Temperature, Kinetic Theory, and the Gas Laws

NJ-OER TOPIC-13

Learning Outcomes

- Convert temperatures between the Celsius, Fahrenheit, and Kelvin scales.
- Define, describe and calculate thermal expansion
- State the ideal gas law in terms of molecules and in terms of moles.
- Use the ideal gas law to calculate change in pressure, temperature, volume or the number of molecules or moles
- State the relationship between the kinetic energy, temperature and root mean square velocity of a gas
- Interpret a phase diagram.
- State Dalton’s law.

Concepts

TF = Temperature in Fahrenheit

TC = Temperature in Celsius

T=TK=Temperature in Kelvin

ΔL=Expansion (Lf-L0)

L = Original length

α = Coefficient of linear expansion

k=universal Boltzmann constant

R = 8.31 J/ (mole K) universal gas constant

P = Pressure

V= Volume

NA = Avogadro number

N= number of atoms or molecules

n= number of moles

m =mass of molecule in kg

M= molar mass in kg/mole

vrms = Root mean square of speed of a molecule

Units

SI UNITS

Volume is in cubic meters "m^3"

Pressure is in Pascal "Pa"

Temperature in Kelvin "K"

Energy in Joules "J"

vrms in meters per second "m/s"

R is in J/ (mole K)

K is in J/K

Formulas and Constants

TF= 9/5 TC +32

TK= TC +273.15

$\Delta L = \alpha L \Delta T$

$\Delta A = 2\alpha A \Delta T$

$\Delta V = 3\alpha V \Delta T$

$PV = NkT$

$PV = nRT$

P1 V1/(n1 T1)=P2 V2/(n2 T2)

k=1.38×10−23 J/K

R=8.31$Jmol \cdot K$

n/N=R/k=NA= 6.02×10^{23} mol−1

KE = 3/2 nRT = 3/2 NKT for monatomic gas

vrms = sqrt (3RT/Mm) Mm is the molar mass

CLASSWORK FOR UNIT CONVERSIONS

Complete the table below for unit conversion using the given temperature

TF= 9/5 TC +32 TK= TC +273

TC(Celcius)	TF(Fahrenheit)	TK(Kelvin)
90	?	?
?	100	?
?	?	300
300	?	?
?	212	?
?	?	0

Solution for the first row: TK=90+273=363Kelvin TF=(9/5)90+32=204 Fahrenheit

CLASSWORK FOR THERMAL EXPANSION

Complete the table below

Object	Alpha	Initial Measurement	Ti	Tf	Change
Copper Wire	$16.7\ \ 10^{-6}$	Length=?	30 C	230 C	ΔL=0.03
Aluminum Plate	$23.0\ \ 10^{-6}$	L=5meters W=3meters	70 degrees C	?	ΔA= - 0.02 m^2
Unknown Plate	?	L=4 meters W=2meters	23 C	73 C	ΔA=0.005 m2
Copper Sphere	$16.7\ \ 10^{-6}$	Radius 0.4 meters	30 C	70 C	ΔV=?

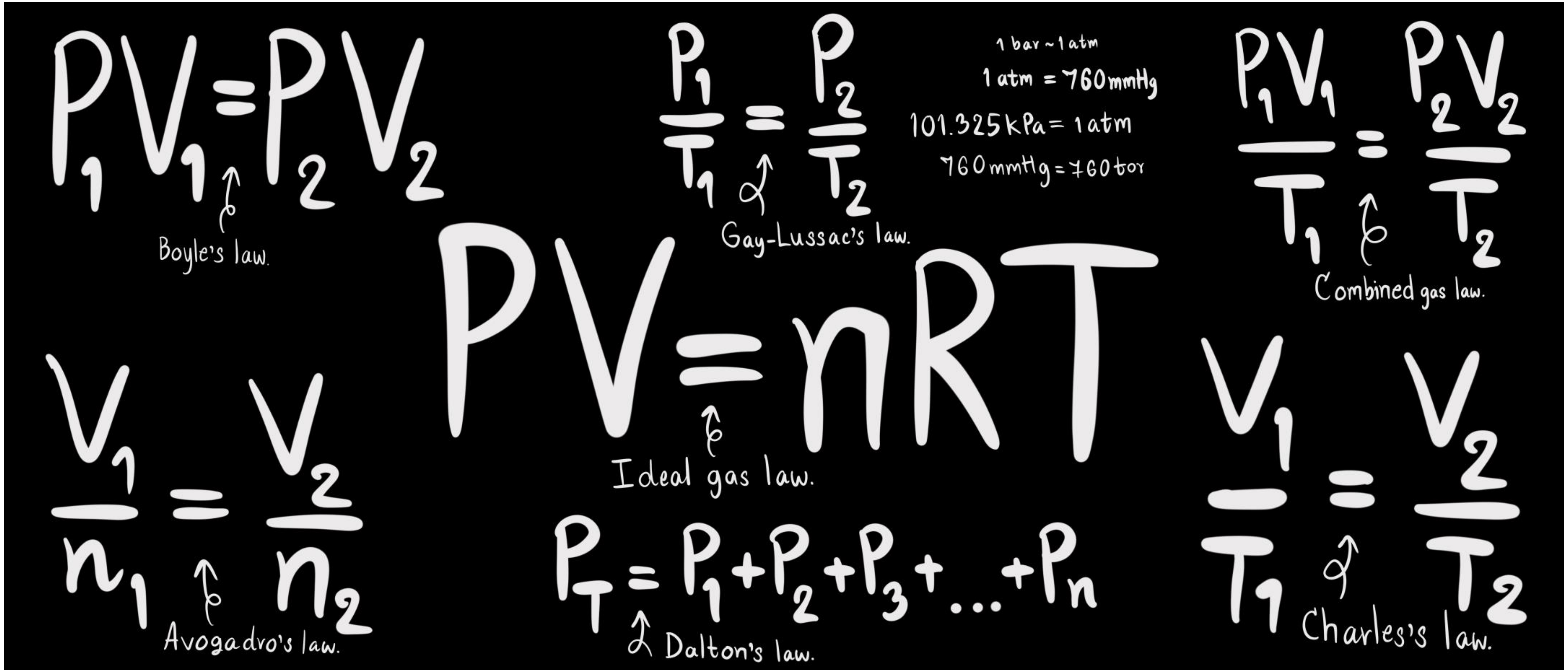
$\Delta L=\alpha L\Delta T$ $\Delta A= 2\alpha A\Delta T$ $\Delta V=3\alpha V\Delta T$ V(sphere)=4/3 πr^3

Model word problem for the first row: A copper wire is heated from 30 degrees celcius to 230 degrees Celcius. As a result it expanded by 0.03 meters. What was the original length.

Solution:0.03 = L (16.7 10^-6)(230-30) L=89.8 meters

IDEAL GAS

An **ideal gas** is a hypothetical gas composed of randomly moving point size gas molecules where interparticle interactions are negligeable.



CLASSWORK: IDEAL GAS STATES

$PV = NkT$ $PV = nRT$ $k = 1.38\times10{-}23\ J/K$ $R = 8.31 Jmol\cdot K$

Volume is in cubic meters "m^3" Pressure is in Pascal "Pa" Temperature in Kelvin "K"

Q: Three moles of ideal gas has 100,000 Pascal pressure at 242 degrees Kelvin. What is its volume ?

n=3 P=100,000 V=? T=242 V=nRT/P V= 0.06 m^3

Complete the table below, use unit conversion if necessary.

Pressure	Volume	number	Constant	Temperature
100,000 Pa	?	3 moles	R	242K
1 atm	0.2 m^3	?	R	600K
75 kPa	0.15 gallon	?	R	-10 Celcius
?	$8\ 10^{(-18)}\ m^3$	1000 molecules	k	400 K

TK=TC+273 1 atm=101,325 Pascal 1kPa=1 kilopascal=1000 Pascal 1 Gallon=0.003785 m^3

IDEAL GAS PROCESS EQUATION

$P_1 V_1/(n_1 T_1) = P_2 V_2/(n_2 T_2)$

This is a comprehensive equation for a gas going from State 1 to State 2

Each state has Pressure Volume Temperature and number of moles or molecules

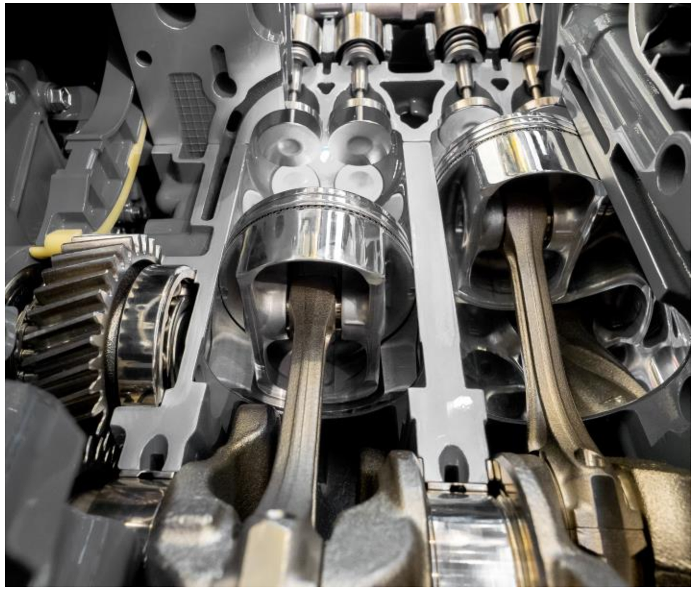
If any of the variables is a constant, they could be crossed out

Above equation is unit independent, as long as units are consistent for both states. The only unit that must be used is Temperature in Kelvin.

IDEAL GAS PROCESSES

Some Typical Systems with Constants

Hot air balloon has elastic surface and exposed to atmospheric pressure. P is constant



Sealed piston has moveable walls. P T V can change but number of moles is constant

Sealed solid container has constant volume. It has constant number of moles unless it leaks or gas is pumped

KEY STRATEGIES

- Identify the variables for the initial state, label them with index "1"
- Identify the variables for the final state, label them with index "2"
- Use the ideal gas process equation. If anything is constant, cross it out from both sides.
- Solve for the unknown. Unknown will have the unit of the other state variable

IDEAL GAS PROCESS CLASSWORK

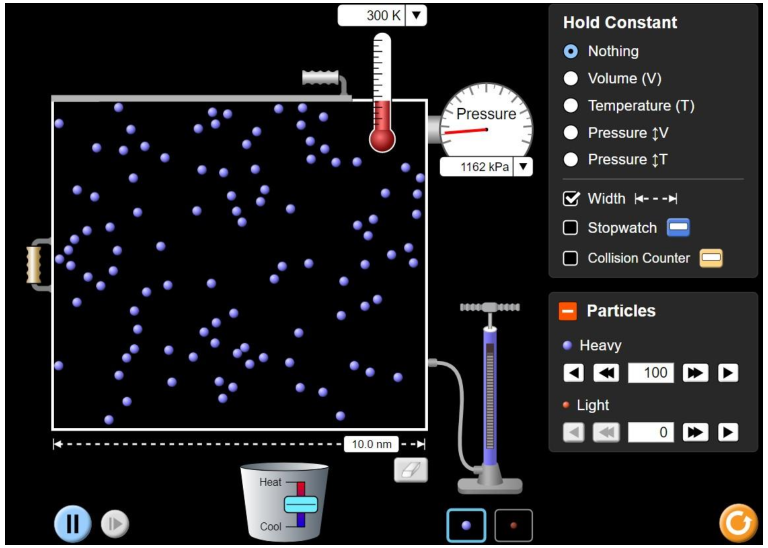
3 Moles of gas has pressure 100,000 Pascal is at 250-degree Kelvin. What happens to the pressure if temperature is raised to 300-degree Kelvin and 0.5 moles of gas is added under constant volume.

$P1=100,000Pa$ $n1=3$ $T1=250K$ $P2=?$ $n2=3.5$ $T2=300K$ $V1=V2$

$P1V1/(n1\ T1) = P2\ V2/(n2\ T2)$ cross out the V's

ACTIVITY IDEAL GAS PROCESSES

- Open Phet simulation https://phet.colorado.edu/sims/html/gas-properties/latest/gas-properties_en.html
- Click on ideal.
- Click on width. The container is 10nm width, 10nm height and there is an unseen depth, which is 3.5nm
- 1nm=10^-9 meters. So the original box has volume V=0.035 10^$^{-23}$ m^3
- Click on particles. You can adjust number of particles inside the container
- You may add heat to the system and observe the temperature change
- The activity is about calculating the pressure and comparing with the values of the pressure gauge.
- Change the units of pressure gauge to kilopascal kPa. 1kPa=1000 Pa.
- Pressure is caused by particles hitting the walls of the container. If fluctuates statistical uncertainties. Make sure your calculated pressure is within the range of what pressure gauge reads. You can see a minimum pressure and maximum pressure.



ACTIVITY IDEAL GAS PROCESSES

- Open Phet simulation https://phet.colorado.edu/sims/html/gas-properties/latest/gas-properties_en.html
- Calculate Pressure using P1V1/(N1 T1)=P2V2/(n2 T2) for the problems below.
- Simulate the problem using the app and compare the Pressure read from the gauge.

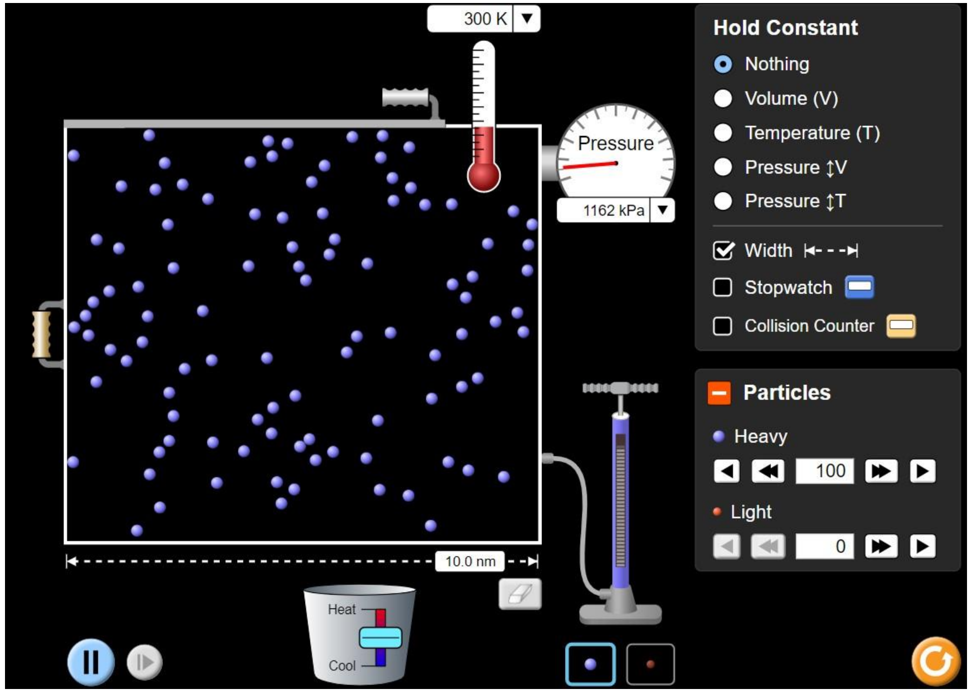
100 gas molecules is inside a container with 0.035 10^{-23} m^3 Volume
It has about 1200 kPa pressure at 300K temperature.

1) Find the new pressure if 50 more molecules are pumped at constant volume and temperature

2) Find the new pressure if 50 more molecules are pumped at constant volume but temperature is increased to 350K

3) Find the new pressure if 50 more molecules are pumped, temperature is raised to 350K and volume is halved.

4) Come up with your own questions. Compare you measure pressure with the pressure given by the pressure gauge.



CLASSWORK FOR KINETIC THEORY OF GAS

KE = 3/2 nRT = 3/2 NKT for monatomic gas
vrms = sqrt (3RT/Mm) Mm is the molar mass

Molar mass of a monatomic gas is 0.040 kg/mol
Calculate the Kinetic energy and root mean square velocity at
A) 300 K
B) 600 K
C) 10 K

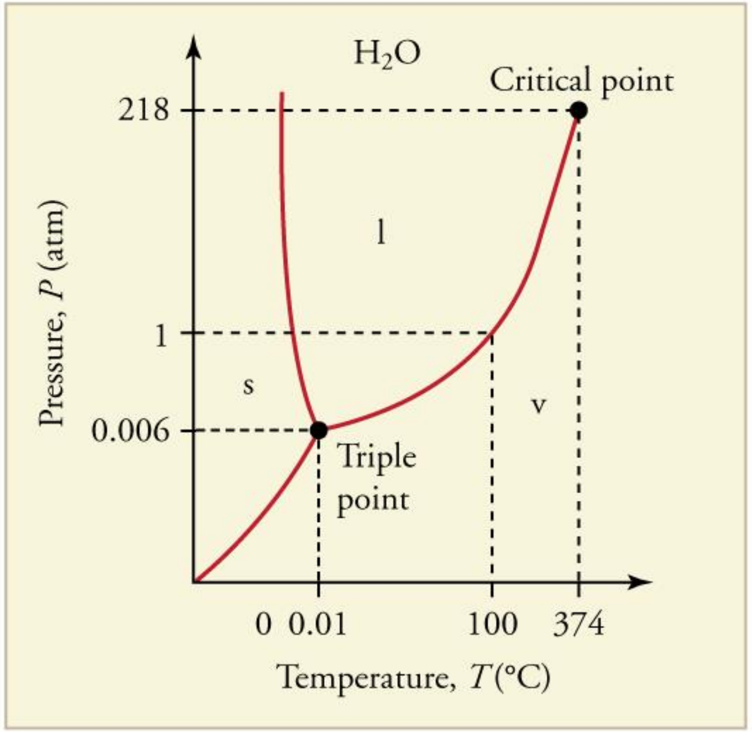
CLASSWORK FOR PHASE CHANGE

A substance has the triple point at 0.02 atm pressure and at 5 degrees Celcius temperature.
Q1) Draw an approximate P T diagram for the substance **near** its triple point.(Draw only near the triple point as a partial graph since the slopes will change as we move away from the triple point). Consider

A) Slope of the sublimation curve is 0.8 atm/C
B) Slope of the evaporation curve is 0.2 atm/C
C) Slope of the melting curve is –4 atm/C

Q2) Identify 6 points on the graph, one for each pure state and one for each phase transition

PT graph for water is given as reference, the image for the particular gas in the question will be different.



REFERENCES

- Slide 1: Open Stax College Physics online textbook
- Slide 8: Adobe id= 437739805 Gas equation on blackboard, ideal gas law equation, combine gas law equation, gas law of chemistry and physics By BN Benz
- Slide 11 Left image: Open Stax College Physics online textbook
- Slide 11 Middle image: Adobe id= 144540334 Inside view of engine cylinders, pistons and valves By OkFoto
- Slide 11 Right image: Adobe id= 90387836 Propane gas cylinder, isolated on white By Christian Delbert
- Slides 14-15: Screenshot from PhET Interactive Simulations University of Colorado Boulder
- Slide 17: Open Stax College Physics online textbook