Announcements – 7 Nov 2013

(not quite)

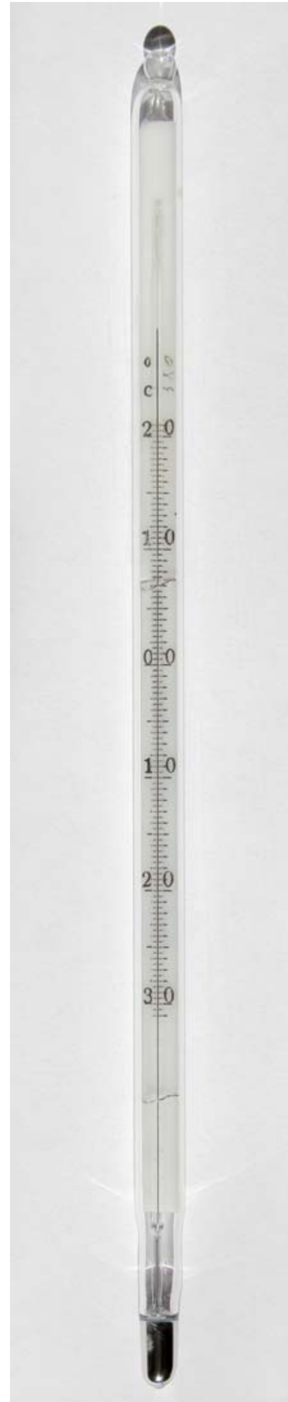
1. Exams should all be in boxes for pick up ~~now~~. tonight

Utah Baroque Ensemble concert

Sunday 7$^{\underline{30}}$ pm

(I'll send email with address)

Temperature scales



Celsius

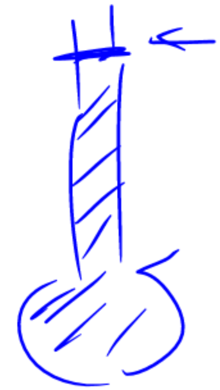
Kelvin $T_K = T_C + 273.15$

Fahrenheit $T_F = \frac{9}{5} T_C + 32$

From warmup: Which is coldest?

a. 0 degrees Centigrade (Celsius)
b. 0 degrees Kelvin
c. 0 degrees Fahrenheit

What is a **thermometer**?



Expansion
Thermocouples
Resistors
Semiconductors

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

Demo: Two thermometers

What is **temperature**?

→ The property that governs heat flow

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

What is heat?

microscopic random kinetic energy

Temperature, cont.

Is there a maximum temperature? Not really

Is there a minimum temperature? Yes 0 K

Thermal expansion:

For a given material, a 1°C change will cause length to change by same fraction

$$\Delta L = \alpha L_o \Delta T$$

$$\Delta A = \gamma A_o \Delta T$$

$$\Delta V = \beta V_o \Delta T$$

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

What went wrong here?

$\Delta L = (11\cdot 10^{-6}/°C)(1\,m)(1°C) = 11\cdot 10^{-6}\,m$

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?

1.000011 m

Demo

Bimetallic strip

Video

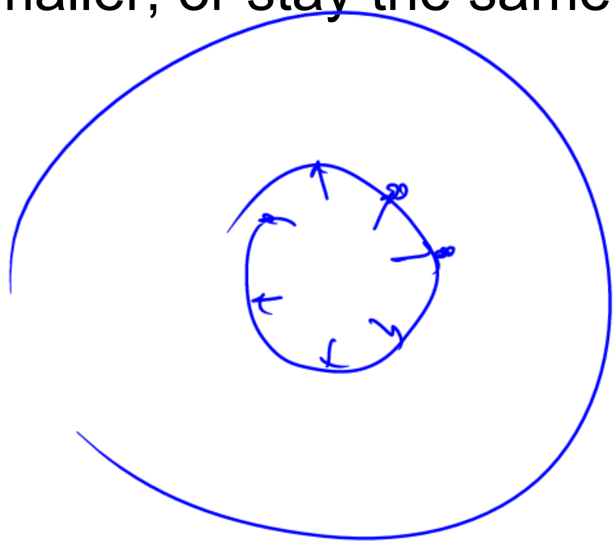
Bimetallic strip

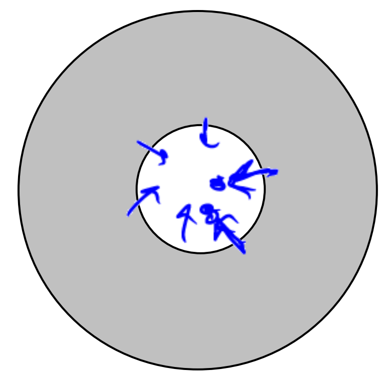
Microscopic View

Why do most materials expand when heated?

From warmup: 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

Ring and ball

Ideal gases

1. Molecules bounce off each other like superballs (elastic)
2. They do not stick (no attractive forces)
3. Never condense into liquids or solids
4. Are like "frictionless surfaces", "massless pulleys", "perfect fluids", etc.

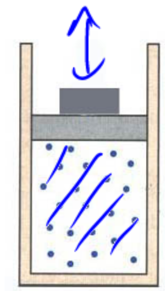
Mostly true as long as the gas is far from boiling point
(a.k.a. the condensing point)

Experimental Thermodynamics

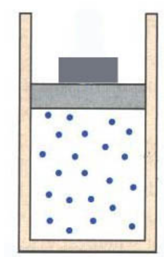
Wish to explain behavior of huge numbers of particles in terms of simple variables

Experiments on gases:

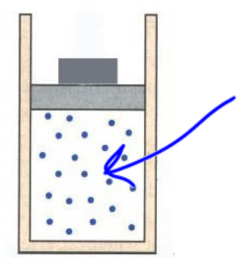
Hold T constant, increase P… Volume ___decrease___



Hold P constant, increase T… Volume ___increase___



Hold P, T constant, increase N… Volume ___increase___



Combine the experimental results

$$\frac{PV}{NT} = \text{constant} = k_B$$

Boltzmann's constant

$$k_B = 1.381 \times 10^{-23}\ \text{J/K}$$

$$PV = Nk_BT$$

Ideal gas law!
"Physics version"

Important:

- P in pascal
- V in m^3
- N is number of *molecules*
- T in Kelvin
- $k_B = 1.381 \times 10^{-23}$ J/K

From warmup

Suppose we have two jars of gas: one of helium and one of neon. If both jars have the same volume, and the two gases are at the same pressure and temperature, which jar contains the greatest number of gas molecules? (Both gases obey the ideal gas law. The mass of a neon molecule is greater than the mass of a helium molecule.)

a. jar of helium
b. jar of neon
c. same number

Clicker quiz

I am familiar with the quantity called “a mole”

a. yes
b. no

From warmup

Ralph is confused…the book calls two different equations "the ideal gas law". In equation 10.8 (8th edition), the equation is "$PV = nRT$". But in equation 10.11 (8th edition), the equation is "$PV = Nk_BT$". Why are they both called the ideal gas law, when only the first equation looks like what he learned in chemistry?

"Pair share"–I am now ready to share my neighbor's answer if called on.

a. Yes

Avogadro's Number
…and other chemistry concepts

Chemists measure quantity in **moles**:

N_A = 1 mole = $6.022 \cdot 10^{23}$ Avagadro's number (N_A)

$12.044 \cdot 10^{23}$

N = # molecules

n = # moles: $n = N/N_A$ = 2 moles

$N/n = N_A$

"molar mass": mass of one mole

(careful: commonly given in *grams*)

May need to convert to kg!

$n = m/MM$

$\frac{64\,g}{32\,g/mol} = 2$ moles

$$PV = nRT$$

Ideal gas law!
"Chemistry version"
(used in Physics, too…)

Important:

- P in pascal
- V in m^3
- n is number of *moles*
- T in Kelvin
- R = 8.314 J/mol·°K
  - → don't use R = 0.08206 liter-atm/mol·°K

Connection: $R = N_A \times k_B$

$$PV = Nk_BT = nRT$$

$$Nk_B = nR \rightarrow R = \frac{N}{n} k_B$$

$$R = N_A k_B$$

Clicker quiz

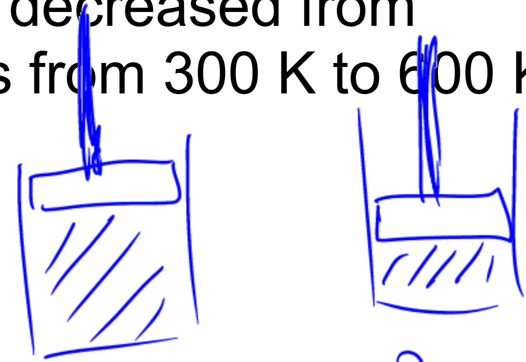
Which will shrink more when cooled to 77K? (I'll use liquid nitrogen)

a. helium balloon
b. air balloon

Demo: Liquid nitrogen and balloons

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.



$P_i = 1\,atm \qquad P_f = ?$

Method 1: Find N (or n)

$$P_i V_i = n R T_i$$

$$n = \frac{P_i V_i}{R T_i} = \frac{(1.01\cdot 10^5\,Pa)(200\cdot 10^{-6}\,m^3)}{(8.31\,J/mol\cdot K)(300\,K)} = .0081\text{ moles}$$

$$P_f V_f = n R T_f$$

$$P_f = \frac{n R T_f}{V_f} = \frac{(.0081\text{ moles})(8.31\,J/mol\cdot K)(600\,K)}{40\cdot 10^{-6}\,m^3} = 1.01\cdot 10^6\,Pa$$

Answer: 1.01×10^6 Pa, 10 atm

Method 2: ratios

$$\frac{P_i V_i = \cancel{n}\cancel{R}T_i}{P_f V_f = \cancel{n}\cancel{R}T_f}$$

$$P_f = P_i \frac{V_i}{V_f}\frac{T_f}{T_i}$$

$$= (1\text{ atm})\frac{200\ \cancel{\text{cm}^3}}{40\ \cancel{\text{cm}^3}}\left(\frac{600\text{ K}}{300\text{ K}}\right)$$

$$= 10\text{ atm}$$

Answer: 1.01×10^6 Pa, 10 atm

Clicker quiz

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.

Using the ideal gas law, what is the final pressure in the jug? (Note: assuming the jug doesn’t burst, N and V are constant.)

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

$$\frac{P_f V_f}{P_i V_i} = \frac{n R T_f}{n R T_i}$$

$$P_f = P_i \frac{T_f}{T_i} = (1\ \text{atm})\left(\frac{773\text{K}}{293\text{K}}\right) = 2.6\ \text{atm}$$

Worked Problem

1 L jug

Same situation as last 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)?

$$PV = nRT$$

$$P_f = \frac{nRT_f}{V_f} = \frac{(1\,\text{mol})(8.31\,\frac{\text{J}}{\text{mol}\cdot\text{K}})(773\,\text{K})}{.001\,\text{m}^3}$$

$$= \boxed{63\ \text{atm}}$$

Answer: 63 atm

Demos

Liquid nitrogen “balloon pop”
Liquid nitrogen tower

Video

Barrel Crush

Worked Problem

$\rho = \frac{m}{V} \rightarrow m = \rho \cdot V = 807 \frac{kg}{m^3} \cdot (.001) m^3 = .807\ kg$

How much volume will 1 liter of liquid nitrogen fill when it becomes gas?

- Density of LN = 0.807 g/cm^3
- Molar mass of N_2 = 28 g/mol
- Temperature in this room = about 70° F (=294.3 K)
- Atmospheric pressure in Provo = 0.85 atm

$n = \frac{.807\ kg}{.028\ kg/mol} = 28.82\ mol$

$PV = nRT$

$V = \frac{(28.82)(8.31)(294.3)}{(.85)(1.01 \cdot 10^5)} = .821\ m^3 = 821\ L$

Answer: 821 L

Worked Problem

What is the mass of all the air in this room? The average molar mass of the molecules in air (mainly nitrogen and oxygen) is 29.0 g/mol.

Answer: more than you'd expect!

Worked Problem

Use the ideal gas law to determine the density of air at 1 atm and 80° F (300K). (MM_{air} = 29 g/mol)

Answer: 1.175 kg/m^3