Purdue University Department of Physics

Physics 22000

General Physics

Lecture 18 – Gases

Fall 2016 Semester

Prof. Matthew Jones

SUPPLEMENTAL INSTRUCTION

Free Study Sessions!

Rachel Hoagburg

Come to SI for more help in PHYS 220

Tuesday and Thursday	7:30-8:30PM Shreve C113

Office Hour

Tuesday 1:30-2:30 4th floor of Krach

For other SI-linked courses and schedules, visit purdue.edu/si or purdue.edu/boilerguide

Ideal Gas Law

$$PV = NkT$$

- Because one mole has Avogadro's number of particles, $N = nN_A$, we can write:

$$PV = nN_AkT$$

  where n is the number of moles of gas.
- Boltzmann constant: $k = 1.38 \times 10^{-23}\ \mathrm{J/K}$
- Avogadro's number: $N_A = 6.02 \times 10^{23}\ /\mathrm{mole}$
- Ideal gas constant: $R = N_Ak = 8.31\,\mathrm{J/mole\ /K}$

$$PV = nRT$$

Kinetic Energy of Gas Particles

- By considering gas particles colliding with the walls of a container, we deduced that

$$Nm\overline{v^2} = 3PV$$

- Average kinetic energy of one gas particle:

$$\overline{K} = \frac{1}{2}m\overline{v^2} = \frac{3}{2}\frac{PV}{N} = \frac{3}{2}kT$$

- The temperature of the gas is some measure of the average kinetic energy of gas particles.

Temperature and Particle Motion

- You have two containers holding identical gases that have been sitting in the same room for a long time. One container is large and the other one is small. Which one has a higher temperature?
  - Because the average kinetic energy per particle is the same in each container, the temperatures of the two gases are the same.
  - The total kinetic energy of the particles in the large container is larger because it contains more particles.

Temperature and Particle Motion

- What will happen if you mix a container of hot gas with a container of cold gas?
  - The faster-moving particles of the hot gas will collide with the slower-moving particles of the cold gas. Following a collision, on average the faster-moving particle will be moving more slowly than before, and the slower particle will be moving more rapidly.
  - Eventually, the particles of the two gases will have the same average kinetic energy and, therefore, the same temperature.
  - This is called thermal equilibrium.

Remember!

Only when temperature is measured in Kelvin can we use

$$\overline{K} = \frac{3}{2}kT$$

to determine the average kinetic energy of the particles.

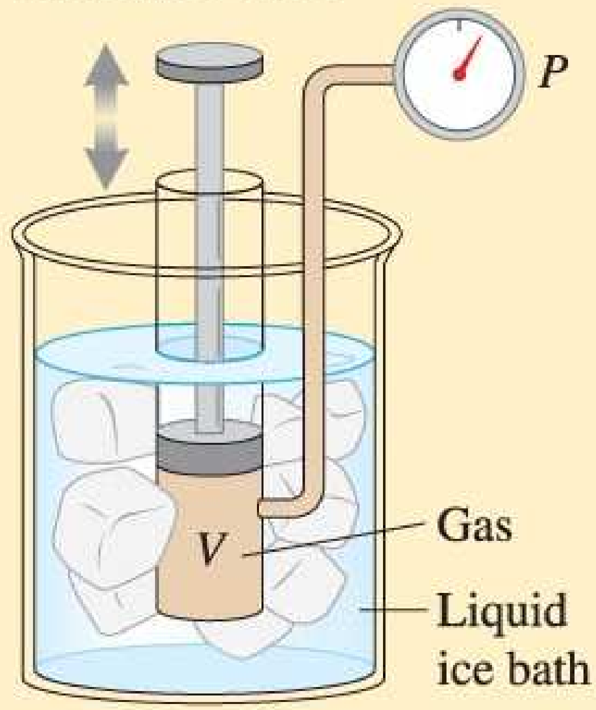
After all, negative kinetic energy is nonsense…

Testing the Ideal Gas Law

Testing experiment

Experiment 1: Isothermal process. *n* moles of gas are in a variable volume *V* container that is held in an ice bath at constant 0 °C (273 K) temperature *T*. How does the pressure of the gas change as we change the volume of the container? We push the piston slowly so that the temperature of the gas is always the same as the ice bath.

Isothermal process: constant *n* and *T*

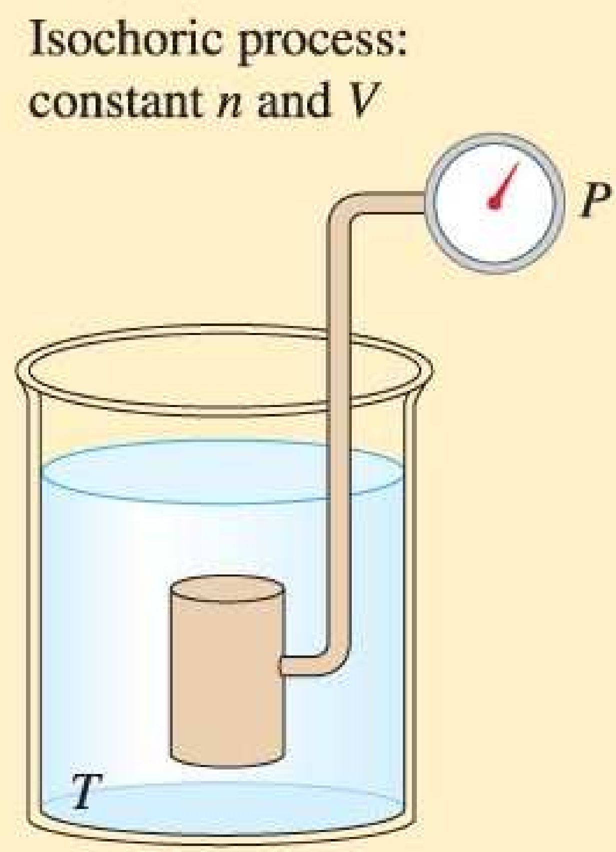


Testing the Ideal Gas Law

Prediction	Outcome
According to the ideal gas law $PV = nRT$, during a constant temperature process, the product of PV should remain constant. We predict that as the volume decreases, the pressure will increase so that the product remains constant.	Data collected: $V\ (m^3)$ — $P\ (N/m^2)$ 3.0×10^{-4} — 2.0×10^5 6.0×10^{-4} — 1.0×10^5 9.0×10^{-4} — 0.67×10^5 The product of volume and pressure remains constant in all experiments.

Testing the Ideal Gas Law

Experiment 2: Isochoric process. *n* moles of gas and the gas volume *V* are kept constant. The container is placed in different-temperature baths. How does the gas pressure change as the temperature changes?



Testing the Ideal Gas Law

According to the ideal gas law $PV = nRT$, during a constant volume process, the ratio $\frac{P}{T} = \frac{nR}{V}$ should remain constant. We predict that the pressure should increase in proportion to the temperature.

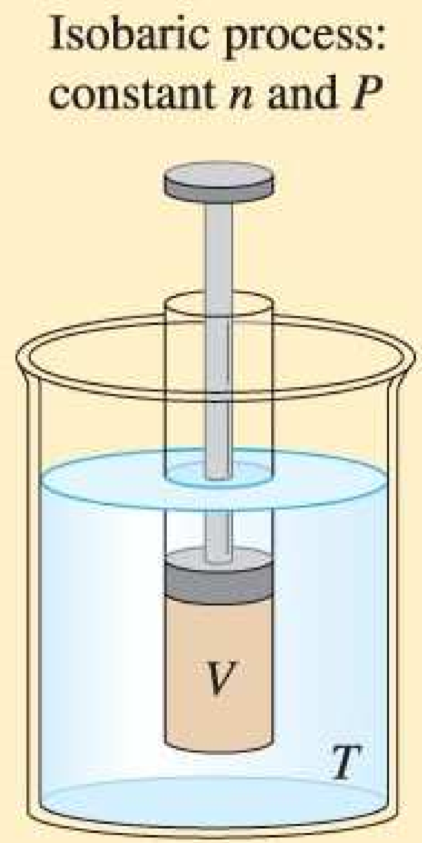
Data collected:

T (K)	P (N/m^2)
300	1.0×10^5
400	1.3×10^5
500	1.7×10^5

The ratio of pressure and temperature is constant in all experiments.

Testing the Ideal Gas Law

Experiment 3: Isobaric process. *n* moles of gas and the gas pressure *P* are held constant, as a piston in the gas container can move freely up and down keeping the pressure constant. How does the gas volume change as the temperature changes?



Testing the Ideal Gas Law

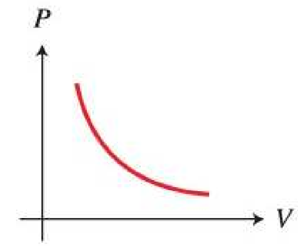
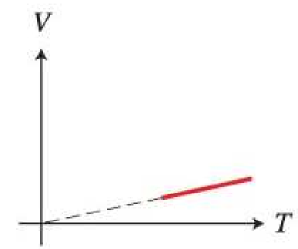
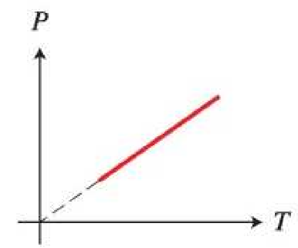
According to the ideal gas law $PV = nRT$, during a constant pressure process, the ratio $\frac{V}{T} = \frac{nR}{P}$ should remain constant. We predict that the volume should increase in proportion to the temperature.

Data collected:

T (K)	V (m^3)
300	3.0×10^{-4}
400	4.0×10^{-4}
500	5.0×10^{-4}

The ratio of volume and temperature remains constant in all experiments.

Ideal Gas Law Processes

Name	Constant quantities	Changing quantities	Equation	Graphical representation
Isothermal	N or n, T	P, V	$PV = \text{constant}$ $P_1V_1 = P_2V_2$	
Isobaric	N or n, P	V, T	$\frac{V}{T} = \text{constant}$ $\frac{V_1}{T_1} = \frac{V_2}{T_2}$	
Isochoric	N or n, V	P, T	$\frac{P}{T} = \text{constant}$ $\frac{P_1}{T_1} = \frac{P_2}{T_2}$	

Ideal Gas Law Processes

[No name]	*N* or *n*	*P*, *V*, *T*	$\frac{PV}{T} = \text{constant}$ $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
[No name]		*P*, *V*, *T*, *N* or *n*	$\frac{PV}{NT} = k$ $\frac{PV}{nT} = R$

Reflection on the Process of Construction of Knowledge for the Ideal Gas Law

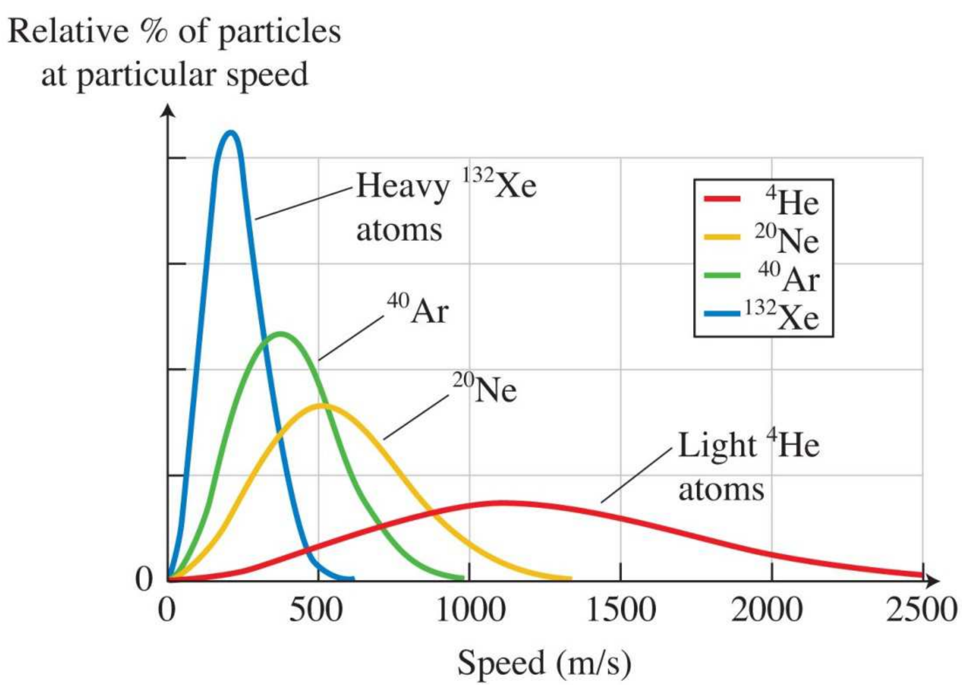
- The first step was to construct a simplified model of a system that could represent a real gas—the ideal gas model.
  - This involved making assumptions about the internal structure of gases.
  - The model was based partly on observations and partly on our knowledge of particle motion and interactions.
- We used this model to devise a mathematical description of the behavior of gases, the ideal gas law.

Reflection on the Process of Construction of Knowledge for the Ideal Gas Law

- We then tested the model's applicability to real gases by using it to predict how macroscopic quantities describing the gas would change during specific processes.
  - Macroscopic quantities: temperature, pressure, volume, and the amount of gas
  - Processes: isothermal, isobaric, and isochoric
  - Ideal gas law: used to construct equations that described those processes
- These predictions were consistent with the outcomes of the new testing experiments.

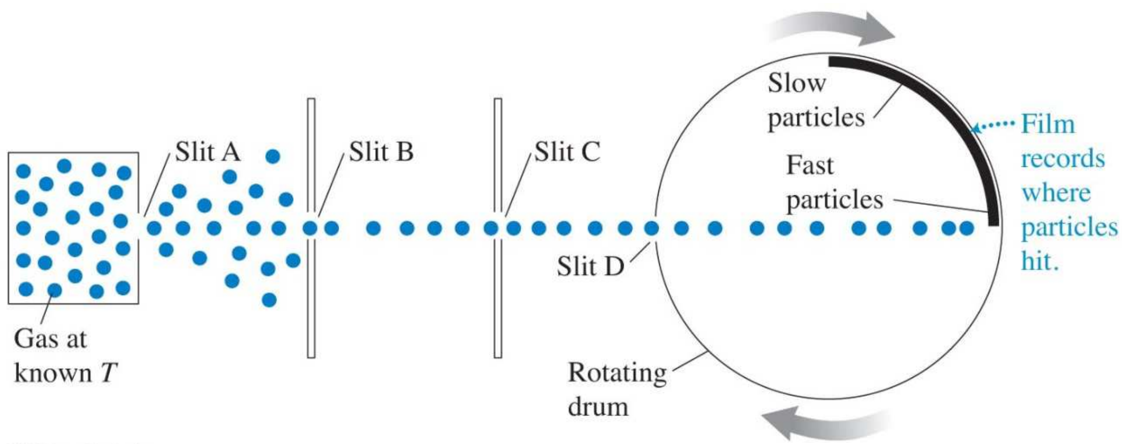
Speed Distribution of Particles

- In 1860, James Clerk Maxwell included the collisions of the particles in his calculations involving an ideal gas.
- This inclusion led to the following prediction: at a particular temperature, the collisions of gas particles with each other cause a very specific distribution of speeds



Speed Distribution of Particles

- Fast-moving particles hit the film almost directly across from the slit, whereas slow-moving particles hit somewhat later.
- The density of particles hitting a particular part of the film indicates the particles' relative speed.



- Measured speed distribution patterns match the Maxwell-predicted distributions.

Limitations of the Ideal Gas Law

- For real gases such as air, measurements of pressure and volume at conditions of normal pressure and temperature are consistent with predictions made by the ideal gas law.
  - At very high pressures or very low temperatures, real measurements differ from those predictions.
  - The ideal gas law describes gases accurately only over certain temperature and pressure ranges.

Examples

32. * Even the best vacuum pumps cannot lower the pressure in a container below 10^{-15} atm. How many molecules of air are left in each cubic centimeter in this "vacuum?" Assume that the temperature is 273 K.

Examples

38. * **Scuba diving** The pressure of the air in a diver's lungs when he is 20 m under the water surface is $3.0 \times 10^5\ N/m^2$, and the air occupies a volume of 4.8 L. How many moles of air should he exhale while moving to the surface, where the pressure is $1.0 \times 10^5\ N/m^2$?

Examples

46. **Capping beer** You would like to make homemade beer, but you are concerned about storing it. Your beer is capped into a bottle at a temperature of 27 °C and a pressure of $1.2 \times 10^5\ N/m^2$. The cap will pop off if the pressure inside the bottle exceeds $1.5 \times 10^5\ N/m^2$. At what maximum temperature can you store the beer so the gas inside the bottle does not pop the cap? List the assumptions that you made.