Thermal Physics

IB Physics Content Guide

Big Ideas

- The macroscopic effects of volume, pressure, and temperature can be understood with a microscopic model
- Kinetic Energy on a molecular level is observed as temperature and heat
- The heat required to change the temperature or phase of a material is a property of the material itself
- The properties of an ideal gas are proportional to each other and can be calculated under certain conditions

1 – Heat vs Temperature

I can explain the relationship between temperature and molecular kinetic energy			
I can describe the energies present in an object's total internal energy			
I can convert between Celsius and Kelvin			
I can describe the nature of molecules when at a temperature of absolute zero			
I can compare temperature (average KE) and heat (total KE)			
I can relate average molecular kinetic energy with absolute temperature			
I can calculate the average molecule speed for a molecule at a certain temperature			
I can describe the molecular process that allows heat to flow			

2 – Specific Heat Capacity

I can define specific heat capacity with proper units			
I can describe the effect of larger or smaller specific heat values			
I can relate specific heat capacity to the heat energy and temperature change			
I can describe how a calorimeter uses the conservation of heat to study a material's specific heat			
I can experimentally determine the specific heat capacity of a material			

3 – Specific Latent Heat

I can identify key features in a material's heating curve			
I can describe why a heating curve plateaus during phase changes			
I can describe the different ways that the heat added to a system can become internal energy			
I can define specific latent heat with proper units			
I can calculate the heat required to cause a certain amount of a substance to change phases			
I can compare the processes of evaporation and boiling			

4 – Conduction, Convection, and Radiation

I can define the thermal transfer processes of conduction, convection, and radiation			
I can quantify and calculate thermal conductivity			
I can describe convection in terms of fluid density differences			

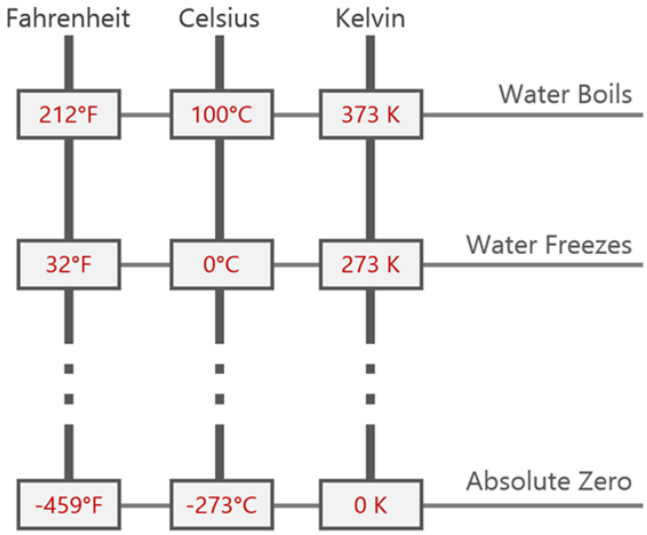
5 – Gas Properties

I can define pressure with appropriate fundamental and derived units			
I can describe the importance of having a large quantity like the "mole" defined			
I can use the average atomic weight of an element to convert between mass and moles			

6 – Gas Laws

I can describe the conditions necessary for a substance to be considered an ideal gas			
I can describe the relationship between volume, pressure, and temperature for an ideal gas			
I can describe changes in pressure in terms of kinetic molecular theory			
I can use the Ideal Gas Law to solve for pressure, volume, amount, or temperature			
I can use the Ideal Gas Law to describe how changing one or more variable(s) affects another			
I can calculate the total internal energy for an ideal gas			

Temperature



Temperature Conversion:

$$\text{Temperature (K)} = \text{Temperature (°C)} + 273$$

Conditions for Absolute Zero:

Molecules stop moving.
This is the coldest possible temperature.

Absolute Zero = 0 K = -273°C

Kinetic Theory and Temperature

	Variable Symbol	Description	Unit
$\bar{E}_K = \frac{3}{2}k_B T$ $k_B = 1.38 \times 10^{-23}\,\text{J K}^{-1}$	$\bar{E}_K$	Average Kinetic Energy	[J]
	k_b	Boltzmann Constant	[J K^{-1}]
	T	Temperature	[K]

Internal Energy

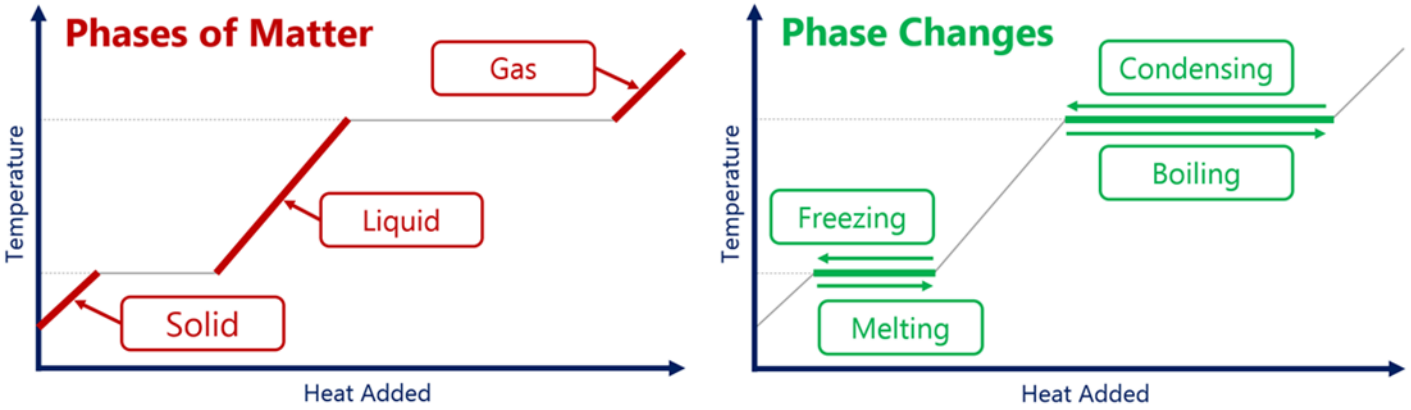
$$U = E_K + E_P$$

U	Total Internal Energy
E_K	Kinetic Energy → Temperature
E_P	Potential Energy → Phase Change

Specific Heat Capacity and Specific Latent Heat

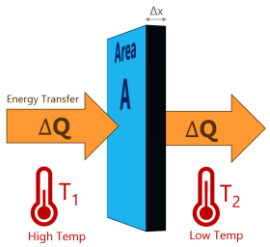
	Variable Symbol	Description	Unit
$Q = mc\Delta T$ $Q = mL$	Q	Heat Energy	[J]
	m	Mass	[kg]
	c	Specific Heat Capacity	[J kg^{-1} K^{-1}]
	ΔT	Change in Temperature	[K] or [°C]
	L	Specific Latent Heat	[J kg^{-1}]

Heating Curves



Thermal Conduction

	Variable Symbol	Description	Unit
$\frac{\Delta Q}{\Delta t} = -kA\frac{\Delta T}{\Delta x}$	ΔQ	Energy transferred across material	[J]
	Δt	Time to transfer energy	[s]
	$\frac{\Delta Q}{\Delta t}$	Rate of energy transfer (Power)	[J s^{-1}] or [W]
	k	Thermal conductivity	[W m^{-1} K^{-1}]
	A	Cross sectional area of material	[m^2]
	ΔT	Temperature difference across material	[K] or [°C]
	Δx	Material thickness or length	[m]



Thermal Energy Transfer

Conduction	Convection	Radiation
Energy is transferred through molecular collisions	Energy circulates through the expansion and rising of hot fluids	Energy is transferred through electromagnetic radiation. Can travel through a vacuum

Pressure

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

Variable Symbol	Description	Unit	
P	Pressure	[N m^{-2}]	Pascals [Pa]
F	Force	Newtons [N]	
A	Area	Square Meters [m^2]	

Atmospheric Pressure	1 atm	101,325 Pa ≈ 100 kPa

The Mole

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

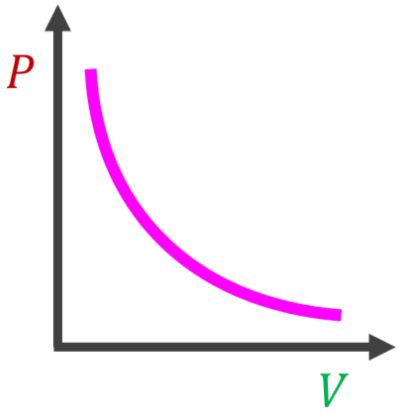
$$N_A = 6.02 \times 10^{23}$$

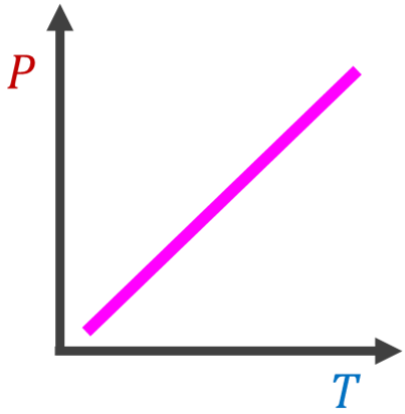
Variable Symbol	Description	Unit
n	# of Moles	[mol]
N	# of Molecules	[molecules]
N_A	# of Molecules per mole	[mol^{-1}]

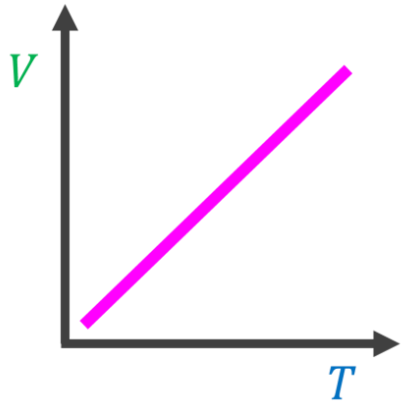
Ideal Gas Assumptions

- Large # of identical molecules
- Volume of molecules is negligible
- Motion is random
- No forces between molecules (all internal energy is E_K)
- All collisions are elastic

Ideal Gas Relationships







Ideal Gas Equations

$$PV = nRT$$

$$PV = Nk_BT$$

$$U = \frac{3}{2}nRT = \frac{3}{2}Nk_BT$$

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

$$R = 8.31\ \text{J K}^{-1}\text{mol}^{-1}$$

Variable Symbol	Description	Unit
P	Pressure	[Pa]
V	Volume	[m^3]
n	Amount (moles)	[mol]
R	Gas Constant	[$J\ K^{-1}\ mol^{-1}$]
T	Temperature	[K]
N	Amount (molecules)	[molecules]
k_B	Boltzmann Constant	[$J\ K^{-1}$]
U	Total Internal Energy	[J]

$$P = \frac{1}{3}\rho v^2$$

Variable Symbol	Description	Unit
P	Pressure	[Pa]
ρ	Density	[$kg\ m^{-3}$]
v	Velocity	[$m\ s^{-1}$]