Physics 141.
Lecture 23.

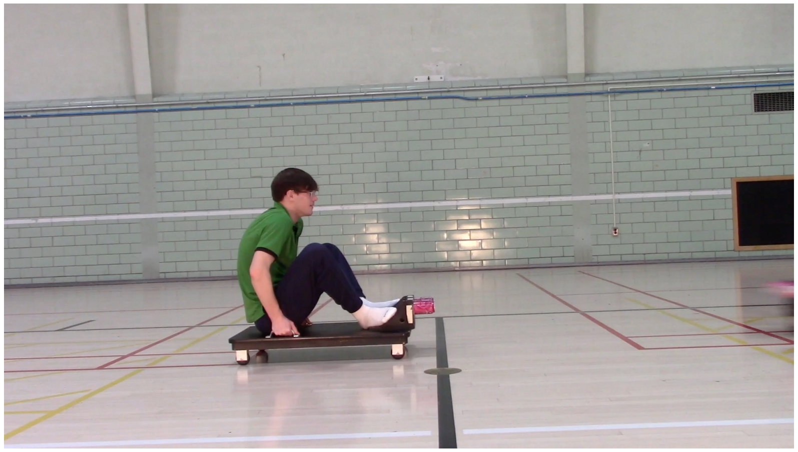
The first and the best airline in the world.

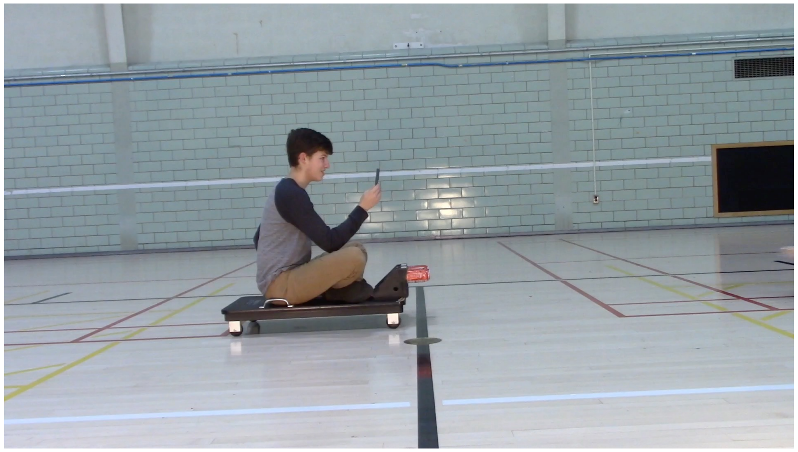
Physics 141.
Lecture 23.

- Course information:
  - Laboratory # 5 – lab report is due on Friday 12/6 at noon.
  - Homework set # 10 is due on Friday 12/6 at noon.
  - Results Exam # 3.
- Quiz
- Start the discussion of Supplement S1, Gases and Heat Engines:
  - The ideal gas law.

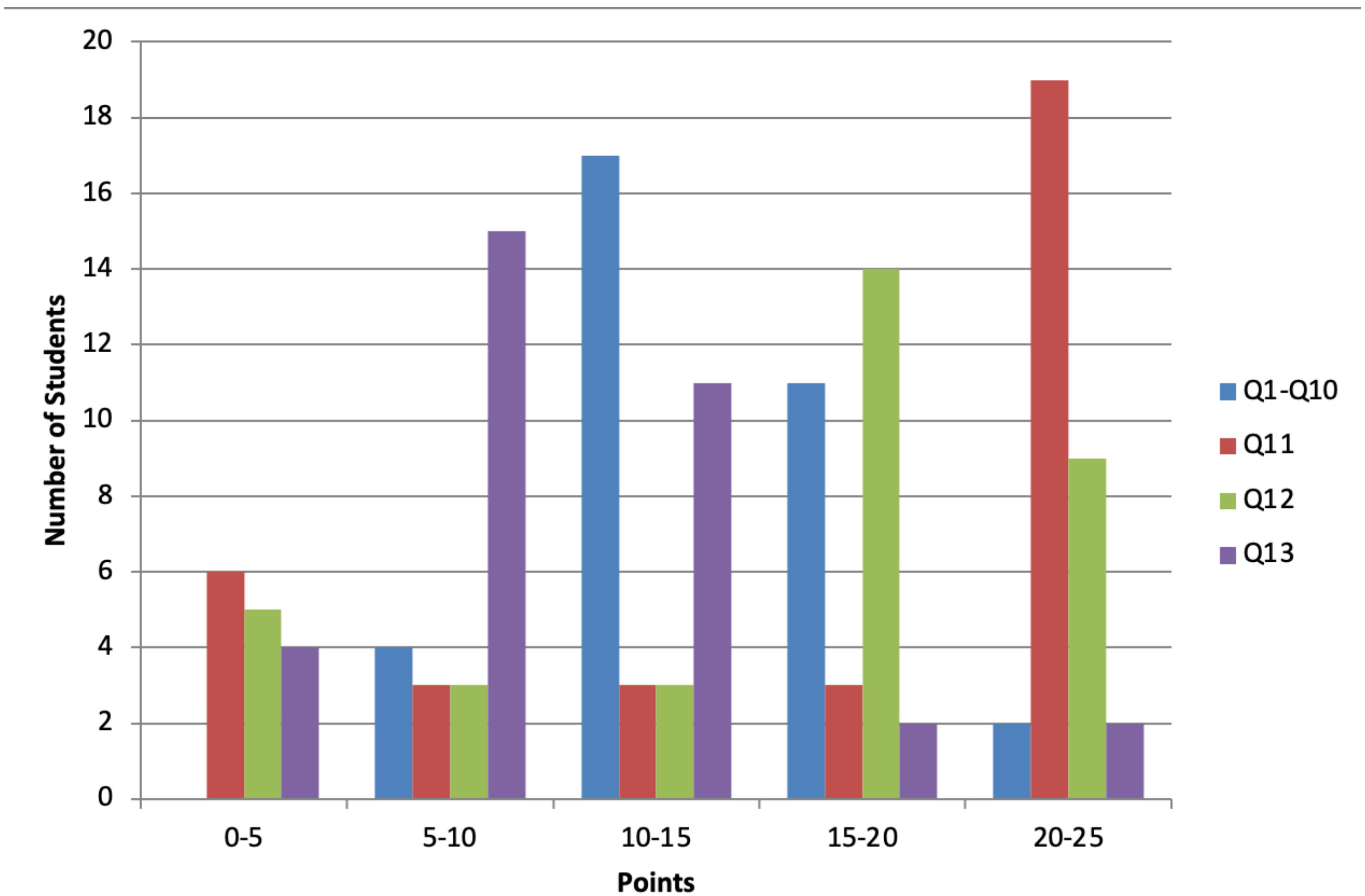
Analysis of experiment # 5.
Updated Timeline.

- ✓ 11/14: collisions in the May room
- ✓ 11/18: analysis files available.
  - https://www.pas.rochester.edu/~tdimino/phy141/lab05/
- ✓ 11/25: each student has determined his/her best estimate of the velocities before and after the collisions.
- ? 11/25: complete discussion and comparison of results with colliding partners and submit final results (velocities and errors).
- 11/27: results will be compiled, linear momenta and kinetic energies will be determined, and results will be distributed.
- 12/2: office hours by lab TA/TIs to help with analysis and conclusions.
- 12/6: students submit lab report # 5.

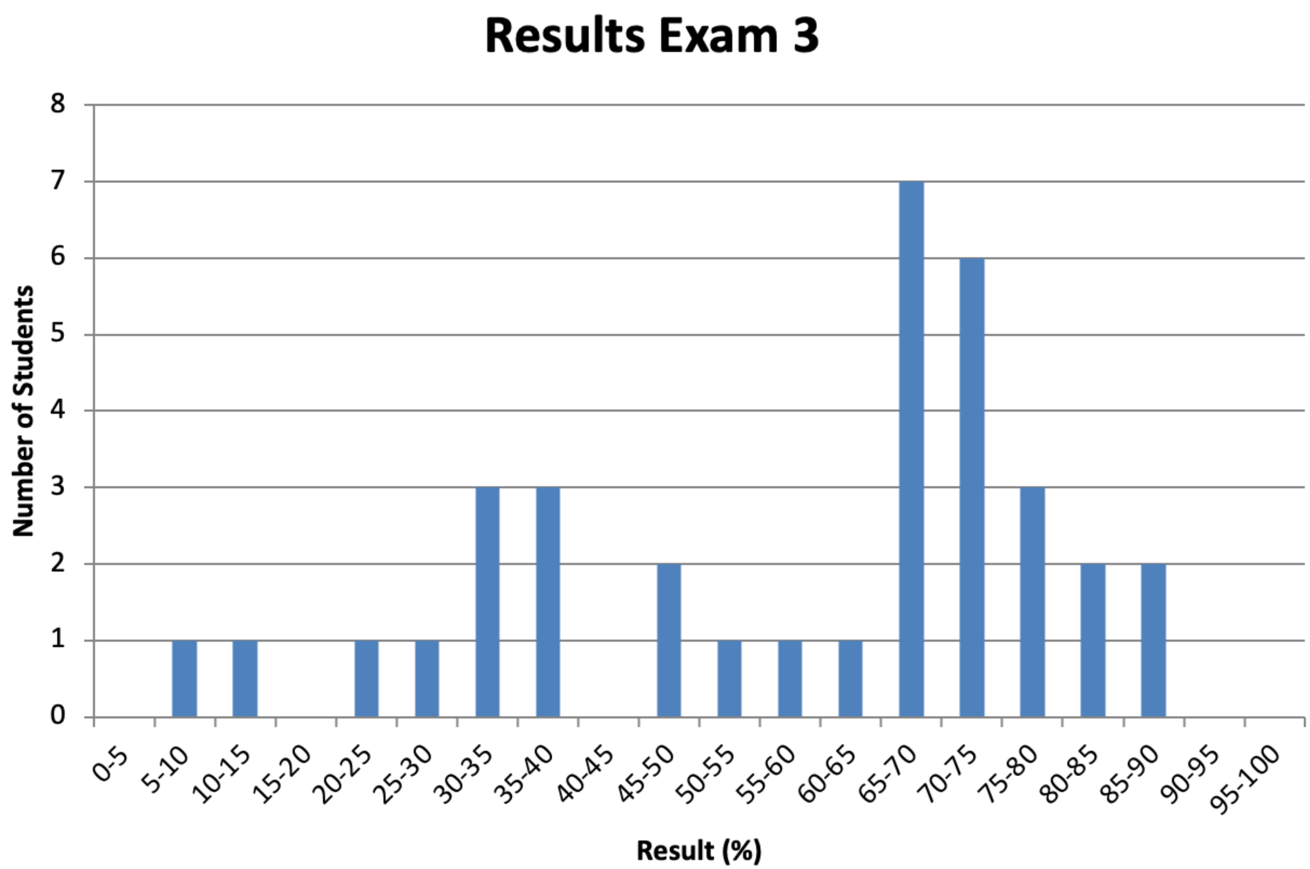




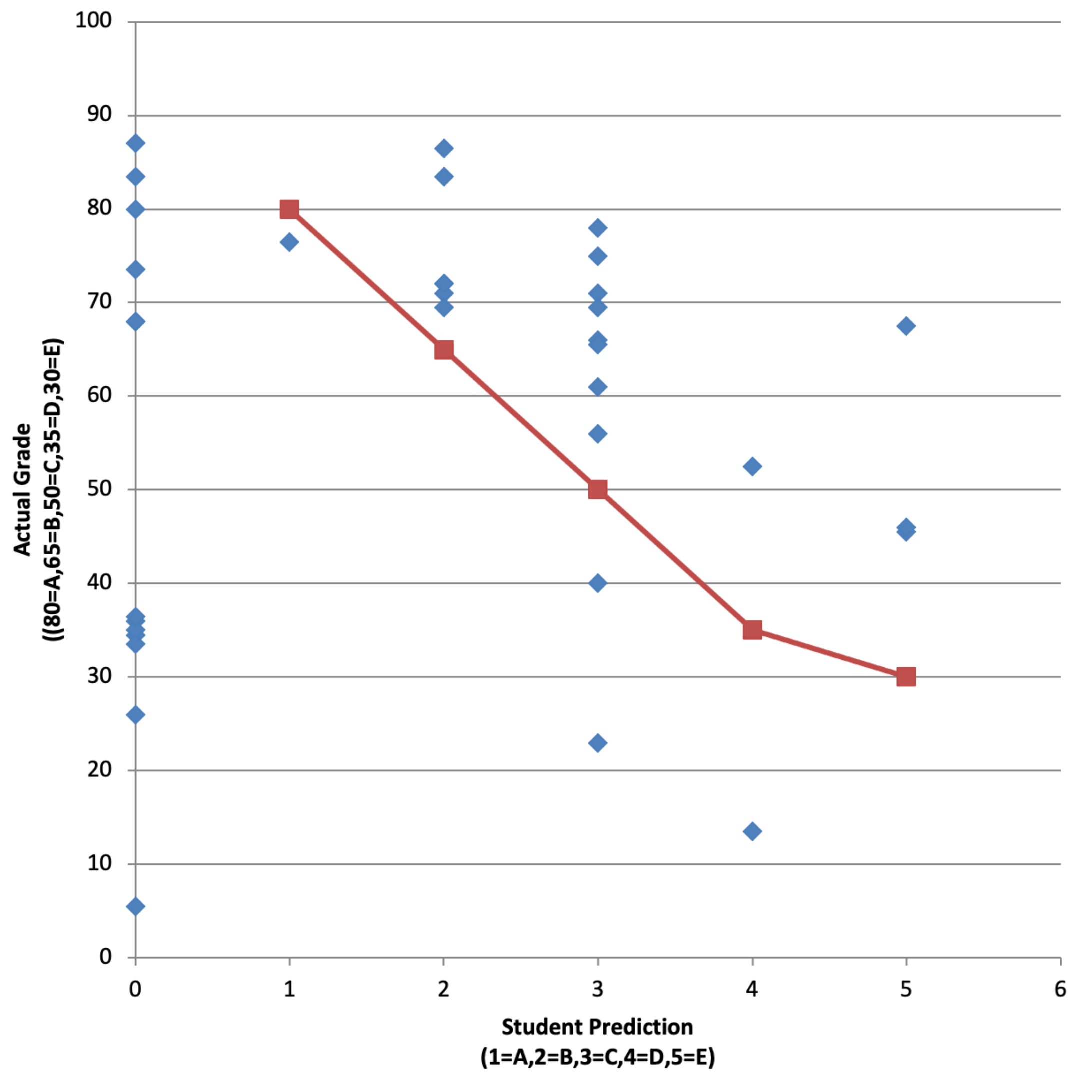
Results Exam 3.



Results Exam 3.



Results Exam 3.

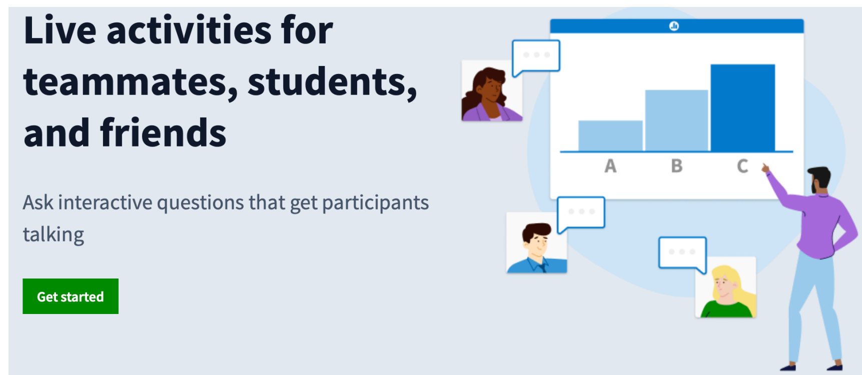


Student Course Opinion Questionnaires.

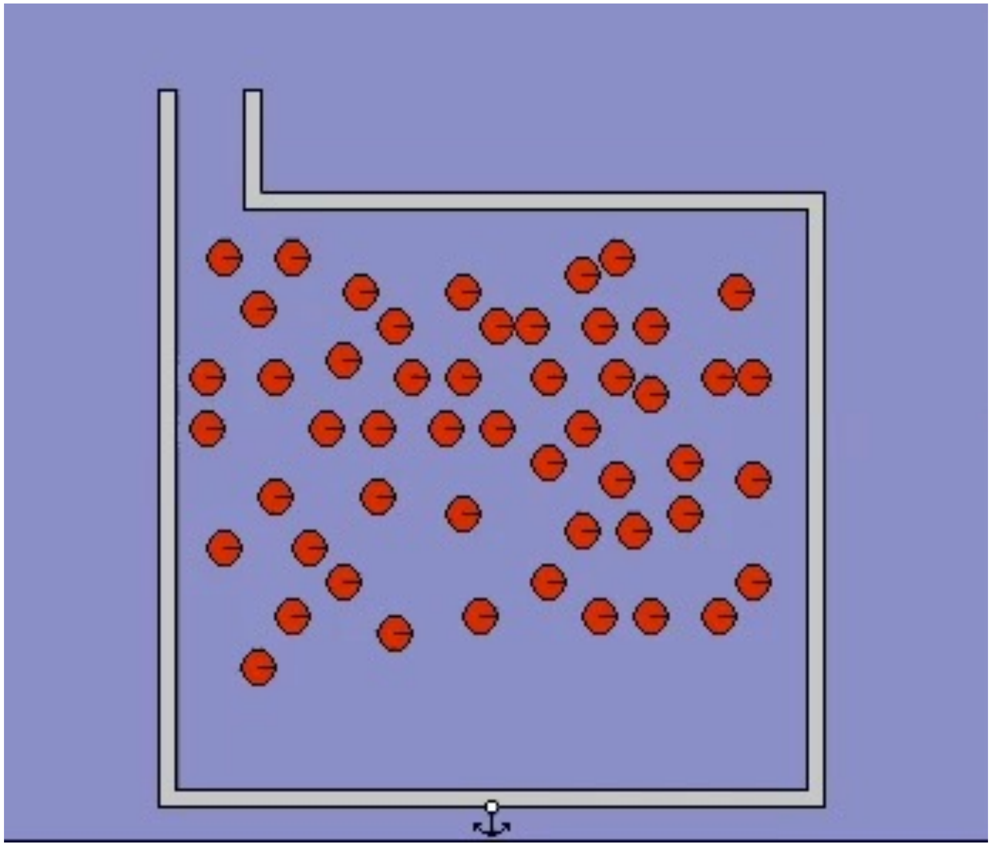
- At this time of the year, the University asks each student to complete an on-line survey about the courses he/she is enrolled in.
- This survey is used both at the College level and at the Departmental level to monitor the teaching effectiveness of our faculty.
- You will receive an email from the Dean's office with the proper URL to access the on-line survey.
- I will not see the responses until after the grades have been handed in, so your response may not benefit you directly, but the responses of previous students have shaped your experience in Physics 141.
- If 90% of the Physics 141 students participate in the survey by Tuesday 12/10, **everyone will receive 5% bonus points on the final exam**.

Quiz lecture 23.
PollEv.com/frankwolfs050

- The quiz today will have three questions.
- I will collect your answers electronically using the Poll Everywhere system.
- You have 60 seconds to answer each question.



Supplement S1.
The kinetic theory of gases.



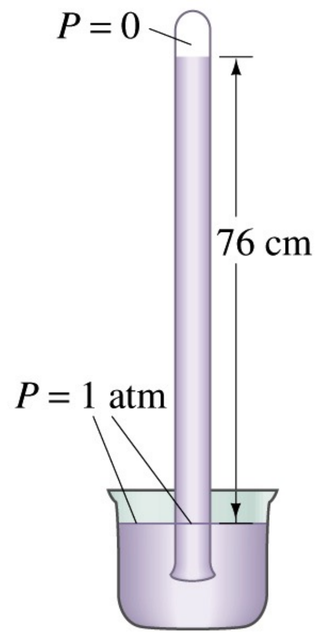
http://eml.ou.edu/Physics/module/thermal/ketcher/Idg4.avi

The kinetic theory of gases. Thermodynamic variables.

- The kinetic theory of gases provides a framework to connect the microscopic properties of the molecules in a gas (such as their rms velocity) to the macroscopic properties of the gas (such as volume, temperature, and pressure).
- The volume of a gas is defined by the size of the enclosure of the gas. During a change in the state of a gas, the volume may or may not remain constant (this depends on the procedure followed).
- The temperature of a gas has been defined in terms of the entropy of the system (see discussion in Chapter 12).
- We will now briefly discuss pressure.

Thermodynamic variables. Pressure.

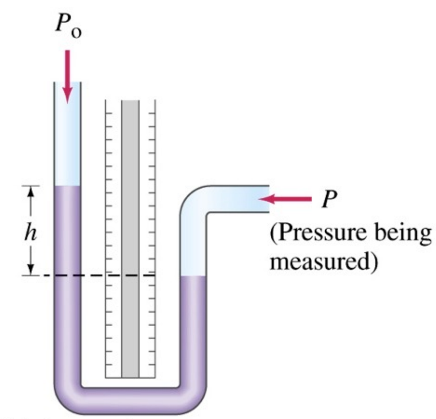
- Pressure is an important thermodynamic variable.
- **Pressure is defined as the force per unit area**.
- **The SI unit is pressure is the Pascal: 1 Pa = 1 N/m^2**. Another common unit is the atm (atmospheric pressure) which is the pressure exerted by the atmosphere on us (1 atm = 1.013 x 10^5 N/m^2).
- A pressure of 1 atm will push a mercury column up by 76 cm.



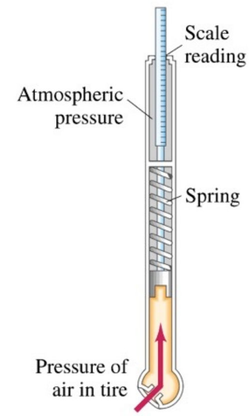
Note: if we would use water, the column would be about 10 m high.

Thermodynamic variables. Pressure.

- Many devices that measure pressure, actually measure the pressure difference between the pressure of interest and the atmospheric pressure.
- Atmospheric pressure changes with altitude. The higher you go, the less air is pressing on your head! Airplanes use the atmospheric pressure to measure altitude.
- But keep into consideration that the atmospheric pressure at a fixed location and altitude is not constant!

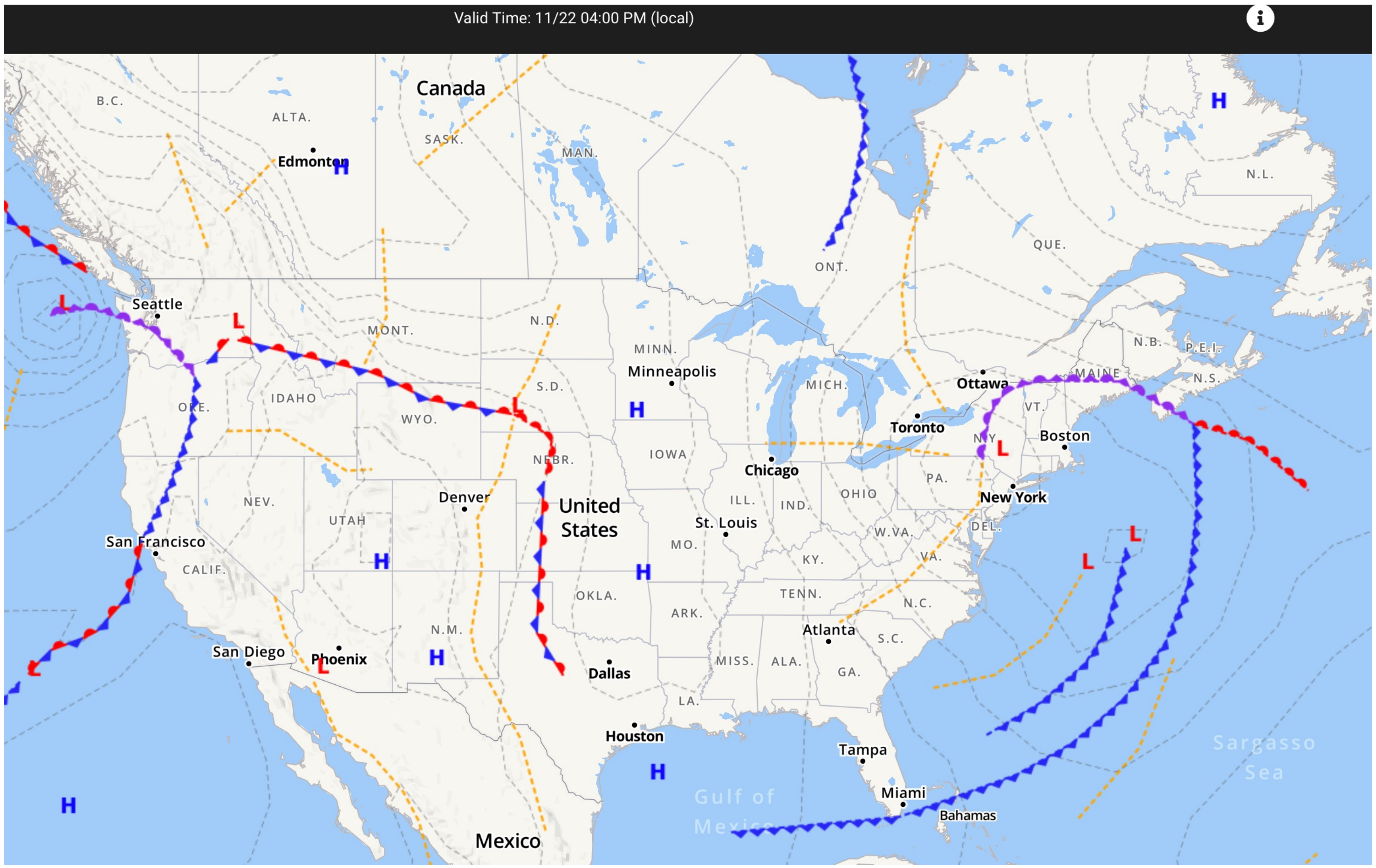


(a) Open-tube manometer



(c) Tire gauge

Thermodynamic variables. Pressure.



The kinetic theory of gases. Thermodynamic variables.

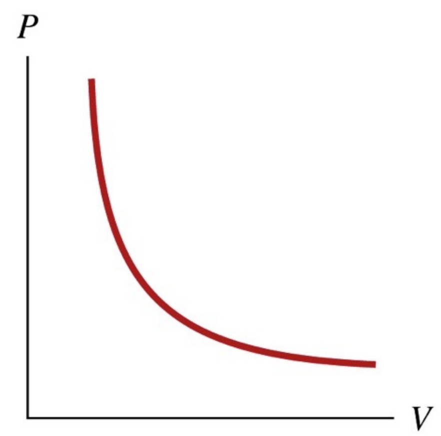
- The **volume** of a gas is defined by the size of the enclosure of the gas. During a change in the state of a gas, the volume may or may not remain constant (this depends on the procedure followed).

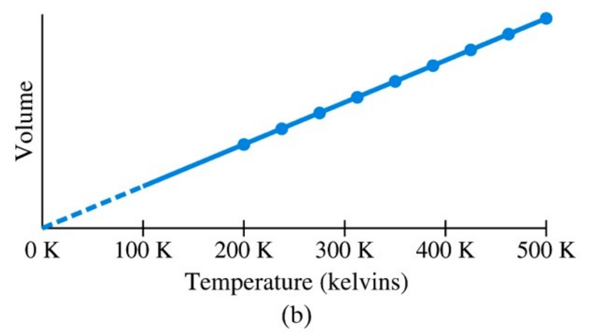
- The **temperature** of a gas has been defined in terms of the entropy of the system (see discussion in Chapter 12).

- The **pressure** of a gas is defined as the force per unit area. The SI unit is pressure is the Pascal: 1 Pa = 1 N/m^2. Another common unit is the atm (atmospheric pressure) which is the pressure exerted by the atmosphere on us (1 atm = 1.013×10^5 N/m^2).

The equation of state of a gas.

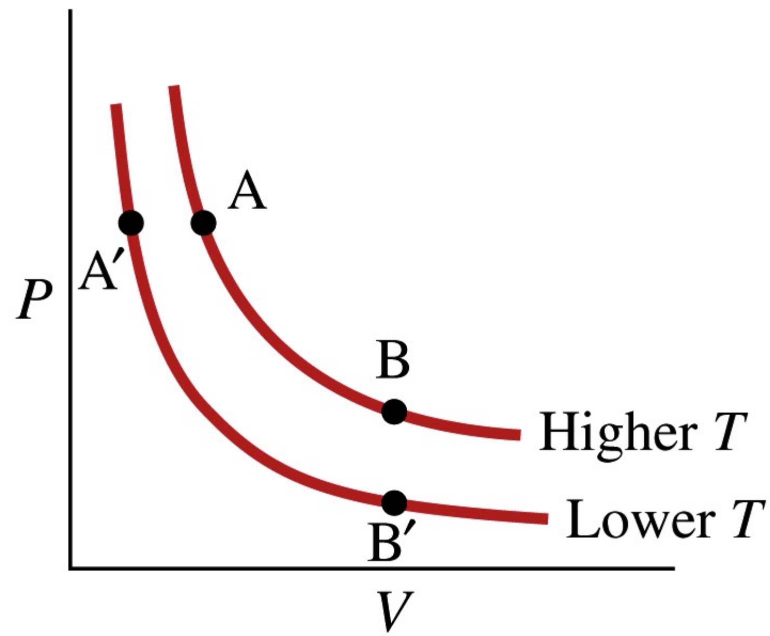
- In order to specify the state of a gas, we need to measure its temperature, its volume, and its pressure. The relation between these variables and the mass of the gas is called **the equation of state**.
- The equation of state of a gas was initially obtained on the basis of observations.
  - Boyle's Law (1627 - 1691): ***pV* = constant** for gases maintained at constant temperature.
  - Charle's Law (1746 - 1823): ***V/T* = constant** for gases maintained at constant pressure.
  - Gay-Lussac's Law (1778 - 1850): ***p/T* = constant** for gases maintained at constant volume





The equation of state of a gas.

- Combining the various gas laws, we can obtain a single more general relation between pressure, temperature, and volume: $pV = \text{constant } T$.
- Another observation that needs to be included is the dependence on the amount of gas: if pressure and temperature are kept constant, the volume is proportional to the mass m: $pV = \text{constant } mT$.



The equation of state of a gas.

- The equation of state of a gas can be written as

$$pV = NkT$$

where
  - p = pressure (in Pa).
  - V = volume (in m^3).
  - N = number of molecules of gas (1 mole = 6.02×10^{23} molecules or atoms). Note the number of molecules in a mole is also known as Avogadro's number N_A.
  - T = temperature (in K).
- Note: the equation of state is the equation of state of an ideal gas. Gases at very high pressure and/or close to the freezing point show deviations from the ideal gas law.

The equation of state of a gas. Example problem.

- A cylinder contains oxygen at 20°C and a pressure of 15 atm at a volume of 12 l. The temperature is raised to 35°C , and the volume is reduced to 8.5 l. What is the final pressure of the gas?

- Since the amount of gas does not change, we can rewrite the ideal gas law in the following way: pV/T = constant. Since we know the initial state, we can determine the missing information about the final state:

$$\frac{p_i V_i}{T_i} = \frac{p_f V_f}{T_f}$$

The equation of state of a gas. Example problem.

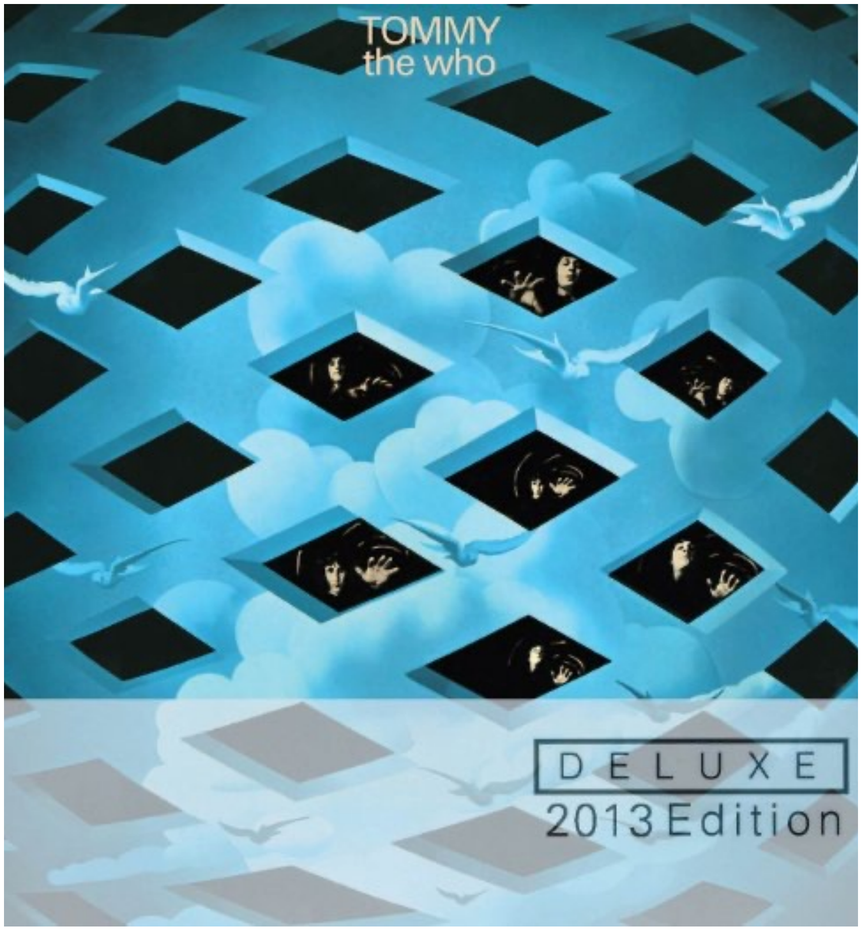
- The final pressure of the gas is equal to

$$p_f = p_i \frac{V_i}{V_f} \frac{T_f}{T_i}$$

- Note:
  - This relation will preserve the units of pressure.
  - The units of volume cancel, and we can keep the volume in units of liters. Note: for whatever we unit we choose, zero volume in SI units, correspond to zero volume in all other units.
  - The units of temperature must be in Kelvin. The temperature ratio $T_i/T_f = (273.15 + 20)/(273.15 + 35) = 0.951$ when T is expressed in Kelvin. The ratio would be 0.571 when T is expressed in Celsius.

- When we use the correct units, we find that $p_f = 22$ atm.

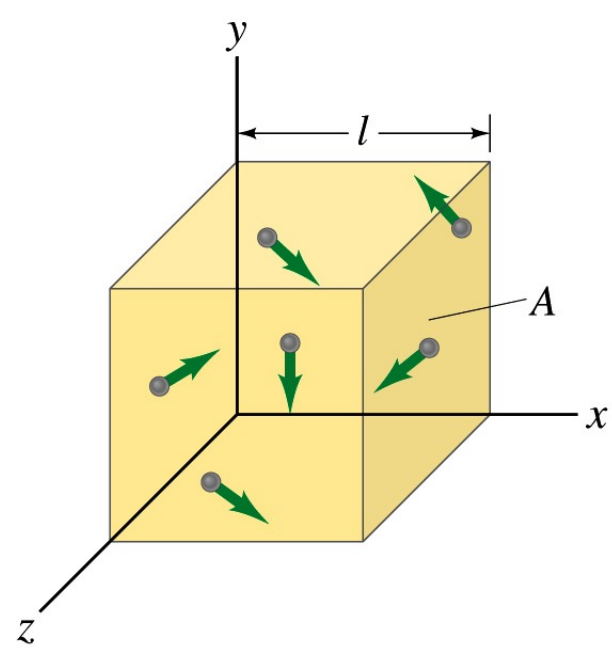
3 Minute 34 Second Intermission.



- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 3 minute 34 second intermission.
- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Solve a WeBWorK problem.

The molecular point of view of a gas.

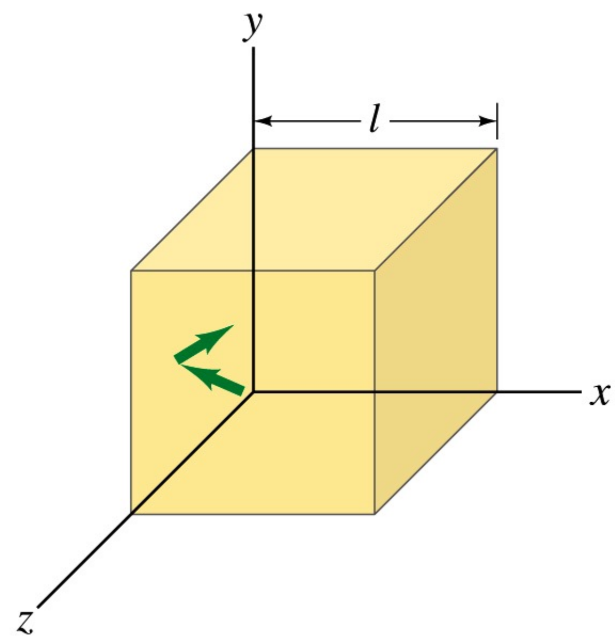
- Consider a gas contained in a container.
- The molecules in the gas will continuously collide with the walls of the vessel.
- Each time a molecule collides with the wall, it will carry out an elastic collision.
- Since the linear momentum of the molecule is changed, the linear momentum of the wall will change too.
- Since force is equal to the change in linear momentum per unit time, the gas will exert a force on the walls.



The molecular point of view of a gas.

- Consider the collision of a single molecule with the left wall.
- In this collision, the linear momentum of the molecule changes by $mv_x - (-mv_x) = 2mv_x$.
- The same molecule will collide with this wall again after a time $\Delta t = 2l/v_x$.
- The force that this single molecule exerts on the left wall is thus equal to

$$F = \frac{\Delta p}{\Delta t} = \frac{2mv_x}{\frac{2l}{v_x}} = \frac{mv_x^2}{l}$$



The molecular point of view of a gas.

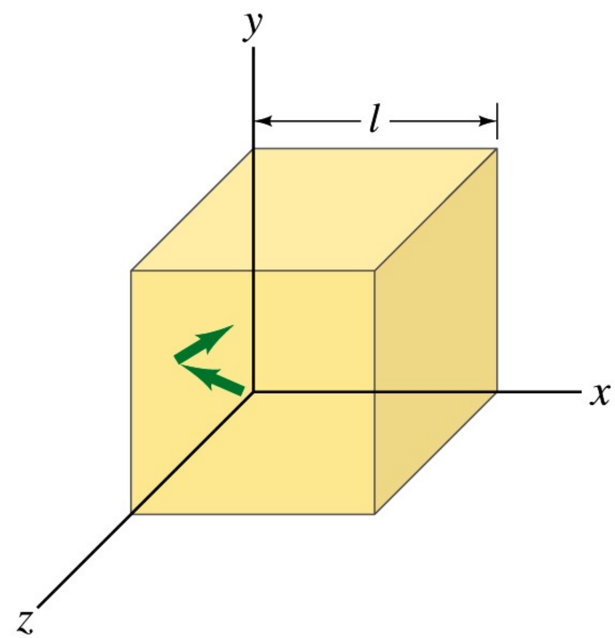
- The pressure exerted on the left wall by this molecule is equal to

$$p_{left} = \frac{F_{left}}{A} = \frac{m v_x^2}{lA}$$

where A is the area of the left wall.

- The volume of the gas is equal to lA and we can thus rewrite the pressure on the left wall:

$$p_{left} = \frac{m v_x^2}{V}$$



The molecular point of view of a gas.

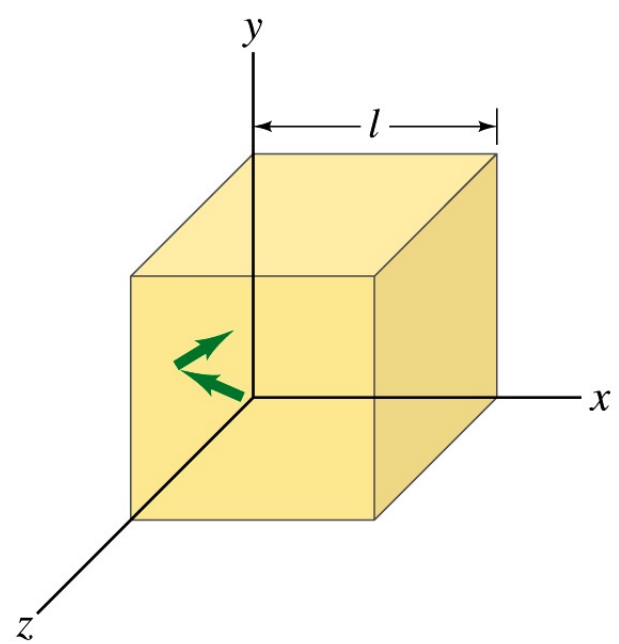
- The pressure that many molecules exerts on the left wall is equal to

$$p_{left} = \frac{m(v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \cdots)}{V}$$

- This equation can be rewritten in terms of the average of the square of the x component of the molecular velocity and the number of molecules:

$$p_{left} = \frac{mNv_{x,rms}^2}{V}$$

- Assuming that there is no preferential direction, the rms velocity along the of the x, y, and z axis will be the same.



The molecular point of view of a gas.

- The force on the left wall can be rewritten in terms of the average squared velocity

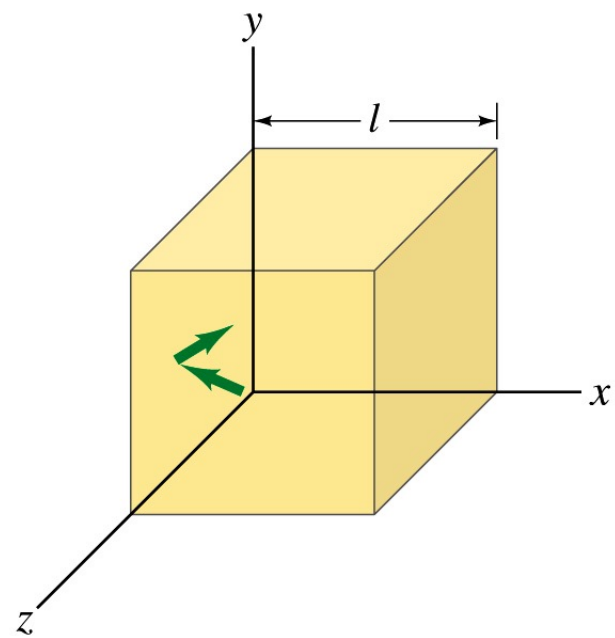
$$p_{left} = \frac{mNv_{rms}^2}{3V}$$

- Assuming there is no preferential direction of motion of the molecules, the pressure on all walls will be the same and we thus conclude:

$$pV = \frac{mNv_{rms}^2}{3}$$

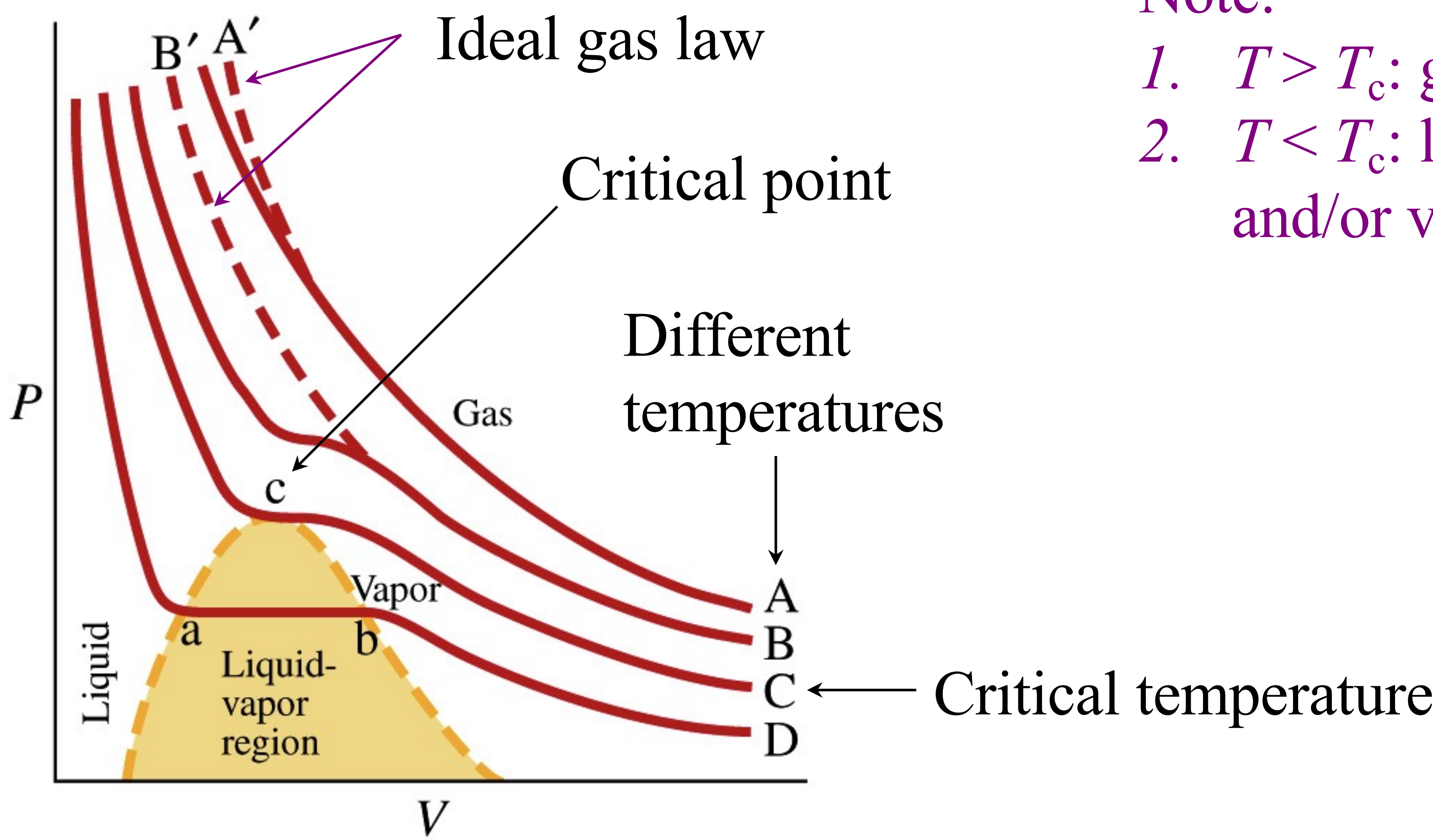
- Compare this to the ideal gas law:

$$pV = NkT$$



$$K_{average} = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$$

The real equation of state. Different points of view.

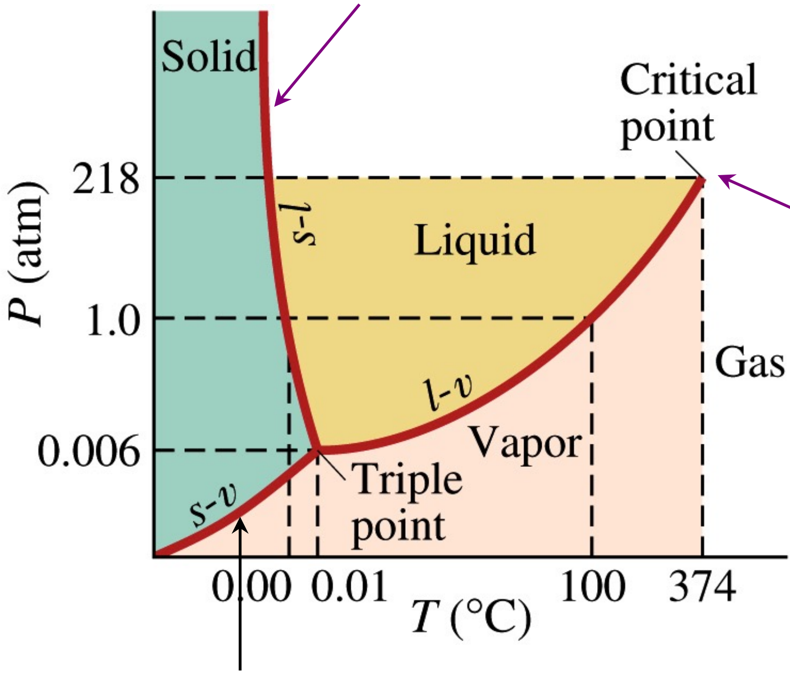


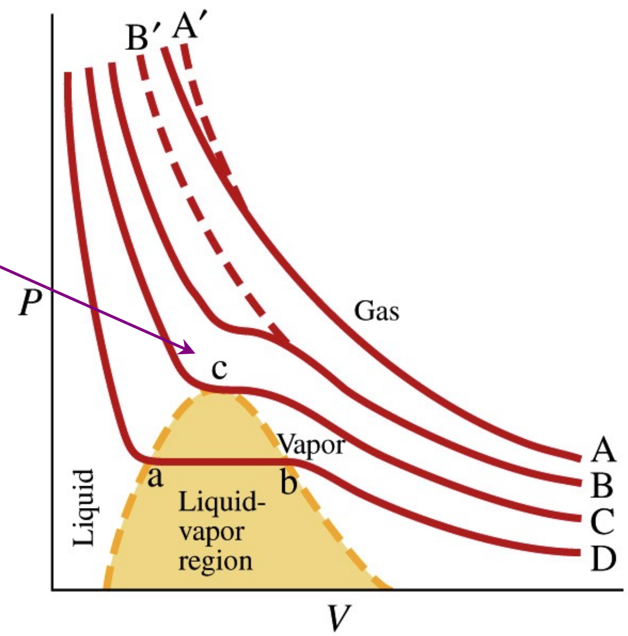
Note:

1. $T > T_c$: gas
2. $T < T_c$: liquid and/or vapor.

The real equation of state. Different points of view.

Note the curvature of the solid-liquid line.
Curvature to the left implies expansion on cooling.

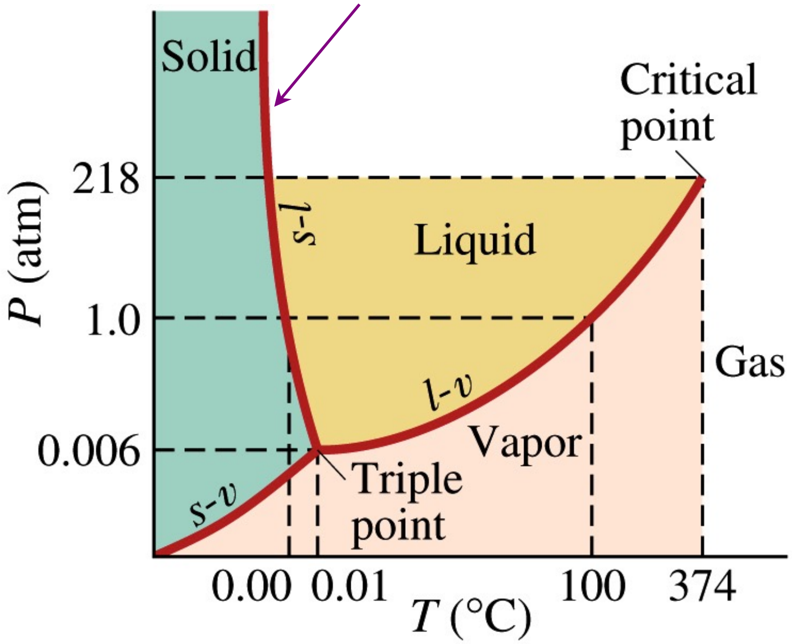




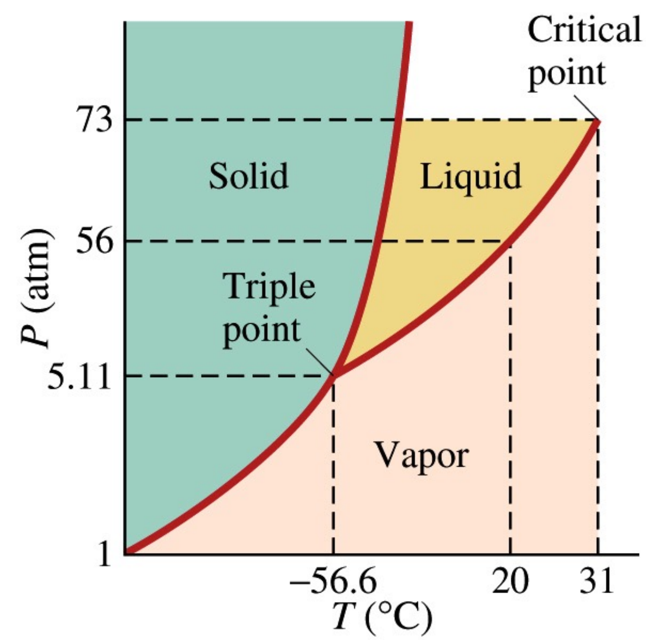
Direct change from solid to vapor.

The real equation of state.
Different points of view.

Note the curvature of the solid-liquid line.
Curvature to the left implies expansion on cooling.



Water



CO_2

Done for today!
Have a happy and safe thanksgiving holiday.