Heat and Temperature
Dr. Coman

Guess what today's topic will be !

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CREDITS

- College Physics, Serway
- http://ebooks.bfwpub.com/
- http://hyperphysics.phy-astr.gsu.edu
- http://www.lon-capa.org/~mmp/
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Objectives: Temperature and the Kinetic Theory of Gases

- Use the kinetic theory of gases to distinguish between heat and temperature;
- Interpret and apply the concept of energy per degree of freedom.
- Recognize thermal properties and processes
- Use these properties and processes to explain and interpret thermal phenomena
- Interpret and apply the laws of thermodynamics to explain natural phenomena.
- Explain the difference between heat and temperature
-

Goals :

- To study temperature and temperature scales
- To describe thermal expansion and its applications
- To explore and solve problems involving heat, phase changes and calorimetry
- To study heat transfer
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Defining, introducing new concepts

- Temperature
- Temperature scales
- Heat as a form of energy
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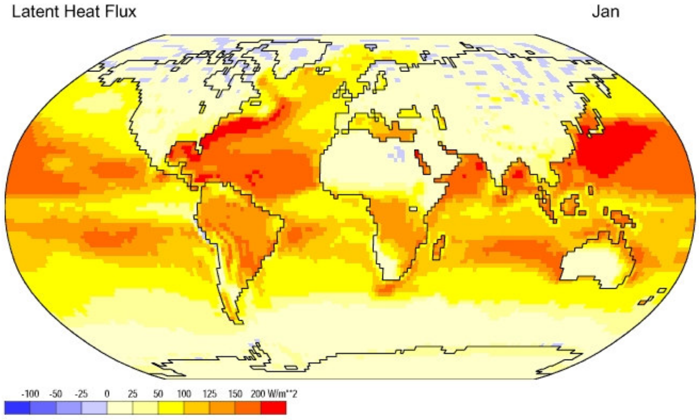
OUTLINE: Heat and Temperature

- Atoms molecules and phases of matter



Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies

- Temperature scales
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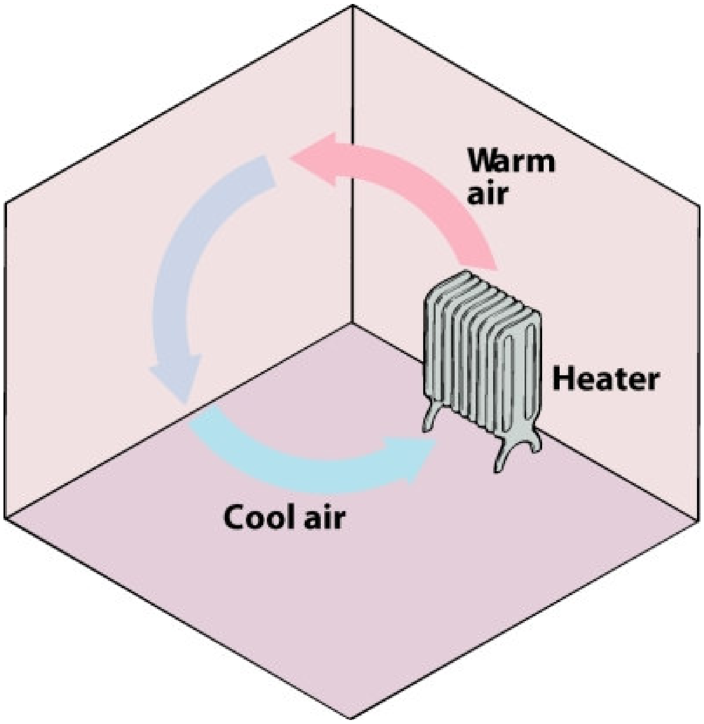
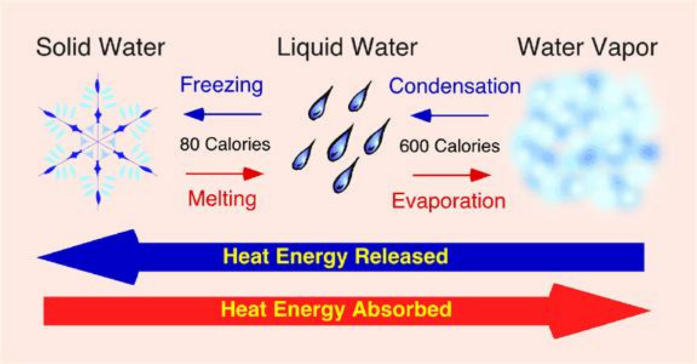
    - Thermometers



- Ideal gas law
- Heat as Energy transfer
    - Conduction
    - Convection
    - Radiation

OUTLINE II: Heat and Temperature

- Specific Heat
- Phases of Matter and Phase Changes



- Evaporation and Condensation
- Linear Thermal Expansion
    - Why can't engineers build a perfect bridge, without gaps
- The laws of Thermodynamics
    - Time's Arrow - Entropy
-

When in the world am I ever going to use it ?

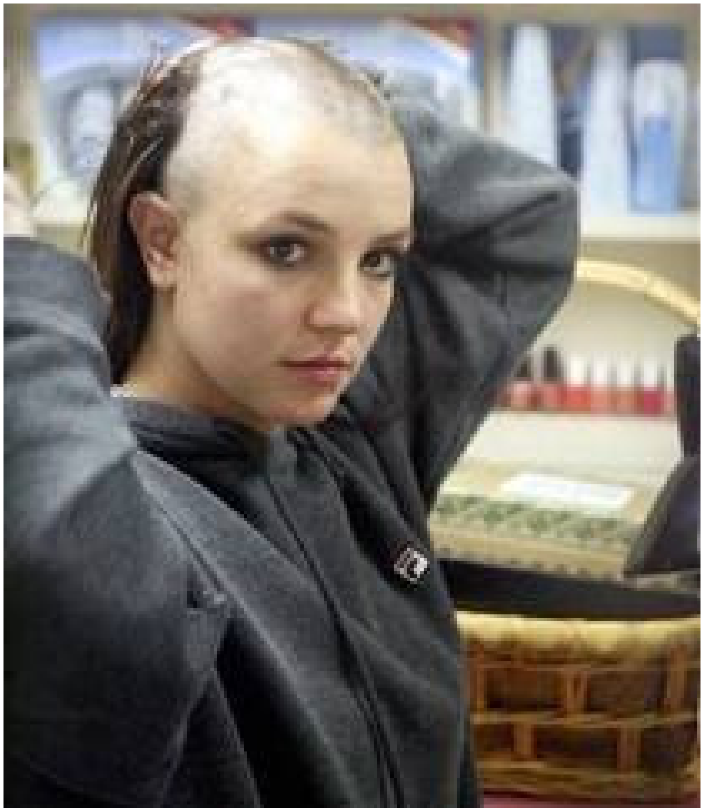
- Low T act as anesthetic
    - Cryosurgery - low $T \rightarrow$ metabolic rate drops
- Freezing small parts of the brain to treat Parkinsons

- Whether you are an engineer required to built a bridge

- How to cool down a shaving blade
-

When in the world am I ever going to use it ?

- Do you have to use cold water or hot water to rinse a shaving blade



- Life saver:
- How many ice cubes you need to add to your favorite drink to decrease its temperature by 10 degrees

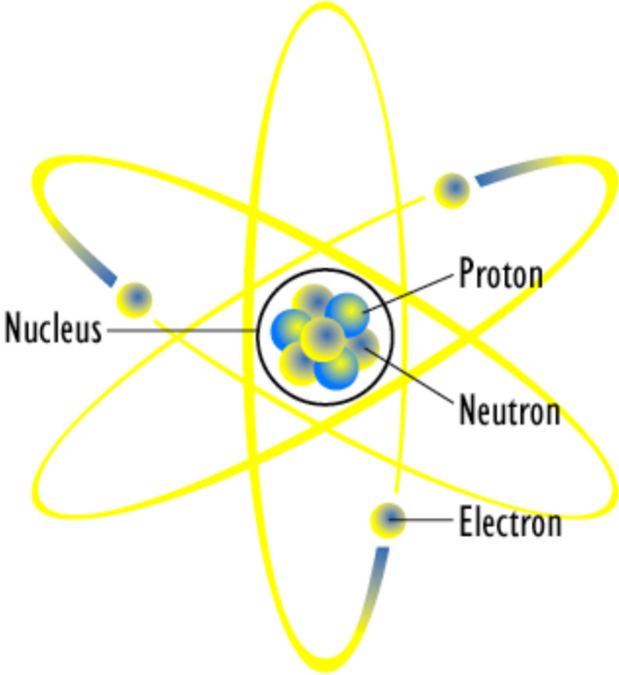
-

When am I ever going to use it ?

- Pilots and balloonists: how changes in air T affect air ρ
- Scuba divers how body's ΔT affect how much air they will use
    - $pV = cst \rightarrow$ Boyle law
- Equalizing the pressure on their bodies and the gases within their bodies
- We will define a consistent temperature scale in terms of the properties of gases that have low densities
- Define T as a measure of the average internal molecular kinetic energy of an object.

Introduction: what is matter made of ?

- Ancient Greeks knew that matter was made up of very small particles.
- Democritus wrote that matter was made up of tiny indivisible particles he called atoms.



- We now know that atoms are not indivisible, but are themselves made up of even smaller particles.
-

The simplest atoms :

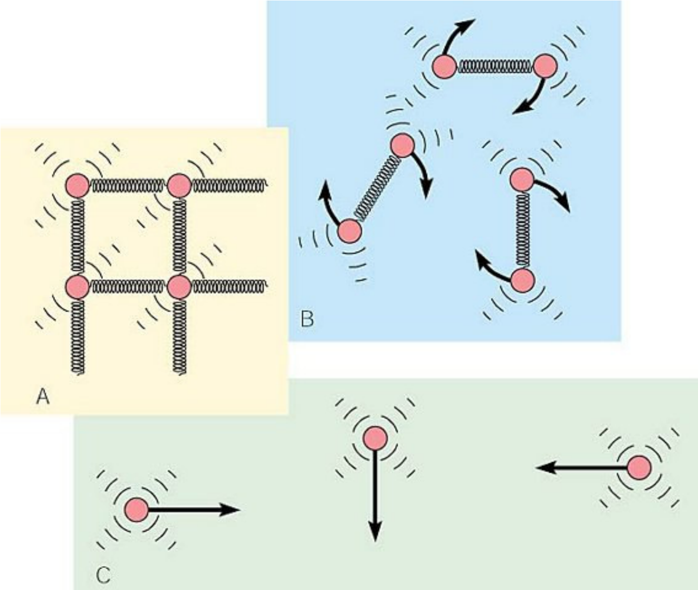
- **Hydrogen**
- **Helium**
-

Phases of Matter-Cohesive forces

- In a solid, molecules vibrate around a fixed equilibrium position → kinetic energy
  - Molecules are fixed distances apart and have strong cohesive forces.

  LINK states of matter jar file very nice
  - In a liquid, molecules can rotate and roll over each other → kinetic energy
  - In a gas, the molecules move rapidly in random free paths → kinetic energy
-

Solids, liquids, gases



- (A) In a solid, molecules vibrate around a fixed equilibrium position and are held in place by strong molecular forces.
- (B) In a liquid, molecules can rotate and roll over each other because the molecular forces are not as strong.
- (C) In a gas, the molecules move rapidly in random free paths.
-

Kinetic energy: translational, vibrational, rotational

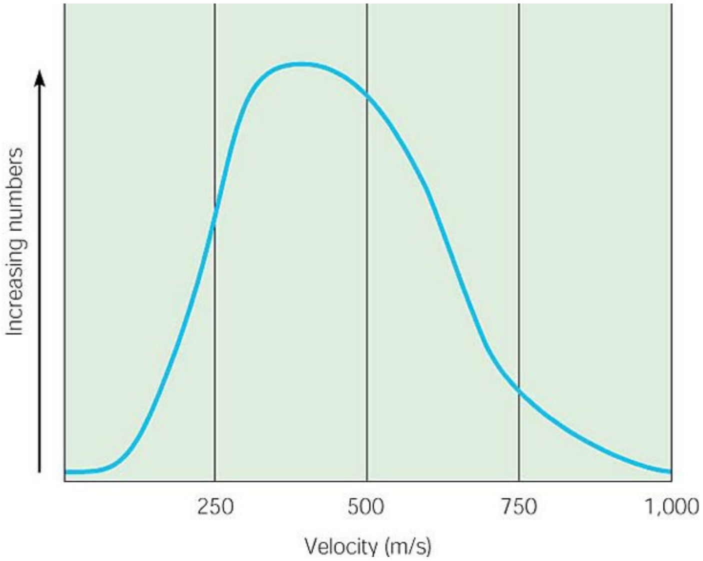
- Molecules Move.
- All molecules have kinetic energy due to movements.
- This kinetic energy can be in the form of:
  - Vibrational energy.
  - Rotational energy.
  - Translational energy where the entire molecule has motion.
-

Kinetic energy of Molecules: translational, vibrational, rotational

- (A) Translational motion is the motion of a molecule as a whole moving from place to place.
- (B) Rotational motion is the motion of a turning molecule.
- (C) Vibrational motion is the back-and-forth movement of a vibrating molecule.
-

Temperature as the average translational kinetic energy

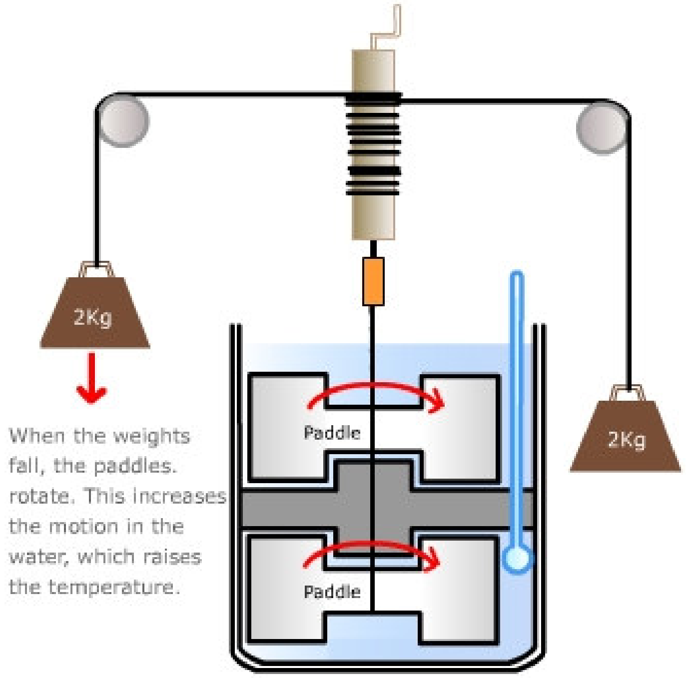
- $Temperature:$ a measure of the average translational kinetic energy associated with the disordered microscopic motion of atoms and molecules



- The temperature of a gas can be raised either by heating it, by doing work on it (compressing the gas), or a combination of the two.
- The number of oxygen molecules with certain velocities that you might find a sample of air at room at temperature.
- Notice that a few are barely moving and some have velocities over $1,000\,\frac{m}{s}$ at a given time, but the average velocity is somewhere around $450\,\frac{m}{s}$.
-

Methods used to increase temperature:

- From a temperature difference, with energy moving from a region of higher temperature to a region of lower temperature.
- From an object gaining energy by way of a temperature conversion.
- By doing work,



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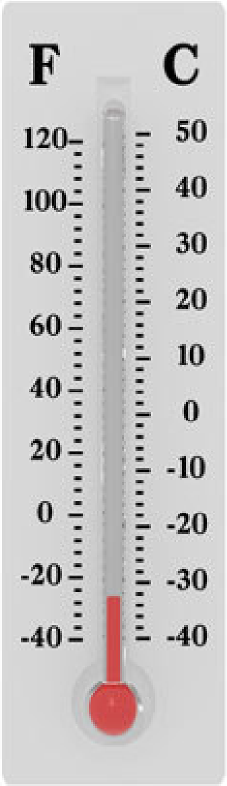
Measuring temperature: Thermometers

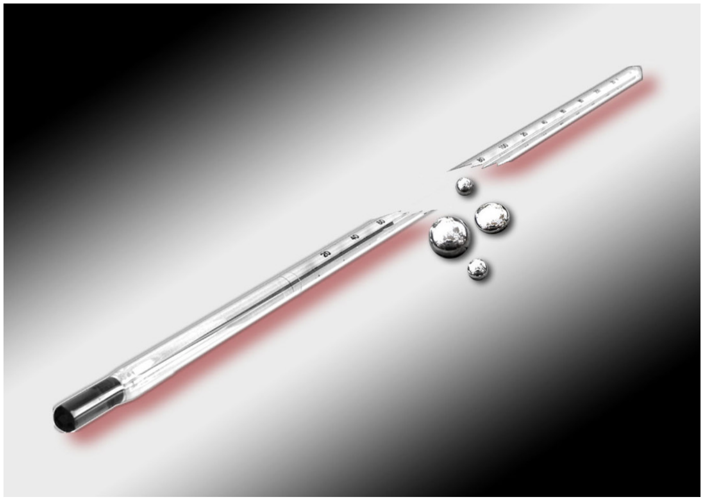
- Conceptually a thermometer is used to measure the temperature of an object.
- What a thermometer really measures is the average translational kinetic energy associated with the motion of molecules.



- There is a physical transfer of kinetic energy to the thermometer which then responds due to the increase in its kinetic energy.
-

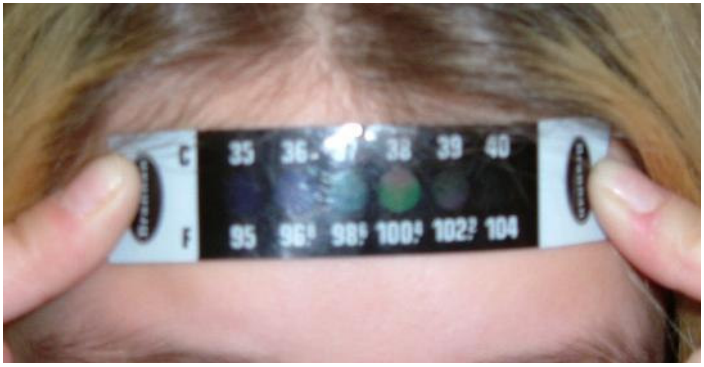
Thermometers types:

- Mercury based.



- Ethylene glycol based.
- Infrared

- Liquid crystals



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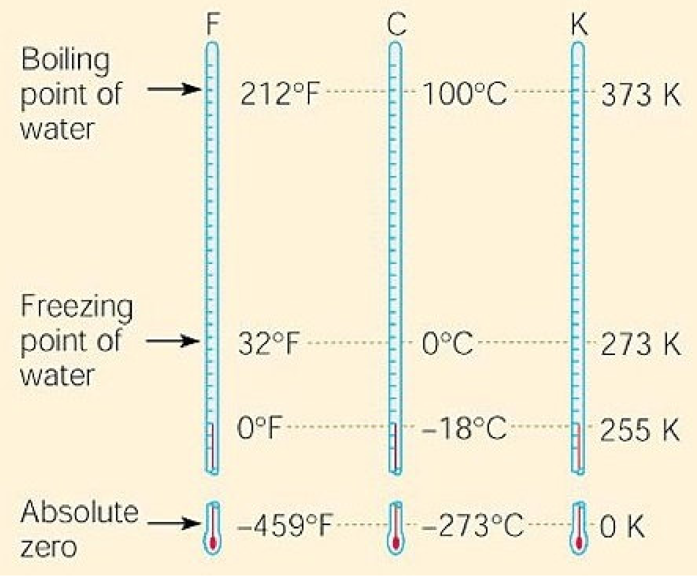
Temperature Scales.

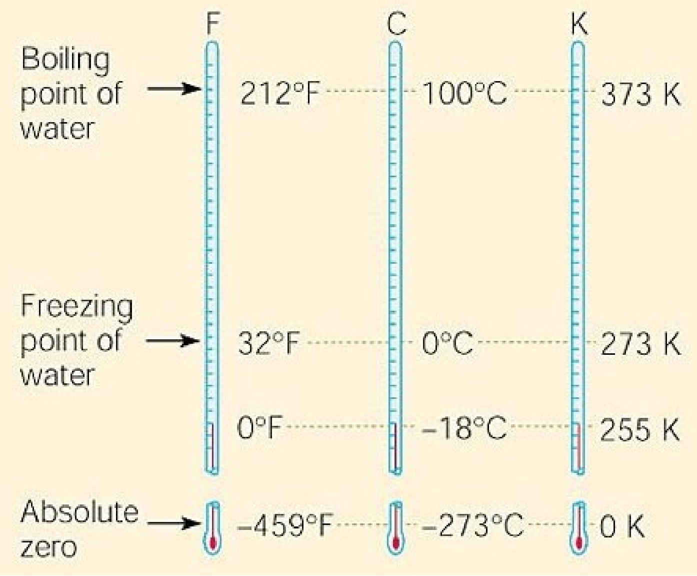
- Fahrenheit scale
- Sets boiling point of water at 212^oF and freezing point of water at 32^oF.



- 180 divisions between these two.
- Like most English measures is quite cumbersome.
-

Temperature Scales: Celsius

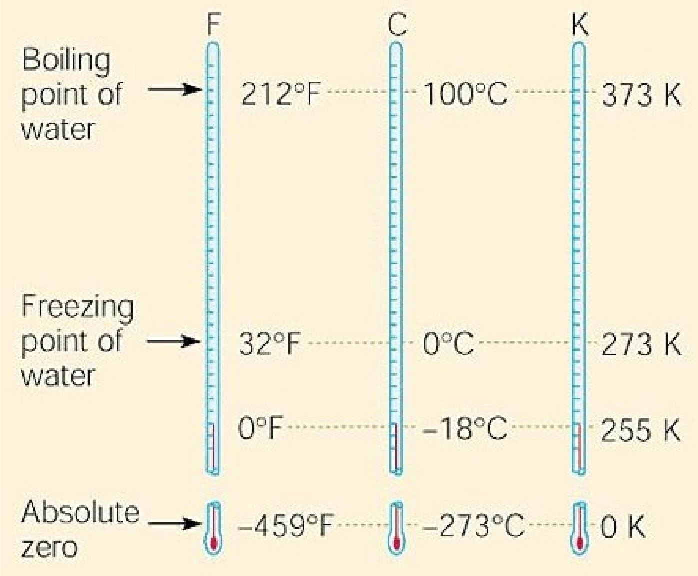
- Celsius scale.



- Sets boiling point of water at 100^oC and freezing point of water at 0^oC.
- 100 divisions between these two points.
-

Temperature Scales: Kelvin

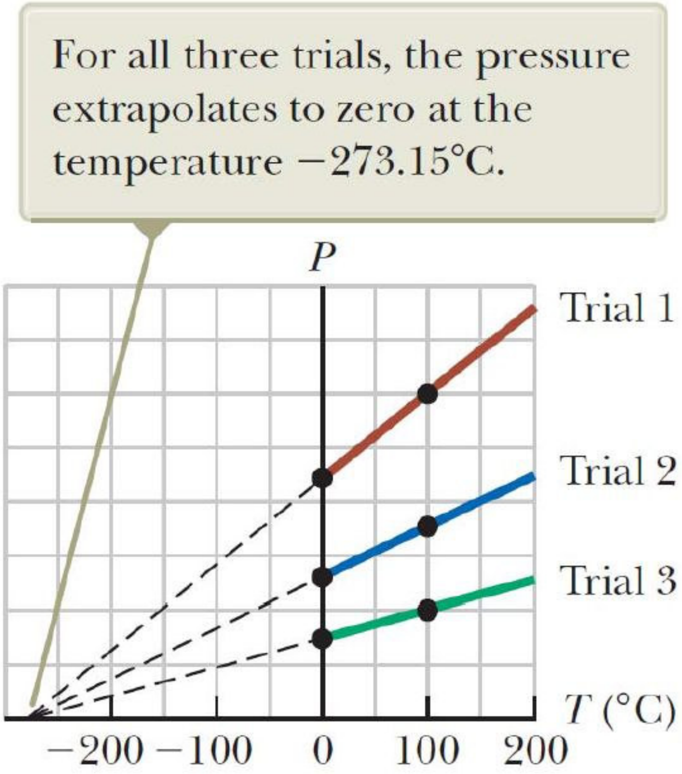
- Kelvin or absolute scale.



- Begins at absolute zero, the temperature at which all kinetic energy is changed into potential energy.
- ie, all molecular motion ceases.
- Boiling point of water is 373.15^oK and freezing point of water is 273.15^oK.
- Divisions are same as for Celsius scale
-

Absolute Temperature: Kelvin

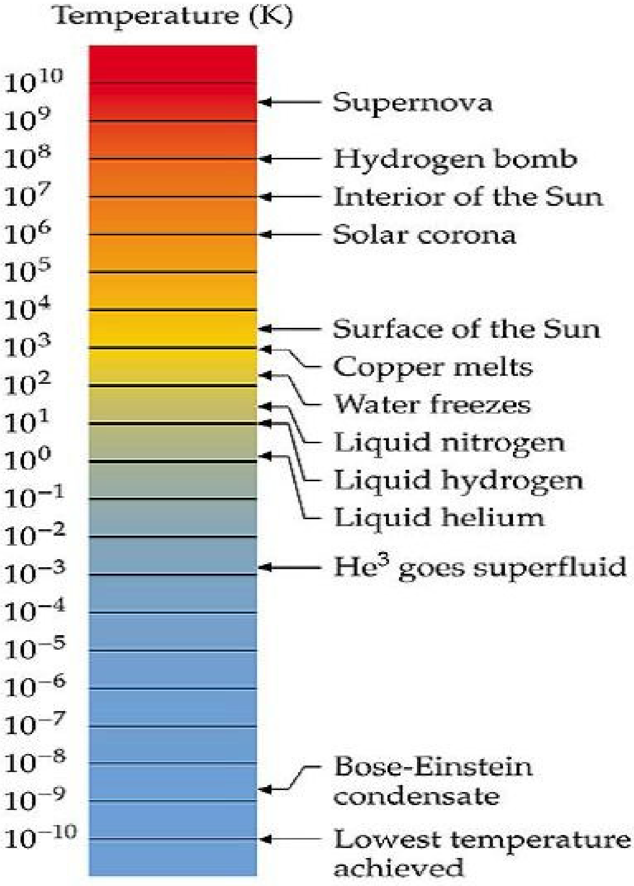
- For all gases a p versus T graph:



- If we extend the straight lines in the figure toward negative temperatures: in every case, the pressure is zero when the temperature is -273.15^oC.
- All of the lines have the same x-intercept.
- We use this property to define a new temperature scale with this intercept as zero, called the Kelvin scale.
-

Interesting Kelvin Temperatures

- Cosmic background radiation (not shown) is at roughly 3^oK



- The temperature of the big bang would be about $10^{32}{}^\wedge oK$.
- The lower half corresponds to temperatures below $1K$.
-
-

Conversions between temperature scales.

-

$$T_F = 1.8\,T_C + 32^oC = \frac{9}{5} \cdot T_C + 32^oC$$

$$T_C = \frac{T_F - 32^oF}{1.8} = \frac{5}{9} \cdot \left(T_F - 32^oF\right)$$

- 1.8 accounts for the divisions between freezing point of water and boiling point of water.
  - There are 1.8 divisions in the F scale for every 1 division in the C scale.

$$T_K = T_C + 273.15$$

-

Fahrenheit versus Celsius task

- If you plot a graph with Fahrenheit temperatures along the vertical axis and the corresponding Celsius temperatures along the horizontal axis, the slope of the will be
- $32\frac{F^o}{C^o}$
- $1.8\frac{F^o}{C^o}$
- $0\frac{F^o}{C^o}$
- $-32\frac{F^o}{C^o}$

Fahrenheit versus Celsius task

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- $0\frac{F^o}{C^o}$
- $-32\frac{F^o}{C^o}$

Temperature conversion: classroom task

- Example
- The temperature of Lake Superior in August averages 34^OF. What is the temperature in Celsius ?

$$T_C = \frac{T_F - 32^O F}{1.8}$$

$$T_C = \frac{34^O F - 32^O F}{1.8} \rightarrow T_C = \frac{2^O F}{1.8}$$

- Task: calculate the temperature in degrees Celsius corresponding to 102^o F !
-

Temperature conversion: classroom task

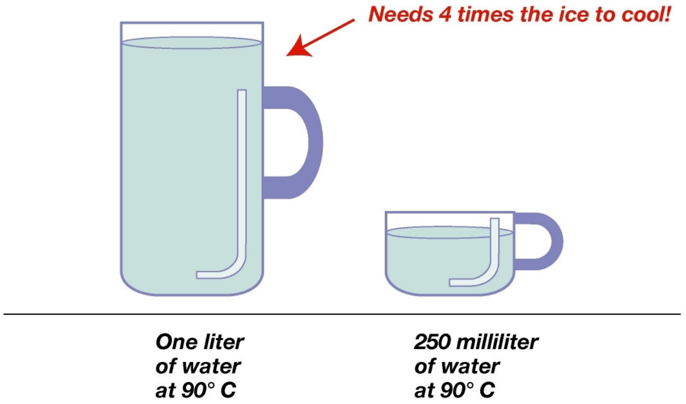
- Example:
- What is the equivalent Celsius temperature of 400.0 K? The equivalent Fahrenheit temperature?
  $T_K = T_C + 273.15 \rightarrow T_C = T_K - 273.15$
  $T_C = 400K - 273.15 = \ 127.0^oC$
  $T_F = 1.8\ \cdot 127.0^oC + 32^oC$
-

Temperature conversion: classroom task

- Example:
- What is the equivalent Celsius temperature of 400.0 K? The equivalent Fahrenheit temperature?
  $T_K = T_C + 273. \rightarrow T_C = T_K - 273.$
  $T_C = 400K - 273. = \ 127.0^oC$
  $T_F = 1.8 \frac{.^o F}{.^o C} \cdot 127^oC + 32^oF$
-

Heat definition

- The quantity of heat, Q absorbed or given off during a fixed change in temperature
- is also proportional to the mass (m) of the substance.

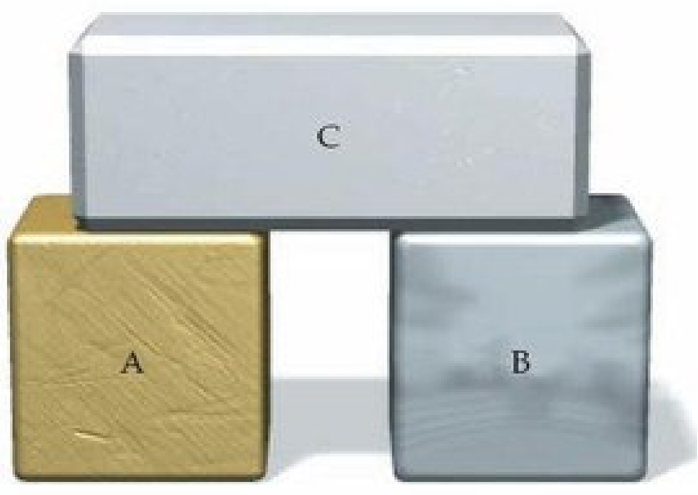


$Q \sim m$

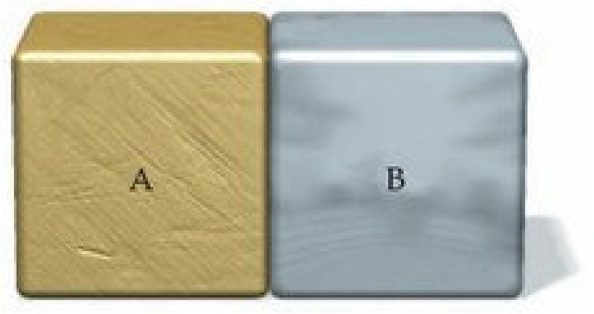
- The quantity of heat, Q absorbed or given off to obtain different changes in temperature
  $Q \sim \left(T_{f-}T_i\right)$
- Putting this all together we get:
  $Q \sim m \cdot \Delta T \rightarrow Q = c \cdot m \cdot \Delta T$
- c is the specific heat of the substance.
- Specific heat is the energy needed to increase the temperature of $1gram$ of a substance 1^oC.
-

Thought Experiment:

- Suppose that we place a warm Cu bar in close contact with a cold Fe bar
- The two bars are in thermal contact.



(a)



(b)

- What happens ?
- The Cu bar contracts slightly as it cools
- The Fe bar expands slightly as it warms.
- Eventually the bars reach thermal equilibrium with each other.

Thought Experiment 2:

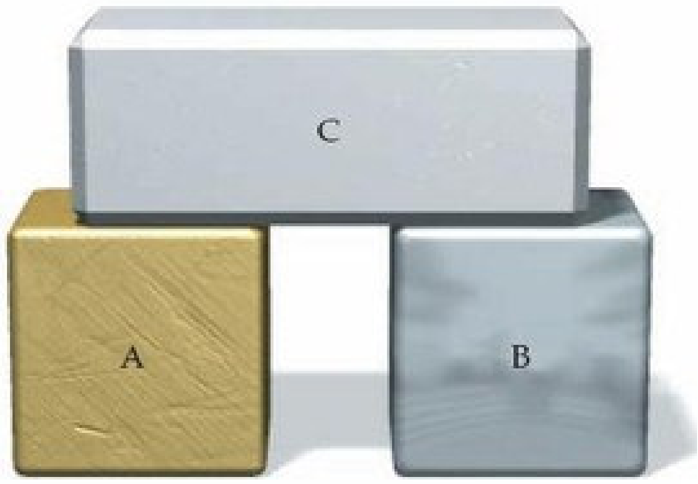
- We place a warm Cu bar in a cool running stream of water.
- What happens ?
- The bar cools until it stops contracting,
- The bar and the water are in thermal equilibrium.

Thought Experiment 3:

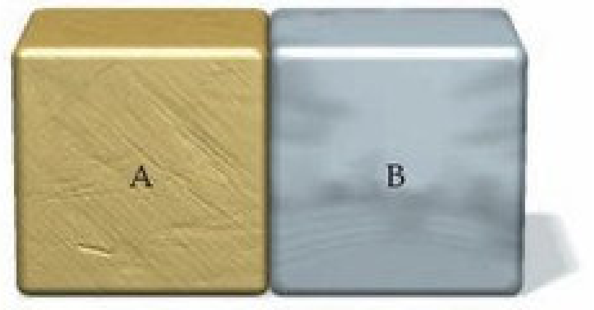
- Next, we place a cold Fe bar in the stream, near but not touching the Cu
- The Fe bar will warm until the iron and the water reach thermal equilibrium.
- If we remove the bars and place them in thermal contact with each other, their lengths do not change.
- They are in thermal equilibrium with each other.
- Common sense, $\rightarrow$ no logical way to deduce this fact
- The zeroth law of thermodynamics

The zeroth law of thermodynamics:

- Systems A and B are in thermal contact with system C, but not with each other. When A and B are each in thermal equilibrium with C, they are in thermal equilibrium with each other



(a)



(b)

THERMAL Equilibrium , The 0^th law of thermodynamics:

- Some physical properties change with T : thermometric property
- Heating a gas while V =cst $\rightarrow p$increases
- Heating a gas while p =cst $\rightarrow V$increases
- Δ in a thermometric property $\rightarrow$ indicates a ΔT

Ideal Gas Law I

- Molecules: a collection of perfectly hard spheres which collide but which otherwise do not interact with each other.
- All collisions between atoms or molecules are perfectly elastic
- No intermolecular attractive forces
- All the internal energy is in the form of kinetic energy
  - Any change in internal energy is accompanied by a change in temperature.
- An ideal gas can be characterized by three state variables:
  - absolute pressure P
  - volume V
  - and absolute temperature T
-

Equations of State for an Ideal Gas

- Boyle's Law
  - At a constant temperature, pressure is inversely proportional to the volume

  $p \sim \frac{1}{V} \text{ for constant } T$
- Charles' Law
  - At a constant pressure, the temperature is directly proportional to the volume
  -

  $T \sim V \text{ for constant } p$
- Gay-Lussac's Law
  - At a constant volume, the pressure is directly proportional to the temperature

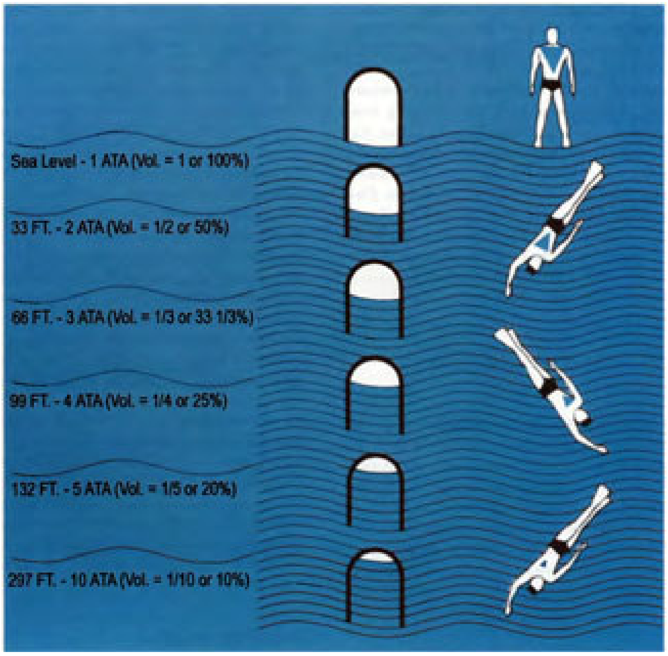
  $p \sim T \text{ for constant } V$
-

Classroom Task

- An ideal gas is confined to a container with adjustable volume. The number of moles and temperature are constant. By what factor will the volume change if pressure triples?
- $\frac{1}{9}$
- $\frac{1}{3}$
- 3.0
- 9.0
-

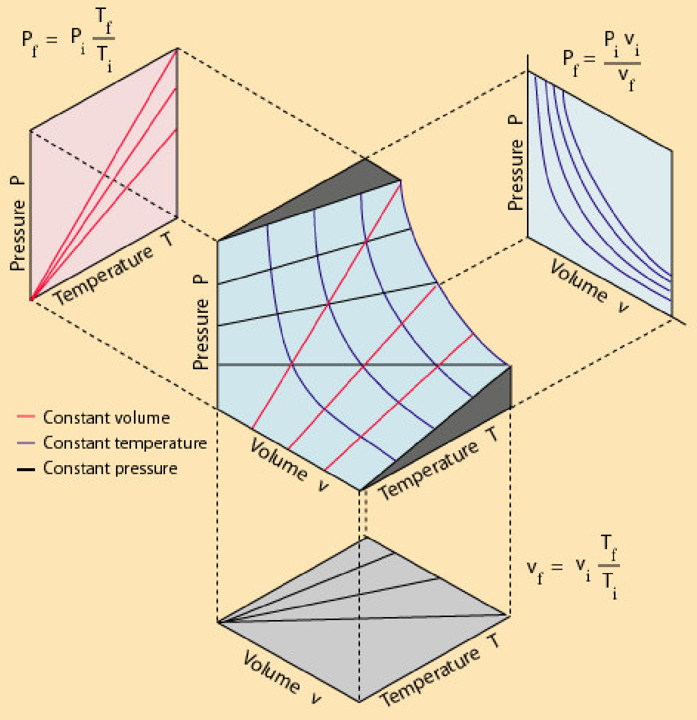
Scuba Diving Safety Rules Derived From Boyle's Law:

- Don't hold your breath underwater.
  - if he ascends (even a few feet) to an area of lesser water pressure, the air trapped in his lungs will expand according to Boyle's Law.
  - The expanding air can stretch the diver's lungs and lead to a pulmonary barotrauma.
- Divers should Ascend Slowly



  - A diver's body absorbs compressed nitrogen gas while he dives.
  - As he ascends to a depth with less water pressure, this nitrogen gas expands according to Boyle's Law.
  - it can form tiny bubbles in his blood and tissue and cause decompression sickness.
- Dalton's law: in mixtures of breathing gases the concentration of the individual components of the gas mix is proportional to their partial pressure →
  - Partial pressure is a useful measure for expressing limits for avoiding nitrogen narcosis and oxygen toxicity.
-

Vizualization of the Ideal Gas Law



- [Vizualization of the Ideal Gas Law LINK swf]
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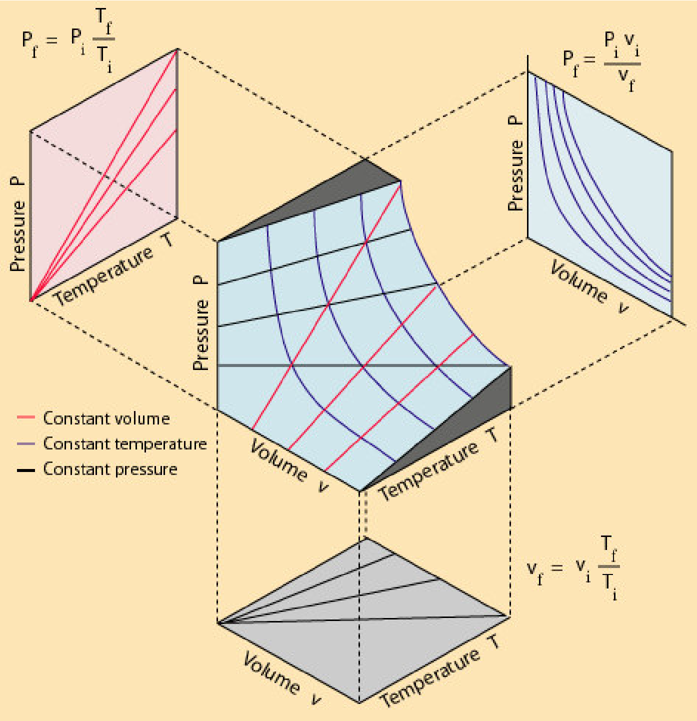
Ideal Gas Law II

- An ideal gas can be characterized by three state variables:
  - absolute pressure P
  - volume V
  - and absolute temperature T

  $p \cdot V = n_{moles} \cdot R \cdot T = N \cdot k \cdot T \rightarrow$

  $\frac{pV}{nT} = \text{const.}$
  - n_{moles} = number of moles
  - R = universal gas constant = $8.3145 \frac{J}{mol \cdot K}$
  - N = number of molecules $= n_{moles} \cdot N_A$
  - k = Boltzmann constant = $1.38066 \cdot 10^{-23} \frac{J}{K}$ = $8.617385 \cdot 10^{-5} \frac{eV}{K}$
  - $k = \frac{R}{N_A}$
  - N_A = Avogadro's number = $6.0221 \cdot 10^{23} \frac{particles}{mol}$
-

Definition: A mole (mol)



- An amount of gas is often expressed in moles.
- A mole (mol) of any substance is the amount of that substance that contains Avogadro's number, N_A of particles
    - (such as atoms or molecules).
- Avogadro's number is defined as the number of carbon atoms in exactly $12g$ $(1mol)$ of C^{12}:
- If we have n_{moles} moles of a substance, then the number of molecules N is: $N{=}n_{moles}{\cdot}N_A$
-

Charles' Law:

- A gas is at a constant pressure. By what factor does the volume change if the gas' temperature is changed from 20^oC oC to 40^oC ?
  $p_i \cdot V_i = n \cdot R \cdot T_i \qquad T_i = 20 + 273^oK,$
- constant pressure $\rightarrow$
  $p_i = p_f$
  $p_{f.}V_{f=}n \cdot R \cdot T_f \qquad T_{f=}40 + 273^oK$
-
-

Ideal Gas Law, calculate no of moles:

A vessel contains $4L$ of He gas at a temperature of $0^{o}C$ and a pressure of $5atm$. How many moles of gas there are? How many He molecules are inside the vessel?

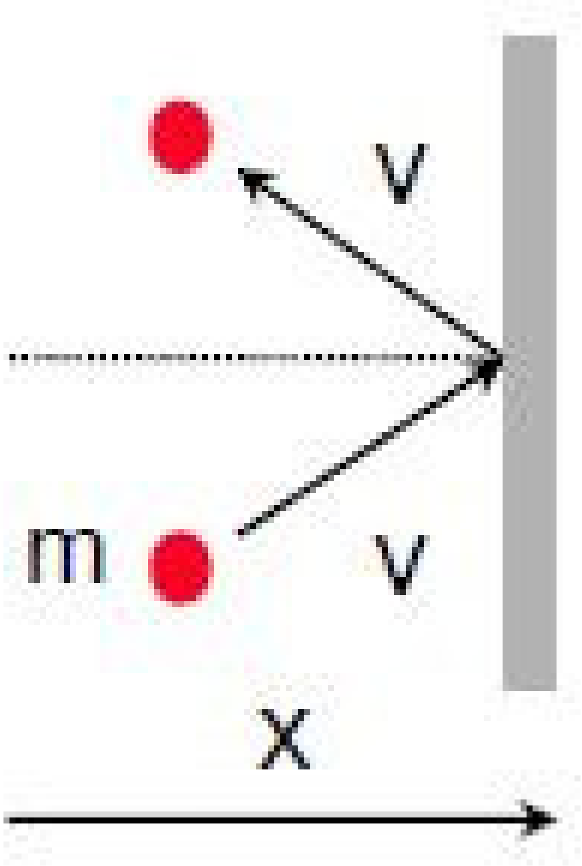
- Solution:

$$p\cdot V=n\cdot R\cdot T\rightarrow n=\frac{p\cdot V}{R\cdot T}=\frac{5atm\cdot 4L}{0.0821\,\frac{L\cdot atm}{\text{mole}\cdot K}\cdot(273K)}$$

-

Pressure and no of molecules relationship

- The pressure is proportional to the number of molecules per unit volume → $p \sim \frac{N}{V}$
- The pressure is proportional to the average translational kinetic energy of a molecule → $p \sim \left(m\frac{v^2}{2}\right) \rightarrow$



$p = \frac{2}{3}\frac{N}{V}\left(m\frac{v^2}{2}\right) \rightarrow$

- Why $\frac{2}{3}$?

  $\Delta p_x = 2mv_x$
- there are 3 directions: $V = x \cdot y \cdot z$
-

Equipartition theorem, energy per degree of freedom

- "equipartition" means "equal division,
- The total kinetic energy of a system is shared equally among all of its independent parts, on the average, once the system has reached thermal equilibrium
- When a substance is in equilibrium, there is an average energy of $\frac{1}{2}kT$ per molecule or $\frac{1}{2}RT$ per mole associated with each degree of freedom.
-

Equipartition theorem, energy per degree of freedom

- Each component of position and momentum (including angular position and angular momentum) that appears as a squared term in the expression for the energy of the system is called a degree of freedom.

  $\frac{1}{2}mv_x^2=\frac{1}{2}k_BT$

  $\frac{1}{2}mv_y^2=\frac{1}{2}k_BT$

  $\frac{1}{2}mv_z^2=\frac{1}{2}k_BT \rightarrow$

  $K_{\text{total translation}}=Nm\frac{\overline{v}^2}{2}=\frac{3}{2}Nk_BT$

  $K_{\text{total translation}}=\frac{3}{2}nRT$
-

RMS Speed of Gas Molecules

$$v_{av}^2=\frac{3\cdot k_B\cdot T}{m}=\frac{N_A\cdot 3\cdot k_B\cdot T}{N_A\cdot m}=\frac{3\cdot R\cdot T}{m}\rightarrow$$

- The square root of v_{av}^2 is referred to as the root-mean-square (rms) speed:
-

$$v_{rms}=\sqrt{\left(3\cdot R\cdot\frac{T}{M}\right)}$$

-

Classroom task

$$v_{rms} = \sqrt{\left(3 \cdot R \cdot \frac{T}{M}\right)}$$

- The oxygen ($M = \text{molar mass} = 32 \frac{g}{\text{mol}}$ and nitrogen ($M = \text{molar mass} = 28 \frac{g}{\text{mol}}$ molecules in this room have equal average
- kinetic energies, but the oxygen molecules are faster.
- kinetic energies, but the oxygen molecules are slower.
- kinetic energies and speeds.
- speeds, but the oxygen molecules have a higher average kinetic energy.
- speeds, but the oxygen molecules have a lower average kinetic energy.
-

Classroom task

$$v_{rms} = \sqrt{\left(3 \cdot R \cdot \frac{T}{M}\right)}$$

- The oxygen ($M = \text{molar mass} = 32 \frac{g}{\text{mol}}$ and nitrogen ($M = \text{molar mass} = 28 \frac{g}{\text{mol}}$ molecules in this room have equal average
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- kinetic energies and speeds.
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-

Kinetic Theory of Gases: Assumptions

- The number of molecules in the gas is large and the average separation between them is large compared to their dimensions
- The molecules obey Newton's laws of motion, but as a whole they move randomly
- The molecules interact only by short-range forces during elastic collisions
- The molecules make elastic collisions with the walls
- The gas under consideration is a pure substance, all the molecules are identical
-

Classroom task

- A mass of He gas occupies a volume V at standard temperature and pressure. What volume is occupied if the mass is halved, the absolute temperature doubled, and the pressure increased by a third?
- If mass is halved how about n no of moles ?
- $\left(\frac{3}{16}\right)V$
- $\left(\frac{4}{3}\right)V$
- $\left(\frac{3}{4}\right)V$
- $\left(\frac{3}{8}\right)V$
- $\left(\frac{1}{3}\right)V$
  $m=\frac{M}{N_A}$ $\text{where } M = \text{molar mass}, m = \text{mass}, \ N_A = 6.023 \cdot 10^{23}$ is the Avogadro's number;
-

Ideal gas law applications: problem

- A stoppered test tube that has a volume of $10.0 mL$ has $1.00 mL$ of water at its bottom. The water has a temperature of $100^o C$ and is initially at a pressure of 1.00 atm. The test tube is held over a flame until the water has completely boiled away. Estimate the final pressure inside the test tube (when the water is completely boiled away) ?
- Solution:
  $$p=\frac{NkT}{V}$$
  no of particles N, mass of water and molar mass are related through Avogadro's number:
  $$\frac{m}{N}=\frac{M}{N_A} \quad \rightarrow \quad N=m\frac{N_A}{M}=\rho V\frac{N_A}{M}$$
- Classroom task substitute and calculate the pressure !
-

Ch 17

- A closed container with a volume of $6.00L$holds $10.0g$ of liquid helium at $25.0K$ and enough air to fill the rest of its volume at a pressure of $1.00atm$. The helium then evaporates and the container warms to room temperature $293K$. What is the final pressure inside the container?
- Solution:
  $p_F = p_{He} + p_{air}$
  $p_{air} = \frac{n_{air}RT}{V} = \frac{m_{air}RT}{M_{air}V} = \frac{\rho_{air}VRT}{M_{air}V}$
  $p_{He} = \frac{n_{He}RT}{V} = \frac{m_{Her}RT}{M_{He}V}$
-

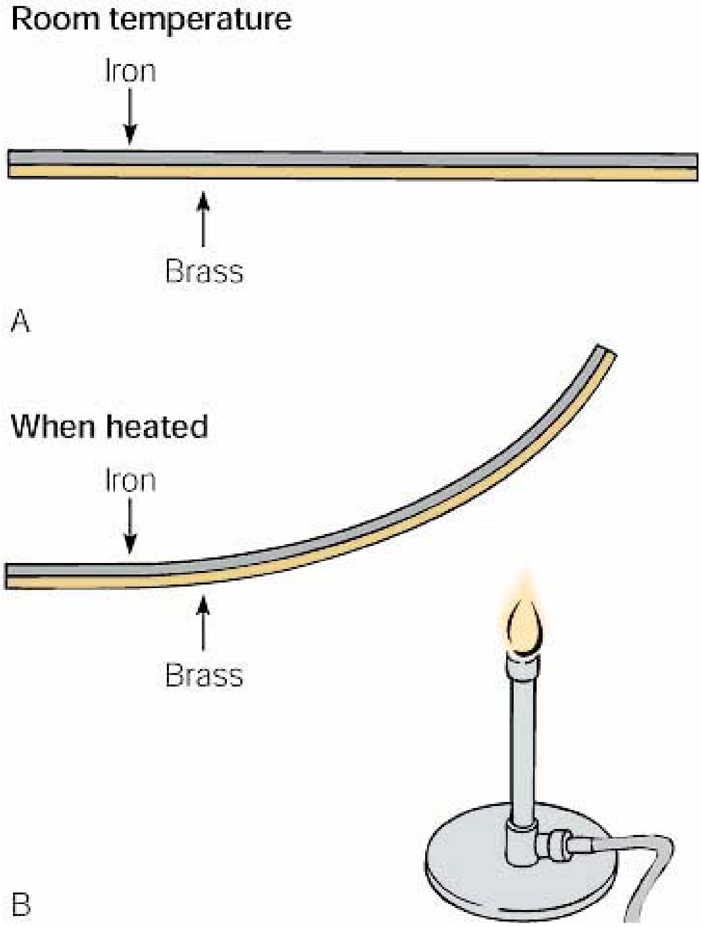
Ch 17 problem

- An automobile tire is filled to a gauge pressure of $200kPa$ when its temperature is 20^oC. (Gauge pressure is the difference between the actual pressure and atmospheric pressure.) After the car has been driven at high speeds, the tire temperature increases to 50^oC. (a) Assuming that the volume of the tire does not change and that air behaves as an ideal gas, find the gauge pressure of the air in the tire. (b) Calculate the gauge pressure if the tire expands so the volume of the enclosed air increases by 10 percent.
- Solution:
  $\frac{p_2V_2}{T_2} = \frac{p_1V_1}{T_1} \rightarrow p_2 = \frac{T_2}{T_1}p_1$ since $V_1 = V_2$
  b) $p_2 = \frac{V_1T_2}{V_2T_1}p_1$
- Classroom task substitute and calculate the pressure !
-

Thermal Linear Expansion

- Most materials expand as T increases;
- A property used to charaterize expansion: expansion coefficient, α

  $\Delta L = (L_f - L_i) = L_i \cdot \alpha \cdot \Delta T$
- A bimetallic strip is two different metals, such as iron and brass, bonded together as a single unit, shown here at room temperatures.



- Since one metal expands more than the other, the strip will bend when it is heated.
- In this example, the brass expands more than the iron, so the bimetallic strip bends away from the brass.
-

Thermal Linear Expansion: application

- What is the change in length of a column of mercury $3cm$ long if its T increases from 37^oC to 41^oC? The linear expansion coefficient of Hg is $60 \cdot 10^{-6}\ \frac{1}{.^o C}$.

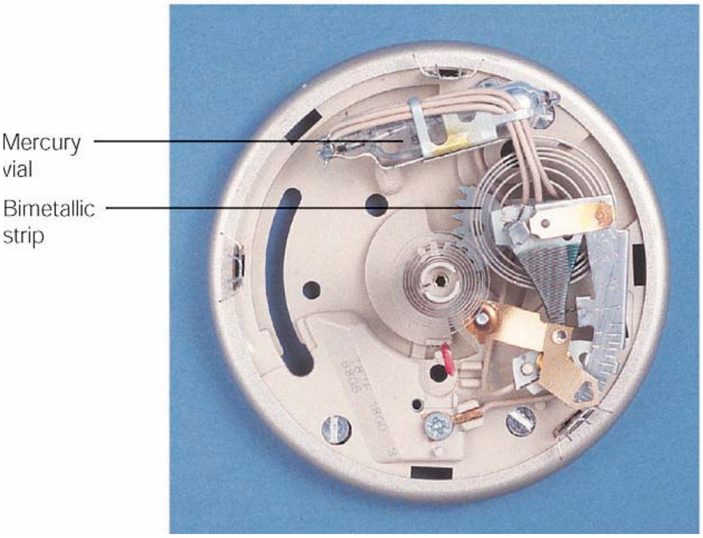
  $\Delta L = (L_f - L_i) = L_i \cdot \alpha \cdot \Delta T = 3cm \cdot 60 \cdot 10^{-6} \frac{1}{.^o C} \cdot (41^oC - 37^oC)$
-

Thermal Linear Expansion: application

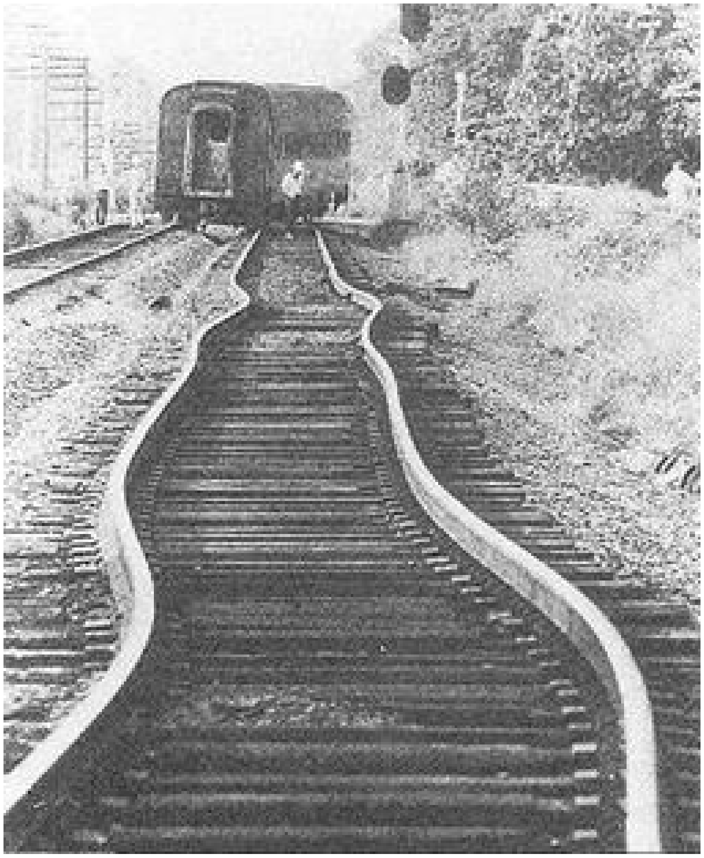
$$\Delta\ L=\left(L_{f\,-}L_i\right)=L_i\cdot\alpha\cdot\Delta T$$

- A bimetallic strip is two different metals, such as iron and brass, bonded together as a single unit, shown here at room temperatures.
- Since one metal expands more than the other, the strip will bend when it is heated.
- In this example, the brass expands more than the iron, so the bimetallic strip bends away from the brass.

Thermal Linear Expansion applications



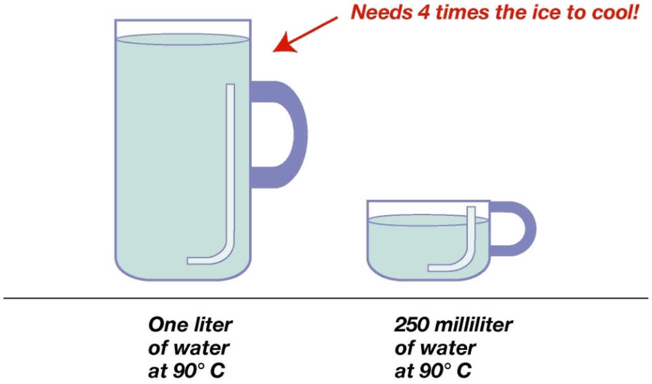
- This thermostat has a coiled bimetallic strip that expands and contracts with changes in the room temperature.
- The attached vial of mercury is tilted one way or the other, and the mercury completes or breaks an electric circuit that turns the heating or cooling system on or off.



-

Heat definition

- Heat, Q : one of the many forms energy can take
- The quantity of heat, Q absorbed or given off during a fixed change in temperature, ΔT
    - is proportional to the mass m of the substance.



$Q \sim m$

-
    - The quantity of heat, Q absorbed or given off to obtain different changes in temperature

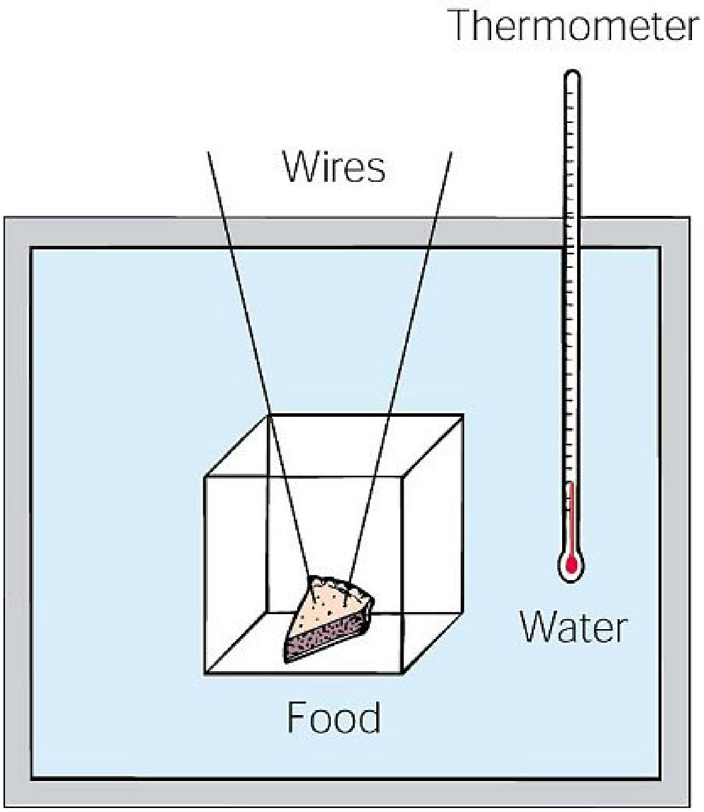
  $Q \sim (T_{f} - T_{i})$
- Putting this all together we get:

  $Q \sim m \cdot \Delta T \rightarrow Q = s \cdot m \cdot \Delta T$
- s: Specific heat- the energy needed to increase the temperature of $1 gram$ of a substance $1^{o}C$.
-

Measures of Heat.

- The metric unit of measuring work, energy, or heat is the joule.
- Another unit of heat is the calorie.
- A calorie is the amount of energy needed to increase the temperature of 1 gram of water 1^{o}C -from 14.5^{o}C to 15.5^{o} C.
- A kilocalorie is the amount of energy needed to increase the temperature of 1 kg of water $1^{o}C$.
-

The calorie value of food



- The Calorie value of food is determined by measuring the heat released from burning the food.
- If there is $10.0kg$ of water and the temperature increased from 10OC to 20^oC the food contained 100 Calories ($100,000$ calories).
- The food illustrated here would release much more energy than this.
-

Measures of Heat in the English system.

- Joule worked with the English system of measurement used during his time.
- When a 100 lb object falls 7.78 ft, it can do $778 ft \cdot lb$ of work.

- If the work is done against friction, as by stirring 1 lb of water, the heat produced by the work raises the temperature 1^oF.
-

Heat - units

- The English unit of heating is the BTU.
- A BTU is the amount of energy needed to increase the temperature of 1 lb of water 1^oF.
- A Quad is 1 quadrillion BTU 10^{15} BTU.
- 778 ft-lb = 1 BTU
- 4.184 ft-lb = 1 calorie
- 4,184 J = 1 kcalorie
-

• Specific Heat

- Specific Heat: the energy needed to increase the temperature of 1 gram of a substance $1^{o}C$.
- Three variables that influence energy transfer.
- Of these three metals, aluminum needs the most heat per gram per degree when warmed,
  - and releases the most heat when cooled.
- Why can you eat the bread out of a slice of pizza taken right out of the oven but not the cheese?
-

Variables that influence heat transfer

- The temperature change.
- The mass of the substance.
- The nature of the material being heated.
- The amount of heat Q needed to increase the initial temperature T_i of a pot of water to a final temperature T_f is proportional to $T_f - T_i$.
  $Q = m \cdot s \cdot (T_f - T_i) = m \cdot s \cdot \Delta T$
-

Example: Heat supplied

- How much heat must be supplied to $500.0g$ of water to increase its temperature from 20.0^oC to 30.0^oC ?
- Water has a specific heat of $1.0\,\frac{cal}{g\cdot{}^oC}$.

  $Q = m\cdot s\cdot\Delta T\rightarrow$

  $Q_w=(500.0g)\cdot\left(1.\frac{cal}{g\cdot{}^oC}\right)\cdot 10.0^oC=5,000cal$ or

  5 kcalories
-

Example: Heat supplied

- How much heat is needed to increase the temperature of $500.0g$ of lead from 20.0^oC to 30.0^oC ?
- Lead has a specific heat of $0.03\,\frac{cal}{g\cdot{}^oC}$

  $Q_{Pb} = m\cdot s\cdot\Delta T\rightarrow$

  $Q_{Pb}=(500.0g)\cdot\left(0.03\,\frac{cal}{g\cdot{}^oC}\right)\cdot 10.0^oC=150cal$ or 0.15 kcalories
-

Application: Heat supplied-problem

- How many calories of heat are required to increase the temperature of a $45kg$ person by 2.0^oC ?
- Iron from has a specific heat of $0.11\,\frac{cal}{g\cdot{}^oC}$.

  $Q = m\cdot c\cdot\Delta T\rightarrow$

  $Q_w=(4,500g)\cdot\left(1.\frac{cal}{g\cdot{}^oC}\right)\cdot 2.0^oC=9,000cal$ or 9 kcalories
-

Example: Heat supplied

- How much heat must be supplied to a $500.0g$ pan to increase its temperature from 20.0^oC to 100.0^oC if the pan is made of iron .
- Iron from table 5.2 has a specific heat of $0.11\,\frac{cal}{g\cdot{}^oC}$.

  $Q = m\cdot c\cdot\Delta T \rightarrow$

  $Q=(500.0g)\cdot\left(0.11\,\frac{cal}{g\cdot{}^oC}\right)\cdot 80.0^oC=4,400cal$ or 4.40 kcalories
-

Example: Heat supplied

- How much heat must be supplied to a $500.0g$ pan to increase its temperature from 20.0^oC to 100.0^oC if the pan is made of and aluminum.
- Aluminum from table 5.2 has a specific heat of $0.22\,\frac{cal}{g\cdot{}^oC}$

  $Q = m\cdot c\cdot\Delta T \rightarrow$

  $Q=(500.0g)\cdot\left(0.22\,\frac{cal}{g\cdot{}^oC}\right)\cdot 80.0^oC=8,800cal$ or 8.80 kcalories
-

Heat as a conserved quantity

- When two materials of different temperatures are involved in heat transfer
- and are perfectly insulated from the surroundings,
- the heat lost by one is equal to the heat gained by the other.

  $Q_{lost}=Q_{gained} \rightarrow$

  $m_1\cdot c_1\cdot\Delta T_{lost} = m_2\cdot c_2\cdot\Delta T_{gained}$
- m_1 mass of the object that gives off (loses) heat
- m_2 mass of the object that absorbs (gains) heat
-

Other Causes of temperature changes

Energy conversion: potential into heat

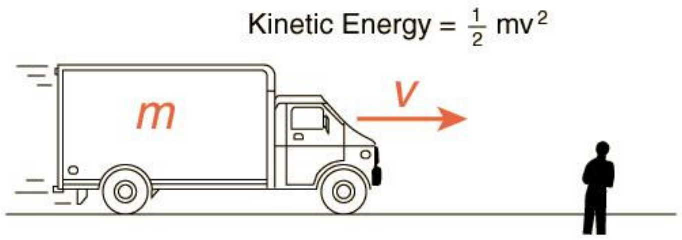
- Determine the T change for a lead ball dropped from 20 meters assuming that only half of the thermal energy generated on impact goes into the ball.
  $m{\cdot}g{\cdot}\frac{h}{2}{=}Q{=}m{\cdot}s{\cdot}\ \Delta\ T \rightarrow$

  $$\Delta\ T{=}\frac{g\cdot h}{2\cdot s}{=}\frac{g\cdot 10}{2\cdot s}{=}\frac{9.8\,\frac{m^2}{s^2}\cdot 10m}{2\cdot 0.03\,\frac{kcal}{kg\cdot {}^oC}\cdot 4186\,\frac{\left(kg\cdot\frac{m^2}{s^2}\right)}{kcal}}\rightarrow$$

  $$\Delta\ T{=}\frac{98}{2\cdot 0.03\cdot 4186}{=}0.07^oC$$
-

A car as a deadly weapon; energy conversion

- A 2,200.0 kg automobile is moving at $56\,\frac{mi}{hr}=25.0\,\frac{m}{s}$. How many kilocalories are generated when the car brakes to a stop?



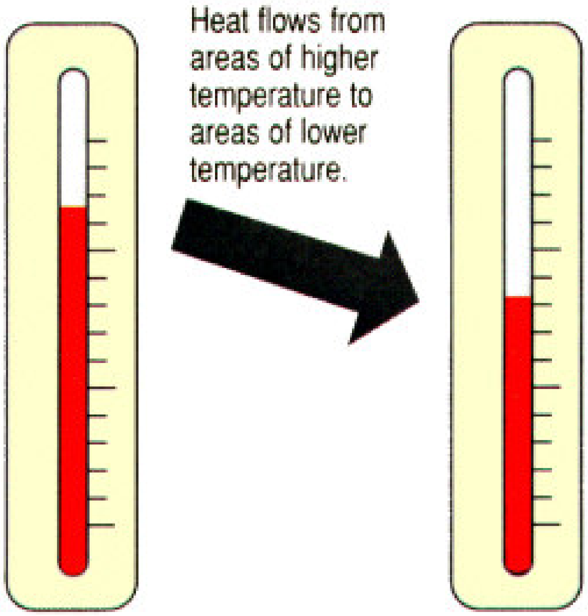
$$KE=\frac{1}{2}m\cdot v^2\ KE=\frac{1}{2}\cdot(2,200kg)\cdot\left(25.0\,\frac{m}{s}\right)^2=(1,100kg)\cdot\left(625.0\,\frac{m^2}{s^2}\right){=}687,500kg\cdot\frac{m^2}{s^2}=\ 687,500J=$$

$$=687,500J\cdot\frac{1kcal}{4,184J}\ =164\ kcalories$$

-

Heat as transferred energy

- HEAT is energy in transit from a high temperature object to a lower temperature object.



- An object does not possess "heat".
- Heat flow and work are both ways of transferring energy.
-

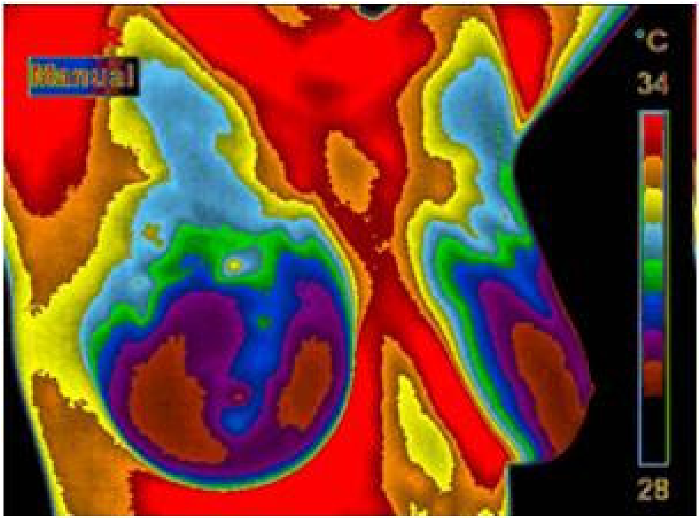
Heat as Energy Transfer.

- Heat is a measure of the total internal energy that has been absorbed or transferred from one body to another.
- Increasing the internal energy is called heating.
- Decreasing the internal energy is called cooling.
- Heat, Q characterizes a process
- T characterizes a state
-

Diagnostic and therapeutic Uses of Heat/Cold

- Relieving pain heat applied to a sore muscle
- Muscle relaxes, blood flow increases to decrease T
- Microwave or ultrasound diathermy depositing Q into the body locally
- Low T act as anesthetic
  - Cryosurgery - low T → metabolic rate drops
- Freezing small parts of the brain to treat Parkinsons
-

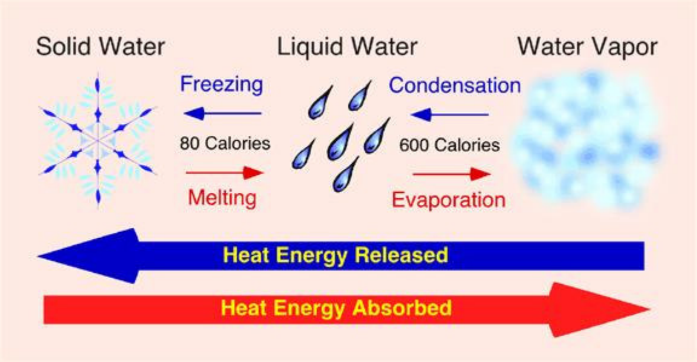
Diagnostic Uses of Heat



- Thermography : mapping T, elevated T malignant tumor, more blood flow to cool down
- Metabolic activity and vascular circulation in both pre-cancerous tissue and the area surrounding a developing breast cancer is almost always higher than in normal breast tissue.
-
-

TO BE CONTINUED: Phase changes

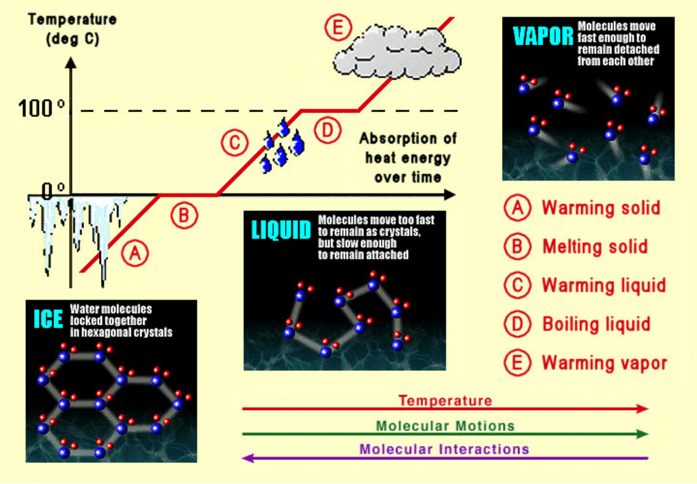
- When a substance changes from one state to another, the transition is called a phase change. [LINK - phase changes movie]
- A phase change always absorbs or releases energy, a quantity of heat that is not associated with a temperature change.



- Latent heat is the hidden energy of a phase change, which is energy that goes in or comes out of internal potential energy.
  - the energy required to accomplish the phase change.
-

Solid, liquid, gas transition

- A phase transition can occur when enough heat is supplied



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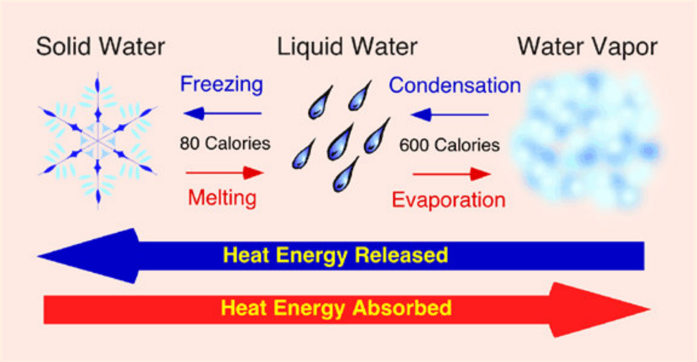
Phase transitions

- Three major types of phase change.
- Solid-liquid.
- Liquid-gas.



- Solid-gas
-

Solid-liquid phase change

- Solid-liquid phase change occurs at the same temperature.

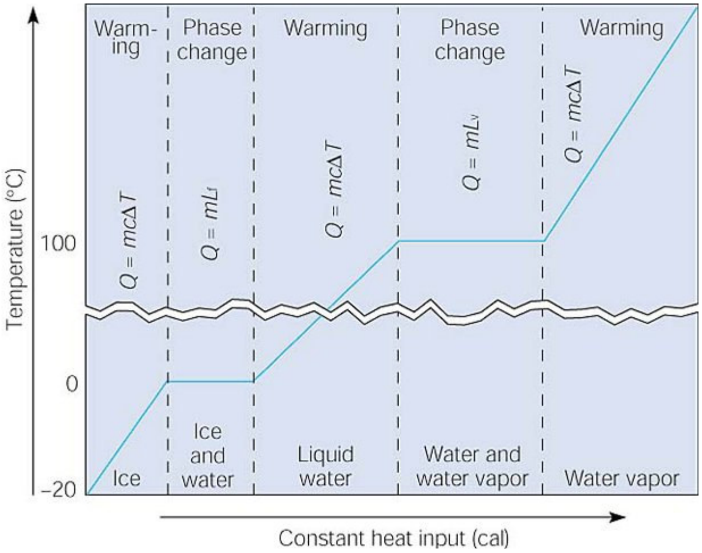
- The temperature at which a substance changes from a liquid to a solid is called the freezing point.
- LINK: Phase changes (4017.0K)
- The temperature at which a solid changes to a liquid is the melting point.
-

Liquid-gas phase change

- Liquid-gas phase change occurs at the same temperature.
- The temperature at which a liquid changes from the liquid phase to the gaseous phase is the boiling point.
- The temperature at which a gas or vapor changes to the liquid phase is the condensation point.
-

Solid-gas phase change

- A phase change directly from a solid to a gas or vapor is called sublimation.



- The relationships between
- [LINK: Sublimation (3584.0K)]
  - Heat is absorbed during warming and phase changes as water is warmed from ice at -20^oC to water vapor at some temperature above 100^oC.
- Note: the specific heat for ice, liquid water, and water vapor (steam) have different values.

Solid-gas phase change

Specific Heat: perspiration

- The great cooling effect produced by water evaporating comes from its high

- a. conductivity.
- b. specific heat.
- c. latent heat.
- d. transparency.
-

Latent heat of fusion.

- The latent heat of fusion is the heat involved in a solid-liquid phase change in melting or freezing.
- A melting solid absorbs energy and a freezing liquid releases this same amount of energy, warming the surroundings.
- The total heat involved in a solid-liquid phase change depends on the mass of the substance involved.
  $Q_f = m \cdot L_f$
- L_f is the latent heat of fusion for the substance involved
-

Latent heat of vaporization

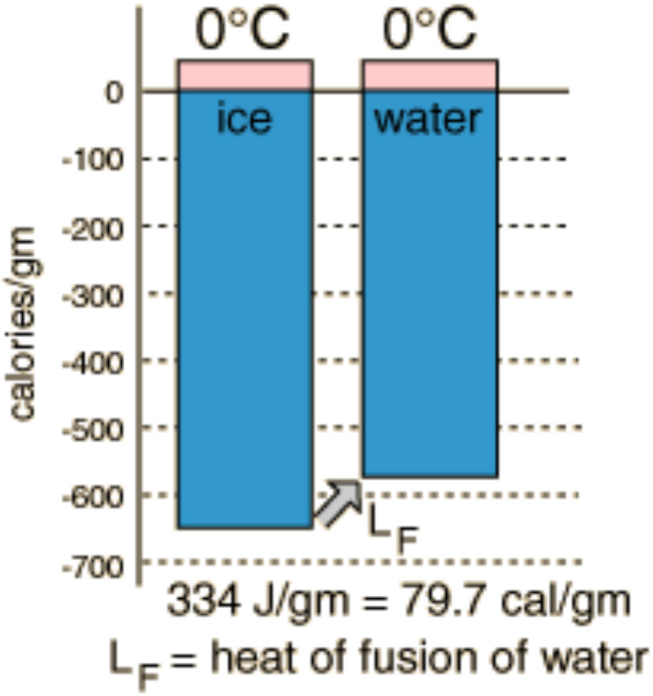
- The amount of heat involved during a phase change from a liquid to a gas or vapor is called the latent heat of vaporization.
- Q depends on the amount of water vapor that condenses:
  $Q_v = m \cdot L_v$
  - L_v involved in a liquid-gas phase change where there is evaporation or condensation.
  - The escaping molecules absorb energy from the surroundings, and a condensing gas releases this exact same amount of energy.
- L_v is the latent heat of vaporization for the substance involved.
-

Application: reducing body's T

- How many grams of alcohol must be evaporated from the surface of a $70kg$ person to reduce his T by 2^oC ?
- Solution:
  $m_{alcohol} \cdot L_V = c_b \cdot m_b \cdot \Delta T \rightarrow m_{alcohol}$
- $L_V = 0.8 \frac{J}{kg}$
-

Example: solidification

- How much energy does a refrigerator remove from $100.0g$ of water at 20.0^oC to make ice at (minus) -10.0^oC



- Three steps.
  $Q_1 = Q_{20.0^oC \rightarrow 0^oC} = m \cdot c \cdot \Delta T$ to cool from 20.0^oC to$0^oC \rightarrow$
  $Q_1 = 100.0g \cdot 1.00 \frac{cal}{g^oC} \cdot (0.0^oC - 20.0^oC) = -2,000cal$
-

Step two: fusion

$$Q_2 = Q_f = m \cdot L_f = 100.0g \cdot 80.0 \frac{cal}{g} = 8,000cal$$

$$Q_3 = Q_{0.0^oC \rightarrow -10^oC} = 100.0g \cdot 0.500 \frac{cal}{g} \cdot (-10.0^oC - 0.0^oC) = -500cal \rightarrow$$

$$Q_{total} = Q_1 + Q_2 + Q_3 = -2,000 + (-)8,000 + (-)500cal$$

-

Evaporation and Condensation.

- Evaporation occurs when enough energy is inputed into a system to cause liquid molecules to overcome attractive forces near the surface, escape, and become a gas or vapor.
- In evaporation, more molecules are leaving the liquid state than are returning.
- In condensation, more molecules are returning to the liquid state than are leaving.
- When the condensation rate is equal to the evaporation rate,
- the air above the liquid is saturated (holds all the vapor that it is capable of holding).
-

Increasing the rate of evaporation.

- An increase in temperature of the liquid will increase the average kinetic energy of the molecules
  - thus increase the number of high energy molecules capable of escaping from the liquid state.
  - Increase the surface area of the liquid in contact with the air.
- Because of the large heat of vaporization of water, the evaporation from a liquid surface is a very effective cooling mechanism.
- The human body makes use of evaporative cooling by perspiration
- to give off energy even when surrounded by a temperature higher than body temperature.
- The cooling process is an example of the approach to thermal equilibrium.
-

- Removal of water vapor from near the surface will prevent the return of molecules to the liquid phase.
- Reducing atmospheric pressure will reduce one of the forces holding molecules in a liquid.
-

- The laws of thermodynamics describe what happens to energy as it is transformed into work and to other forms.
- Thermodynamics is concerned with internal energy, which is the total internal kinetic and potential energy of a system.
- The system is the component we want to describe.
- The state of the system are the variable under which it exists, temperature, pressure, volume, heat, etc…
- Everything outside of the system is the surroundings.
- A very simple heat engine. The air in (B) has been heated, increasing the molecular motion and thus the pressure.
- Some of the heat is transferred to the increased gravitational potential energy of the weight as it is converted to mechanical energy.
-

- The First Law of Thermodynamics.
- The energy supplied to a system is equal to the change in internal energy
- The total increase in the thermal energy of a system is the sum of the work done on it and the heat added to it.
- (Conservation of Energy)
- A heat engine can convert thermal energy into mechanical energy.
- 1. A heat source and cold source are needed.
- 2. Heat moves from warm to cold.
- 3. In the process, mechanical work can be done.
-

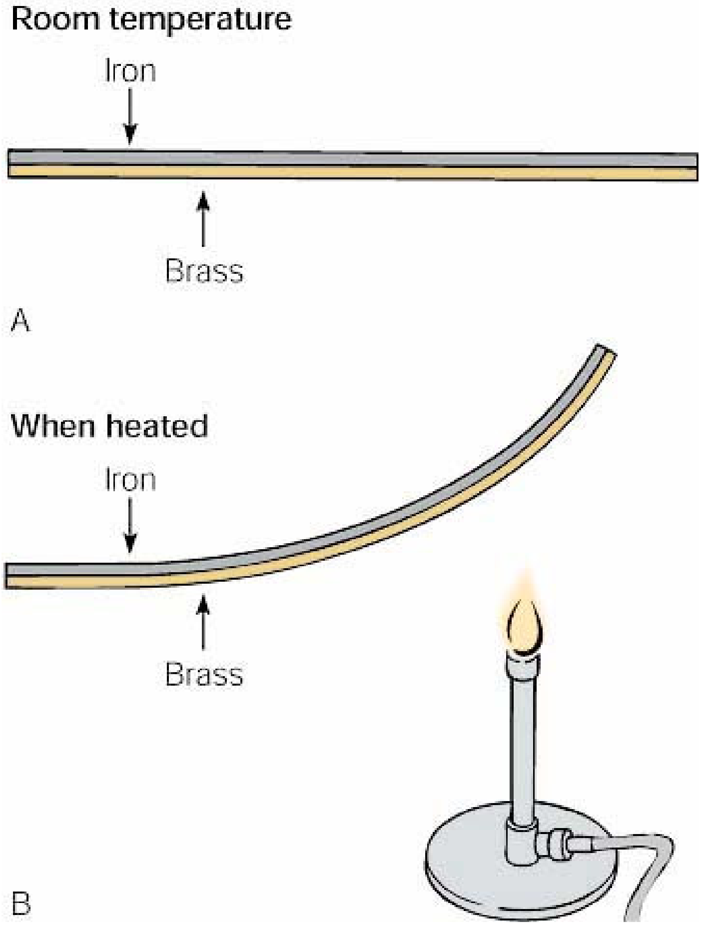
- The Second Law of Thermodynamics.
- Heat flows from objects with a higher temperature to objects with a cooler temperature.
- Natural processes go in a direction that increases the total entropy of the universe.
- a measure of the disorder.
- measure of the "multiplicity" associated with the state of the objects
- Heat only flows from hot to cold.
- No system is $100\,\%$ efficient.
- Entropy occurs on a small scale - bedroom
- The universe is gradually cooling down due to entropy.
- Energy consumption always → disorder
-

- The heat supplied QH to a heat engine goes into the mechanical work W and the remainder is expelled in the exhaust (QL).
- The work accomplished is therefore the difference in the heat input and output $Q_H - Q_L$,
- so the work accomplished represents the heat used, $W = J \cdot (Q_H - Q_L)$
- A heat pump uses work (W) to move heat from a low temperature region Q_L to a high temperature region Q_H.
- The heat moved Q_L requires work W, so J $Q_L = W$.
-

- Entropy.
- Energy is always degrading toward a more disorderly state.
- The total entropy of the universe is continually increasing.
- The natural process is for the sate of order to degrade into a state of disorder with a corresponding increase in entropy.
-

- Eventually all of the useable energy in the universe will diminish to unusable forms.
- The universe will at some time reach a limit of disorder called the heat death of the universe.
- The heat death of the universe is the theoretical limit of disorder,
- with all molecules spread far, far apart,
- vibrating slowly
- with a uniform low temperature.
-

- Temperature is associated with the average energy of the molecules of a
- substance. These numbered circles represent arbitrary levels of molecular kinetic energy that, in turn, represent temperature.



- The two molecules with the higher kinetic values [25 in (A)] escape, which lowers the average value from 11.5 to 8.1 (B).
- Thus evaporation of water molecules with more kinetic energy contributes to the cooling effect of evaporation in addition to the absorption of latent heat.
-

Ch 17 problem

- Distribution of speeds for molecules in this classroom LINK swf
- The average magnitude of the speeds of the molecules in a gas: $v_{av}^2 = \frac{3 \cdot k_B \cdot T}{m} = \frac{N_A \cdot 3 \cdot k_B \cdot T}{N_A \cdot m} = \frac{3 \cdot R \cdot T}{m} \rightarrow$
- The square root of v_{av}^2 is referred to as the root-mean-square (rms) speed:
- $$v_{rms} = \sqrt{\left(3 \cdot R \cdot \frac{T}{M}\right)}$$

Ch 17 problem

- * By what factor must the absolute temperature of a gas be increased to double the rms speed of its molecules?
- $$v = \sqrt{\left(3 \cdot R \cdot \frac{T}{M}\right)}$$

Ch 17

- A vessel holds a mixture of helium, He and methane, CH_4.
  Calculate the ratio of the rms speed of the He atoms to that of the CH_4 molecules !
- Solution:
  $$\frac{v_{RMS,He}}{v_{RMS,CH_4}} = \frac{\frac{\sqrt{3RT}}{\sqrt{M_{He}}}}{\frac{\sqrt{3RT}}{\sqrt{M_{CH_4}}}}$$
- where M is the molar mass .

  What's the molar mass of methane and helium ?
-

Ch 17

- Which speed is greater, the speed of sound in a gas or the rms speed of the molecules of the gas ?
- Solution:
- The speed of sound in an IDEAL gas

  $v_{RMS}=\frac{\sqrt{3RT}}{\sqrt{M}}$
- The speed of sound in a real gas

  $v_{RMS}=\frac{\sqrt{\gamma RT}}{\sqrt{M}}$

  For a monatomic gas, $\gamma = 1.67$ whereas for a diatomic gas, $\gamma = 1.40$.

  Classroom task : Calculate their ratio !
-

Links

http://oyc.yale.edu/front-page/

http://freevideolectures.com/Course/76/PHYS-1A-Mechanics

http://freevideolectures.com/Course/2139/Physics-I-Classical-Mechanics

http://www.techsupportalert.com/content/easy-way-use-linux-windows.htm

http://oedb.org/library/beginning-online-learning/200-free-online-classes-to-learn-anything

-

These notes only make sense to those student that were in attendance!

Is hell endothermic or exothermic?

Do you have to supply heat to hell to maintain as such?

heat a form of energy=

As mass enters hell, mass that has $T_i then$T of hell decreases

$Q = m \cdot c \cdot \ \Delta T = m \cdot c \cdot \left(T_{f\_}T_i\right)$

cold spoon in a hot coffee → $Q_{\text{from hot coffee to the cold spoon}}$

Do you replace spark plugs when the engine is hot?

as T↑ expansion

$T_k = 400K = T_F = 1.8 \cdot 26.85 + 32 = 80.330^oF$

mass=m → kg,

time=t → sec,

distance=d→meters

mole → 1mole → $N_A = 6.023 \cdot 10^{23}$

1 g of H → 1mole

T → Kelvin

if there is no translational kinetic at a molecular level → $T_{\text{absolute}} = 0$

$K_{\text{rotatinal}} = I \cdot \frac{\omega^2}{2}$

air → 78.5 % nitrogen N_2, 20.5 % → O_2,

$v_{O_2} >$
O_8^{16}

N_7^{14}

$$\frac{T_F - 32}{1.8} = T_C$$

$T_K = T_C + 273.15$

$T_C = TK - 273.15$

$T_K \to T_C \to T_F$

$T_F = 1.8 \cdot T_C + 32$

$y = m \cdot x + b$

$T_F \to y\text{axis}$

$T_C \to \text{x axis}$

→straight line whose slope, m=1.8

$\circ\, b = 32^o F$

Task 1: calculate the temperature in degrees Celsius corresponding to $28^o F$!

$$c_{\text{water}} = 1 \frac{\text{cal}}{g \cdot {}^o C}$$

1 cal=4.184 J

$J \neq kg \cdot {}^o C$

$Q = c \cdot m \cdot \ \Delta\, T \to c$

$c = \text{specific heat} = \dfrac{J}{kg \cdot {}^o C}$ how many Joules of energy in forms of heat you add per unit mas/per kg to obtain a change of $1^o C$

$$c_{\text{water}} = 4860 \frac{J}{kg \cdot {}^oC} = 4.84 \frac{J}{g \cdot {}^oC} \rangle c_{\text{substance}}$$

$$\Delta T = (15.5 - 14.5) = 1^oC$$

$V = \text{constant} = \text{isovolumetric} = \text{isochoric} \rightarrow \Delta V = 0 \rightarrow V_f = V_i$

$p = \text{constant} = \text{process} = \text{isobaric} \rightarrow \Delta p = p_f - p_i = 0$

$T = \text{constant} = \text{isothermal}\ \Delta T = 0$

$Q_{\text{transferred in or out}} = 0 \rightarrow \text{adiabatic process}$

Lift up 0.1 kg=1000 grams =TV remote 1 meter above ground you'll need 1 Joule of energy

$J \neq kg \cdot {}^oC$

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$Task2$: Is $\alpha_{\text{brass}} >$

$$\alpha = \frac{\Delta\, L}{L_i} \cdot \frac{1}{\Delta\, T} = \frac{L_{f\,-}L_i}{L_i} \cdot \frac{1}{\Delta\, T} \rightarrow \frac{1}{C}$$

$$\beta_{\text{volumic}} = 3 \cdot \alpha$$

$$p \cdot V = nR \cdot T$$

$n =$ no of moles

$R =$ universal gas constant

$V_{\text{air in lungs}} \uparrow p_{\text{air inside lungs}} \downarrow$

$$p_i V_i = nRT_i$$

$$p_f V_f = nRT_f$$

$$\frac{p_i V_i}{p_f V_f} = \frac{nRT_i}{nRT_f}$$

$$\frac{V_i}{V_f} = \frac{T_i}{T_f} \rightarrow$$

$$\frac{V_f}{V_i} = \frac{T_f}{T_i} = \frac{40 + 273.15}{20 + 273.15} = 1.068$$

$$V_f = 1.068 \cdot V_i$$

$$N = n_{\text{moles}} \cdot N_A = 0.89232 \cdot 6.023 \cdot 10^{23} = 5.37 \cdot 10^{23} \text{particles}$$

$$nR = N_{\text{particles}} \cdot k_B$$

$E_{\text{internal}} \sim T$

$E_{\text{internal}} = \frac{3}{2} nRT$

$E_{\text{internal}} = \frac{3}{2} N_{\text{particles}} \cdot k_B T$

$N_{\text{particles}} m \frac{v^2}{2} = \frac{3}{2} N_{\text{particles}} \cdot k_B T$

$v = \sqrt{\frac{3k_B T}{m}}$

$v \sim \sqrt{T}$

$T \to 4T \to v \uparrow$ by a factor of $\sqrt{4} = 2$

$v \sim \frac{1}{\sqrt{M}}$

Do O molecules move faster than N molecules at a fixed $T = 20^o C = (20 + 273.15)K$?

$M_O = 2 \cdot 16 = 32g$

$M_N = 2 \cdot 14 = 28g \leftarrow \ = 6.023 \cdot 10^{23}$molecles

$v_O = \sqrt{\frac{3RT}{M_O}}$

$v_N = \sqrt{\frac{3RT}{M_N}}$

$\frac{v_o}{v_N} > 1 \to v_O > v_N$

$$\frac{v_o}{v_N} = \frac{\sqrt{\frac{3RT}{M_O}}}{\sqrt{\frac{3RT}{M_N}}} = \sqrt{\frac{\frac{3RT}{M_o}}{\frac{3RT}{M_n}}} = \sqrt{\frac{\frac{1}{M_0}}{\frac{1}{M_N}}} = \frac{M_N}{M_o} = \frac{28}{32} < 1$$

$$v_o = 0.875 \cdot v_N$$

$$v_n > v_O$$

$$K_O = m_O \cdot \frac{v_O^2}{2}$$

$He_2^4 \rightarrow M_He = 2 \cdot 4 = 8g$ per mole

initially: $pV = nRT \rightarrow V_i = \frac{nRT}{p}$

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finally: $\frac{1}{3}pV = \frac{n}{2}R2T \rightarrow V_{f=} \frac{\frac{n}{2}R2T}{\frac{1}{3}pV} = 3\frac{nRT}{pV}$

$$pV = n_{\text{moles}}RT_K$$

$$pV = N_{\text{particles}}k_BT_K$$

$$n_{\text{moles}}R = N_{\text{particles}}k_B$$

$$p_iV_i = n_{\text{moles}}RT_i$$

$$p_fV_f = n_{\text{moles}}RT_f$$

$$V_i = V_f$$

$$\frac{p_iV_i}{p_fV_f} = \frac{n_{\text{moles}}RT_i}{n_{\text{moles}}RT_f}$$

$$\frac{p_i}{p_f} = \frac{T_i}{T_f} \rightarrow p_f$$

$$p_{f=}p_i \cdot \frac{T_f}{T_i} = 200 \cdot \frac{50 + 273.15}{20 + 273.15} = 220.46kPa = 220000.46\,\frac{N}{m^2}$$

Task 3: calculate p_f if tires expand by 10%

$$V_f = V_i + V_i \cdot \frac{10}{100} = V_i \cdot (1 + 0.1) = V_i \cdot 1.1$$

$$\frac{V_f}{V_i} = \frac{V_i \cdot 1.1}{V_i}$$

Task 1: calculate the temperature in degrees Celsius corresponding to 28^oF!

$$p_i V_i = n_{\text{moles}} R T_i$$

$$p_f V_f = n_{\text{moles}} R T_f$$

$$V_i = V_f$$

$$\frac{p_i V_i}{p_f V_f} = \frac{n_{\text{moles}} R T_i}{n_{\text{moles}} R T_f}$$

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$$T_k = 400K = T_F = 1.8 \cdot 26.85 + 32 = 80.330^oF$$

$R = 0.0821 = \dfrac{L \cdot atm}{\text{mole} \cdot K}$ when V in L and p is in atm

$R = 8.315 \dfrac{J}{\text{mole} \cdot K} \leftarrow$ when V in m^3 and p is in $\dfrac{N}{m^2}$

$$\Delta L = 3 \cdot 60 \cdot 10^{-6} \cdot 4 = 0.00072cm = 0.0072mm$$

$78.5\,\% \rightarrow N_7^{14} \leftarrow$

$20.5\,\% \rightarrow O_8^{16}$

$N_2 \rightarrow$ anesthetic

$$K = m \cdot \frac{v^2}{2} = \frac{p^2}{2m}$$

$$p = m \cdot v$$

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