Heat vs Temperature
Temperature – What is it?

Measure of how **hot** or **cold** something feels

Temperature is the average **Kirsinetic Energy** of the molecules of a substance

The faster the particles move, the more temperature **increases**

Circle the container with the highest temperature

Quantitative or Qualitative?

**Kinetic Energy**

\[ E_K = \frac{1}{2}mv^2 \]

More velocity
Does an object’s mass affect its temperature (average kinetic energy)?

No!

More mass does not affect the average KE.
Heating Objects

When most objects are heated they expand.

Old thermometers use mercury because of its uniform thermal expansion.
Total Internal Energy

\[ E_{\text{INT}} = E_K + E_P \]

Kinetic Energy

Potential Energy

State of Matter

Temperature
Temperature Scales

It is important that we can quantify temperature.

Which temperature scale is the most precise?

Fahrenheit (smallest increments)

On which temperature scale(s) would an increase of one degree be largest?

Celsius or Kelvin
Absolute Zero

At absolute zero, all molecules stop moving.

-273.15°C is the coolest.
Celsius and Kelvin

\[ T (K) = T (^\circ C) + 273 \]

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40°C</td>
<td>233 K</td>
</tr>
<tr>
<td>0°C</td>
<td>273 K</td>
</tr>
<tr>
<td>22°C</td>
<td>295 K</td>
</tr>
<tr>
<td>100°C</td>
<td>373 K</td>
</tr>
</tbody>
</table>
Temperature Scales

Fahrenheit

0° - Really cold outside
100° - Really hot outside

Celsius

0° - Fairly cold outside
100° - Dead

Kelvin

0 - Dead
100 - Dead

Did you hear about the man who got cooled to absolute zero?
He's OK now.
Temperature

Which has a higher temperature?

Burning Match

Ice Sculpture
Heat is the **transfer** of energy

Always flows from **hot** to **cold**
Heat Flow

Which is correct?

Heat flows from the hand to the ice cube

Heat flows from the ice cube to the hand
Why does heat flow?

Fast moving particles collide with slow moving particles and increase their velocity, kinetic energy, and temperature.
Does an object’s mass affect its heat energy (total kinetic energy)?

Yes! More mass means larger total energy.
Heat Energy

Which has more heat energy?

- Burning Match
- Ice Sculpture

More Mass = Larger Total Energy
Specific Heat
**Conductors and Insulators**

<table>
<thead>
<tr>
<th><strong>Conductor</strong></th>
<th>A material through which energy can be easily transferred as heat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Insulator</strong></td>
<td>A material that transfers energy poorly</td>
</tr>
</tbody>
</table>
Specific Heat is the amount of \textbf{Energy} required to raise the temperature of 1 kg of a substance by 1 K.

Specific Heat of Copper:

\[390 \text{ J kg}^{-1} \text{ K}^{-1}\]
Specific Heat

The **Lower** the number, the less energy it takes to heat up.

1) Which substance take the most energy to heat up?

   **Water**

2) Which substance take the least energy to heat up?

   **Lead**

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Heat (J kg(^{-1}) K(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>910</td>
</tr>
<tr>
<td>Copper</td>
<td>390</td>
</tr>
<tr>
<td>Iron</td>
<td>448</td>
</tr>
<tr>
<td>Lead</td>
<td>130</td>
</tr>
<tr>
<td>Water</td>
<td>4180</td>
</tr>
<tr>
<td>Air</td>
<td>1000</td>
</tr>
<tr>
<td>Dry Earth</td>
<td>1250</td>
</tr>
</tbody>
</table>
## Specific Heat

Which metal will heat up faster, Aluminum or Iron?

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Heat (J kg(^{-1}) K(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>910</td>
</tr>
<tr>
<td>Copper</td>
<td>390</td>
</tr>
<tr>
<td><strong>Iron</strong></td>
<td><strong>448</strong></td>
</tr>
<tr>
<td>Lead</td>
<td>130</td>
</tr>
<tr>
<td>Water</td>
<td>4180</td>
</tr>
<tr>
<td>Air</td>
<td>1000</td>
</tr>
<tr>
<td>Dry Earth</td>
<td>1250</td>
</tr>
</tbody>
</table>

- Image of Aluminum
- Image of Iron
Specific Heat

If Iron heats up faster based on its specific heat, then why do aluminum fry pans heat up faster?

more mass

<table>
<thead>
<tr>
<th>Aluminum Skillet</th>
<th>Iron Skillet</th>
</tr>
</thead>
<tbody>
<tr>
<td>C = 910 J kg(^{-1}) K(^{-1})</td>
<td>C = 448 J kg(^{-1}) K(^{-1})</td>
</tr>
</tbody>
</table>
### Specific Heat Equations

The equation relating heat energy, mass, specific heat, and change in temperature is:

\[ Q = mc\Delta T \]

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Energy</td>
<td>( Q )</td>
<td>([ J ])</td>
</tr>
<tr>
<td>Mass</td>
<td>( m )</td>
<td>([ kg ])</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>( c )</td>
<td>([ J \ kg^{-1} K^{-1} ])</td>
</tr>
<tr>
<td>Change in Temp</td>
<td>( \Delta T )</td>
<td>([ K ] ) or ([ ^\circ C ])</td>
</tr>
</tbody>
</table>
Specific Heat Calculations

How much energy is needed to increase the temperature of 0.755 kg of iron 20 K?

\[ Q = mc\Delta T = (0.755)(448)(20) \]

\[ Q = 6,765 \text{ J} \]

How much energy must a refrigerator absorb from 0.225 kg of water to decrease the temperature of the water from 35 °C to 5 °C?

\[ Q = mc\Delta T = (0.225)(4180)(5 - 35) \]

\[ Q = -28,215 \text{ J} \]
More Specific Heat Calculations

Air has a density of 1.3 kg m\(^{-3}\) and a specific heat capacity of 1000 J kg\(^{-1}\) K\(^{-1}\). If 500 kJ was transferred to a room of volume 80 m\(^3\), what was the temperature rise?

\[
Q = 500,000 \text{ J}
\]

\[
c = 1000 \text{ J kg}^{-1} \text{ K}^{-1}
\]

\[
m = D \times V = (1.3)(80) = 104 \text{ kg}
\]

\[
\Delta T = \frac{Q}{mc} = \frac{500,000}{(104)(1,000)}
\]

\[
\Delta T = 4.81 \text{ K}
\]

How long will it take a 2.20 kW kettle to raise the temperature of 800 g of water from 16.0°C to its boiling point if the specific heat capacity of water is 4180 J kg\(^{-1}\) K\(^{-1}\)?

\[
Q = mc\Delta T = (0.8)(4180)(100 - 16) = 280,896 \text{ J}
\]

\[
2.2 \text{ kW} = 2,200 \text{ W} = 2,200 \text{ J s}^{-1}
\]

\[
\frac{280,896 \text{ J}}{2,200 \text{ J s}^{-1}} = 128 \text{ s}
\]
Conservation of Heat

If our system is closed to the surroundings, heat must be conserved.

Heat energy lost by the metal

Heat energy gained by the water
Conservation of Heat

Heat energy gained by the water = heat energy lost by the metal

If you have 0.05 kg of water at 20°C and you put in 0.031 kg of an unknown substance that is originally 100°C, you measure that the final temp of everything is 25°C. What is the unknown metal?

Step 1: Find the Heat Energy of the Water

\[ Q = mc\Delta T = (0.05)(4180)(25 - 20) \]

\[ Q = 1,045 \text{ J} \]
Conservation of Heat

Heat energy gained by the water = heat energy lost by the metal

If you have 0.05 kg of water at 20°C and you put in 0.031 kg of an unknown substance that is originally 100°C, you measure that the final temp of everything is 25°C. What is the unknown metal?

Step 2: Using the heat energy step one. Find mystery specific heat

\[ 1,045 \text{ J} = mc\Delta T = (0.031)(c)(100 - 25) \]

\[ c = 449 \text{ J kg}^{-1} \text{ K}^{-1} \]
Conservation of Heat

Heat Transfer between Metal and Water

- **Metal:** Copper
- **Specific Heat:** 0.385 J/g·K
- **Mass:** 120.00 g
- **Temperature:** 100.00 °C

- **Water**
  - **Mass:** 60.00 g
  - **Temperature:** 20.00 °C
  - **Specific Heat of Water:** 4.18 J/g·K

Graph and Temperature Data: 32.42 °C
# Specific Heat Lab

Measure the specific heat of the metal nuts

<table>
<thead>
<tr>
<th>Water</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>0.06 kg</td>
</tr>
<tr>
<td>Initial Temp</td>
<td>20°C</td>
</tr>
<tr>
<td>Final Temp</td>
<td>32.42°C</td>
</tr>
<tr>
<td>Change in Temp</td>
<td>12.42°C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metal Pieces</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>0.12 kg</td>
</tr>
<tr>
<td>Initial Temp</td>
<td>100°C</td>
</tr>
<tr>
<td>Final Temp</td>
<td>32.42°C</td>
</tr>
<tr>
<td>Change in Temp</td>
<td>67.58°</td>
</tr>
</tbody>
</table>

Specific Heat of Water

\[
Q = mc\Delta T = (0.06)(4180)(12.42) = 3,115 \text{ J}
\]

Specific Heat of Metal

\[
c = \frac{Q}{mc} = \frac{3,115}{0.12(384)} = 384 \text{ J kg}^{-1} \text{ K}^{-1}
\]
# Review of Specific Heat

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Energy</td>
<td>Q</td>
<td>[J]</td>
</tr>
<tr>
<td>Mass</td>
<td>m</td>
<td>[kg]</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>c</td>
<td>[J kg$^{-1}$ K$^{-1}$]</td>
</tr>
<tr>
<td>Change in Temp</td>
<td>$\Delta T$</td>
<td>K or °C</td>
</tr>
</tbody>
</table>

$$Q = mc\Delta T$$
A 5 g lead bullet moving at 263 m s\(^{-1}\) is stopped in a block of wood. All of the kinetic energy goes into heat energy added to the bullet. The initial temperature of the bullet is 24 ℃. What is the final temperature of the bullet in ℃?

**Kinetic Energy (KE) → Heat Energy (Q)**

\[
\frac{1}{2}mv^2 = mc\Delta T
\]

\[
\frac{1}{2}(263)^2 = (128)\Delta T
\]

\[
\Delta T = 270^\circ\text{C}
\]

\[
T_f = 24 + 270
\]

\[
T_f = 294^\circ\text{C}
\]
10. Object P has a mass $m_P$ and specific heat capacity $c_P$. Object Q has a mass $m_Q$ and specific heat capacity $c_Q$. The temperature of each object increases by the same amount. Which of the following gives the ratio of thermal energy transferred to object P to thermal energy transferred to object Q?

\[
\frac{Q_P}{Q_Q} = \frac{m_P c_P \Delta T_P}{m_Q c_Q \Delta T_Q} = \frac{m_P c_P}{m_Q c_Q}
\]

A. \( \frac{m_P c_Q}{m_Q c_P} \)

B. \( \frac{m_P c_P}{m_Q c_Q} \)

C. \( \frac{m_Q c_Q}{m_P c_P} \)

D. \( \frac{m_Q c_P}{m_P c_Q} \)
Heating Curve

- **SOLID**
- **LIQUID**
- **GAS**

Temperature (°C): 0°C, 100°C
Melting Point

Plateau: A state of little or no change in a graph. This indicates a change in state of matter.
Why a Plateau?

Bonds are breaking as solid changes to liquid and then again when liquid changes to gas. This takes time!
Adding Heat | Internal Energy

All heat added becomes internal energy

$$E_{\text{INT}} = E_K + E_P$$

Changing the temperature of the solid, liquid, or gas?

**Changing** $E_K$ (Kinetic Energy)

Causing the substance to change phases?

**Changing** $E_P$ (Potential Energy)
Specific Latent Heat is the amount of energy transferred when 1 kg of the substance changes phase at a constant temperature.

<table>
<thead>
<tr>
<th>Melting or Freezing</th>
<th>Latent Heat of Fusion</th>
<th>$L_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling or Condensing</td>
<td>Latent Heat of Vaporization</td>
<td>$L_v$</td>
</tr>
</tbody>
</table>

Specific Latent Heat for Water (H$_2$O):

<table>
<thead>
<tr>
<th>Latent Heat of Fusion</th>
<th>334,000 J kg$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latent Heat of Vaporization</td>
<td>2,260,000 J kg$^{-1}$</td>
</tr>
</tbody>
</table>
# Specific Latent Heat Equation

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Energy</td>
<td>Q</td>
<td>[J]</td>
</tr>
<tr>
<td>Mass</td>
<td>m</td>
<td>[kg]</td>
</tr>
<tr>
<td>Specific Latent Heat</td>
<td>L</td>
<td>[J kg(^{-1})]</td>
</tr>
</tbody>
</table>

\[ Q = mL \]

*This equation works for heat energy gained as well as heat energy lost*
Heating Curve

\[ Q = mc\Delta T \]

- Solid Changing Temp
- Liquid Changing Temp
- Gas Changing Temp

Temperature (°C)

Heat Added
Heating Curve

\[ Q = mL \]

- Melting/Fusion
- Freezing
- Condensing
- Vaporization

Temperature (°C)

Heat Added
Try This...

If the latent heat of fusion of a certain kind of chocolate is 160,000 J kg\(^{-1}\), how much thermal energy is removed from you when a 10 g bar of chocolate melts in your mouth?

\[ Q = mL = (0.01 \text{ kg})(160,000 \text{ J kg}^{-1}) \]

\[ Q = 1,600 \text{ J} \]
Specific Heat Combined

\[ Q_{\text{total}} = mc\Delta T + mL \]

Sometimes, the heat that is added is used to change temperature AND cause a phase change.
How much heat is needed to transform 0.5 kg of ice at -20 °C into water at 50 °C?

\[ Q_{total} = mc\Delta T + mL + mc\Delta T \]

- **Specific Heat of Ice**: 2090 J kg\(^{-1}\) K\(^{-1}\)
- **Specific Heat of Water**: 4180 J kg\(^{-1}\) K\(^{-1}\)
- **Latent Heat of Fusion**: 334,000 J kg\(^{-1}\)
- **Latent Heat of Vaporization**: 2,260,000 J kg\(^{-1}\)

\[ \Delta T = 0°C - (-20°C) \]

\[ Q = (0.5)(2090)(20) + (0.5)(334,000) + (0.5)(4180)(50) \]

\[ Q = 20,900 + 167,000 + 104,500 = 292,400 \text{ J} \]

\[ \Delta T = 50°C - 0°C \]
Evaporation vs Boiling

**Evaporation:**
- Occurs only at the surface of a liquid
- Can occur at any temperature

**Boiling:**
- Bubbles form throughout liquid
- Occurs at a precise temperature

Some molecules have a KE high enough to escape and become a gas

When these faster molecules are lost, the average KE of the liquid decreases, resulting in evaporative cooling

KE is high enough for molecules to form bubbles within the liquid
10. A solid piece of tungsten melts into liquid without a change in temperature. Which of the following is correct for the molecules in the liquid phase compared with the molecules in the solid phase?

<table>
<thead>
<tr>
<th>Kinetic energy</th>
<th>Potential energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. same</td>
<td>greater</td>
</tr>
<tr>
<td>B. same</td>
<td>same</td>
</tr>
<tr>
<td>C. greater</td>
<td>greater</td>
</tr>
<tr>
<td>D. greater</td>
<td>same</td>
</tr>
</tbody>
</table>

Changing the temperature of the solid, liquid, or gas?

**Changing $E_K$ (Kinetic Energy)**

Causing the substance to change phases?

**Changing $E_P$ (Potential Energy)**

11. The *specific* latent heat of a substance is defined as the energy required at constant temperature to

A. change the phase.
B. change the phase of 1 kg.
C. change the phase of 1 m³.
D. change the phase of 1 kg every second.

$L \rightarrow [J\ kg^{-1}]$
Try This…

How much heat is needed to transform 1.4 kg of water at 23°C into water vapor at 120 °C?

\[ Q_{total} = mc\Delta T + mL + mc\Delta T \]

\[ \Delta T = 100°C - 23°C \]
\[ \Delta T = 120°C - 100°C \]

\[ Q = (1.4)(4180)(77) + (1.4)(2,260,000) + (1.4)(2000)(20) \]

450,604 3,164,000 56,000

\[ Q = 3,670,604 \text{ J} \]
Kinetic Gas Theory & The Mole
Warm Up

A liquid in a calorimeter is heated at its boiling point for a measured period of time.

The following data are available:

- Power rating of heater = 15 W = 15 J s\(^{-1}\)
- Time for which liquid is heated at boiling point = 4.5 \(\times\) \(10^2\) s = 450 s
- Mass of liquid boiled away = 1.8 \(\times\) \(10^{-2}\) kg = 0.018 kg

Use the data to determine the specific latent heat of vaporization of the liquid.

\[
Q = mL
\]

\[
L = \frac{Q}{m} = \frac{6750}{0.018} = 375,000 \text{ J kg}^{-1}
\]

\[
Q = (15 \text{ J s}^{-1})(450 \text{ s}) = 6750 \text{ J}
\]
Assumptions:
• Large # of identical molecules
• Volume of molecules is negligible
• Motion is random
• No forces between molecules
• All collisions are elastic

If these assumptions are true we have an

Ideal Gas

Kinetic Energy is conserved
What is the force of this ball on the wall?

\[ \text{Impulse} = F \Delta t = \Delta p \]

\[
F = \frac{\Delta p}{\Delta t} = \frac{m\Delta v}{\Delta t} = \frac{(5)(16)}{(0.2)}
\]

\[ F = 400 \text{ N} \]
When many molecules collide with the sides of a container it is measured as **pressure**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>$F$</td>
<td>$[N]$</td>
</tr>
<tr>
<td>Area</td>
<td>$A$</td>
<td>$[m^2]$</td>
</tr>
<tr>
<td>Pressure</td>
<td>$p$</td>
<td>$[N \cdot m^2]$</td>
</tr>
</tbody>
</table>

\[ p = \frac{F}{A} \]

$[Pa]$ Pascal
Units of Pressure

There are several different units used to measure pressure of a gas.

1 atm = 101,325 Pa = 760 Torr = 760 mm Hg

100 kPa is a pretty good approximation.
Atmospheric Pressure

What is the force from atmospheric pressure on this doormat?

\[(101,325 \, N \, m^{-2})(0.33 \, m^2)\]

\[F = 33,100 \, N\]
Temperature Review

Measure of how **hot** or **cold** something feels

Temperature is the average **kinetic energy** of the molecules of a substance

<table>
<thead>
<tr>
<th>Kelvin Scale (K)</th>
<th>Absolute Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- The boiling point of water: 373.15 K, 100 °C
- The freezing point of water: 273.15 K, 0 °C
- Absolute zero: 0 K, -273 °C
**Average Kinetic Energy**

\[
\bar{E}_K = \frac{3}{2} k_B T
\]

\(k_B \rightarrow \text{Boltzmann's constant}\)

\(k_B = 1.38 \times 10^{-23} \, \text{J} \, \text{K}^{-1}\)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Kinetic Energy</td>
<td>(\bar{E}_K)</td>
<td>[J]</td>
</tr>
<tr>
<td>Absolute Temperature</td>
<td>(T)</td>
<td>[K]</td>
</tr>
</tbody>
</table>
### IB Physics Data Booklet

#### Sub-topic 3.1 – Thermal concepts

- \( Q = mc\Delta T \)
- \( Q = mL \)

#### Sub-topic 3.2 – Modelling a gas

- \( p = \frac{F}{A} \)
- \( n = \frac{N}{N_A} \)
- \( pV = nRT \)
- \[
\frac{\bar{E}_K}{2} = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T
\]

#### Quantity Table

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Approximate value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration of free fall (Earth's surface)</td>
<td>( g )</td>
<td>( 9.81 \text{ m s}^{-2} )</td>
</tr>
<tr>
<td>Gravitational constant</td>
<td>( G )</td>
<td>( 6.67 \times 10^{-11} \text{ N m}^2\text{kg}^{-2} )</td>
</tr>
<tr>
<td>Avogadro's constant</td>
<td>( N_A )</td>
<td>( 6.02 \times 10^{23} \text{ mol}^{-1} )</td>
</tr>
<tr>
<td>Gas constant</td>
<td>( R )</td>
<td>( 8.31 \text{ J K}^{-1}\text{mol}^{-1} )</td>
</tr>
<tr>
<td>Boltzmann's constant</td>
<td>( k_B )</td>
<td>( 1.38 \times 10^{-23} \text{ J K}^{-1} )</td>
</tr>
</tbody>
</table>
Calculate the average translational kinetic energy of molecules in the air at 27°C

\[ k_B = 1.38 \times 10^{-23} \text{ JK}^{-1} \]
\[ T = 27^\circ C + 273 = 300 \text{ K} \]

\[ \overline{E}_k = \frac{3}{2} k_B T = \frac{3}{2} (1.38 \times 10^{-23})(300) \]

\[ \overline{E}_k = 6.21 \times 10^{-21} \text{ J} \]
What is Kinetic Energy?

\[ \overline{E}_{K} = \frac{3}{2} k_B T \]

\[ \overline{E}_{K} = \frac{1}{2} m v^2 \]

\( k_B \rightarrow \) Boltzmann's constant
\( k_B = 1.38 \times 10^{-23} \text{ } J \text{ } K^{-1} \)
Calculate the average speed for oxygen molecules at 0°C.
(the mass of an oxygen molecule is $5.32 \times 10^{-26} \text{ kg}$)

$$m = 5.32 \times 10^{-26} \text{ kg}$$

$$k_B = 1.38 \times 10^{-23} \text{ JK}^{-1}$$

$$T = 0°C + 273 = 273 \text{ K}$$

$$\frac{3}{2} (1.38 \times 10^{-23})(273) = \frac{1}{2} (5.32 \times 10^{-26})v^2$$

$$5.62 \times 10^{-21} \text{ J} = \frac{1}{2} (5.32 \times 10^{-26})v^2$$

$$v = 461 \text{ m/s}$$
Which molecules move faster?

H₂ gas at 23°C

\[ E_k = \frac{1}{2}mv^2 \]

If the gases have the same kinetic energy (temp), the lighter one must be moving faster

O₂ gas at 23°C
Grouping Items

We can use many different terms to describe the amount of substance.

A pair of shoes

BONUS!

A Baker’s Dozen = 13
A Score = 20
A Gross = 144
Counting Atoms

The primary counting unit for atoms is called The Mole

1 mole = \(6.02 \times 10^{23}\)

This is also called Avogadro's Number named after the scientist who first proposed this concept.
How Big is a Mole??

6.02 x 10^{23}

AVOGADRO'S NUMBER

How big is a mole? (Not the animal, the other one.) - Daniel Dulek

6,020,000,000,000,000,000,000,000,000
A Mole of Moles

What would happen if you were to gather a mole (unit of measurement) of moles (the small furry critter) in one place?

—Sean Rice

Things get a bit gruesome.

First, some definitions. A mole is a unit. It’s not a typical unit, though. It’s really just a number—like “dozen” or “billion.” If you have a mole of something, it means you have 602,214,129,000,000,000,000 of them (usually written $6.022 \times 10^{23}$). It’s such a big number because it’s used for counting numbers of molecules, which there are a lot of.
Atoms don’t weigh very much on their own:

1 Carbon Atom = \(1.9927 \times 10^{-23} \text{ g}\)

\[0.000000000000000000000019927 \text{ g}\]

1 mole of Carbon Atoms =

\[(1.9927 \times 10^{-23} \text{ g}) \times (6.02 \times 10^{23}) = \sim 12 \text{ g}\]

Where else have you seen this number for Carbon?
The mole is defined as

A. $\frac{1}{12}$ the mass of an atom of the isotope carbon-12.

B. the amount of a substance that contains as many elementary entities as the number of atoms in 12 g of the isotope carbon-12.

C. the mass of one atom of the isotope carbon-12.

D. the amount of a substance that contains as many nuclei as the number of nuclei in 12 g of the isotope carbon-12.
Molar Mass

Molar Mass – the mass of \( \boxed{1 \text{ mole}} \) of a substance

<table>
<thead>
<tr>
<th>Unit</th>
<th>g mol(^{-1})</th>
</tr>
</thead>
</table>

Molar mass of N = 14.01 g mol\(^{-1}\)
Molar mass of S = 32.07 g mol\(^{-1}\)
Molar Mass

1 mole of copper can be represented by this stack of pure copper pennies

How many atoms are in 1 mole of copper?

\[6.02 \times 10^{23}\text{ atoms}\]
Molar Mass

1 mole of copper can be represented by this stack of pure copper pennies

What is the mass of one mole of copper?

63.55 g
More than one mole...

How much mass would 3 moles of Copper have?

\[ 3 \text{ mol} \times 63.55 \text{ g mol}^{-1} = 190.65 \text{ g} \]

How many moles are in 28 g of Nitrogen?

\[ \frac{28 \text{ g}}{14.01 \text{ g mol}^{-1}} = \sim 2 \text{ mol} \]
Example IB Questions

11. What is the mass of carbon-12 that contains the same number of atoms as 14 g of silicon-28?

A. 6 g
B. 12 g
C. 14 g
D. 24 g

\[
\frac{14 \text{ g}}{28 \text{ g mol}^{-1}} = 0.5 \text{ mol}
\]

\[
0.5 \text{ mol} \times 12 \text{ g mol}^{-1} = 6 \text{ g}
\]

11. A sample contains 4 g of helium and 20 g of neon. The mass number of helium is 4 and the mass number of neon is 20.

What is the ratio \( \frac{\text{number of atoms of neon}}{\text{number of atoms of helium}} \)?

A. 0.2
B. 1
C. 5
D. 80

\[
\frac{4 \text{ g}}{4 \text{ g mol}^{-1}} = 1 \text{ mol}
\]

\[
\frac{20 \text{ g}}{20 \text{ g mol}^{-1}} = 1 \text{ mol}
\]
Gas Laws
Calculate the average speed for nitrogen molecules at 20°C.
(the mass of an nitrogen molecule is $2.3 \times 10^{-26}$ kg)

\[ m = 2.3 \times 10^{-26} \text{ kg} \]
\[ k_B = 1.38 \times 10^{-23} \text{ J K}^{-1} \]
\[ T = 20^\circ C + 273 = 293 \text{ K} \]

\[
\frac{3}{2} (1.38 \times 10^{-23})(293) = \frac{1}{2} (2.3 \times 10^{-26})v^2
\]

\[
6.07 \times 10^{-21} \text{ J} = \frac{1}{2} (2.3 \times 10^{-26})v^2
\]

\[
v = 726 \text{ m s}^{-1}
\]
Warm Up

How many grams is 2.7 moles of the diatomic form of oxygen (32 g mol\(^{-1}\))?

\[
2.7 \text{ mol} \times 32 \text{ g mol}^{-1} = 86.4 \text{ g}
\]
Ideal Gas

Assumptions:
• Large # of identical molecules
• Volume of molecules is negligible
• Motion is random
• No forces between molecules
• All collisions are elastic

No longer ideal when...
• Compressed
  • Molecules close together

• Close to Phase Change
  • All internal energy is from $E_k$
Boyle’s Law | Volume and Pressure

\[ p \alpha \frac{1}{V} \]
Boyle’s Law | Volume and Pressure

When diaphragm contracts the lung volume increases, decreasing the air pressure inside. With a pressure differential, air flows into the lungs (high pressure to low pressure)

\[ P_{\text{lungs}} = 1-3 \text{ torr lower} \]

Inspiration

Diaphragm contracts

\[ P_{\text{lungs}} = 1-3 \text{ torr higher} \]

Expiration

Diaphragm relaxes
Pressure Law | Temp and Pressure

Temperature ↑ Pressure

$p \propto T$
If temperature exceeds a certain amount, the increasing pressure could make a pressurized container explode!
Charles’s Law | Temp and Volume

Temperature → Volume

$V \propto T$

Graph showing the relationship between temperature (in Kelvin) and volume (in liters).
When the temperature of the air inside a balloon decreases, so does the volume. (this effect is even more dramatic when the gas condenses into a liquid)
Ideal Gas Law

\[ p \propto \frac{1}{V} \quad p \propto T \quad V \propto T \]

\[ pV = nRT \]
**Ideal Gas Law**

\[ pV = nRT \]

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>( p )</td>
<td>([ \text{Pa} ])</td>
</tr>
<tr>
<td>Volume</td>
<td>( V )</td>
<td>([ \text{m}^3] )</td>
</tr>
<tr>
<td>Amount</td>
<td>( n )</td>
<td>([ \text{mol} ])</td>
</tr>
<tr>
<td>Temperature</td>
<td>( T )</td>
<td>([ \text{K} ])</td>
</tr>
</tbody>
</table>

Gas Constant

\( R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1} \)
### Sub-topic 3.1 – Thermal concepts

$$Q = mc\Delta T$$

$$Q = mL$$

### Sub-topic 3.2 – Modelling a gas

$$p = \frac{F}{A}$$

$$n = \frac{N}{N_A}$$

$$pV = nRT$$

$$E_K = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T$$

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Approximate value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration of free fall (Earth’s surface)</td>
<td>$g$</td>
<td>$9.81 \text{ m s}^{-2}$</td>
</tr>
<tr>
<td>Gravitational constant</td>
<td>$G$</td>
<td>$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$</td>
</tr>
<tr>
<td>Avogadro’s constant</td>
<td>$N_A$</td>
<td>$6.02 \times 10^{23} \text{ mol}^{-1}$</td>
</tr>
<tr>
<td><strong>Gas constant</strong></td>
<td>$R$</td>
<td><strong>8.31 J K^{-1} \text{ mol}^{-1}</strong></td>
</tr>
<tr>
<td>Boltzmann’s constant</td>
<td>$k_B$</td>
<td>$1.38 \times 10^{-23} \text{ J K}^{-1}$</td>
</tr>
</tbody>
</table>
Try This

What is the pressure of 23 mol of a gas behaving ideally in a 0.25 m³ container at 310 K?

\[ p = ? \]

\[ V = 0.25 \text{ m}^3 \]
\[ n = 23 \text{ mol} \]
\[ R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1} \]
\[ T = 310 \text{ K} \]

\[ pV = nRT \]

\[ p(0.25) = (23)(8.31)(310) \]

\[ p = 237,000 \text{ Pa} \]
A fixed mass of an ideal gas has a volume of 0.14 m\(^3\) at 301 K. If its temperature is increased to 365 K at the same pressure, what is its new volume, \(V_2\)?

\[\rho V = nRT\]

Rearrange so constants are on one side

\[\frac{V_1}{T_1} = \frac{V_2}{T_2}\]

\[\frac{0.14 \text{ m}^3}{301 \text{ K}} = \frac{V_2}{365 \text{ K}}\]

\[V_2 = 0.17 \text{ m}^3\]
Try This

A sample of ammonia is found to occupy 0.250 L under laboratory conditions of 27 °C and 0.850 atm. Find the volume of this sample at 0 °C and 1.00 atm.

\[ pV = nRT \]

Rearrange so constants are on one side

\[ \frac{pV}{T} = nR \]

\[ \frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} \]

\[ \frac{(0.850)(0.250)}{(27 + 273)} = \frac{(1.00)(V_2)}{(0 + 273)} \]

\[ V_2 = 0.19 \text{ L} \]
Draw these graphs

\[ pV = nRT \]
Related Constants

Gas Constant
\[ R = 8.31 \, \text{J} \, \text{K}^{-1} \, \text{mol}^{-1} \]

\[ \frac{R}{k_B} = \frac{8.31 \, \text{J} \, \text{K}^{-1} \, \text{mol}^{-1}}{1.38 \times 10^{-23} \, \text{J} \, \text{K}^{-1}} = 6.02 \times 10^{23} \, \text{mol}^{-1} \]

\[ N_A \]

Boltzmann's constant
\[ k_B = 1.38 \times 10^{-23} \, \text{J} \, \text{K}^{-1} \]
$$\bar{E}_K = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T$$

**Boltzmann's constant**

$$k_B = 1.38 \times 10^{-23} \text{ J K}^{-1}$$

**Gas Constant**

$$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$$
### IB Physics Data Booklet

#### Sub-topic 3.1 – Thermal concepts

- \( Q = mc\Delta T \)
- \( Q = mL \)

#### Sub-topic 3.2 – Modelling a gas

- \( p = \frac{F}{A} \)
- \( n = \frac{N}{N_A} \)
- \( pV = nRT \)
- \( \bar{E}_K = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T \)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Approximate value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration of free fall (Earth’s surface)</td>
<td>( g )</td>
<td>9.81 m s(^{-2})</td>
</tr>
<tr>
<td>Gravitational constant</td>
<td>( G )</td>
<td>( 6.67 \times 10^{-11} ) N m(^2) kg(^{-2})</td>
</tr>
<tr>
<td>Avogadro’s constant</td>
<td>( N_A )</td>
<td>( 6.02 \times 10^{23} ) mol(^{-1})</td>
</tr>
<tr>
<td>Gas constant</td>
<td>( R )</td>
<td>( 8.31 ) J K(^{-1}) mol(^{-1})</td>
</tr>
<tr>
<td>Boltzmann’s constant</td>
<td>( k_B )</td>
<td>( 1.38 \times 10^{-23} ) J K(^{-1})</td>
</tr>
</tbody>
</table>
12. An ideal gas is contained in a thermally insulated cylinder by a freely moving piston.

The gas is compressed by the piston and as a result the temperature of the gas increases. What is the explanation for the temperature rise?

A. The rate of collision between the molecules increases.

B. Energy is transferred to the molecules by the moving piston.  

C. The molecules of the gas are pushed closer together.

D. The rate of collision between the molecules and the walls of the cylinder increases.