

Temperature, Kinetic Theory, and the Gas Laws

NJ-OER TOPIC-13

Image: CC by Texas Education Agency (TEA) is licensed under Creative Commons Attribution License v4.0

Original Publication Year 2022 General Physics I by Moe Tabanli is licensed under a <u>Creative Commons</u> <u>Attribution-NonCommercial-ShareAlike 4.0 International License</u>, except where otherwise noted.



To learn more about the Open Textbook Collaborative, visit https://middlesexcc.libguides.com/OTCProject

Under this license, any user of this textbook or the textbook contents herein must provide proper attribution as follows: If you redistribute this textbook in a digital or print format (including but not limited to PDF and HTML), then you must retain this attribution statement on your licensing page.

If you redistribute part of this textbook, then you must include citation information including the link to the original document and original license on your licensing page.

If you use this textbook as a bibliographic reference, please include the link to this work <u>https://opennj.net//physics-tabanli</u> in your citation.

For questions regarding this licensing, please contact library@middlesexcc.edu

Funding Statement

This material was funded by the Fund for the Improvement of Postsecondary Education (FIPSE) of the U.S. Department of Education for the Open Textbooks Pilot grant awarded to Middlesex College (Edison, NJ) for the Open Textbook Collaborative.

Open Textbook Collaborative

The <u>Open Textbook Collaborative</u>. (OTC) project is a statewide project managed by Middlesex College along with assistance from Brookdale Community College, Ocean County College, Passaic County Community College, and Rowan University.

The project engages a consortium of New Jersey community colleges and Rowan University to develop open educational resources (OER) in career and technical education STEM courses.

The courses align to <u>career pathways in New Jersey's growth industries</u> including health services, technology, energy, and global manufacturing and supply chain management as identified by the New Jersey Council of Community Colleges.

General Physics I

Moe Tabanli

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-LO)

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"m³" 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=NkTPV = nRTP1 V1/(n1 T1)=P2 V2/(n2 T2) *k*=1.38×10–23 *J/K R***=**8.31*Jmol*·*K* n/N=R/k=NA= 6.02×10²³ 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 | ∆V=? |

 $\Delta L = \alpha L \Delta T$ $\Delta A = 2 \alpha A \Delta T$ $\Delta V = 3 \alpha V \Delta T$ 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 negligible.



CLASSWORK: IDEAL GAS STATES

PV=NkT PV=nRT $k=1.38\times10-23$ J/K $R=8.31Jmol\cdot K$ Volume is in cubic meters "m³" 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 m³

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 m³

IDEAL GAS PROCESS EQUATION

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

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

Figure 1: CC by Texas Education Agency (TEA) is licensed under Creative Commons Attribution License v4.0

Figure 3: "20lb. Steel Propane Cylinder" by Hustvedt is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported License

Figure 2: "Engine, Partial Cross-Sectional View" by MJ Bird is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported License

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 <u>https://phet.colorado.edu/sims/html/gas-properties/latest/gas-properties_en.html</u>
- 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 m³
- 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 <u>https://phet.colorado.edu/sims/html/gas-properties/latest/gas-properties_en.html</u>
- 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 m³ 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.

Image: CC by Texas Education Agency (TEA) is licensed under Creative Commons Attribution License v4.0



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: Mj-bird, CC BY-SA 3.0, via Wikimedia Commons
- Slide 11 Right image: Hustvedt, CC BY-SA 3.0, via Wikimedia Commons
- Slides 14-15: Screenshot from PhET Interactive Simulations University of Colorado Boulder
- Slide 17: Open Stax College Physics online textbook