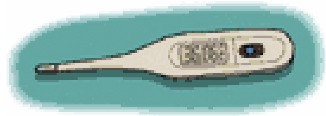
Announcements

1. Exam 3 average: 74 (as of Monday, noon)
2. You can pick up your exams at the usual place, usual time
   a. Get your virtual "bubble sheets" from the Testing Center website
3. Exam solutions will be posted at the usual place, usual time.

Temperature scales



Demo: flaming jar

<u>Celsius (Centigrade)</u>

<u>Kelvin</u>

<u>Fahrenheit</u>

Thermometers:

- Expansion
- Thermocouples
- Resistors
- Semiconductors

What **is** temperature?

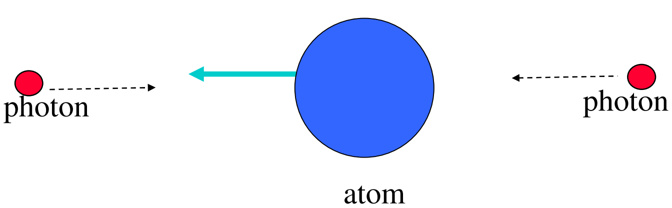
Two objects in thermal contact will come to thermal equilibrium (the same temperature)

The hottest things have been?
10^{32} Kelvin, at $t=10^{-44}$ sec after the

What is the coldest we can get to?

Less than a nanokelvin: 10^{-9} K!

"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:
Lengths all change by the same percentage) per degree.

$$\frac{\Delta L}{L_0} \sim \Delta T$$

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

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

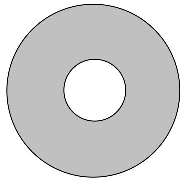
For reference: $\alpha_{steel} \approx 11\times10^{-6}$ /°C

Demo: bimetallic strip

Why do most materials expand when heated?

Q4. 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



Demo: ball and washer

Ideal gases:

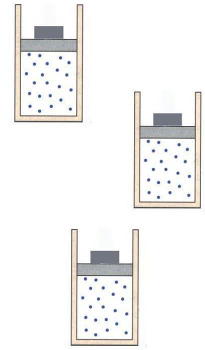
1. Molecules collide like billiard balls due to repulsive forces
2. No attractive forces
3. Never condense into liquids or solids
4. Don't exist

Essentially ideal:

Thermodynamics:

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

Experiments on ideal 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

$$\boxed{PV = Nk_BT}$$ Ideal gas law!

Must use:
T in Kelvin
Absolute P

N is number of *particles* (typically 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:

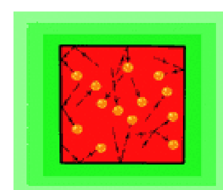
$$\boxed{PV = nRT}$$

with $R = N_A \times k_B$ = 8.314 J/mole°K
= 0.08206 liter-atm/mole°K

Absolute Zero?

Demo: liquid nitrogen, helium balloon, air balloon

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 kinetic energy of a molecule:

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

Molecular View of Pressure

Pressure: due to collision forces from molecules

Force per molecule averaged over time
$F = ma = m\Delta v/\Delta t$

Δv is proportional to v_{rms}
Δt (time between collisions) is proportional to $1/v_{rms}$

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

(ideal gas law)

Demo: collision and pressure

Q5. You have a mixture of heavy and light molecules in an ideal gas.

The molecules that move the fastest are :
a. heavy
b. light
c. same

Demo: shaking light and heavy balls

Q6. 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.

An old-fashioned glass mile jug is “empty” (still has air), at 20° C. You seal it, then throw it into a fire at 500° C.

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

Q7. 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 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?

Q8. Did you discuss at least half of the discussion quiz questions today with a neighbor?

a. Yes b. No