TUESDAY: air & water & clouds

Temperature, Density, Pressure

- Does air weigh anything? Pressure & the mass of the atmosphere
- Molecules in a Box – Ideal Gas Law

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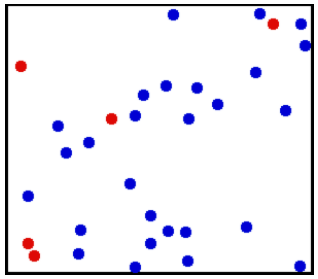
Molecular View of a Gas



http://en.wikipedia.org/wiki/File:Translational_motion.gif

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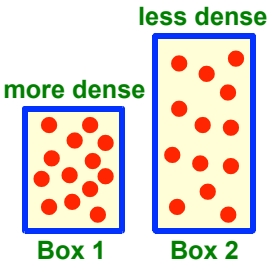
What is (atmospheric) Density?

- Density is measure of the amount of mass in a unit volume: ρ = Mass / Volume = m / V



- Same number of molecules and mass in both boxes
- Box 1 takes up less space (volume)
- Box 2 takes up more space (volume)
- Box 1 therefore has higher density than box 2

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Why do we care about Density?

- Changes in density drive vertical motion in the atmosphere *and* ocean
- Lower density air rises when it's surrounded by denser air

Think of a hollow plastic ball submerged under water: what happens if you release it?

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What is (Air) Temperature?

- Temperature is a measure of how fast air molecules are moving around
- Average energy of motion (kinetic energy) of air molecules is ½*m*v^2, where v – average speed of air molecules (v ~ 400 m/s ≈ 900 mi/h at room temperature)
- Temperature ~ kinetic Energy of air molecules
- Sensation of warmth is created by air molecules bouncing off your skin: the warmer it is the faster the molecules randomly move and the more collisions with your skin

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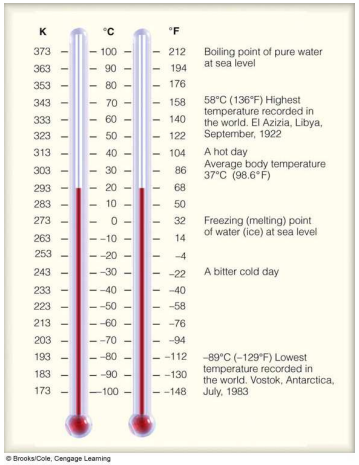
Temperature Scales

Temperature measurements:

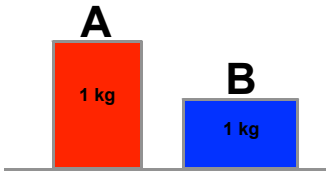
- Conventional thermometry (liquid in glass)
- Electronically (e.g. through resistance in a metal such as nickel)
- Remote sensing using radiation emitted by the air and surface (particularly from satellites)
- Why is there a point of absolute zero?



What is Pressure?

- Molecules bumping against an object exert a force on that object
- Pressure is force per unit area, p = F / A

Which box is exerting a greater pressure upon the ground?



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What is Atmospheric Pressure?

- Atmospheric pressure is force per unit area of a column of air above you (extending all the way to the top of the atmosphere)
- It arises from gravity acting on a column of air
- p = F / A = m*g / A

  (g – acceleration due to gravity)
- That is, pressure is the weight of the column of air above you – a measure of how hard this column of air is pushing down

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Question

How much do you carry on your “shoulders”?

or

What's the approximate mass of the column of air above you (~ 1 ft^2 ~ 0.1 m^2)?

A) ~ 20 lb (~ 9 kg)

B) ~ 200 lb (~ 90 kg)

C) ~ 2,000 lb (~ 900 kg)

D) ~ 20,000 lb (~ 9,000 kg)

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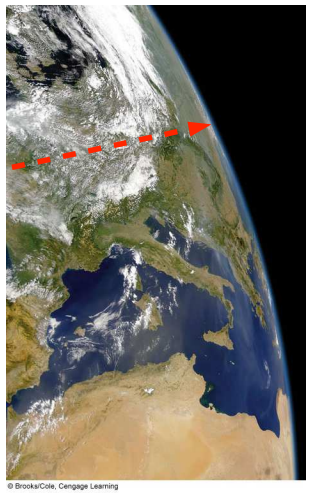
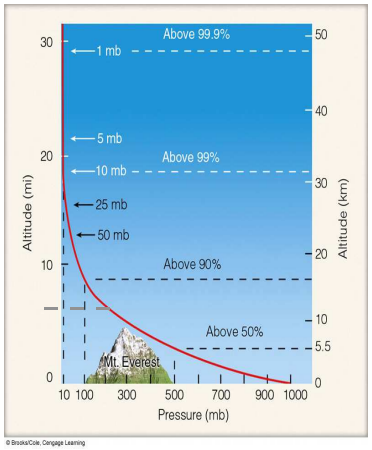
Vertical Structure

- **the atmosphere is very thin!**
- 99% of mass within 30 km (~19 mi) of the surface
- Gravity holds most of the air close to ground
- The weight of the overlying air is the pressure at any point



Vertical Structure

- In Fort Collins, 15% of the mass of the total atmosphere is below our feet
- At the top of Long's Peak, you are above 40% of the total atmosphere's mass
- You are closer to outer space than to Colorado Springs!
- Commercial aircraft max out at about 7 mi (~ 250 mb) → 75% of mass of atmosphere is below them (cabins are pressurized to about 750 mb)



Why care about Pressure?

- Pressure is fundamental for weather: pressure differences between different columns of air make our atmosphere move, i.e. produce winds
- Pressure defines many of our most prominent weather patterns: midlatitude cyclones & anticyclones (low & high pressure systems), hurricanes (tropical cyclone – low pressure), etc.

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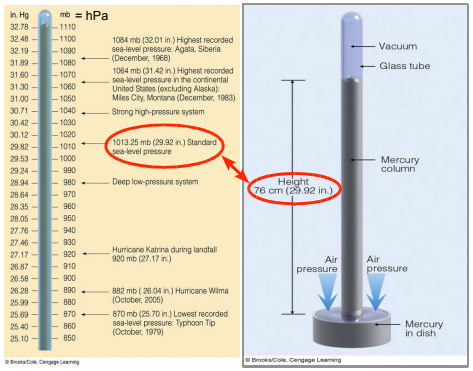
How do we measure pressure?

sea level (average)	unit
1	atmosphere
760	mm of mercury
29.92	in. of mercury
33.9	ft. of water
1013.25	millibars



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Equation of State
a.k.a. the Ideal Gas Law

- Relates fundamental thermodynamic quantities of air with each other:

$$p = \rho R T \text{ or } \rho = p / (RT)$$

pressure (p) equals the product of density (ρ), universal gas constant (R) and absolute temperature (T)

- T constant (isothermal): pressure and density are directly proportional ($p \sim \rho$)
- p constant (isobaric): density and temperature are inversely proportional ($\rho \sim 1/T$)
- ρ constant: pressure and temperature are directly proportional ($p \sim T$)

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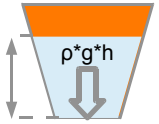
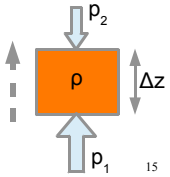
Hydrostatic Pressure & "Pressure Gradient Force"

- Pressure of a fluid column of height h and constant density:

$$p = F / A = m*g / A = \rho*V*g / A = \rho*g*h$$



- Hydrostatic pressure does not depend on surface area ("hydrostatic paradox")
- Pressure gradient: $(p_2 – p_1)/\Delta z = \Delta p/\Delta z$, accelerates fluid parcels from high to low pressure



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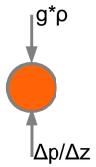
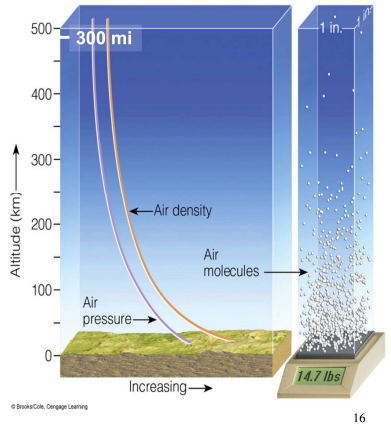
Hydrostatic Balance

- A balance between gravity and the "pressure gradient force":

$$\Delta p/\Delta z = –g*\rho$$



- remember the "pressure gradient force" causes an acceleration from high to low pressure



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