Astro 210

Lecture 16

October 1, 2010

Announcements

- HW4 due
- HW5 available, due next Friday
- **required** Night Observing begins next week
  check online for schedule and weather info
  download & bring question sheet

Last time: planet temperatures

planet T set by an **equilibrium**

Q: between which opposing effects?

Q: why are these effects exactly balanced?

Plantary Temperatures Calculated

Can get excellent estimate of planetary T from
(fairly) simple first-principles calculation!

key is energy (power) balance: $\boxed{\text{absorption} = \text{emission}}$
diagram: sun, planet. label $R_\odot$, d, R

$\boxed{\text{Absorption}}$
recall: if surface of area S_{surf} emit flux F_{surf}
then radiated power = luminosity [energy/sec] is $L = F_{\text{surf}} S_{\text{surf}}$
Sun: $L_\odot = F_\odot S_\odot = 4\pi R_\odot^2 \sigma T_\odot^4$
at planet, flux is $F = L/4\pi d^2 = \sigma T_\odot^4 (R_\odot/d)^2$ [energy/area/sec]

....but we know not all incoming sunlight is absorbed!
Q: Why not?
Q: What substance would *absorb all incident sunlight?*
Q: What substance would absorb no *incident sunlight?*
Q how could we simply quantify all of this?

Not all sunlight bsorbed...or else wouldn't see Earth from space!
some is *reflected*!
recall: perfect absorber is blackbody
perfect reflector: ideal mirror
real substances/planets: somewhere between

Define: **albedo**

$$A = \frac{\text{amount of light reflected}}{\text{incident light}} \tag{1}$$

ideal mirror: $A = 1$
blackbody $A = 0$
Earth surface (average value) $A_{\text{Earth}} \approx 0.4$

iClicker Poll: Sun, Shadows, and the Earth

Which of these is larger?

A The surface area of sunlit portion of Earth

B The area of Earth's shadow

C (a) and (b) are equal

Planetary Energy Balance: Absorption

albedo A is fraction of incident radiation *reflected*
$\rightarrow$ fraction absorbed is $1 - A$

absorbed flux is $F_{\rm abs} = (1 - A) L_\odot / 4\pi d^2 = (1 - A)\sigma T_\odot^4 (R_\odot/d)^2$
over sunlit surface of planet, energy absorbed per sec:

$$
\begin{aligned}
W_{\rm abs} &= \text{area intercepting sunlight} \times F_{\rm abs} & (2)\\
&= \pi R^2 \, (1 - A)\sigma T_\odot^4 \, \left(\frac{R_\odot}{d}\right)^2 & (3)\\
&= (1 - A)\pi R^2 \frac{R_\odot^2}{d^2} \sigma T_\odot^4 & (4)
\end{aligned}
$$

note: effective absorbing area is πR^2
$\rightarrow$ planet's cross section – i.e., area of shadow

Planetary Energy Balance: Emission

emitted flux: $F_{\text{emit}} = \sigma T^4$ (avg surface T)

what area emits?
diagram: side view

case I: slowly rotating, no atm: backside cool
$\rightarrow$ only dayside emits
case II: both sides hot $\rightarrow$ both sides emit

emitting area:

$$S_{\text{emit}} = \begin{cases} 2\pi R^2 & \text{slow rot} \\ \approx 4\pi R^2 & \text{fast rot} \end{cases} \tag{5}$$

$\rightarrow$ energy emitted per sec:

$$W_{\text{emit}} = S_{\text{emit}} \sigma T^4 \tag{6}$$

Planetary Temperatures: The Mighty Formula

In equilibrium: $\boxed{W_{\text{abs}} = W_{\text{emit}}}$

$$(1-A)\ \pi R^2 (R_\odot/d)^2\ \sigma T_\odot^4 = \begin{pmatrix} 2\pi R^2 \\ 4\pi R^2 \end{pmatrix} \sigma T^4 \quad \begin{cases} \text{slow rot} \\ \text{fast rot} \end{cases} \tag{7}$$

and so planet surface temperature is

$$T = \begin{pmatrix} (1-A)/2 \\ (1-A)/4 \end{pmatrix}^{1/4} \left(\frac{R_\odot}{d}\right)^{1/2} T_\odot \quad \begin{cases} \text{slow rot} \\ \text{fast rot} \end{cases} \tag{8}$$

note:

- planet T set by Sun surface T
- *independent* of planet radius R!
- drops with distance from Sun, but as $T \propto 1/\sqrt{d}$

Calculate for $T_\odot = 5800$ K, and d in AU:

$$T = \begin{cases} 332 \text{ K } \left(\frac{1-A}{d^2}\right)^{1/4} & \text{slow rot} \\ 279 \text{ K } \left(\frac{1-A}{d^2}\right)^{1/4} & \text{fast rot} \end{cases} \tag{9}$$

where d in AU!

Example: *the Earth*

inputs: $d = 1$ AU, approximate $A = 0$

atm: day and night temp roughly same $\rightarrow$ fast rot (case II)

$$T_{\text{average}} = 279 \text{ K} \sim 6^\circ \text{ C} \sim 43^\circ \text{ F} \tag{10}$$

pretty close!

and recall: haven't accounted for greenhouse effect,

small deviations from perfect blackbody emission, ...

∞

Q: so what do we expect for the Moon?

Atmospheres: Gas Properties

gases on microscopic scale
a swarm of particles, for example atoms or molecules

- gas particles have empty space between them
  not packed together as in liquid or solid

- gas particles are in constant random motion
  collide with each other, container walls (if any)
  exchange energy & momentum $\rightarrow$ distribution of speeds

on macroscopic scales (i.e., how we see things)
particle motions percieved as *temperature*

iClicker Poll: Gas Particle Speeds

consider a parcel of gas:

- macroscopically, gas is at rest (not moving/blowing)
- at room temperature T

in this gas:

the average particle **velocity** $\vec{v}$ and **speed** $v = |\vec{v}|$ are:

A $\vec{v} = 0$ and $v = 0$

B $\vec{v} = 0$ and $v > 0$

C $\vec{v} \neq 0$ and $v = 0$

D $\vec{v} \neq 0$ and $v > 0$

average particle velocity vector vanishes: $\langle \vec{v} \rangle = 0$
why? *not* because particles are still
rather: equal numbers with $v_x > 0$ vs $v_x < 0$ $\rightarrow$ averages to zero
otherwise: gas would have net v_x, wouldn't be at rest!

note microscopic–macroscopic (particle–bulk) correspondence:
micro: equal probabilities for particle $\vec{v} > 0$ and $\vec{v} < 0$
macro: corresponds to bulk gas speed $\vec{u}_{\rm gas} = 0$

since particles are moving, speeds $\langle v^2 \rangle = \langle v_x^2 \rangle + \langle v_y^2 \rangle + \langle v_z^2 \rangle > 0$
$\rightarrow$ avg KE of one gas particle is nonzero
Q: what does this mean for bulk, macroscopic gas?

particle motion $\rightarrow$ particle kinetic energy
proportional to bulk temperature

$$\langle KE \rangle_{\text{per particle}} = \frac{1}{2} m \langle v^2 \rangle = \frac{3}{2} kT \tag{11}$$

example of general rule of thumb:
in thermal system, typical particle energy $E_{\text{particle}} \sim kT$
with $k = 1.38 \times 10^{-23}$ Joules/Kelvin: Boltzmann's constant

for thermal gas: average particle speed ("root mean square") is

$$v_{\text{rms}} = \sqrt{\frac{3kT}{m}} \tag{12}$$

where m = mass of 1 gas particle $= \mu m_p$
and: m_p = proton mass $= 1.67 \times 10^{-27}$ kg
"molecular weight"

$$\mu = \text{tot } \# \text{ of } n, p = \text{sum atomic weights} \tag{13}$$

also: peak speed (most probable)

$$v_p = \sqrt{2kT/m} < v_{\rm rms}$$

Q: how can this be less than average?

Note:

- $v_{\rm rms} \propto \sqrt{T}$: hotter $\to$ faster on avg
  T measures avg ptle energy, speed
- $v_{\rm rms} \propto 1/\sqrt{m}$: more massive particles $\to$ slower on avg

Example: air is mostly N_2 and O_2 molecules

Q: in this room, which faster: ?

but: if peel orange,
smell does not propagate at $v_{\rm rms} \sim 500$ m/s:
$\to$ don't smell it within 10 ms!
Q: why not?