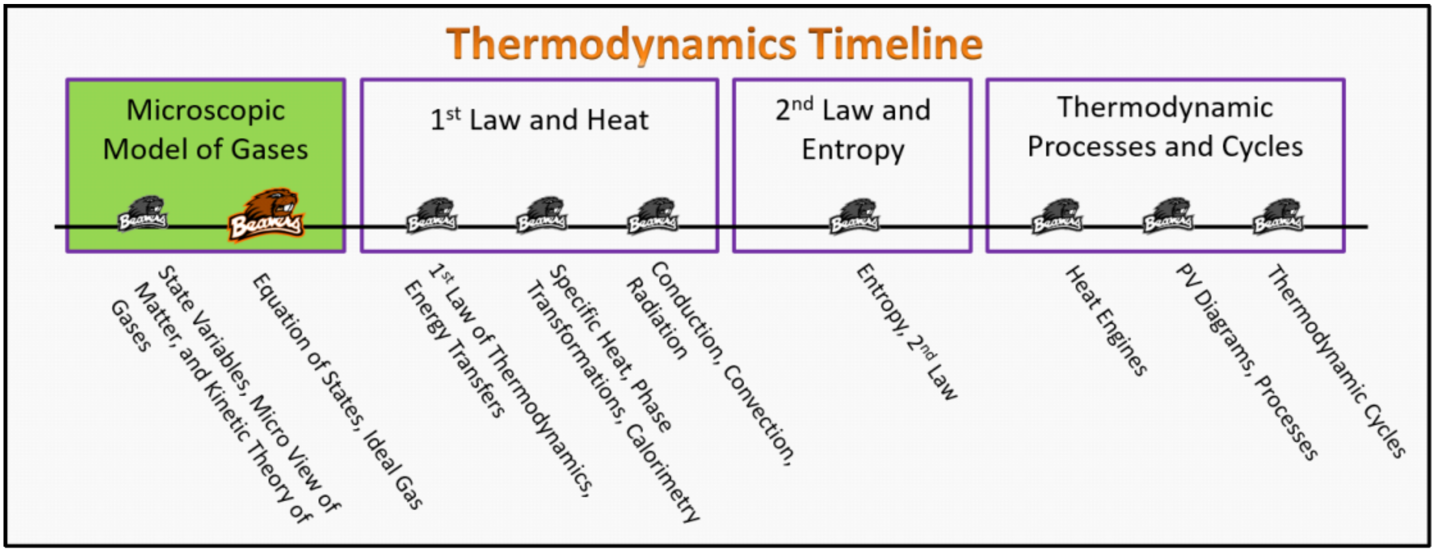
(MG.L2.123) Template for Boxsand

Thursday, March 29, 2018 8:34 PM

Microscopic Model of Gases

Familiarize Stage (MG.L2.1)

Lecture 2
Equation of States, Ideal Gas



MG.L2.1-01

Description: The nature of pressure

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: Which of the following statements best describes the microscopic cause of pressure in an ideal gas.

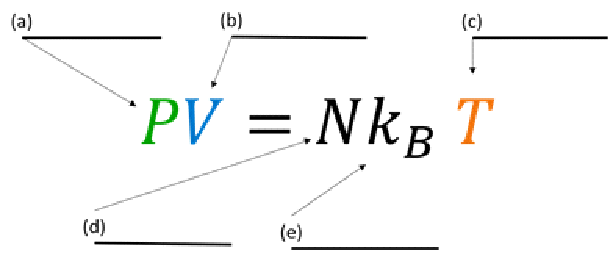
(1) Particles repel each other, pushing outward on the container holding them
(2) Particles are attracted to each other, sucking the walls of the container inward
(3) Particles push on the walls of the container with a gravitational force
(4) Particles collide with the walls of a the container creating a large number of small impulses that when added up equal an outward force

MG.L2.1-02

Description: Infographic quiz ideal gas law - label matching

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: Match each term in the equation with the correct description from the following list. (1) Volume, (2) Boltzmann's constant, (3) Temperature, (4) Pressure, (5) Number of particles



MG.L2.1-03

Description: When the ideal gas law is relevant?

Learning Objectives: [x,xx,...] Put the learning objective numbers here

Problem Statement: Strictly speaking, the ideal gas law is only relevant for what type of system?

(1) An open system.
(2) An inert gas.
(3) A system of weakly interacting particles.
(4) A system of non-interacting particles.
(5) A system at low temperature and high pressure.
(6) A system at high temperature and pressure.

MG.L2.1-04

Description: Comparing different forms of the ideal gas law

Learning Objectives: [x,xx,...] Put the learning objective numbers here

Problem Statement: One form of the ideal gas law uses a big N which represents the number of particles. Another form uses a small n which represents the number of moles. Which form should always be used?

(1) The one with n
(2) The one with N
(3) Depends on whether you're doing physics or chemistry.
(4) Depends on whether the information given (or asked for) involves number of particles or moles
(5) Both are equivalent as long as you convert between them

MG.L2.1-05

Description: Comparing different forms of the ideal gas law

Learning Objectives: [x,xx,...] Put the learning objective numbers here

Problem Statement: The ratio of the number of particles (N) divided by the number of moles (n) is equal to which of the following? Here R is the Rydberg constant, k_B is Boltzmann's constant, and T is the temperature in Kelvin.

(1) R/k_B
(2) k_B/R
(3) $R \cdot T/k_B$
(4) $k_B \cdot T/R$

MG.L2.1-06

Description: Ideal gas law proportional reasoning

Learning Objectives: [x,xx,...] Put the learning objective numbers here

Problem Statement: Consider an ideal gas. If the volume increases while the pressure and number of particles remains constant, what happens to the temperature?

(1) Decreases
(2) Increases
(3) Remains the same
(4) Not enough information

MG.L2.1-07

Description: Ideal gas law proportional reasoning

Learning Objectives: [x,xx,...] Put the learning objective numbers here

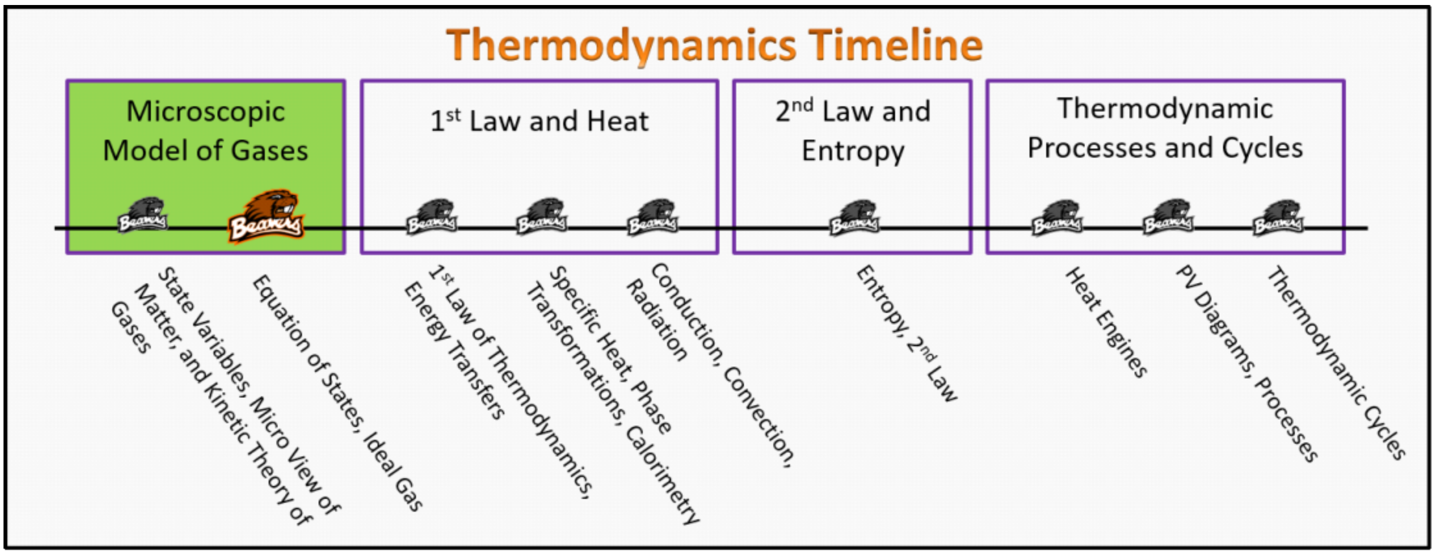
Problem Statement: Consider an ideal gas. If the pressure increases by a factor of 2 while the volume halves, what happens to the temperature?

(1) Decreases
(2) Increases
(3) Remains the same
(4) Not enough information

Microscopic Model of Gases

Foundation Stage (MG.L2.2)

Lecture 2
Equation of States, Ideal Gas



Textbook Chapters (* Calculus version)

- **BoxSand** :: KC videos (ideal gas law)
- **Knight** (College Physics : A strategic approach 3rd) :: 12.2
- ***Knight** (Physics for Scientists and Engineers 4th) :: 18.6
- **Giancoli** (Physics Principles with Applications 7th) :: 13-5 ; 13-6 ; 13-7

Warm up

MG.L2.2-01:

Description: Apply energy analysis to determine change in thermal energy.

Learning Objectives: [?] - Can you identify the objectives from the previous lecture, and this lecture, that this question is relevant to?

Problem Statement: A closed system with 2 regions (**A** and **B**) are isolated from the surroundings. Regions **A** and **B** both contain an equal number of different monatomic ideal gases. The gases are in thermal equilibrium with each other. When in equilibrium, an ideal gas can be modeled with the ideal gas equation of state $\mathbf{P\,V = N\,k_B\,T}$, where **P** is pressure, **V** is volume, **N** is the number of particles, **T** is temperature, and $\mathbf{k_B}$ is a positive constant. Which of the following statements are necessarily true?

(1) The average translational kinetic energy of **A** and **B** are equal.
(2) The temperature of **A** is equal to **B**.
(3) The product **P V** for **A** is equal to the product **P V** for gas **B**.
(4) The volume of gas **A** is equal to **B**.
(5) The pressure of gas **A** is equal to **B**.

Selected Learning Objectives

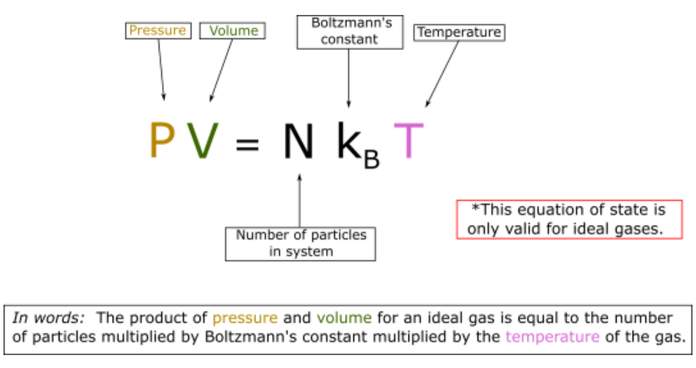
1. Coming soon to a lecture template near you.

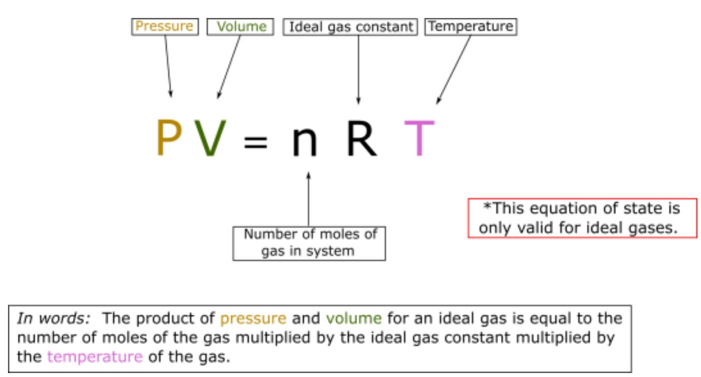
Key Terms

- Equation of state
- Ideal gas
- Ideal gas equation of state (i.e. ideal gas law)
- Van der Waals equation of state
- Pressure (macro)

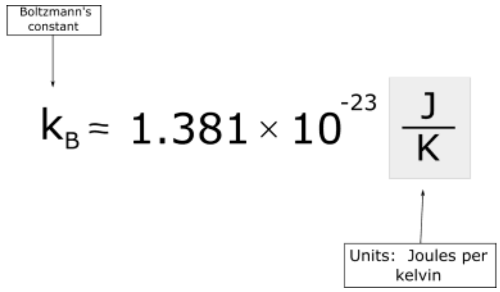
Key Equations

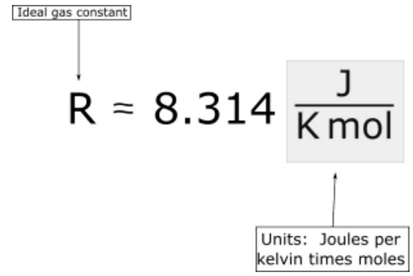
Ideal gas equation of state (ideal gas law)

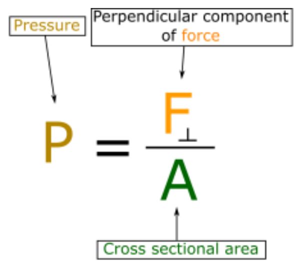




Constants







In words: Pressure is equal to the perpendicular component of force with respect to the surface divided by the cross sectional area of the surface.

Key Concepts

- Consider a container of gas, at any instant of time, the pressure, volume, temperature, and number of particles in our system have unique values. If the system is not in equilibrium then these state variables constantly change as the system tends towards equilibrium. Thus only at equilibrium are we able to write a nice mathematical relationship between each state variable that is not dependent on time. This mathematical description of how these state variables relate to one another in equilibrium is known as an equation of state.
- An ideal gas is essentially a non-interacting collection of point-like particles other than the elastic collisions between each other and container walls that obey Newton's laws of motion. The motion of the particles is also random (i.e. direction and speed of particles have a large range of values). In order to model real gases as an ideal gas, the following assumptions must hold true:
  - The number of particles must be very large.
    - Why large numbers? Recall that our state variables P,V,T,N are macroscopic quantities which are fundamentally linked to the microscopic quantities of the gas via statistics (recall the kinetic theory of gases and Boltzmann's postulate). Thus the gas must have large numbers of particles to use these macroscopic equations of state.
  - The volume of the container should be much larger than the volume of particles. This statement is equivalent to saying, the density of the gas should be very low.
    - Why low density? Real gases do have attractive interactions, but if the interactions are weak, then low density ensures the gas particles are almost always far enough apart that the attractive interactions are negligible, thus capable of modeling with an idea gas which is assumed to have no attractive interactions.
- The ideal gas equation of state (i.e. the ideal gas law) is the equation of state used to model gases for which the above assumptions are valid.
  - An ideal gas can be composed of atoms, molecules, or even fundamental particles like electrons so long as the above assumptions are valid.
- Van der Waals equation of state is probably the most common equation of state the allows for interactions between gas particles and also takes into account the finite size of the particles. The mathematical representation of van der Waals is shown below with an explanation of what each terms represents.
  - $\left(P + \frac{N^2}{V^2 N_A^2}\,a\right)\left(V - \frac{N}{N_A}\,b\right) = N\,k_B\,T$
    - "a" and "b" are fitting parameters:
      - a relates to the average interaction between the particles
      - b relates to the excluded volume that arises on contact because the particles now have finite sizes
- Macroscopically, pressure is the perpendicular component of force divided by the area that it acts over.

Questions

Act I: Connecting micro to macro

MG.L2.2-02:

Description: Conceptual question about change in pressure for ideal gas if other state variables are changed or held constant. (5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Determine if the pressure increases, decreases, or stays the same in the following scenarios. Try to use the microscopic arguments of the gas particles to support your decision to your neighbors.

(a) The volume of a sealed container decreases while the number of particles and temperature stays the same.

1. Pressure increases
2. Pressure decreases
3. Pressure remains the same.

(b) The temperate of a gas increases while the volume and number of particles stays the same.

1. Pressure increases
2. Pressure decreases
3. Pressure remains the same.

(c) The number of particles increase while the temperature and volume remain constant.

1. Pressure increases
2. Pressure decreases
3. Pressure remains the same.

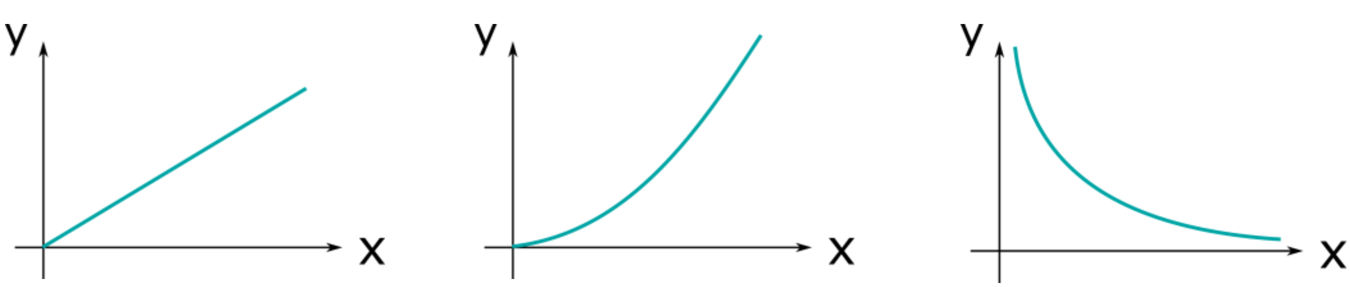
MG.L2.2-03:

Description: Given graphs, identify the proportionality of the shape. (4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Consider the three graphs below. Identify the proportionality of each plot (e.g. If you think the plot represents **y** = 5 $\mathbf{x}^3$, then the proportionality would be $\mathbf{x}^3$).

(a) **(b)** **(c)**



(1) **x**
(2) $\mathbf{x}^2$
(3) $\mathbf{x}^3$
(4) 1/**x**

(1) **x**
(2) $\mathbf{x}^2$
(3) $\mathbf{x}^3$
(4) 1/**x**

(1) **x**
(2) $\mathbf{x}^2$
(3) $\mathbf{x}^3$
(4) 1/**x**

Act II: Ideal gas equation of state

MG.L2.2-04:

Description: Proportional reasoning with ideal gas equation of state. (3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: One mole of an ideal gas has a set of state variables: $\mathbf{T}_1$, $\mathbf{P}_1$, $\mathbf{V}_1$. If the pressure is tripled while the temperature is held constant, what is the final volume in terms of the initial?

(1) $9\mathbf{V}_1$
(2) $3\mathbf{V}_1$
(3) $\mathbf{V}_1$
(4) $\mathbf{V}_1/3$
(5) $\mathbf{V}_1/9$

MG.L2.2-05:

Description: Proportional reasoning with ideal gas equation of state. (4 minutes).

Learning Objectives: [1, 12, 13]

Problem Statement: One mole of an ideal gas has a set of state variables: $\mathbf{T}_1$, $\mathbf{P}_1$, $\mathbf{V}_1$. If the volume is doubled while the temperature is tripled, what is the final pressure in terms of the initial?

(1) $\mathbf{P}_1/3$
(2) $\mathbf{P}_1/2$
(3) $2\mathbf{P}_1/3$

(4) $\mathbf{P}_1$
(5) $3\mathbf{P}_1/2$
(6) $3\mathbf{P}_1/4$
(7) $2\mathbf{P}_1$
(8) $3\mathbf{P}_1$

MG.L2.2-06:

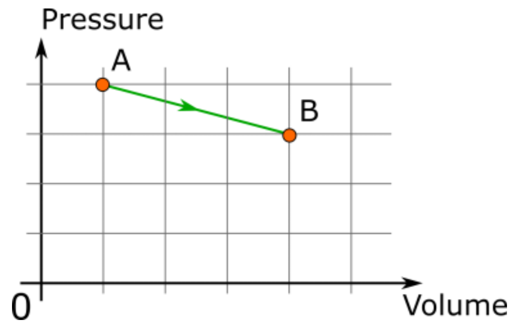
Description: Identify final state variables in terms of initial given a P-V diagram with labeled states. (3 minutes + 2 minutes + 3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: An ideal gas trapped in a cylinder expands while is pressure drops. The starting point for this process is labeled **A** and the end point is labeled **B** in the graph of pressure versus volume shown below.

(a) Which of the following are correct with respect to what happens to the pressure?

(1) $\mathbf{P}_f = 1/2\ \mathbf{P}_i$
(2) $\mathbf{P}_f = 3/4\ \mathbf{P}_i$
(3) $\mathbf{P}_f = \mathbf{P}_i$
(4) $\mathbf{P}_f = 3\ \mathbf{P}_i$



(b) Which of the following are correct with respect to what happens to the volume?

(1) $\mathbf{V}_f = 1/2\ \mathbf{V}_i$
(2) $\mathbf{V}_f = 3/4\ \mathbf{V}_i$
(3) $\mathbf{V}_f = 3\ \mathbf{V}_i$
(4) $\mathbf{V}_f = 4\ \mathbf{V}_i$

(c) What is the final temperature in terms of the initial?

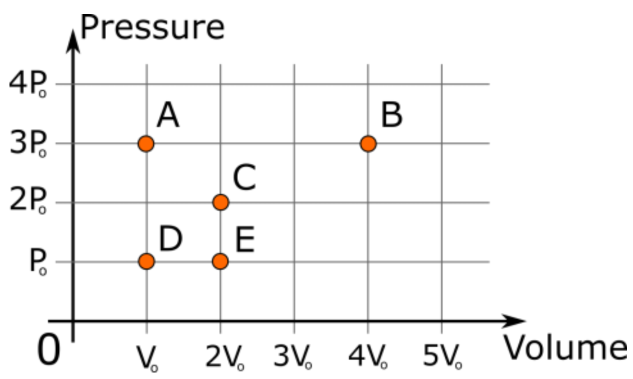
(1) $\mathbf{T}_f = 3/16\ \mathbf{T}_i$
(2) $\mathbf{T}_f = 3\ \mathbf{T}_i$
(4) $\mathbf{T}_f = 4\ \mathbf{T}_i$
(5) $\mathbf{T}_f = 16/3\ \mathbf{T}_i$

MG.L2.2-07:

Description: Rank temperature given P-V diagram with labeled states. (6 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Five points representing five different equilibrium states of one mole of an idea gas are labeled on the pressure-volume graph shown below. Rank the temperatures of the idea gas in each equilibrium state.



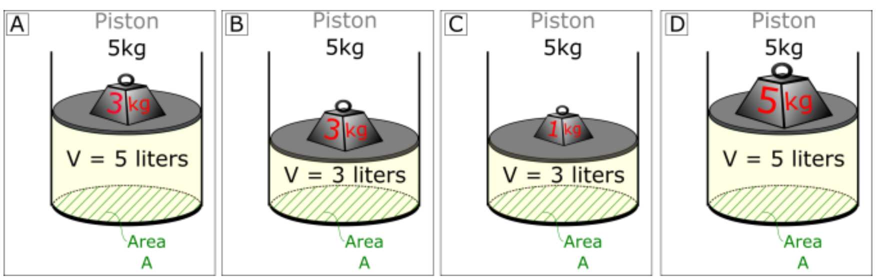
Act III: Pressure - macroscopic view

MG.L2.2-08:

Description: Rank pressure given volume, force, and area. (6 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Cylinders with equal cross-sectional areas contain different volumes of an idea gas sealed in by pistons. There is a weight sitting on top of each piston. The gas is the same in all four cases and is at the same temperature. The pistons are free to move without friction. Rank the pressure of the gas in each cylinder.



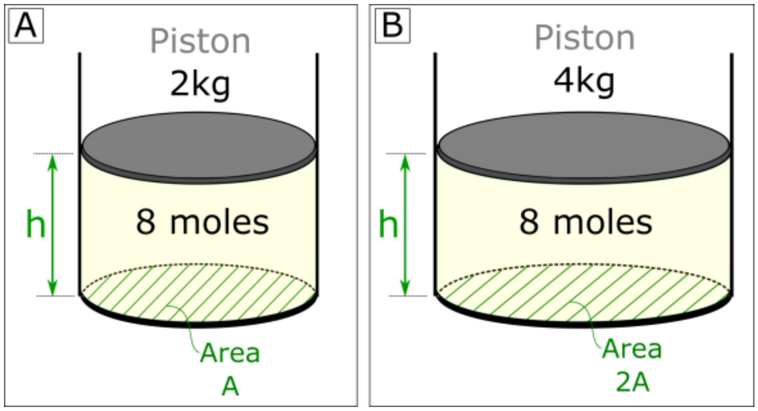
MG.L2.2-09:

Description: Rank pressure given volume, force, and area. (4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Two cylinders are filled to the same height H with ideal gases. The gases are different, and the cross-sectional areas of the cylinders are different. Both cylinders have pistons that are free to move without friction. The temperature of the gas in cylinder A is ___________________ the temperature of the gas in cylinder B.

(1) greater than
(2) less than
(3) equal to



Conceptual questions for discussion

1. Consider 2 equal sized large containers each one filled with the same number of hydrogen gas and neutron gas. Which container, the hydrogen gas container, or the neutron gas container, do you think behaves more like an ideal gas? Support your answer using the definition of ideal gas and the assumptions in the key concepts.
2. Which of the following combinations of pressure and temperature would a gas most closely model an ideal gas at?
   i. low pressure and low temperature.
   ii. low pressure and high temperature.
   iii. high pressure and low temperature.
   iv. high pressure and high temperature.
3. A closed bottle in a large room contains an ideal gas with initial state variables: $\mathbf{P_1},\mathbf{V_1},\mathbf{T_1},\mathbf{N_1}$. If a few particles are taken out of the bottle, such that there still remains enough particles in the bottle to model an ideal gas, what will happen to the temperature of the gas as a function of time?
   i. The temperature will decrease until it reaches a constant value lower than $\mathbf{T_1}$.
   ii. The temperature will increase until it reaches a constant value higher than $\mathbf{T_1}$.
   iii. The temperature will decrease initially, then eventually return to a constant temperature of $\mathbf{T_1}$.
   iv. The temperature will increase initially, then eventually return to a constant temperature of $\mathbf{T_1}$.
   v. The temperature will always remain the same value of $\mathbf{T_1}$.

Hints

MG.L2.2-01: No hints.

MG.L2.2-02: No hints.

MG.L2.2-03: No hints.

MG.L2.2-04: Start with ideal gas law and construct an appropriate proportionally statement for the given scenario.

MG.L2.2-05: Start with ideal gas law and construct an appropriate proportionally statement for the given scenario.

MG.L2.2-06: Label the axes with values (e.g. P, 1P, 2P, 3P…).

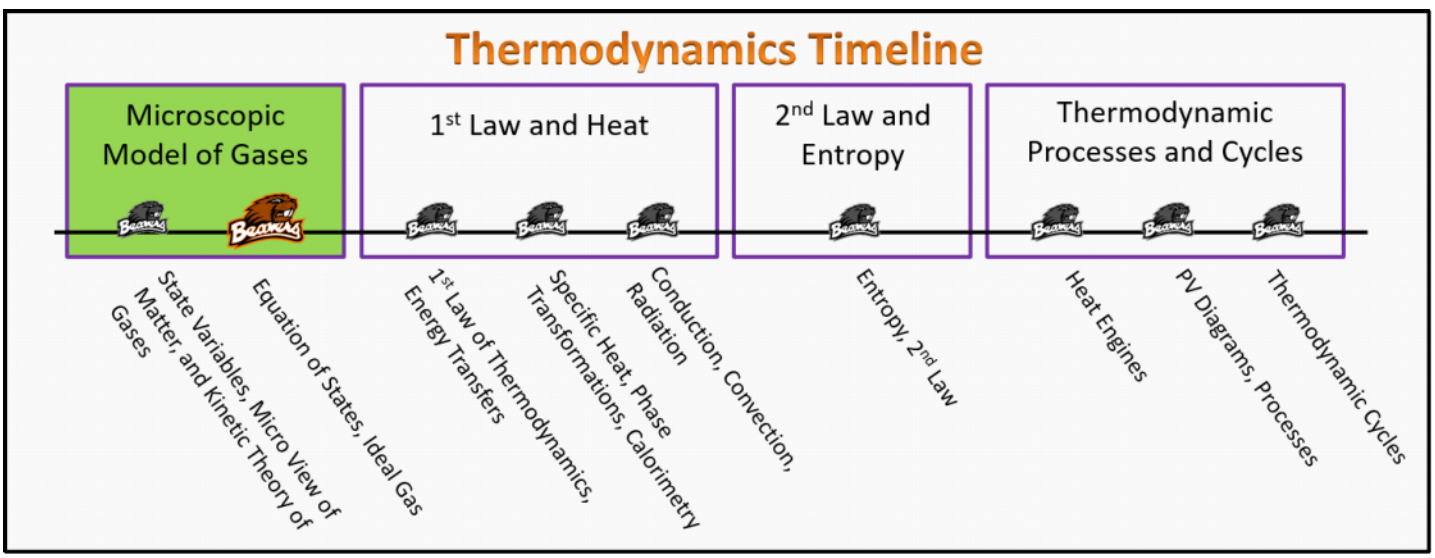
MG.L2.2-07: Look at the ideal gas law, if the number of particles/moles is constant, what is temperature proportional to?

MG.L2.2-08: Pressure is force/area.

MG.L2.2-09: Pressure is force/area.

Microscopic Model of Gases
Practice Stage (MG.L2.3)

Lecture 2
Equation of States, Ideal Gas



MG.L2.3-01

Description: understanding concepts of ideal gases

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: Two balloons are at the same temperature and contain an equal amount of helium. If the first balloon has 3 times the volume as the second balloon, how do the pressures relate?

(1) The first balloon's pressure is 1/3 times the second balloon's pressure.
(2) The first balloon's pressure is 1/2 times the second balloon's pressure.
(3) The first balloon's pressure equals the second balloon's pressure.
(4) The first balloon's pressure is 3 times the second balloon's pressure.

MG.L2.3-02

Description: Proportional reasoning with ideal gas equation of state.

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: One mole of an ideal gas has a set of state variables: $\mathbf{T}_1$, $\mathbf{P}_1$, $\mathbf{V}_1$. If the pressure is decreased by 2/3 and the temperature decreased by 4/5, what is the final volume in terms of the initial volume?

(1) 6/15 $\mathbf{V}_1$
(2) 12/10 $\mathbf{V}_1$
(3) 10/12 $\mathbf{V}_1$
(4) 15/6 $\mathbf{V}_1$/3
(5) 1 $\mathbf{V}_1$

MG.L2.3-03

Description: Proportional reasoning with ideal gas equation of state.

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: Two moles of an ideal gas is in a sealed container. If the average kinetic energy per particle is doubled, by what factor does the pressure change by?

(1) 1/4 $\mathbf{P}_i$
(2) 1/2 $\mathbf{P}_i$
(3) 1 $\mathbf{P}_i$
(4) 2 $\mathbf{P}_i$
(5) 4 $\mathbf{P}_i$

MG.L2.3-04

Description: Proportional reasoning with ideal gas equation of state.

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: Two moles of an ideal gas is in a sealed container. If the root mean square speed is doubled, by what factor does the pressure change by?

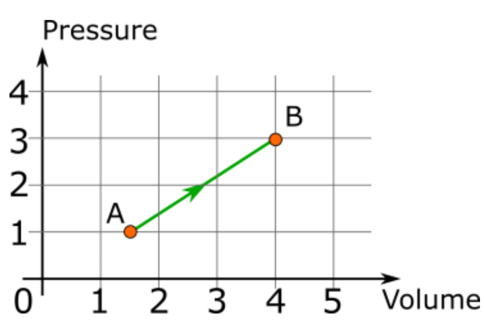
(1) 1/4 $\mathbf{P}_i$
(2) 1/2 $\mathbf{P}_i$
(3) 1 $\mathbf{P}_i$
(4) 2 $\mathbf{P}_i$
(5) 4 $\mathbf{P}_i$

MG.L2.3-05a

Description: Identify final state variables in terms of initial given a P-V diagram with labeled states.

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: An ideal gas trapped in a cylinder expands while is pressure drops. The starting point for this process is labeled **A** and the end point is labeled **B** in the graph of pressure versus volume shown below. Which of the following are correct with respect to what happens to the pressure?



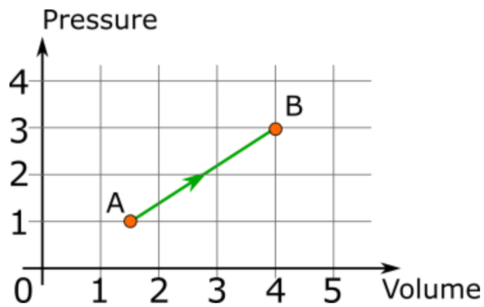
(1) $\mathbf{P}_f = 3\ \mathbf{P}_i$
(2) $\mathbf{P}_f = 2\ \mathbf{P}_i$
(3) $\mathbf{P}_f = \mathbf{P}_i$
(4) $\mathbf{P}_f = 1/3\ \mathbf{P}_i$

MG.L2.3-05b

Description: Identify final state variables in terms of initial given a P-V diagram with labeled states.

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: An ideal gas trapped in a cylinder expands while is pressure drops. The starting point for this process is labeled **A** and the end point is labeled **B** in the graph of pressure versus volume shown below. Which of the following are correct with respect to what happens to the volume?



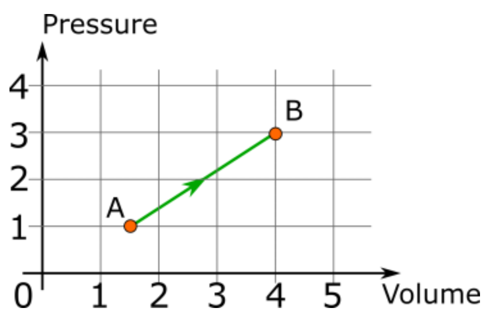
(1) $\mathbf{V}_f = 2.5\ \mathbf{V}_i$
(2) $\mathbf{V}_f = 4\ \mathbf{V}_i$
(3) $\mathbf{V}_f = 8/3\ \mathbf{V}_i$
(4) $\mathbf{V}_f = 1.5\ \mathbf{V}_i$

MG.L2.3-05c

Description: Identify final state variables in terms of initial given a P-V diagram with labeled states.

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: An ideal gas trapped in a cylinder expands while is pressure drops. The starting point for this process is labeled **A** and the end point is labeled **B** in the graph of pressure versus volume shown below. What is the final temperature in terms of the initial?



(1) $\mathbf{T}_f = 8\ \mathbf{T}_i$
(2) $\mathbf{T}_f = 3\ \mathbf{T}_i$
(4) $\mathbf{T}_f = 7.5\ \mathbf{T}_i$
(5) $\mathbf{T}_f = 16/3\ \mathbf{T}_i$

MG.L2.3-06

Description: Proportional reasoning with ideal gas equation of state.

Learning Objectives: [x,xx,…] Put the learning objective numbers here

Problem Statement: Consider an ideal gas with a constant number of particles. If the pressure changes by a factor of 2/3 and the temperature changes by a factor of 4/15, by what factor must the volume have changed?

(1) 8/45
(2) 45/8
(3) 12/30
(4) 30/12
(5) 2/15
(6) 4/3