# *Lecture 21 Announcements*

1. Exam solutions posted to the website
2. You can pick up your exams at the usual place
3. The handwritten problems (out of 8 pts) will hopefully be graded within the next day or two.
   a. You will be able to pick them up same place, too



**From last time…**

**Worked Problem:** A flat roof of area 400 $m^2$ will rip off if it is subjected to a lift force of $5\times10^5$ N. What speed of horizontal wind will rip off the roof? (weight of the roof is included in $5\times10^5$ N number). $\rho_{air} = 1.29\ kg/m^3$

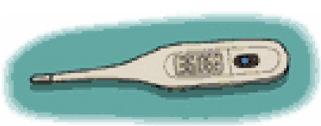
Answer: 44.0 m/s

**Clicker quiz:** A ball is thrown toward you, spinning so that the left side of the ball (as you look at it) spins toward you, and the right side away. The ball will

a. "float" more than a nonspinning ball
b. "sink" faster than a nonspinning ball
c. curve to your left
d. curve to your right



## Temperature scales



Demo: flaming jar

<u>Celsius (Centigrade)</u>

<u>Kelvin</u>

<u>Fahrenheit</u>

What is a **thermometer**?

Expansion

Thermocouples

**Demo:** two thermometers

Resistors

Semiconductors

→ Just find some property you can measure that changes consistently with temperature



## What is **temperature**?

Two objects in thermal contact will come to thermal equilibrium: they then have the "same temperature"

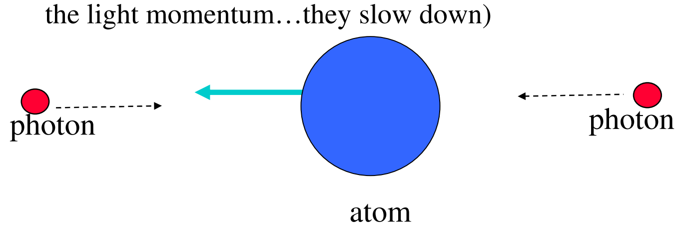
What is "thermal contact"?
→ able to _______________

What is heat?

Is there a maximum temperature?

Is there a minimum temperature?

"Laser Cooling"
Atoms slowed by light (2000 Nobel Prize)
(only atoms moving *toward* the laser beam can absorb the light momentum…they slow down)



**Thermal expansion:**
For a given material, lengths all change by the same percentage, per degree.

$$\Delta L = \alpha L_o \Delta T$$
$$\Delta A = \gamma A_o \Delta T$$
$$\Delta V = \beta V_o \Delta T$$

For solids:
$\gamma = 2\alpha$
$\beta = 3\alpha$

For reference: $\alpha_{steel} \approx 11\times10^{-6}$ /°C

You heat up a 1 meter steel rod by 1 degree C. How long is it now?

Demo: bimetallic strip

What went wrong here?



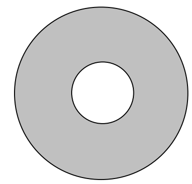
# Microscopic View

Why do most materials expand when heated?

**Clicker quiz:** You heat a disc with a hole in it. Will the radius of the hole get larger, smaller, or stay the same?

a. Larger
b. Smaller
c. Stay the same

(Ralph question)



Demo: ball and washer



# Ideal gases

1. Molecules collide like superballs (elastic) due to repulsive forces
2. No attractive forces
3. Never condense into liquids or solids
4. Are like “frictionless surfaces”, “massless pulleys”, “perfect fluids”, etc.

## Essentially ideal:

## Ideal gas law:

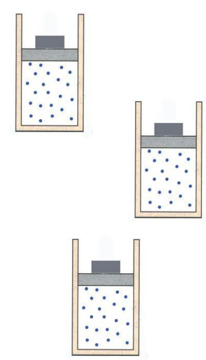
Where does it come from?



# Thermodynamics:

Wish to explain behavior of huge numbers of particles in terms of simple variables: ____________

Experiments on gases:



Hold T constant, increase P
Volume…

Hold P constant, increase T:
Volume…

Hold P, T constant, increase N
Volume…

**Combine the experimental results**

$$\frac{PV}{NT} = \text{constant} = k_B$$ Boltzmann’s constant

$k_B = 1.381 \times 10^{-23}$ J/°K

$$PV = Nk_BT$$ Ideal gas law! (Physics version)

*Must use:*
T in Kelvin
Absolute P

N is number of *molecules*

# Avagadro's Number
## …and other Chemistry concepts

Chemists measure quantity in **moles**:

$N_A$ = 1 mole = Avagadro's number ($N_A$)

$N$ = # molecules

$n$ = # moles: $n = N/N_A$

"molar mass": mass of one mole

(careful: commonly given in *grams*)

$n = m/MM$

May need to convert!

Chemistry Ideal Gas Law:

$$PV = nRT$$

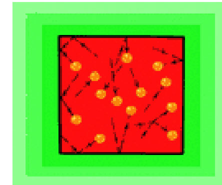
with $R = N_A \times k_B$ = 8.314 J/mole°K

= 0.08206 liter-atm/mole°K

Demo: liquid nitrogen and balloons



# Molecular view



Equipartition Theorem and speed of molecules:

The total kinetic energy of a system is shared equally among all of its independent parts, on the average, once the system has reached thermal equilibrium.

Specifically, each "degree of freedom", of each molecule, has "thermal energy" of: ______

independent parts: larger for molecules that can

- rotate
- vibrate

(requires more than one atom)

→ **such molecules have more "internal energy"**

**Average ("rms") kinetic energy of a molecule:**

Result: $$v_{rms} = \sqrt{\frac{3k_BT}{m}} = \sqrt{\frac{3RT}{MM}}$$



# Molecular View of Pressure

Pressure: due to collision forces from molecules

Force per molecule averaged over time

$F = ma = m\Delta v/\Delta t$

what should $\Delta t$ be?

$\Delta v$ is proportional to $v_{rms}$

$\Delta t$ is proportional to $1/v_{rms}$

Then the force (and hence pressure) is proportional to:

(ideal gas law)

Demo: collisions and pressure



An ideal gas has a mixture of heavy and light molecules

**Clicker quiz 1:** The molecules that move the fastest are…

a. heavy
b. light
c. same

**Clicker quiz 2:** (warmup) The molecules with the most KE are…

a. heavy
b. light
c. same

**Clicker quiz 3:** If you have equal numbers of heavy and light molecules in the gas, the ones that exert the most pressure on average are:

a. heavy
b. light
c. same

(Hint: think of the ideal gas law)

**Worked Problem:** In an engine piston, with air at 1 atm, the volume is decreased from 200 $cm^3$ to 40 $cm^3$, while the temperature increases from 300 K to 600 K. Find the final pressure.

**Method 1: Find N (or n)**

**Method 2: ratios**

Answer: $1.01\times10^6$ Pa, 10 atm



An old-fashioned glass milk jug is "empty" (still has air), at 20° C. You seal it, then put it into a fire at 500° C.

Note: assuming the jug doesn't burst, N and V are constant.

**Clicker quiz:** Using the ideal gas law, what is the final pressure in the jug?

a. 0-1 atm
b. 1-2 atm
c. 2-4 atm
d. 4-10 atm
e. 10+ atm

**Worked Problem:** If instead of being totally empty the jug had a mole of water molecules in it (about 18 g), how much pressure would they exert after being vaporized (assuming the jug still doesn't break)?

Demo: nitrogen in tube and balloon



**Worked Problem:** What is the mass of all the air in this room?