Astro 210
Lecture 17
October 4, 2010

Announcements

⋆ Guest Instructor today: Prof. Athol Kemball
a real observer! and expert on radio astronomy!

- HW5 available, due next Friday
- **required** Night Observing this week
check online for schedule and weather info
download & bring question sheet

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
  but *distribution* (=historgram, bar graph) of particle speeds
  is set by **temperature**
  $\rightarrow$ average speed $v_{\text{rms}} = \sqrt{3kT/m}$

# Microsopic 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**

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



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

# Pressure

collisions with walls $\to$ momentum transfer $\to$ force $\to$ 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 $\rho = M/V = mN/V$, with $m$ gas particle mass
  can rewrite $P = \rho kT/m$

# 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

gravity $\rightarrow$ keep particles

thermal motion $\rightarrow$ run away

• gravity $\rightarrow$ ecape speed

$v_{\text{esc}} = \sqrt{2GM/R} = 2.4 \times 10^3$ m/s for Moon

• thermal motion $\rightarrow$ avg thermal speed

$v_{\text{rms}} = 2.6 \times 10^3$ m/s for H on Moon

$v_{\text{rms}} > v_{\text{esc}}$: many atoms can escape

H lost from Moon (check!)

really: not all particles have same speed

so always some escape

real question: timescale

to keep atm for age of SS

need $\boxed{v_{\rm esc} \geq 6 v_{\rm rms}}$ (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

# LET'S GO: SOLAR SYSTEM

# The Earth

astro-trivia: Earth logo/icon is $\oplus$

recall: $R_{\oplus} = 6.4 \times 10^4$ m $= 6400$ km

get mass from $g = GM_{\oplus}/R_{\oplus}^2$ (need $G$!)

$\rightarrow M_{\oplus} = 6.0 \times 10^{24}$ kg

Average density:

$\rho_{\text{av},\oplus} = 3/4\pi M_{\oplus}/R_{\oplus}^3 = 5,500 \text{kg/m}^3$

between rocks and iron $\rightarrow$ some of both

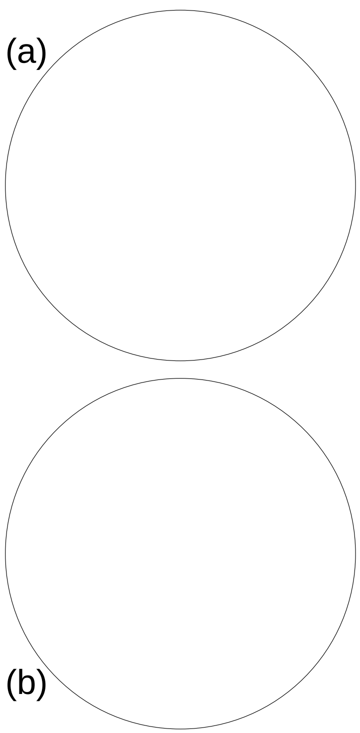
Orbit around Sun: ellipse, eccentricity $e_{\oplus} = 0.017$

# iClicker Poll: Earth's Orbit

Vote your conscience!

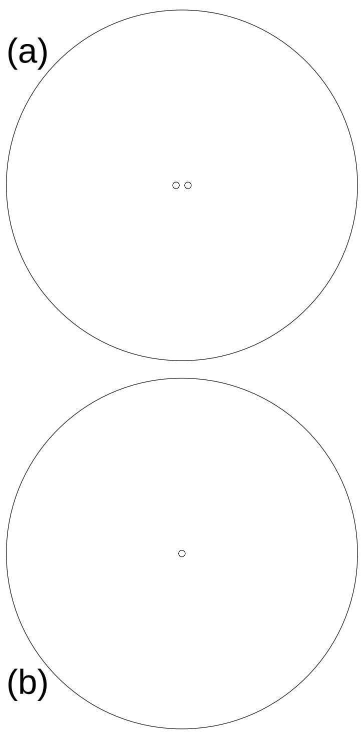
Below: one ellipse with $e = e_{\oplus} = 0.017$, one circle ($e = 0$)

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



# Survey Says

Foci labelled



# Seasons and Eccencricity

Due to elliptical orbit, Earth-Sun distance changes
$r_{\text{ap}} = (1 + e)a_{\oplus} = 1.017$ AU
$r_{\text{peri}} = (1 - e)a_{\oplus} = 0.983$ 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!
$\rightarrow$ eccentricity has tiny effect on temperature

# Earth's Interior

crust: 16–40 km
mantle: $\sim 3000$ km
outer core: $\sim 2,200$ km
inner core: $\sim 1,200$ km

inner core: solid. Fe, Ni
outer core: liquid. Fe, Ni
mantle: "plastic". Fe, Mg, Si, O
crust: solid. ocean basins—basalt: O, Si, Al, Mg
continental plates–granite: O, Si, Al, Na, K
heaviet elements lowest $\rightarrow$ settling ("differentiation")



*Q: how do we know?*

How do we know?
"Refraction" of Earthquakes
*Demo: slinky*

Earthquakes "emit" waves $\rightarrow$ use seismographic info to learn earth structure
*diagram*

# Plate Tectonics

`www:  plot of earthquake sites`

`www:  plot of volcano sites`

`www:  plate locations`

crust not a sigle rigid solid
but collection of "plates"
motions in mantle (convection) cause plate motion
*sketch 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: Mountian`

`www: volcano (Kilauea, HI)`

`www: San Andreas`

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

$\boxed{\text{Earth is evolving!}}$