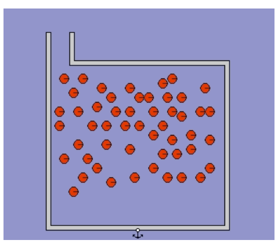
Red Sox - Yankees. Baseball can not get more exciting than these games.

Frank L. H. Wolfs

Department of Physics and Astronomy, University of Rochester

Physics 121, April 17, 2008. Kinetic theory of gases.



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Frank L. H. Wolfs

Department of Physics and Astronomy, University of Rochester

Physics 121. April 17, 2008.

- Course Information
- Topics to be discussed today:
  - The ideal gas law (review).
  - Molecular interpretation of temperature.
  - The real equation of state.
- Quiz

Frank L. H. Wolfs

Department of Physics and Astronomy, University of Rochester

Physics 121.
April 17, 2008.

- Homework set # 9 is due on Saturday morning, April 19, at 8.30 am.
- Midterm Exam # 3 will take place on Tuesday April 22 between 8.00 am and 9.30 am. The material to be covered is the material contained in Chapters 10, 11, 12, and 14.
- I will distribute the formula sheet that will be attached to the exam later this week via email.
- I will review the material covered on the exam on Sunday evening. Further details will be announced via email.
- Extra office hours will be offered by the TAs on Sunday and Monday. The schedule will be announced via email.

- **There will be no class after the exam on Tuesday.**

Physics 121.
April 17, 2008.

- Workshops schedule next week:
  - There will be workshops on Monday to answer questions related to Exam # 3.
  - There will be workshops on Thursday and Friday to discuss the solutions of Exam # 3 and return your blue booklets.
  - During the week of April 28 there will only be workshops on Monday, Tuesday, and Wednesday.

- To increase the efficiency with which we can return the blue booklets of Exam # 3, you will need to write your workshop day/time on the front of each booklet.

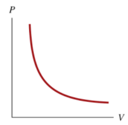
- The results of Exam # 3 will be emailed to you on Monday April 28

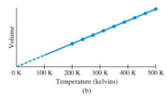
Physics 121.
April 17, 2008.

- Grades: Worst case scenario:
  - Let's assume you got 0% on exam 1 and 0% on exams 2.
  - Clearly you would benefit if we drop one of these grades!
  - If we drop one of these grades, than the one we count will count for 20% of your final grade.
  - If you get 100% on exam # 3 and 100% on the final (and assuming you have 100% on the homework sets, quizzes, and labs) you end up with a final grade for 80% or an A!!!!!
  - No one matches this worst case scenario, but realize that even if you did poorly on the first two exams, you can still get an A in this course.

The equation of state of a gas. A quick review.

- 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. A quick review.

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

$$pV = nRT$$

where

  - p = pressure (in Pa).
  - V = volume (in m^3).
  - n = number of moles 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.
  - R = the universal gas constant (R = 8.315 J/(mol K).
  - 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. A quick review.

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

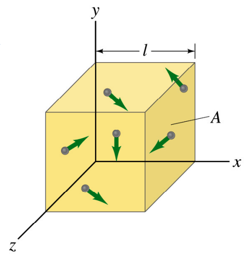
$$pV = nRT = (N/N_A)RT = NkT$$

where

  - N = total number of molecules
  - N_A = Avogadro's number
  - $k = R/N_A$ is the Boltzmann constant = 1.38 x 10^{-23} J/K
- This is the most frequently used form of the equation of state of the gas.

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

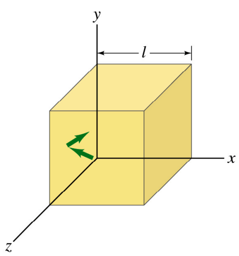
$$mv_x - (-mv_x) = 2mv_x$$

- 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

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



The molecular point of view of a gas.

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

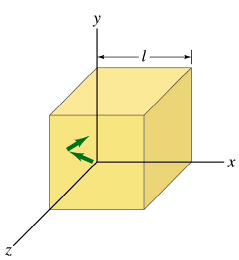
$$F_{left} = mv_x^2/l$$

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

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

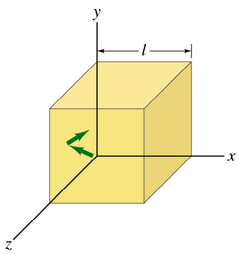
where A is the area of the left wall.
- The volume of the gas is equal to lA and we can thus rewrite the pressure on the left wall:

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



The molecular point of view of a gas.

- The pressure that many molecules exerts on the left wall is equal to
  $p_{\text{left}} = m(v_{1x}^2+v_{2x}^2+v_{3x}^2+ \ldots)/V$
- 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:
  $(v_x^2)_{\text{average}} = (v_y^2)_{\text{average}} = (v_z^2)_{\text{average}}$



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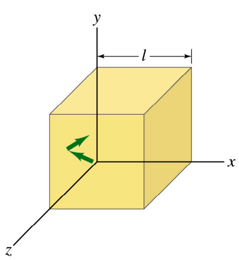
Department of Physics and Astronomy, University of Rochester

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:
  $pV = NkT$



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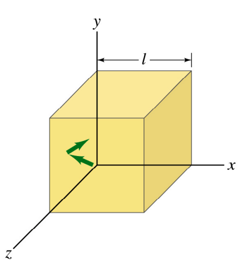
Department of Physics and Astronomy, University of Rochester

The molecular point of view of a gas.

- Comparing
  $pV = mN(v^2)_{\text{average}}/3$
  and the ideal gas law
  $pV = NkT$
  we find that
  $kT = m(v^2)_{\text{average}}/3 = (2/3)K_{\text{average}}$
- We thus conclude that:
  - The average kinetic energy of the gas molecules is proportional to the temperature of the gas.
  - When the temperature approaches zero, the average kinetic energy approaches zero.



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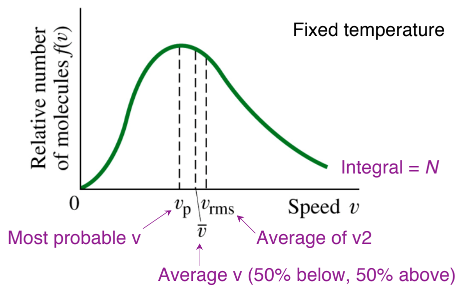
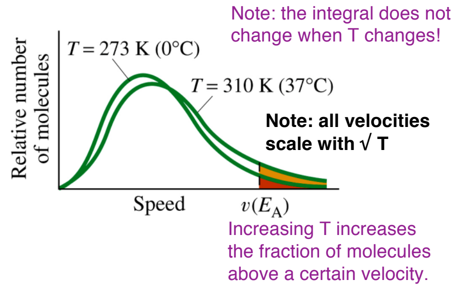
Department of Physics and Astronomy, University of Rochester

Distribution of molecular speeds. The Maxwell distribution.

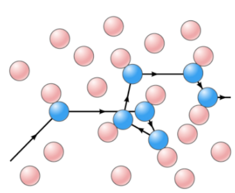


Distribution of molecular speeds. The Maxwell distribution.



Molecular speed and 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 are of the molecules and inversely proportional to the density.



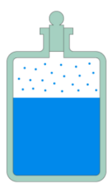
Typical values of the mean-free path are between 10^{-8} and 10^{-7} m

Molecular speed and the propagation of sound.

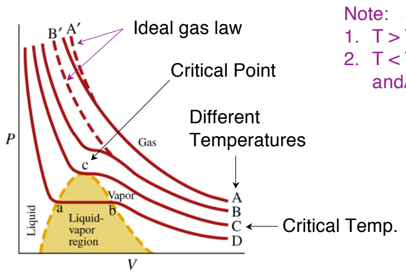
- Typical values for v_{rms}:
  - For H at 300 K, v_{rms} = 1920 m/s
  - For N at 300 K, v_{rms} = 517 m/s
- The speed of sound in these two gases is 1350 m/s for H and 350 m/s for N.
- Note: The speed of sound in a gas will always be less than v_{rms} since the sound propagates through the gas by disturbing the motion of the molecules. The disturbance is passed on from molecule to molecule by means of collisions; a sound wave can therefore never travel faster than the average speed of the molecules. Since v_{rms} increases with T, we expect v_{sound} to increase with T.

Molecular speed and evaporation.

- Evaporation: transformation from the liquid to the gas phase.
- A microscopic view of evaporation:
  - Molecules with high velocity moving close to the surface can overcome the strong attractive forces between the molecules and escape from the liquid (evaporation).
  - The average velocity of the molecules left behind in the liquid will be lowered.
  - Since the average velocity is proportional to the temperature, the temperature of the liquid is lowered when evaporation takes place.



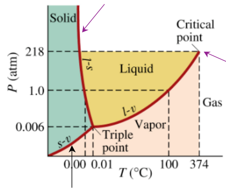
The real equation of state. Different points of view.

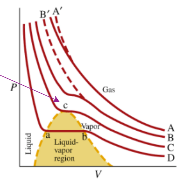


Note:
1. T > T_c: gas
2. T < T_c: liquid and/or vapor.

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.

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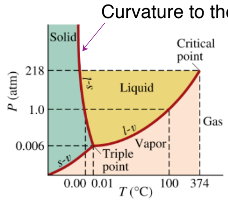
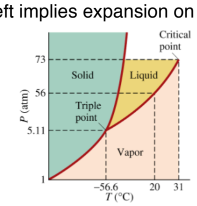
The real equation of state. Different points of view.

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



Water



CO_2

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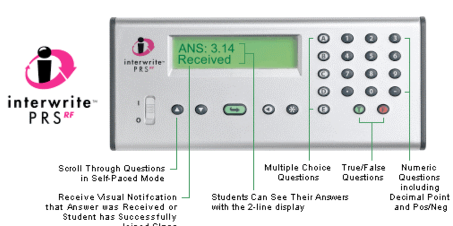
Physics 121. Quiz lecture 24.

- The quiz today will have 3 questions!



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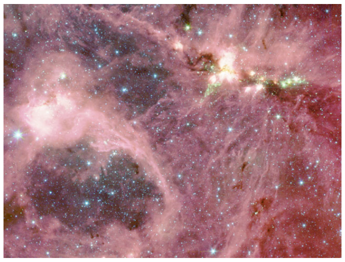
Done for today! Next week:
The first law of thermodynamics.



Massive Star Forming Region DR21 in Infrared.
Credit: A. Marston (ESTEC/ESA) et al., JPL, Caltech, NASA