

Announcements – 11 Nov 2014

1. Prayer
2. Exam 3 starts two weeks from today!
 - a. Covers Ch 9-12, HW 18-24
 - b. Starts Tues before Thanksgiving
 - c. Late fee on Wed after Thanksgiving, 3 pm
 - d. Closes on Thursday after Thanksgiving, 3 pm
3. Photo contest submissions due on Dec 5

“Which of the problems from last night's HW assignment would you most like me to discuss in class today?”

Worked Problem

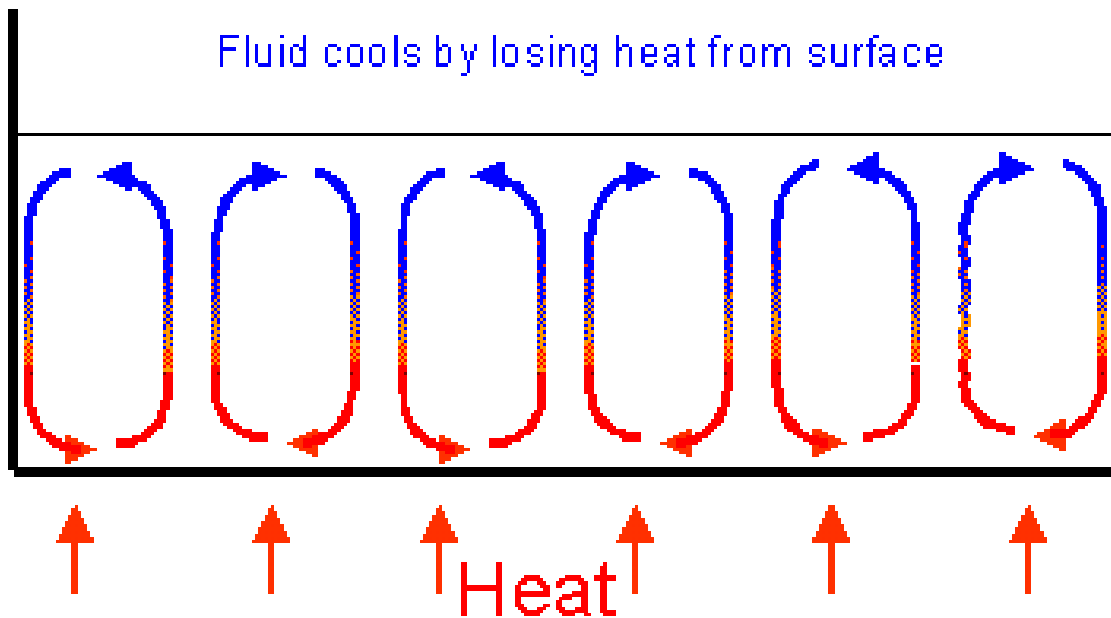
You foolishly decide to build the walls of your new house out of solid aluminum, 5 cm thick. As a result, in the wintertime heat leaks out like a sieve. How much money will this cost you each day? The inside temp is 70° F (21.1° C), the average outside temperature is 25° F (-3.9° C). The surface area is 280 m². The gas company charges you \$0.89 per “therm” (1.055×10^8 J). Only count heat loss through conduction.

Answer: \$24,286. Yikes!

Thermal convection

If air is a good thermal insulator why use fiberglass in attics?

<u>Material</u>	<u>k (J/s·m·°C)</u>
Copper	397
Aluminum	238
Iron	79.5
Glass	0.84
Wood	0.10
Air	0.0234



Convection cell

Warm, low density fluid rises
Cool, high density fluid sinks

Blackbody Radiation

Hot objects glow!

“Glow” carries away energy

$$P_{lost} = e\sigma A(T_{object})^4$$

Power: watts = heat/time

$$\sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$$

(“Stefan-Boltzmann constant”)

e : “emissivity” between 0 and 1

Aluminum, highly polished: $e \approx 0.05$

Aluminum, anodized (black): $e \approx 0.8$

→ Depends on material, surface, shape, temperature, etc.



From warmup

If the temperature of a "black body" doubles, how much does its rate of energy emission change?

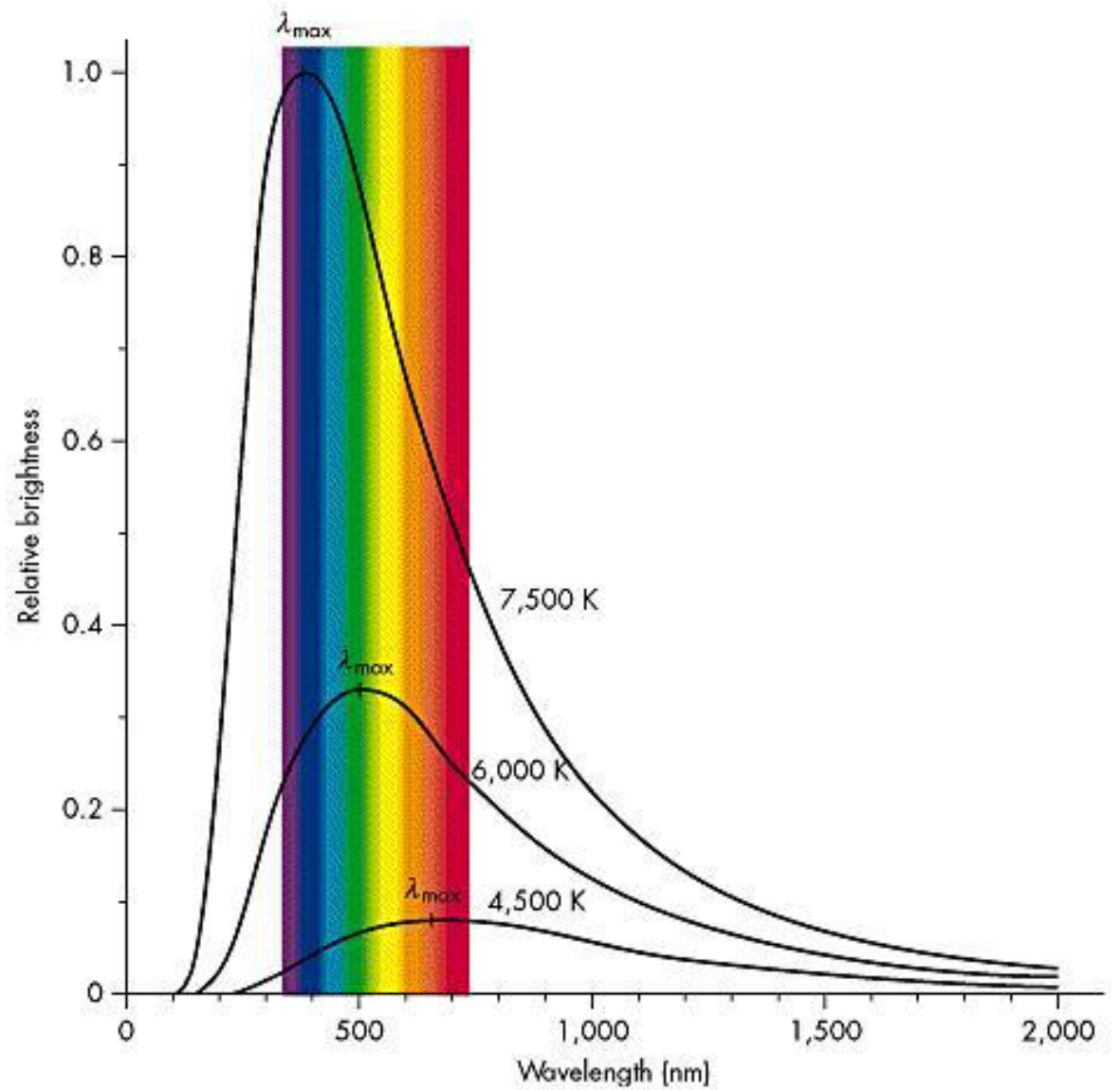
- a. $\times 2$
- b. $\times 4$
- c. $\times 8$
- d. more

But wait! Surroundings are also glowing!

$$P_{\text{gained}} = e\sigma A (T_{\text{surroundings}})^4 \quad \text{absorbed by the object}$$

$$\text{Net power radiated away} = P_{\text{lost}} - P_{\text{gained}}$$

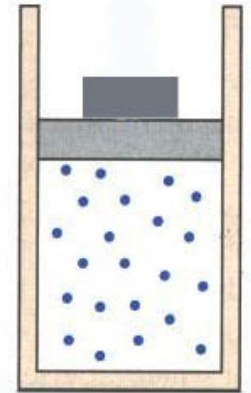
“Color” of emission, IR thermometers



Gases

Boyle's Law: Hold T constant, increase P...
Volume _____

Charles' Law: Hold P constant, increase T...
Volume _____



Émile Clapeyron, 1834: Combined the experimental results into...

$$PV = Nk_B T$$

Ideal gas law! “Physics version”

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

Boltzmann's constant

Important:

P in pascal

V in m^3

T in Kelvin

N is number of *molecules*

Back to microscopic view of heat...

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.

A good model for real gases as long as the gas is far from c_____

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

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 “ $PV = Nk_B T$ ”. 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

Ideal gas law

$$PV = nRT$$

“Chemistry version”
(useful for Physics, too...)

$$R = 8.314 \text{ J/mol}\cdot\text{K}$$

Universal gas constant

→ don't use $R = 0.0821 \text{ liter}\cdot\text{atm/mol}\cdot\text{K}$

Important:

P in pascal

V in m^3

T in Kelvin

n is number of *moles*

Connection: $R = N_A \times k_B$

Avogadro's Number

$$N_A = 1 \text{ mole} =$$

= "Avogadro's number"

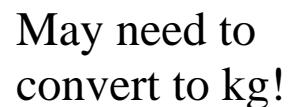
$$\# \text{ moles} = \# \text{ molecules} / N_A$$

$$n = N / N_A$$

"molar mass": mass of one mole
(careful: commonly given in *grams*)

$$n = m_{\text{tot}} / MM$$

May need to
convert to kg!



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.

Method 1: Find N (or n)

Answer: $1.01 \times 10^6 \text{ Pa}$, 10 atm

Method 2: ratios

Answer: 1.01×10^6 Pa, 10 atm

Worked Problem

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

Demo: Liquid nitrogen tower

Answer: 821 L

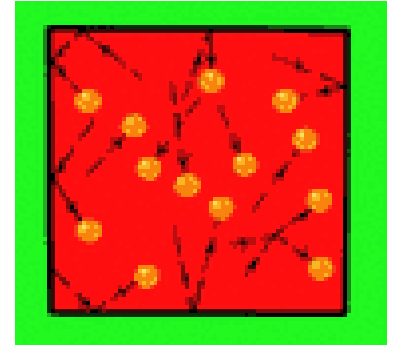
Worked Problem

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!

Molecular View of Pressure

Pressure: Comes from collision forces of molecules hitting wall



Related problem: You throw baseballs (mass 145 g) at a wall (area 9 m^2), at a speed of 85 mph (38 m/s). The collisions are elastic, and last for 0.05 seconds. (This is the time the ball is in contact with the wall.) A baseball hits the wall every 0.5 seconds. How much average pressure is generated by the baseballs? (We'll do this in three steps)

(a) How much force is generated by each hit? (Use impulse)

Answer: 220.4 N

(b) How much force is there, on average?

(c) How much overall pressure is generated by the balls?

Answers: 22.04 N; 2.449 Pa

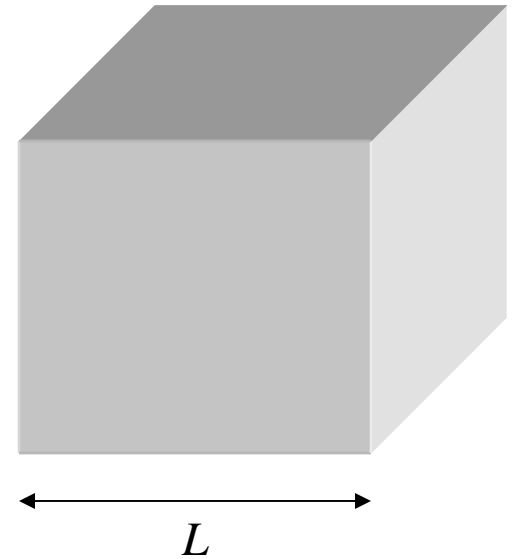
The actual problem

A cube filled with gas (focus on x-direction for now)

Molecules (mass m) hit the right wall, at a speed of v_x . Elastic collisions. How much pressure is generated by the molecules?

(a) How much force is generated by each hit?

(b) How much force is there from one molecule, on average?



Answers: $\frac{2mv_x}{\text{time of collision}}$; $\frac{mv_x^2}{L}$

(c) How much pressure is generated by the molecules?

(d) Expand to N molecules, and 3 dimensions ($v_x = v_y = v_z$). $P = ?$

Answers: $\frac{mv_x^2}{V}$; $\frac{Nm\left(\frac{1}{3}v^2\right)}{V}$

$$PV = Nm \left(\frac{1}{3} v^2 \right)$$

→ Does this remind you of anything?

$$T = \frac{m}{k_B} \frac{1}{3} v^2$$

$$\rightarrow \frac{1}{2} m v^2 = ?$$

This is in my “list of important equations”. Put it on your note card for the exam!

From warmup

An ideal gas has a mixture of heavy and light molecules at the same temperature. The molecules with the most [translational] KE are...

- a. heavy
- b. light
- c. same

Worked Problem

How fast are the oxygen molecules traveling in this room? (300 K)
molar mass = 32 g/mol, or $m = 5.31 \times 10^{-26}$ kg

Answer: 483.46 m/s (= 1081 mph!)

Kinetic Energy

$$\frac{1}{2}mv^2 = \frac{3}{2}k_B T$$

$KE_{\text{tot}} =$ _____

$KE_x =$ _____

$KE_y =$ _____

$KE_z =$ _____

Degrees of Freedom

Each “degree of freedom” has energy of $\frac{k_B T}{2}$

This is called the “Equipartition theorem”. It’s only briefly mentioned in your book! And not by name!

See page 390, Section 12.2 in 8th edition:

“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.”