used to define a temperature scale:
  - Place an unmarked thermometer in a mix of water and ice. This mixture has a consistent and predictable temperature. Place a mark and call this the 'freezing point'.
  - Now place the thermometer in boiling water. Again, the water in this state has a consistent temperature. Mark this point and label it the 'boiling point'.
  - Count the freezing point as 0, and make 100 marks between freezing point and boiling point. This is the Centigrade temperature scale.
  - If instead we make 180 marks between the pure water freezing and boiling points, and make our zero point the (lower) freezing point of salt-water, we get the Fahrenheit temperature scale. Pure water freezes at 32^0 F and boils at 212^0 F.
- To convert between these temperature scales, you can use the following equations:
  - Celcius to Fahrenheit: $T_F = T_C * \frac{9}{5} + 32$
  - Fahrenheit to Celcius: $T_C = (T_F - 32) * \frac{5}{9}$

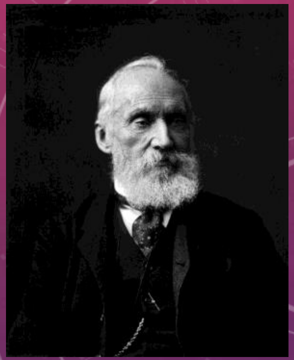


THE S.I. TEMPERATURE SCALE

Gas expansion can be used to define a temperature scale:

- Liquids can expand at different rates at different temperatures, making liquid thermometers (like mercury or alcohol) imprecise.
- A more reliable method is to use the uniform expansion of gas as a thermometer. (One method is to place a fixed weight on a piston containing the gas, then mark increments as the gas expands under heat.)
- This is the basis of the Celcius temperature scale. This scale has a zero at the freezing point of water and 100 at the boiling point of water, just like the Centigrade scale. The degree size is identical.

THE S.I. TEMPERATURE SCALE



The Kelvin temperature scale

- William Thomson, 1st Baron Kelvin, (1824-1907) was working with different gases as gas thermometers. He noticed that the pressure exerted by each gas decreased as temperature dropped, and that at -273^0 C, ALL the gases would reach zero pressure at the same time. He called this low temperature 'absolute zero' on his scale. Kelvin degrees are the same size as the Celcius scale, so water freezes on the Kelvin scale at 273 K, and absolute zero is 0 K.

To convert between the Celcius (Centigrade) and Kelvin scales, you can use the following equations:

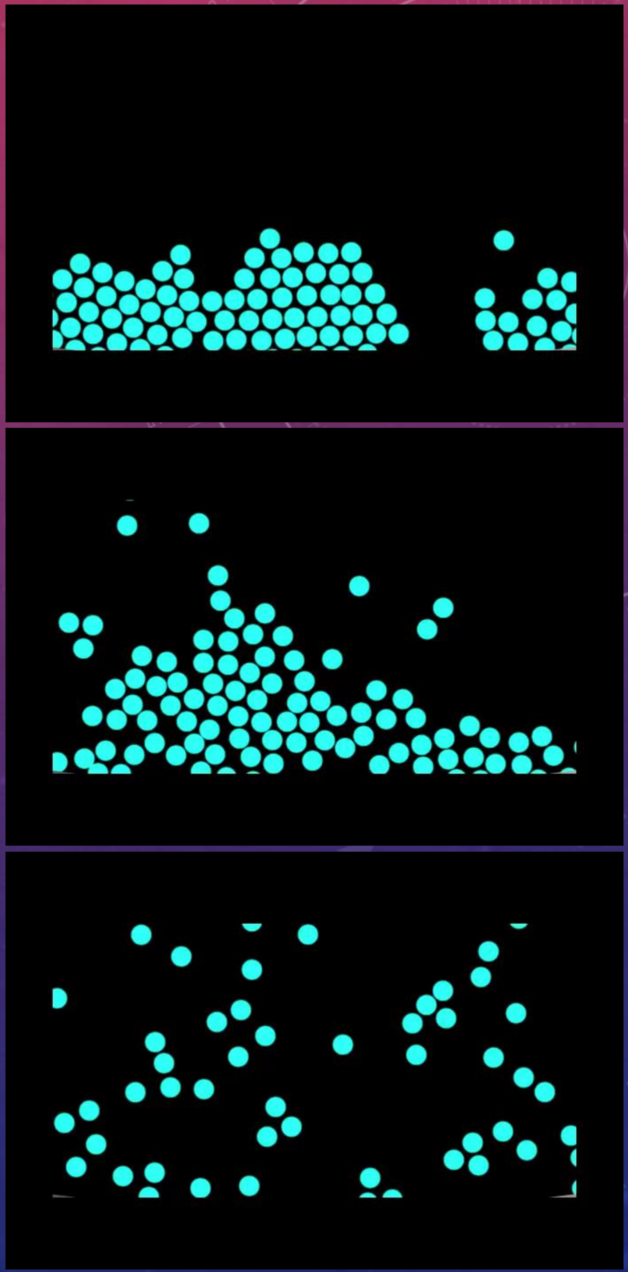
- Celcius to Kelvin: $T_K = T_C - 273$
- Kelvin to Celcius: $T_C = T_K + 273$

THE DISTINCTION BETWEEN HEAT AND TEMPERATURE

We need physical definitions of heat and temperature.

- Each particle in an object has mass and is moving, so it has kinetic energy. We define the internal energy of an object as the total kinetic energy of all its particles. Internal energy is sometimes called thermal energy.
- Temperature is defined as the average kinetic energy per particle.
- We define heat as a transfer of internal energy (or thermal energy).
- Bathtub example – A tub of hot water is drawn, and then a cup is dipped into that water.
  - The water in the tub has more internal energy than the water in the cup because there are more moving particles than in the cup.
  - But both samples of waters have the same temperature, because the cup (with less internal energy) also has fewer particles, so the average energy per particle is the same as the tub's.

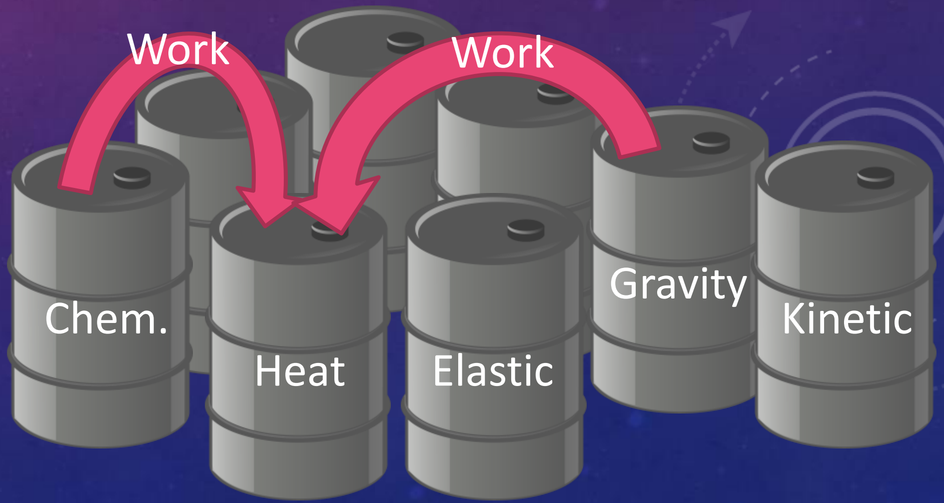
STATES OF MATTER



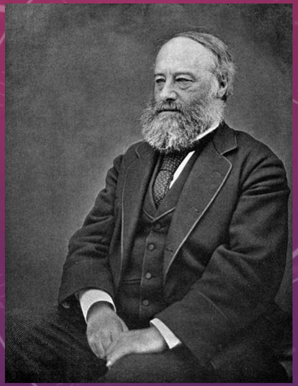
- In the microscopic view of matter, gases are like tiny marbles ricocheting about inside the container, liquids are like marbles rolling around the bottom of their container, and solids are like marbles connected to each other by rubber bands.
- Start with a solid at absolute zero. The tiny marbles are completely motionless and have no kinetic energy. The solid has no internal energy.
  - Adding heat raises the average kinetic energy of each marble, so the marbles begin to wobble back and forth in place.
  - Adding more heat makes the marbles vibrate so much that the bonds between them break. The solid *melts* and turns into a liquid.
  - Adding more heat makes the marbles bounce out of the collection at the bottom of the container, becoming a gas. The liquid has *vaporized*.
- Removing heat reverses this process. Gas *condenses* into liquid, which then *freezes* into a solid.
- *Melting*, *freezing*, *vaporizing*, and *condensing* are called *state changes* or *phase changes*. Within a state, heat changes the temperature. During a state change, heat is absorbed, but the temperature does not change.

SEVERAL USEFUL UNITS OF HEAT

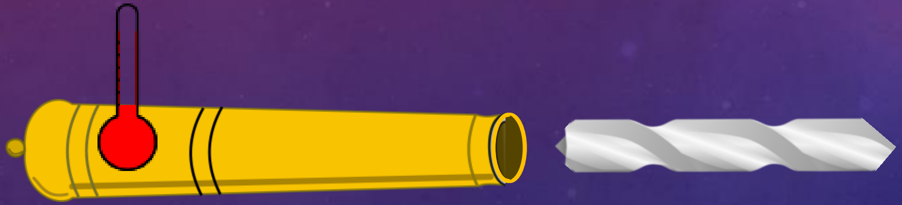
- Heat is such an important quantity that it appears in other areas of study.
  - Engineering: British Thermal Unit (BTU) is the heating capacity of a furnace.
  - Chemistry: Chemical reactions release (exothermic) or absorb (endothermic) heat, which is measured in calories (cal).
  - Nutrition: Food energy is measured in Calories (Cal). These are 1000 chemical calories in one food Calorie, also called a kilo-calorie (kcal).
  - Mechanics: Work and energy are measured in Joules (J) which can be converted to heat units. The mechanical equivalent of heat is: 4.186 Joules = 1 calorie.
  - The SI unit of heat is the Joule.

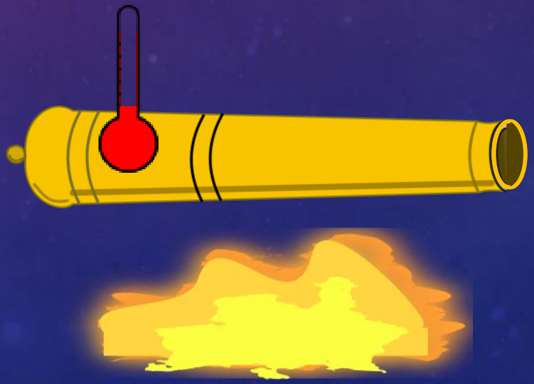


SOME STORIES ABOUT JAMES JOULE



- James Joule (1818-1889) realized that both chemical reactions and work caused heat.
  - Joule had a friend who owned a cannon factory. For strength, the cannons were cast as a solid piece and the barrel was drilled out. Drilling caused a great deal of heat from the friction. So the cannons were immersed in water to keep them from overheating, thus raising the temperature of the water.
  - Joule realized that they could be heated by fire (measured in calories) or they could be heated by doing work on them (measured in Joules). From this, he was able to relate the two units.





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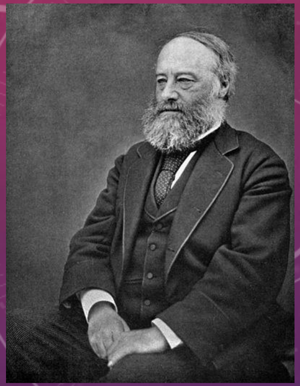
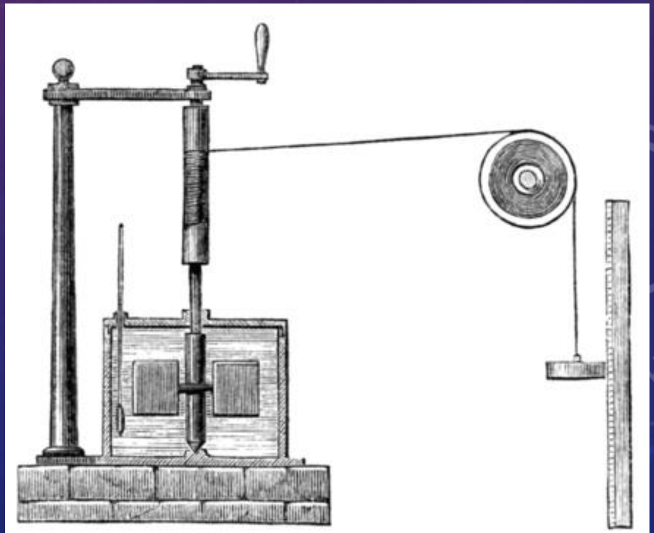


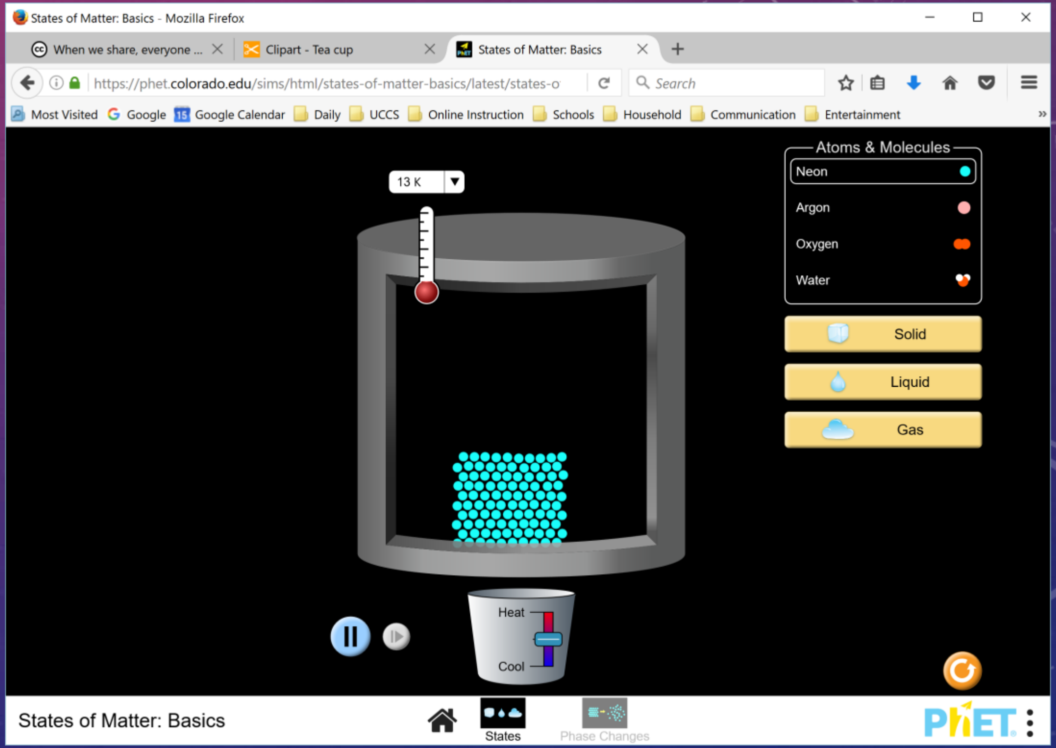
- James Joule (1818-1889) realized that both chemical reactions and work caused heat.
  - While on his honeymoon, he met with William Thompson (Lord Kelvin) to experiment with temperature differences in water at the top and at the bottom of a waterfall due to work done by the water falling due to gravity.
  - He made an apparatus in which the gravitational work done by a dropped weight turned a paddle in water, which raised its temperature.
  - Joule didn't measure heat in units of 'Joules', of course, but in units of 'calorics' (a Greek word for 'heat'), from which we get the word 'calorie'.



STATES OF MATTER SIMULATION

- Link to simulation: https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html

- Things to do:
  - Choose the ‘States’ option when starting up.
  - Switch between ‘Solid’, ‘Liquid’, and ‘Gas’ by pressing the buttons on the right. Observe the different molecular configurations.
  - Switch to ‘Solid’, then add heat below the chamber until the substance turns to liquid (melts).
  - Keep adding heat until the substance turns to gas (vaporizes).
  - Remove heat (add ‘cold’) to reverse the entire process, condensing the gas, then freezing the liquid.
  - Try the same things with different atoms and molecules.



CONCLUSION

- Temperature and heat are different physical quantities
- Fluids can be used to set a temperature scale
  - The freezing/boiling points of water was used to establish the Centigrade and Fahrenheit scales.
  - The expansion of a gas was used to establish the SI temperature scale, the Kelvin scale.
- Heat, which is a transfer of energy, can be measured in several units.
  - The SI unit is the Joule (J).
- James Joule discovered that mechanical work can transfer energy into thermal energy (heat).