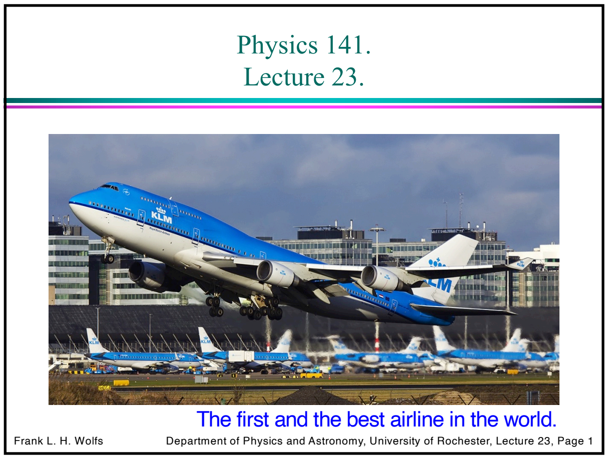
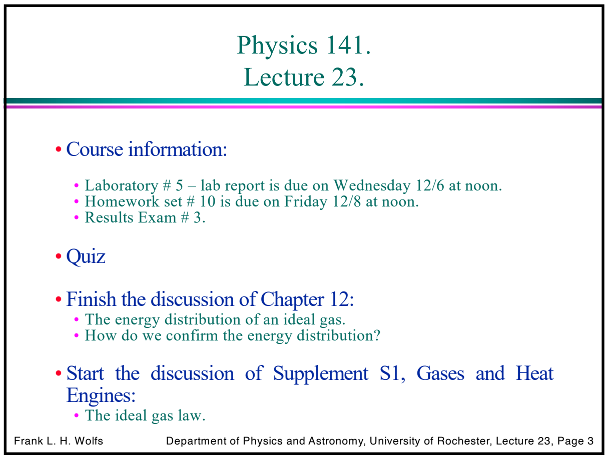


Physics 141.
Lecture 23.

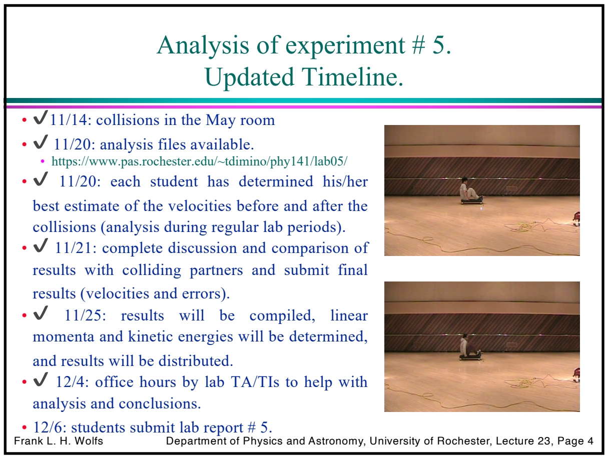
The first and the best airline in the world.

December 5th.
An important day in the Netherlands.



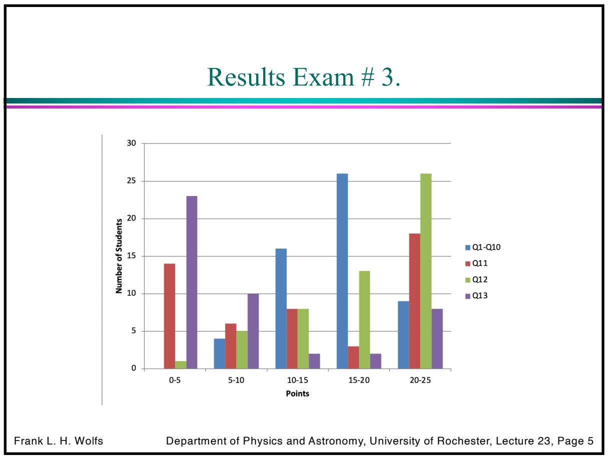
Physics 141.
Lecture 23.

- Course information:
  - Laboratory # 5 – lab report is due on Wednesday 12/6 at noon.
  - Homework set # 10 is due on Friday 12/8 at noon.
  - Results Exam # 3.
- Quiz
- Finish the discussion of Chapter 12:
  - The energy distribution of an ideal gas.
  - How do we confirm the energy distribution?
- Start the discussion of Supplement S1, Gases and Heat Engines:
  - The ideal gas law.

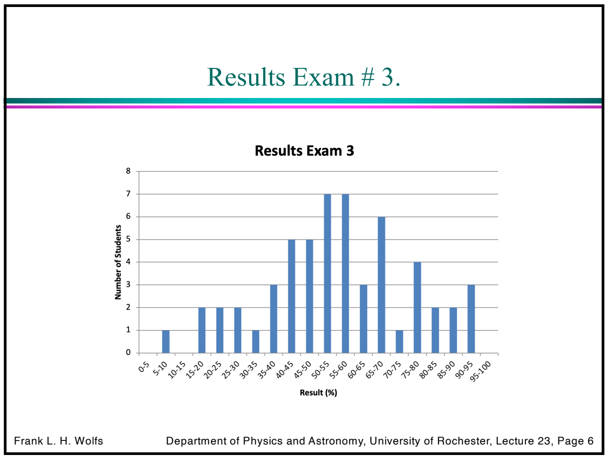


Analysis of experiment # 5.
Updated Timeline.

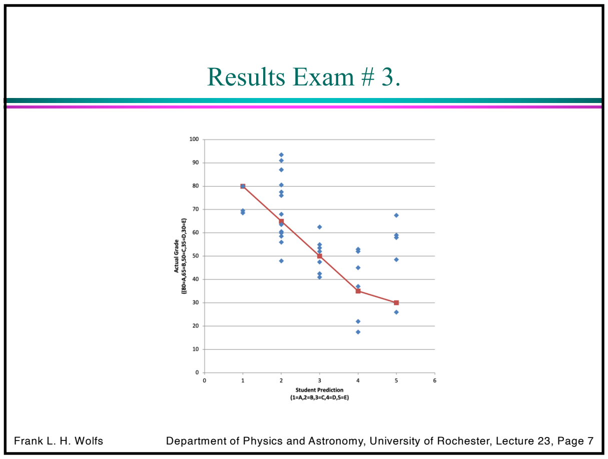
- ✓11/14: collisions in the May room
- ✓ 11/20: analysis files available.
  - https://www.pas.rochester.edu/~tdimino/phy141/lab05/
- ✓ 11/20: each student has determined his/her best estimate of the velocities before and after the collisions (analysis during regular lab periods).
- ✓ 11/21: complete discussion and comparison of results with colliding partners and submit final results (velocities and errors).
- ✓ 11/25: results will be compiled, linear momenta and kinetic energies will be determined, and results will be distributed.
- ✓ 12/4: office hours by lab TA/TIs to help with analysis and conclusions.
- 12/6: students submit lab report # 5.



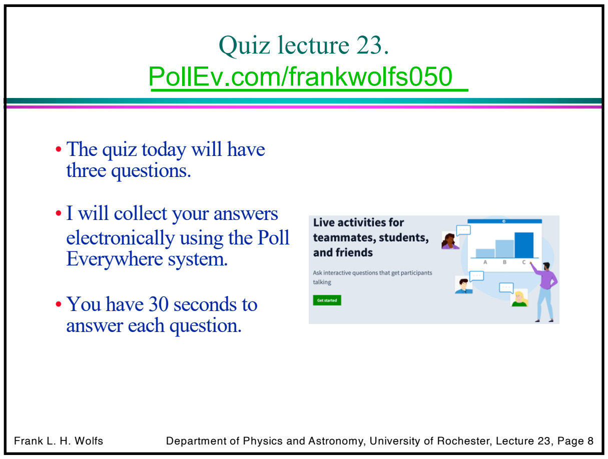
Results Exam # 3.



Results Exam # 3.

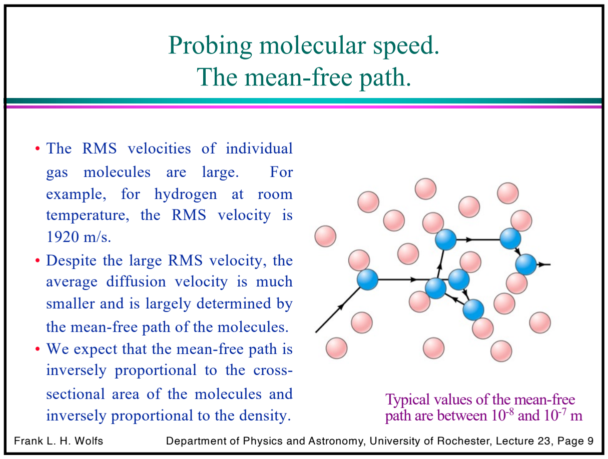


Results Exam # 3.



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 30 seconds to answer each question.



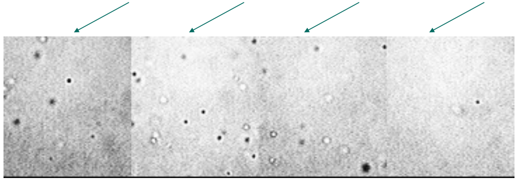
Probing molecular speed.
The mean-free path.

- The RMS velocities of individual gas molecules are large. For example, for hydrogen at room temperature, the RMS velocity is 1920 m/s.
- Despite the large RMS velocity, the average diffusion velocity is much smaller and is largely determined by the mean-free path of the molecules.
- We expect that the mean-free path is inversely proportional to the cross-sectional area of the molecules and inversely proportional to the density.

Typical values of the mean-free path are between 10^{-8} and 10^{-7} m

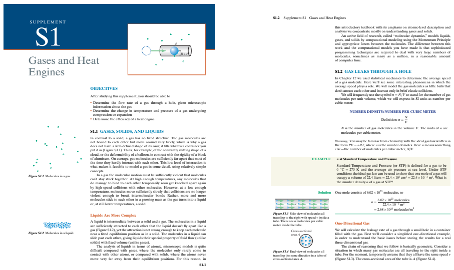
Probing molecular speeds in liquids.

0.5 μm particles in water, 50/50 glycerol-water, 75/25 glycerol-water, glycerol

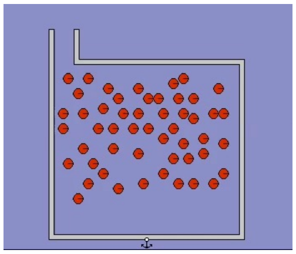


http://www.physics.emory.edu/~weeks/squishy/BrownianMotionLab.html

Chapter 13.
Aka Supplement S1.



Supplement S1.
The kinetic theory of gases.



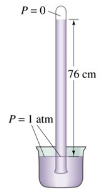
http://eml.ou.edu/Physics/module/thermal/ketcher/Idg4.avi

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.

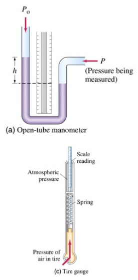
- Pressure is an important thermodynamic variable.
- **Pressure is defined as the force per unit area**.
- **The SI unit is pressure is the Pascal: 1 Pa = 1 N/m^2**. Another common unit is the atm (atmospheric pressure) which is the pressure exerted by the atmosphere on us (1 atm = 1.013 x 10^5 N/m^2).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

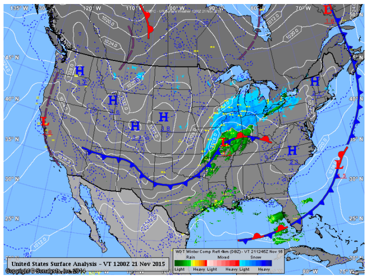
- Many devices that measure pressure, actually measure the pressure difference between the pressure of interest and the atmospheric pressure.
- Atmospheric pressure changes with altitude. The higher you go, the less air is pressing on your head! Airplanes use the atmospheric pressure to measure altitude.
- 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.

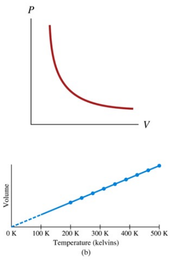


The kinetic theory of gases.
Thermodynamic variables.

- 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 x 10^5 N/m^2).

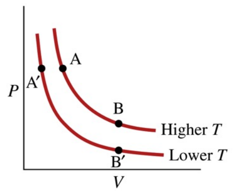
The equation of state of a gas.

- 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.

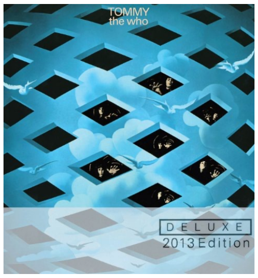
- The equation of state of a gas can be written as

$$pV = NkT$$

where
- p = pressure (in Pa).
- V = volume (in m^3).
- N = number of molecules of gas (1 mole = 6.02 x 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.

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 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:

$$p_iV_i/T_i = p_fV_f/T_f$$

The equation of state of a gas.
Example problem.

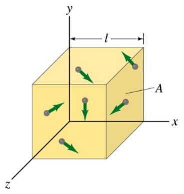
- The final pressure of the gas is equal to

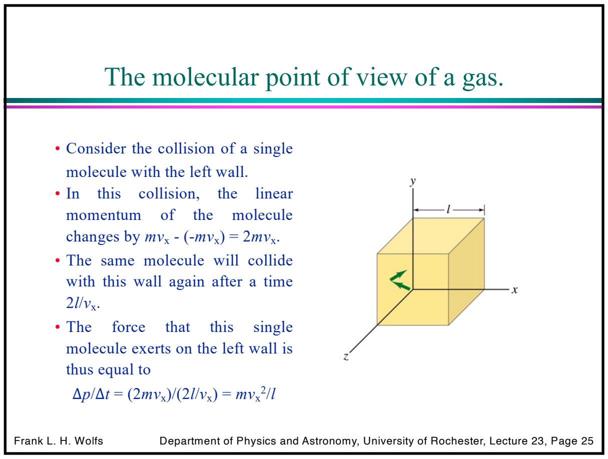
$$p_f = p_i\,(V_i/V_f)\;/\;(T_i/T_f)$$

- 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.

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.

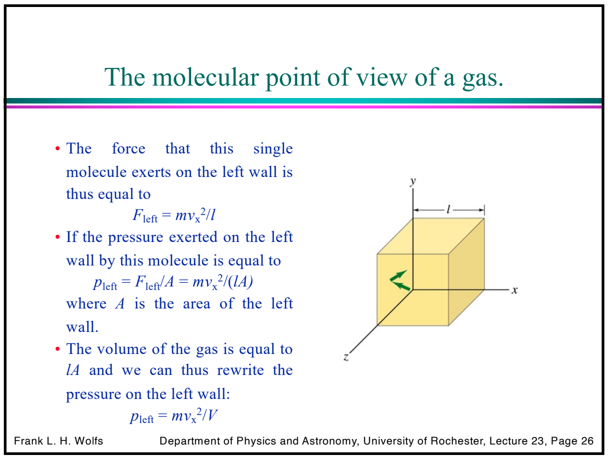




The molecular point of view of a gas.

- 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 $2l/v_x$.
- The force that this single molecule exerts on the left wall is thus equal to

$$\Delta p/\Delta t = (2mv_x)/(2l/v_x) = mv_x^2/l$$



The molecular point of view of a gas.

- The force that this single molecule exerts on the left wall is thus equal to

$$F_{\text{left}} = mv_x^2/l$$

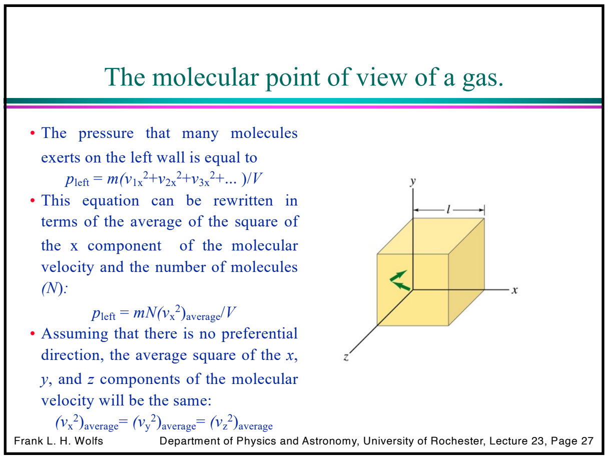
- If the pressure exerted on the left wall by this molecule is equal to

$$p_{\text{left}} = F_{\text{left}}/A = mv_x^2/(lA)$$

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:

$$p_{\text{left}} = mv_x^2/V$$



The molecular point of view of a gas.

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

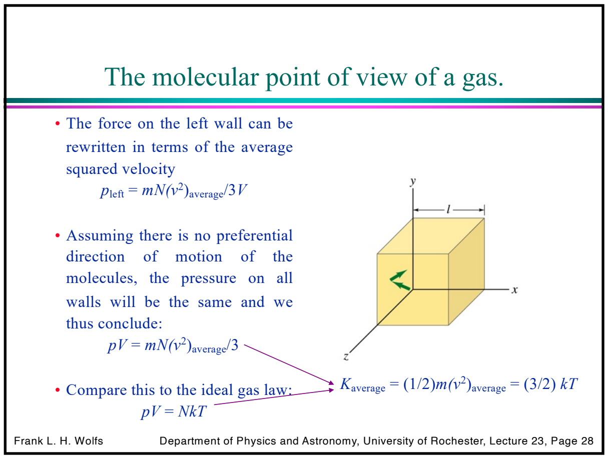
$$p_{\text{left}} = m(v_{1x}^2+v_{2x}^2+v_{3x}^2+\dots)/V$$

- 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 (N):

$$p_{\text{left}} = mN(v_x^2)_{\text{average}}/V$$

- Assuming that there is no preferential direction, the average square of the x, y, and z components of the molecular velocity will be the same:

$$(v_x^2)_{\text{average}} = (v_y^2)_{\text{average}} = (v_z^2)_{\text{average}}$$



The molecular point of view of a gas.

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

  $p_{\text{left}} = mN(v^2)_{\text{average}}/3V$

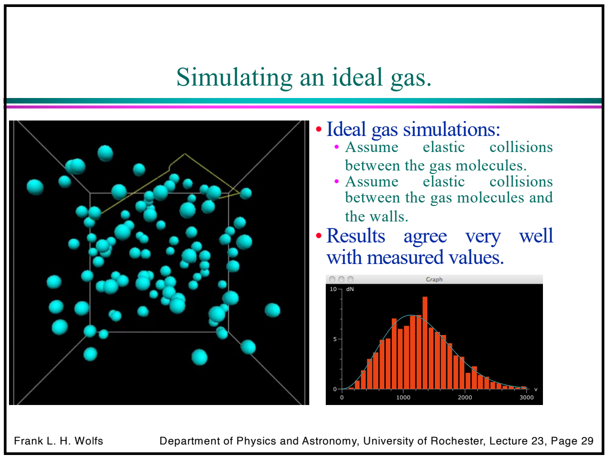
- Assuming there is no preferential direction of motion of the molecules, the pressure on all walls will be the same and we thus conclude:

  $pV = mN(v^2)_{\text{average}}/3$

- Compare this to the ideal gas law:

  $pV = NkT$

$K_{\text{average}} = (1/2)m(v^2)_{\text{average}} = (3/2)\,kT$



Simulating an ideal gas.

- Ideal gas simulations:
  - Assume elastic collisions between the gas molecules.
  - Assume elastic collisions between the gas molecules and the walls.
- Results agree very well with measured values.

Done for today!

Air Transat L-1011 TriStar 150 C-FTNA at Lyon © anon.