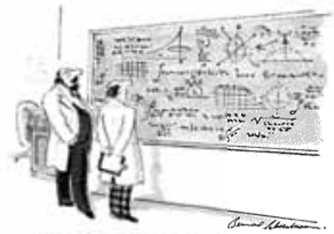
December 10, 2010 Physics 121 Prof. E. F. Redish

- **Theme Music:** **Count Basie & his Orchestra**
  The Party's Over

Cartoon:
Bernard Schoenbaum



"Oh, if only it were so simple."

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Outline

- Modeling Matter:
  The Kinetic Theory of Gases
  - Maxwell's Theoretical Model
  - Bouncing off the wall
- Relating to the Ideal Gas Law
- Making Sense of the Model
- Examples

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Surveys

We have a slight lead over Hamilton's classes (52%-44%) but we are nowhere near 70%!

- Still available until Sunday night!
- Campus evaluation (login at upper right)
  - https://www.CourseEvalUM.umd.edu
- On line
  - Post-instruction attitude survey (5 pts)
  http://perg-surveys.physics.umd.edu/MPEX2post.php

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So where does the energy go?

- When we "lose" mechanical energy as a result of non-conservative forces, we know that since total energy is conserved, it must "hide" somewhere. Where?
- We say it "goes into thermal energy." But what is the mechanism for thermal energy? What does it look like?
- Start with the simplest object – a gas.

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Maxwell's Model

- Assume *n* molecules/m^3 of mass *m* moving with an average speed *v*.
- What happens when a molecule hits the wall?

$$\Delta\vec{p}_{mol} = \vec{F}_{wall\to mol}\Delta t$$
$$\vec{F}_{wall\to mol} = -\vec{F}_{mol\to wall}$$

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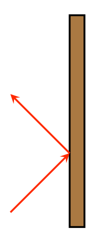
Average force of gas on the wall
= (# of molecules hitting the wall in the time Δt)
x (force each molecule exerts on the wall)

Only the *x*-component matters.

All we need to figure this out is our three basic equations, and a way to count the number of molecules hitting the wall.

$$F_{wall\to molecule} = m\frac{\Delta v_x}{\Delta t} = -F_{molecule\to wall}$$

$$\langle v_x \rangle = \frac{\Delta x}{\Delta t}$$



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- How many molecules are in the box?

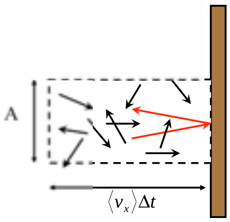
n = number density = # / unit volume

$$N = n \times (\text{Volume}) = nA(\langle v_x \rangle \Delta t)$$

- What's the average momentum change upon collision with a wall?

$$\Delta p_x = 2m\langle v_x \rangle$$

- What fraction of the molecules in the box will hit the wall in the time Δt?



½ (½ going left, ½ going right)

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Technical note

- How does the average *x*-velocity relate to the average speed of the molecule?

$$\langle v \rangle = \sqrt{\langle v_x^2 \rangle + \langle v_y^2 \rangle + \langle v_z^2 \rangle} = \sqrt{3\langle v_x^2 \rangle}$$

$$\langle v_x \rangle = \langle v \rangle / \sqrt{3}$$

- From here on out will drop all those averages
  – but we should keep in mind that that is what we really mean!

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Putting It All Together

$$F = N\frac{\Delta p}{\Delta t} = \tfrac{1}{2}(nAv_x\Delta t)\left(\frac{2mv_x}{\Delta t}\right) = nmv_x^2 A$$

Interpret

$$F = pA \qquad n = \frac{N}{V} \qquad v_x^2 = \tfrac{1}{3}v^2$$

$$pA = \tfrac{1}{3}\frac{N}{V}mv^2 A$$

$$pV = N(\tfrac{1}{3}mv^2) = N\tfrac{2}{3}\left(\tfrac{1}{2}mv^2\right)$$

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The Behavior of a Dilute Gas

- We have three properties that describe a gas: pressure (p), volume (V) and temperature (T). How do they relate?
- A series of experiments show us:
  - For a given sample of a gas, the combination pV/T is a constant if T is measured in Kelvin (degrees C starting from absolute zero = -273 C).
  - The constant is proportional to the amount of gas we have.
  - For different gases, the constant is proportional to the chemical combining weight (# of moles).

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The Ideal Gas Law

- The result is written

$$pV = n_{moles}RT$$

- where R is a constant independent of the kind of gas you have.
- R = 8.31 J/mol-°K
- This result holds for any dilute gas. (It has corrections if the gas gets too dense.)

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Interpreting the Ideal Gas Law

- To relate this to our model, note that since the number of molecules in one mole is the same (Avogadro's number)

$$N = n_{moles}N_A$$

where $N_A = 6.02 \times 10^{26}$ /kg-mole
- This allows us to make the connection to our molecular model.

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Put the equations together

$pV = N\frac{2}{3}(\frac{1}{2}mv^2)$ $\qquad pV = nRT$

Make the N parts look alike.

$n = N/N_A$

$$pV = N\left(\frac{R}{N_A}\right)T$$

Define: $k_B = \left(\frac{R}{N_A}\right)$ so $pV = Nk_BT$

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Interpreting

- The "physicist's form" of the ideal gas law lets us interpret where the p comes from and what T means.
- p arises from molecules hitting the wall and transferring momentum to it;
- T corresponds to the KE of one molecule (up to a constant factor).

$p = Nmv_x^2 \qquad k_BT = \frac{2}{3}\left(\frac{1}{2}mv^2\right)$

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The Ideal Gas Law

Chemist's form

$$pV = n_{moles}RT$$

$n_{moles} = \frac{N}{N_A}$ $\qquad R = k_BN_A$

Physicist's form

$$pV = Nk_BT$$

$p = nmv_x^2$ $\qquad \frac{3}{2}k_BT = \frac{1}{2}mv^2$

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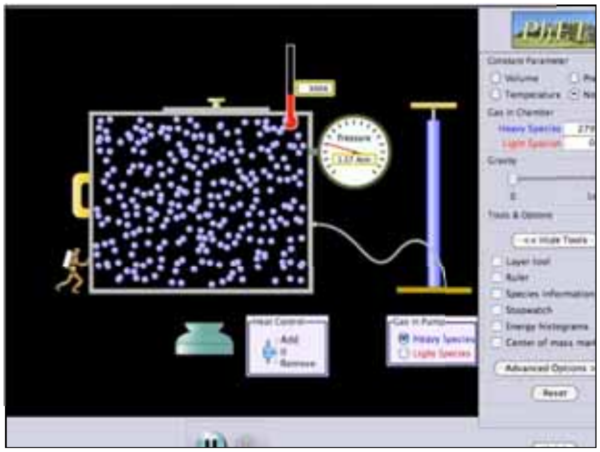

Question

- If the molecules in a gas are all moving freely except when they collide with each other (rarely), why don't they fall to the ground?
- Consider a FBD for a gas molecule.

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An interesting textbook problem: How would you solve this?

- From the engineering version of our (un-used) textbook:
  - On a hot (35 C) day, you perspire 1.0 kg of water during your workout. What volume is occupied by the evaporated water?

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Recap: Kinetic Theory 1

- Our model of matter as made up of lots of little moving particles, lets us resolve some apparent inconsistencies.
- Newton's laws tell us that motion continues forever unless something unbalanced tries to stop it, yet we observe motion always dies away.
- Our model lets us "hide" the energy of motion that has "died away" at the macro level in the internal motion.

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Recap: Kinetic Theory 2

- The model unifies the idea of heat and temperature with our ideas of motion.
- The model opens the possibility of using the hidden energy stored in matter as a result of its (non-0) temperature.
- This leads to heat engines, refrigerators, and the first industrial revolution.

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For the final!

- Final exam: Friday 12/17, 8-12 AM, here.*
- Review slides will soon be posted on the Lecture Slides page (12/17 date).
- Office hours in the CC T 2-4, Th 12-2.
- Q&A session here W 2:00-3:30.

*Unless you have arranged to take it 1-5 in room 1303.

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