Astro 210

Lecture 17

February 26, 2018

Announcements

- **HW5 due online in PDF, Friday 5:00 pm**
- HW3 scores posted
- **Night Observing this week** – dress warmly!
  Campus Observatory. Mon, Tue, Wed, Thur 7–9pm
  bring **report form** available on Moodle
  take and submit **selfie** while there

Last Time: Planetary Temperatures and Atmospheres

Q: what sets planet surface temperatures?
Q: how does this depend on planet size?

Q: how is a gas microscopically different from a solid or liquid?
Q: what is a gas temperature, at a microphysical level?

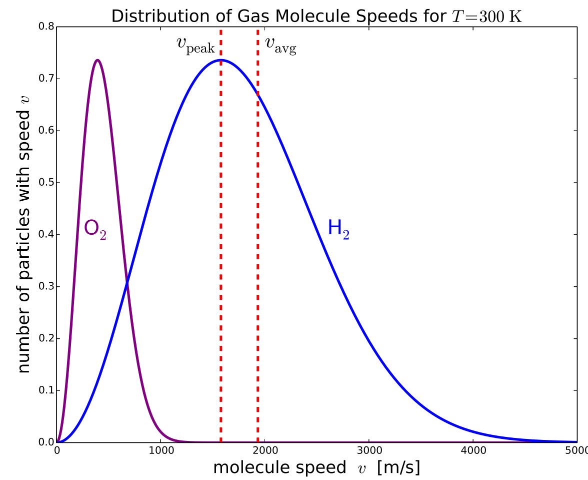
Last time: gasses under a microscope

gasses: collections of particles, e.g., atoms, molecules

`www: gas law simulation`

- in space: "elbow room" – empty space between particles
- in time: constant random motion
  collisions exchange energy, momentum
- *individual* particle velocities random, changing

- *distribution* of particle speeds
  is set by **temperature**
  average speed $v_{\text{avg}} = \sqrt{3kT/m}$
  slower for larger particle mass m



Microscopic View of a Piston

Now consider a large number of gas particles

- in a sealed volume
- with a *piston* of area A

from microscopic viewpoint:
piston constantly bombarded by gas particles
if let free–would be pushed away

to resist bombardment, must *push* on piston = exert *force* F
define **pressure**

$$P = \frac{\text{force on piston}}{\text{area of piston}} = \frac{F}{A} \tag{1}$$

Q: how to intensify bombardment = pressure on piston?
Hint–more than one way to do this

Pressure

collisions with walls $\rightarrow$ momentum transfer $\rightarrow$ force $\rightarrow$ pressure

`www: piston simulation`

ideal gas

pressure P, volume V, total number N of particles
and absolute (Kelvin) temperature T all related
by *ideal gas equation of state*:

$$PV = NkT \tag{2}$$

- N counts individual particles, typically very large!
  alternatively: can count in units of moles of particles
  i.e., in units of $N_{\text{Avo}} = 6 \times 10^{23}$
  then # moles is $n_{\text{moles}} = N/N_{\text{Avo}}$
  and $PV = n_{\text{moles}} RT$, where $R = N_{\text{Avo}} k = 8.3$ Joules mole^{-1} K^{-1}
- since density $\rho = M/V = \mu N/V$, with μ gas particle mass
  can rewrite ideal gas law: $P = \rho k T/\mu$

Planetary Atmospheres

Terrestrial Atmospheres:

- atmospheres are tiny (or zero!) fraction of planet mass
- no light gasses (H_2, He),
  only heavier N_2, O_2, CO_2 (if anything!)

Jovian Atmospheres:

- a significant fraction of planet mass
- mostly H_2, He; some heavier species

Q: why the difference? what factors important?

competition: gravity versus thermal motion

example: why no hydrogen (H_2) atmosphere on the Moon?

qualitatively

gravity: keep particles

thermal motion: run away

quantitatively

- gravity → escape speed

$v_{\rm esc} = \sqrt{2GM/R} = 2.4$ km/s for Moon

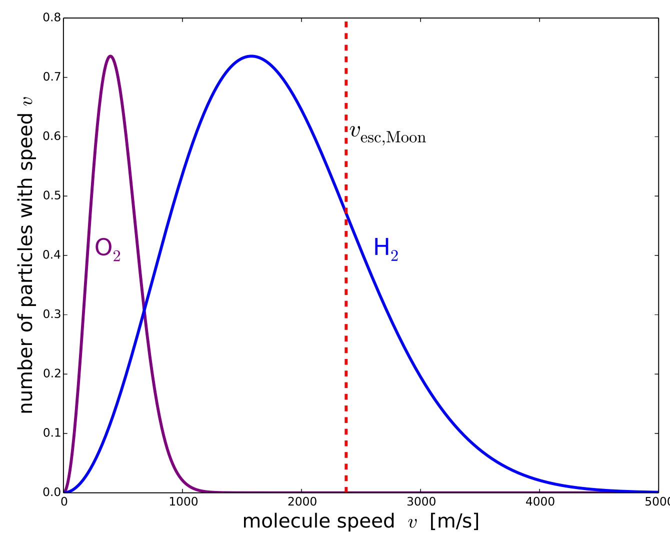
- thermal motion → average thermal speed

$v_{\rm avg} = \sqrt{3kT/m} = 2.6$ km/s for H_2

so for H_2 on Moon: $v_{\rm avg} > v_{\rm esc}$

H molecules escape → *H_2 lost from Moon*

`www: gas escape simulation`



really: not all particles have same speed

so always some escape

real question: timescale

to keep atm for age of SS

need $v_{\rm esc} \geq 6 v_{\rm rms}$ (rule of thumb)

species	$v_{\rm esc}/v_{\rm rms}$	lifetime
H on moon	0.9	hours
H on earth	2.1	days
sodium on moon	4	$\sim 10^3$ yrs
O_2 on earth	12	$\rightarrow\infty$: no escape!

`www: Sodium lunar ‘‘atmosphere’’`

solar UV photon on Moon “soil” $\rightarrow$ thin vapor of sodium

ejected but replenished

LONELY PLANETS GUIDE:

SOLAR SYSTEM

The Earth

our home! best studied planet
also the defining terrestrial planet

astro-trivia: Earth logo/icon is $\oplus$
recall: $R_\oplus = 6.4 \times 10^6$ m $=$ 6400 km
get mass from $g = GM_\oplus/R_\oplus^2$ (need G!)
$\rightarrow M_\oplus = gR_\oplus^2/G = 6.0 \times 10^{24}$ kg

Average density:
$\rho_{\mathrm{av},\oplus} = 3/4\pi M_\oplus/R_\oplus^3 = 5,500 \mathrm{kg/m^3}$
between rocks and iron $\rightarrow$ some of both

Q: how to learn about interior structure?

Journey to the Center of the Earth

Earthquakes release energy impulsively
launch *seismic waves* that propagate in all directions
wave speed varies with pressure & density
• wave paths curved where structure changes smoothly
refraction!
• at sharp jumps in structure (e.g., solid/liquid boundary)
busp waves are partially or totally relfected

So measuring pattern of wave signals
infer interior structure of Earth!

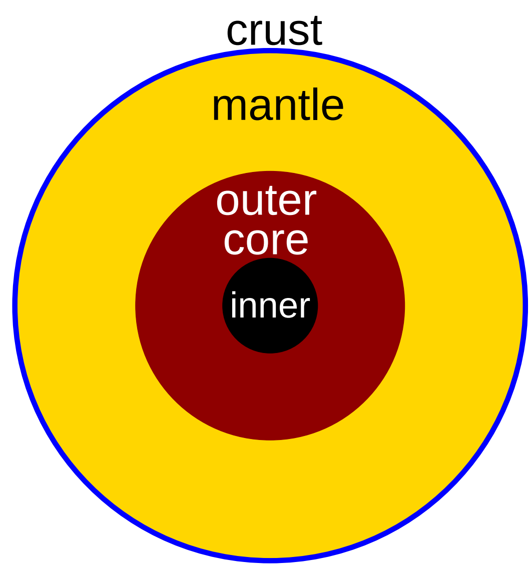
Earth's Interior

crust: 16–40 km → *thin!*

mantle: ~ 3000 km

outer core: $\sim 2,200$ km

inner core: $\sim 1,200$ km



crust: solid. ocean basins—basalt: O, Si, Al, Mg
continental plates–granite: O, Si, Al, Na, K

mantle: "plastic". Fe, Mg, Si, O

outer core: liquid. Fe, Ni

inner core: solid. Fe, Ni

heaviest elements lowest → settling ("differentiation")

Plate Tectonics

`www:  plot of earthquake sites`

`www:  plot of volcano sites`

`www:  plate locations`

crust not a single rigid solid
but collection of “plates”
motions in mantle (convection) cause plate motion

`www:  convection currents`

`www:  satellite laser ranging`

`www:  VLBI: radio telescopes used to detect motion`

`www:  drift animation`

plates move, and interact: collide, slide, buckle

$\Rightarrow$ "plate tectonics"

leads to observed geological features

`www: Mountain`

`www: volcano (Kilauea, HI)`

`www: San Andreas`

ex: San Andreas fault in CA: sliding plates $\rightleftharpoons$

Earth is evolving!

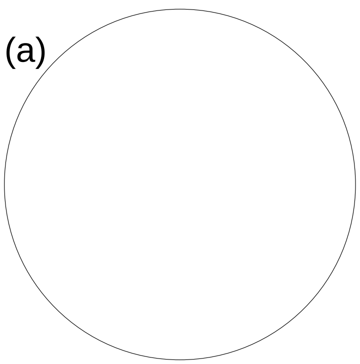
iClicker Poll: Earth's Orbit

Earth orbit around Sun: ellipse, eccentricity $e_{\oplus} = 0.017$

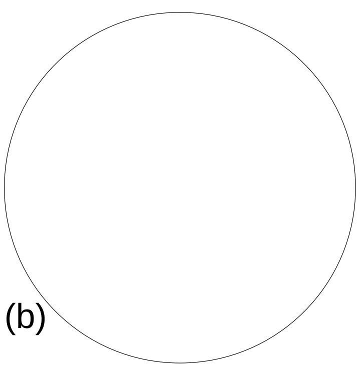
Below: one ellipse with $e = e_{\oplus}$, one circle $e = 0$

Which of these has the eccentricity of Earth's ellipse?

(a)

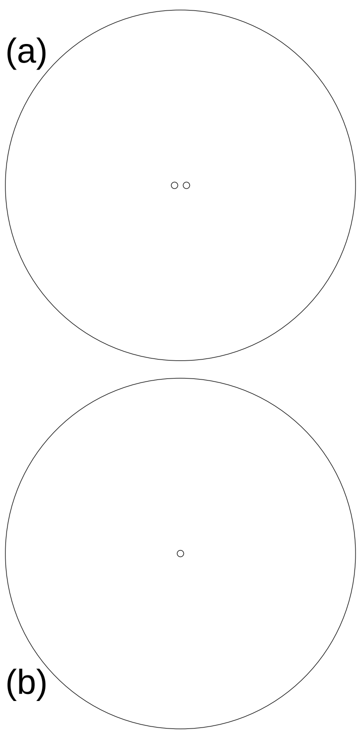


(b)



Survey Says

Foci labeled



Seasons and Eccentricity

Due to elliptical orbit, Earth-Sun distance changes
$r_{\mathrm{ap}} = (1+e)a_{\oplus} = 1.017$ AU
$r_{\mathrm{peri}} = (1-e)a_{\oplus} = 0.983$ AU
...but not by much! 3.2% swing!

if this were the whole story:
temperature swing by $\approx 2\% \times 300$ K $= 6^\circ$ C $= 11^\circ$ F!

also: if yearly temperature variations were due to eccentricity...
Q: how should the seasons compare in the N and S hemispheres?
Q: what is actually observed?
Q: what does this imply about season origin?

Origin of the Seasons

seasons are **exactly opposite** in N and S hemispheres
i.e., right now is spring in S. America, will soon be summer

so: season origin must distinguish hemispheres

recall: Earth's spin axis tilted w.r.t. orbit by 23.5°

- when one hemisphere tilted closest, the other farthest: this is summer/winter
- when tilt $\perp$ Earth-Sun radius: fall/spring

Note: Earth closest to Sun in northern winter!
$\longrightarrow$ eccentricity has tiny effect on temperature

Craters

Craters caused by meteor/comet impact
$\longrightarrow$ explosion results
$\longrightarrow$ large energy release

Resulting features:

- circular "bowl" cleared out
- in larger craters, central peak ("rebound" of underlying rock)

`www: the Moon`

Q: Why Moon's surface heavily cratered but Earth's not?

Why Moon's surface heavily cratered but Earth's not?

▷ small meteors burn in E's atmosphere

▷ erosion

▷ oceans hide some

▷ tectonic activity

▷ volcanos hide some

Some large objects do survive fall

impact on surface

but erosion, geological activity quickly erases evidence

`www: Manicouagan, Canada crater`

`www: Clearwater lakes, also Canada`

`www: Tunguska, Siberia 1929; exploded in air 1908`

`www: Meteor Crater, AZ`