"The Planets"

Astro/EPS C12 (CCN 17045 or 32505)

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LEC: 2 LeConte TWTh, 2:40–5:00pm
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Mon 3–4 and Tue 5–6

CORRECTIONS =(

- PS2: $F = F_0 (r_0/r)^2$, and $r_0 = 1$ AU.

TECHNICAL SUPPLEMENT

- page 12: change π to π^2
- page 13: destroy v_{esc} formula, replace with this one:
- page 16: change m_H (mass of hydrogen) to m_U (atomic mass unit = 1.66×10^{-27} kg)

$$v_{\mathrm{esc.}} = \sqrt{2\,g\,r} = \sqrt{\frac{2Gm_{\mathrm{planet}}}{r}}$$

PS1: question 2C

- $F = mg$, what is g if F and m are both in pounds?

"I Was Too Busy to Be Scared"

Were you scared?
No. I was too busy to be scared. I knew what was happening was not strictly nominal, but we

PS1: question 2C

ORIGIN OF SOLID PLANET ATMOSPHERES

PRIMARY ATMOSPHERE

- composed of whatever gases available at time of formation
  - hydrogen
  - helium
  - methane (CH_4)
  - ammonia (NH_3)
  - water (H_2O)
- light gases (H & He) would have rapidly escaped

ORIGIN OF SOLID PLANET ATMOSPHERES

SECONDARY ATMOSPHERE

- produced by outgassing
  - gases released from melts in the interior
  - volcanically introduced
  - water (H_2O)
  - sulfur dioxide (SO_2)
  - carbon dioxide (CO_2)
  - nitrogen compounds
- also delivered by impacts of asteroids and comets
  - mainly water
  - impacts also REMOVE atmosphere
- interactions with surface

ORIGIN OF GIANT PLANET ATMOSPHERES

- core formed first
- direct gas capture, so giant planets are mostly hydrogen and helium
- further enrichment by accreting solid planetesimals

MAINTAINING AN ATMOSPHERE

- gases gravitationally bound to a planet make up the atmosphere
- massive planets have stronger gravity and can maintain an atmosphere
- individual molecules in a gas are moving fast and colliding

$$E = 1/2\ m\ v^2$$

- hot molecules move faster than cold ones (if all are equally massive)
- light molecules move faster than heavy ones (if all are at the same temperature)

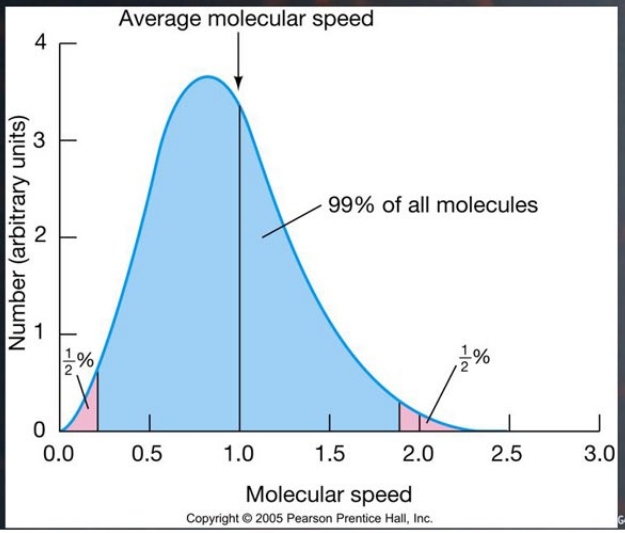
MAINTAINING AN ATMOSPHERE

$$v_{\text{esc.}} = \sqrt{2\,g\,r} = \sqrt{\frac{2Gm_{\text{planet}}}{r}}$$

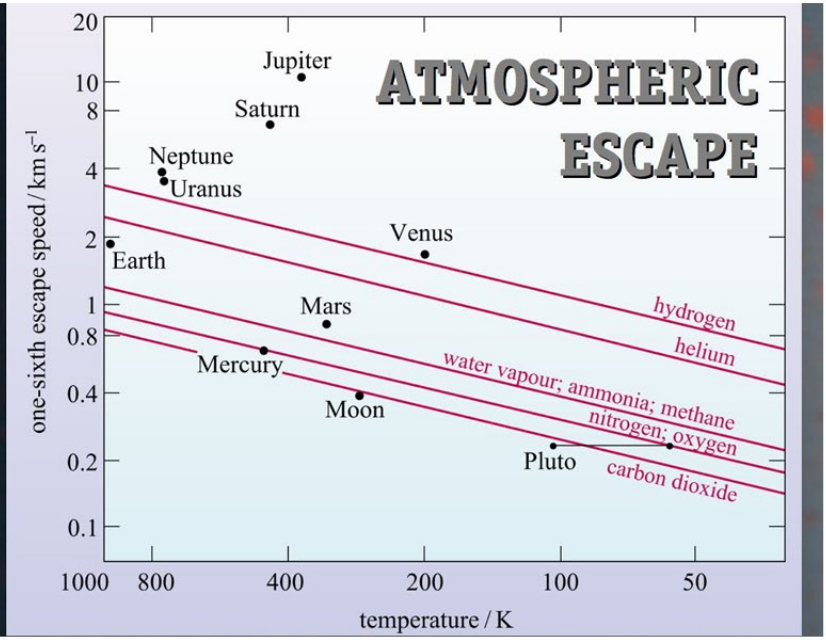
$$\bar{v} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8RT}{\pi \mu M_{\text{u}}}}$$

- v_{esc} = escape velocity from planet
- $\bar{v}$ = average thermal velocity of a molecule
- if $6\,\bar{v} > v_{esc}$, then the atmosphere is escaping the planet !!

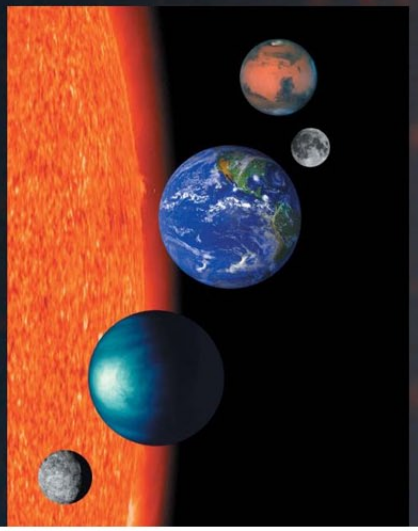
MOLECULAR SPEEDS



ATMOSPHERIC ESCAPE

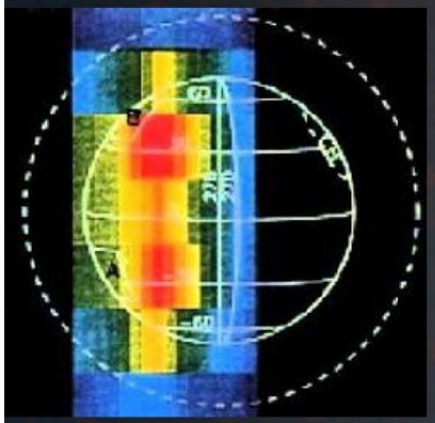


THIN ATMOSPHERES

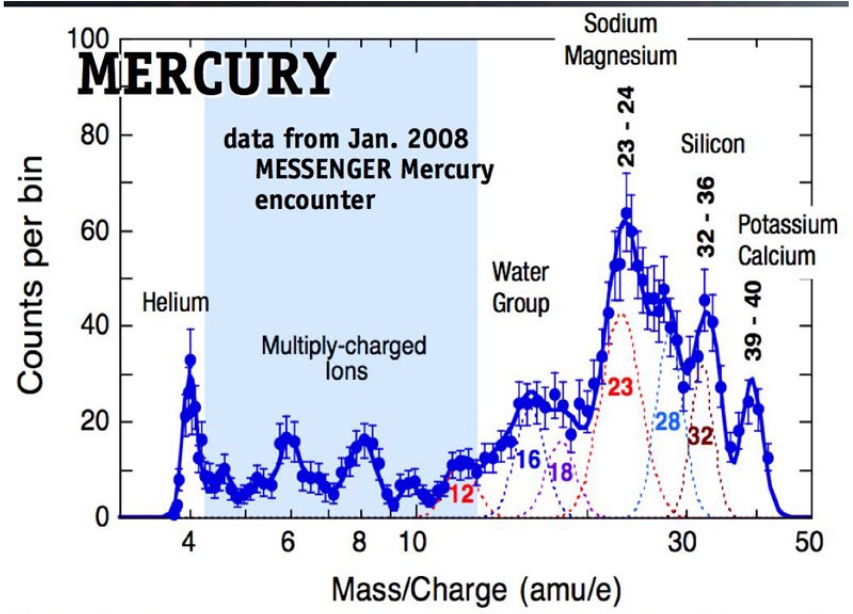


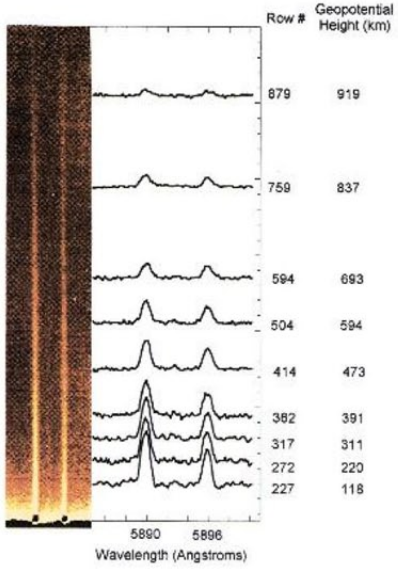
- Mercury and the Moon, the smallest of the terrestrial planets, have only trace atmospheres
- gas atoms rarely collide with each other but can interact with surface

MERCURY



- image shows sodium emission
- potassium, H, He, oxygen and more observed
- since Mercury is not massive enough to hold an atmosphere, gases must be replenished
- solar wind implantation
- micrometeorite impacts
- outgassing?





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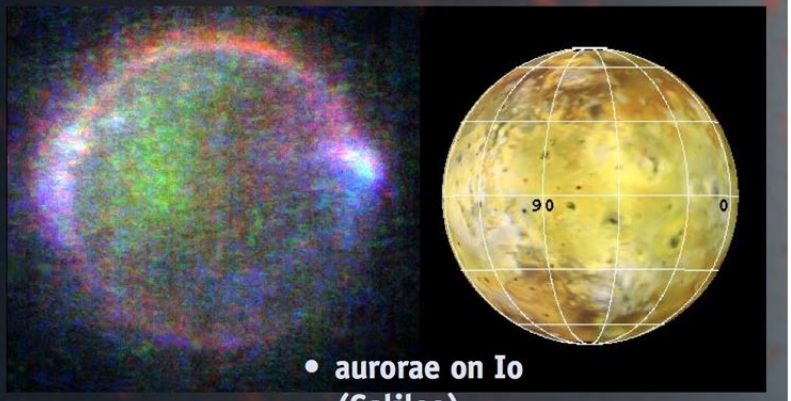
THE MOON

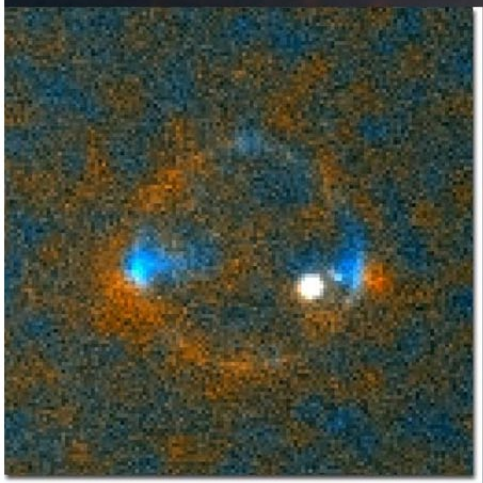
- sodium emission shown here, observed using a coronagraph
- Moon's atmosphere must be continually replenished:
  - solar wind implantation
  - micrometeorite impacts
  - outgassing

IO



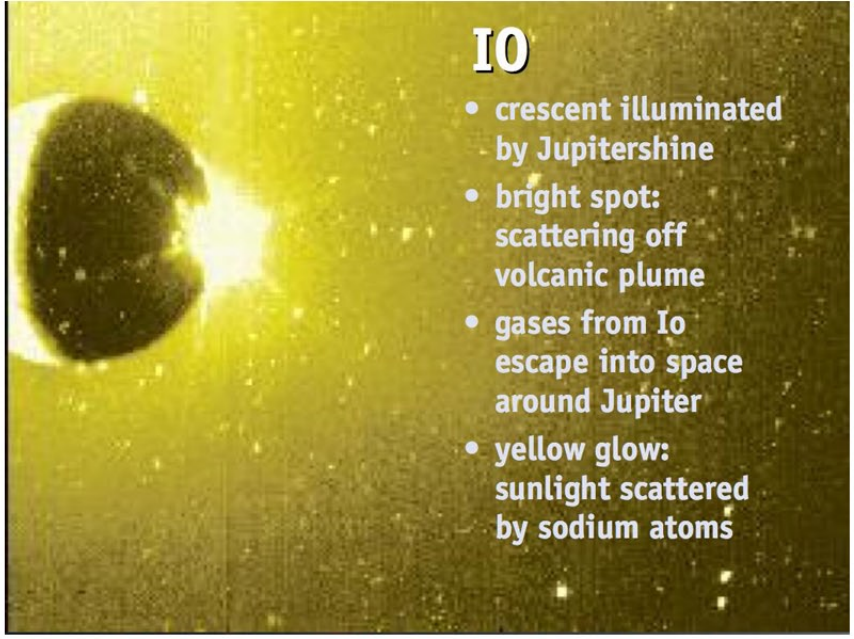
- aurorae on Io (Galileo)

IO



- red: oxygen emission
- blue: SO_2 emission
- source of Io's tenuous atmosphere: volcanoes

IO

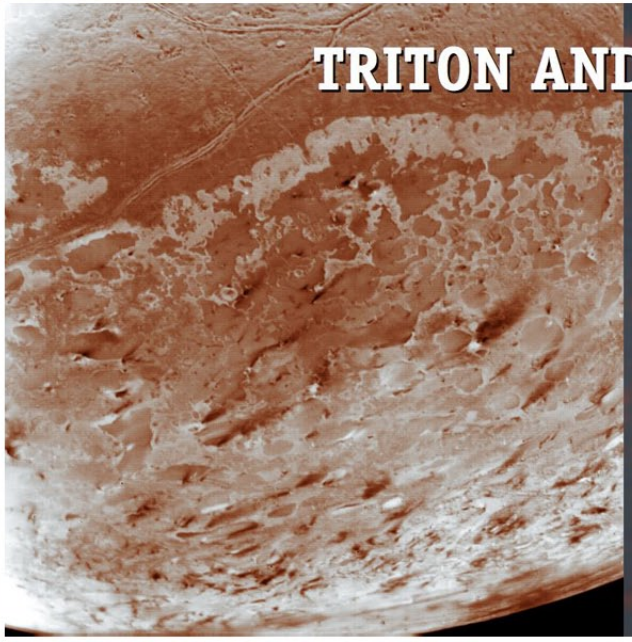


- crescent illuminated by Jupitershine
- bright spot: scattering off volcanic plume
- gases from Io escape into space around Jupiter
- yellow glow: sunlight scattered by sodium atoms

JUPITER'S ICY MOONS

- trace gases (including sodium, CO_2) have been found at the other Galilean satellites
- source: sputtering
- sputtering is when atoms/molecules get ejected from impacts by high-speed ions

TRITON AND PLUTO



- Triton: dark geyser plume deposits
- Triton and Pluto have solid N_2, CH_4, CO, CO_2
- atmospheres should have gas forms of these ices

TRITON

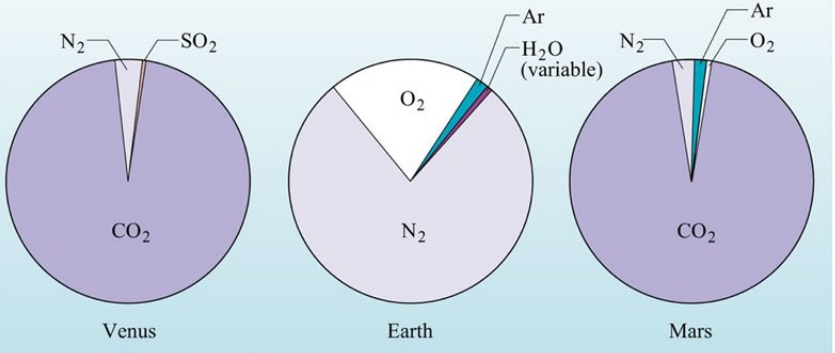
- clouds on horizon
- surface pressure: 15 microbars (1 bar = 1 Earth atmosphere)

Triton • Tenuous Clouds

THICK ATMOSPHERES

	Earth	Venus	Mars	Titan
CO_2	0.03%	96%	95%	~0
N_2	78%	4%	3%	95-99%
O_2	21%	<1%	<1%	~0
H_2O	yes	no	yes	(solid)
CH_4	<1%	<1%	~0	1-5%
Total Pressure:	1 bar	90 bar	7 mbar	1.6 bar

ATMOSPHERIC COMPOSITION



TERRESTRIAL PLANET ATMOSPHERIC COMPOSITIONS

Table 5.2 The major components of the atmospheres at the surfaces of the terrestrial planets.

Mercury		Venus[a]		Earth		Mars	
Gas	Volume ratio[b]	Gas	Volume ratio[b]	Gas	Volume ratio[b]	Gas	Volume ratio[b]
O_2	0.42	CO_2	0.965	N_2	0.781	CO_2	0.953
Na	0.29	N_2	3.5×10^{-2}	O_2	0.209	N_2	2.7×10^{-2}
H_2	0.22	SO_2	1.5×10^{-4}	H_2O[c]	<0.04	Ar	1.6×10^{-2}
He	0.06	H_2O	1×10^{-4}	Ar	9.3×10^{-3}	O_2	1.3×10^{-3}
K	5×10^{-3}	Ar	7×10^{-5}	CO_2	3.4×10^{-4}	CO	7×10^{-4}
		H_2	$<2.5 \times 10^{-5}$	Ne	1.8×10^{-5}	H_2O	3×10^{-4}
		CO	2×10^{-5}				

PHASES OF MATTER

- SOLID -- resists forces against it (like compression); atoms/ molecules fixed with respect to each other
- LIQUID -- has no independent shape; not very compressible; atoms/molecules can move, but are packed tightly just like in solids
- GAS or VAPOR -- can compress or expand; atoms/ molecules can move

PHASE TRANSITIONS

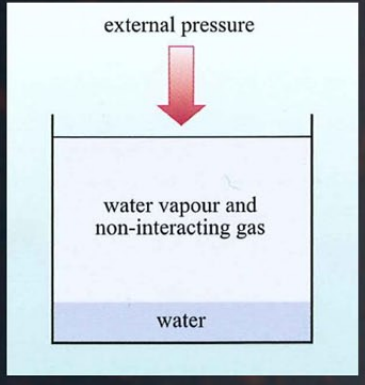
These transitions consume heat:

- VAPORIZE, BOIL -- go from liquid to gas
- SUBLIMATE -- go from solid to gas
- MELT -- go from solid to liquid

These transitions release heat:

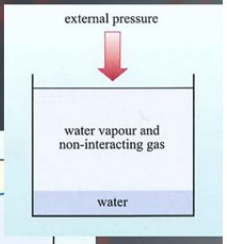
- FREEZE -- go from liquid to solid
- CONDENSE -- go from gas to liquid
- DEPOSIT -- go from gas to solid

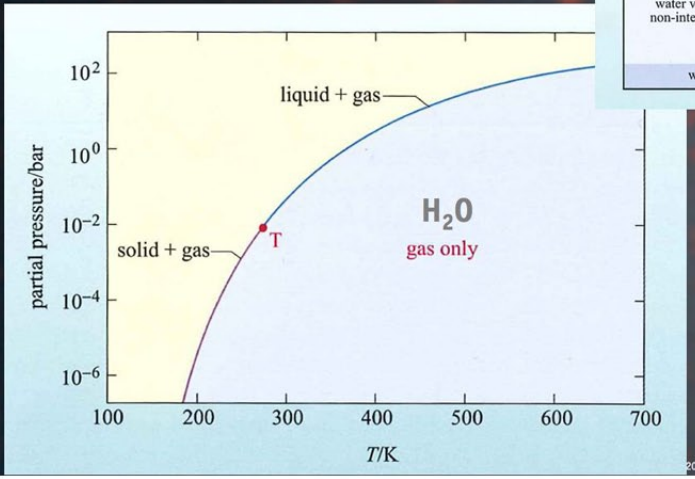
AN EXPERIMENTAL BOX



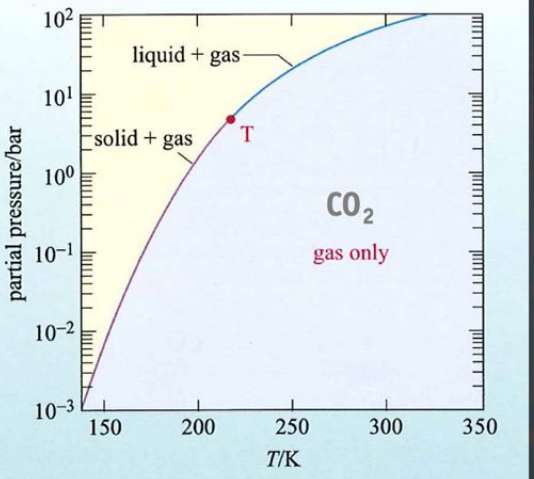
- amount of gas-phase H_2O (A.K.A. water vapor) depends on temperature and pressure in the box
- "partial pressure" is the amount of the total pressure due to just water vapor

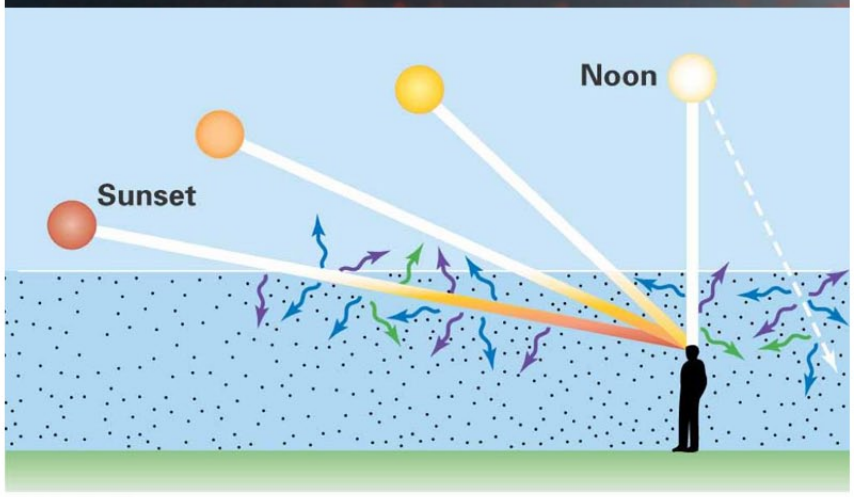
SATURATION VAPOR PRESSURE CURVE





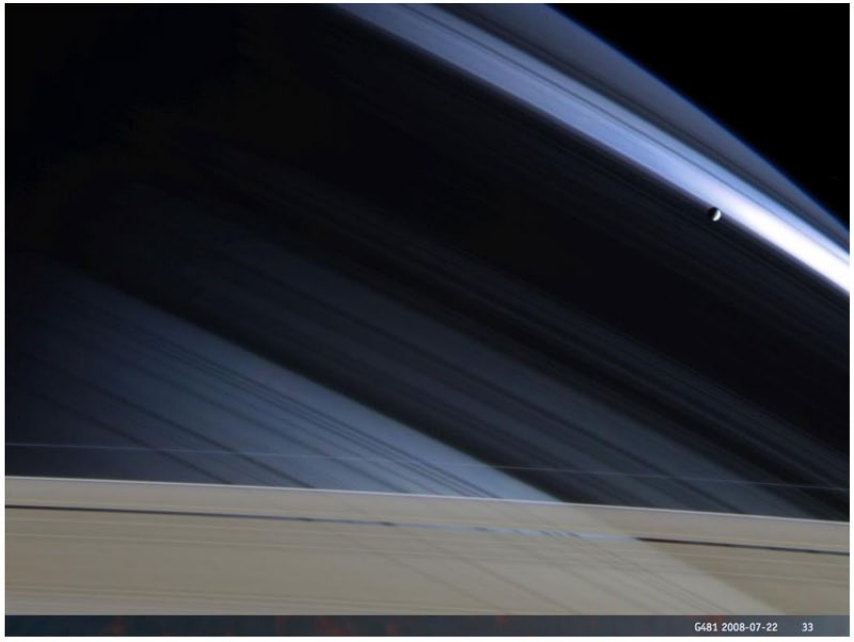
SATURATION VAPOR PRESSURE CURVE





SCATTERING

- light changes direction, but is not absorbed, in scattering events
  - Martian sunset
  - our blue sky
  - interstellar dust



SATURN AND MIIMAS

- Cassini image
- Atmosphere looks blue
  - shading from rings means cooler temps
  - cooler temperatures means lower clouds
  - so the light we see is mainly scattered instead of cloud-reflected light
  - blue is scattered more than red

SATURN AND MIIMAS

- Cassini image

SATURN

- Cassini image

SATURN

- Cassini image
- Northern hemisphere is clearly bluer than southern hemisphere

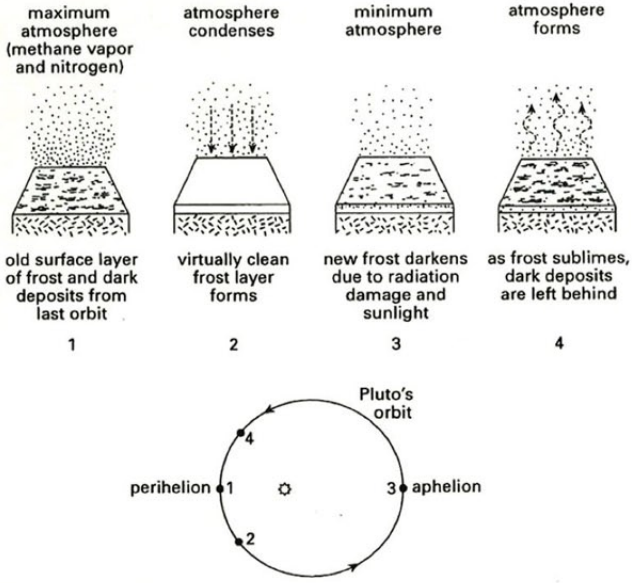


Fig. 4.1: The cycle of seasonal change and frost deposition affecting Pluto's surface.

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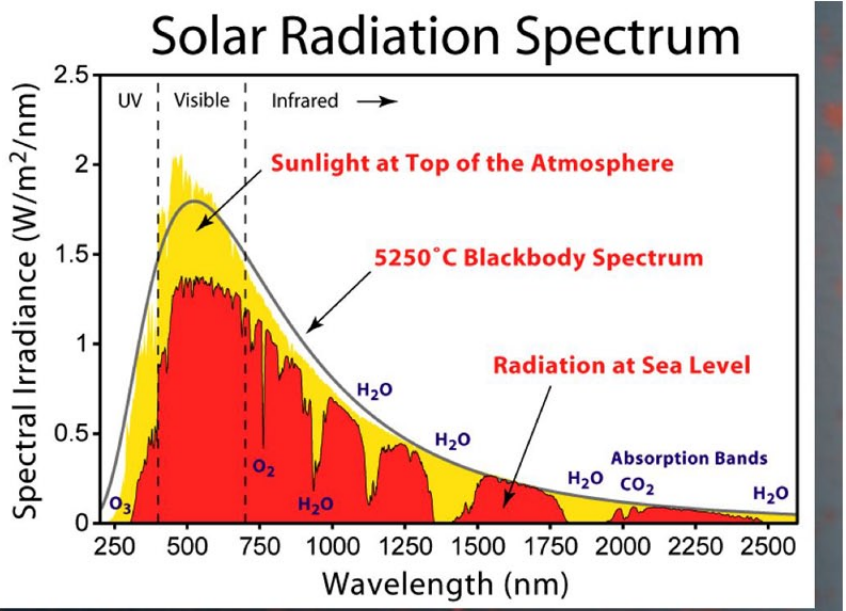

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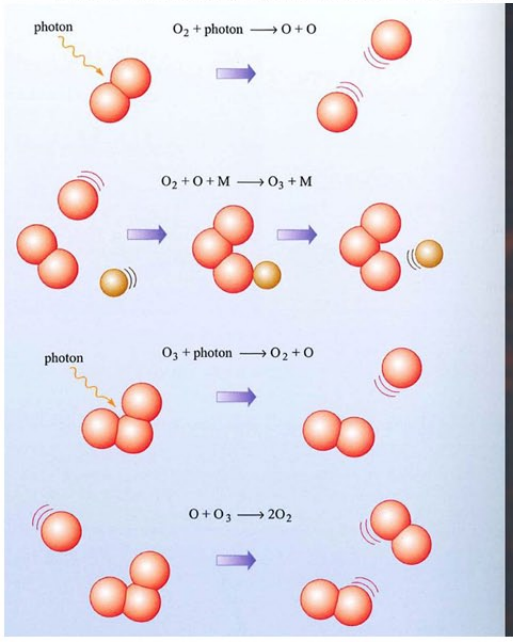

THE "CHAPMAN SCHEME"

- production of ozone (O_3) from oxygen (O_2) is balanced in the normal ozone layer

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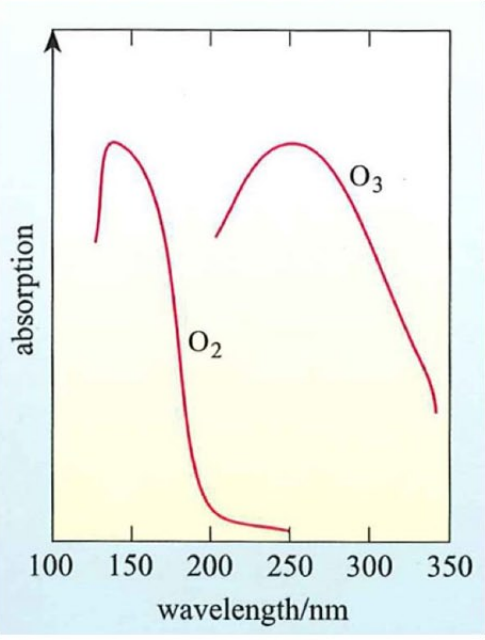

OXYGEN AND OZONE ABSORB UV LIGHT

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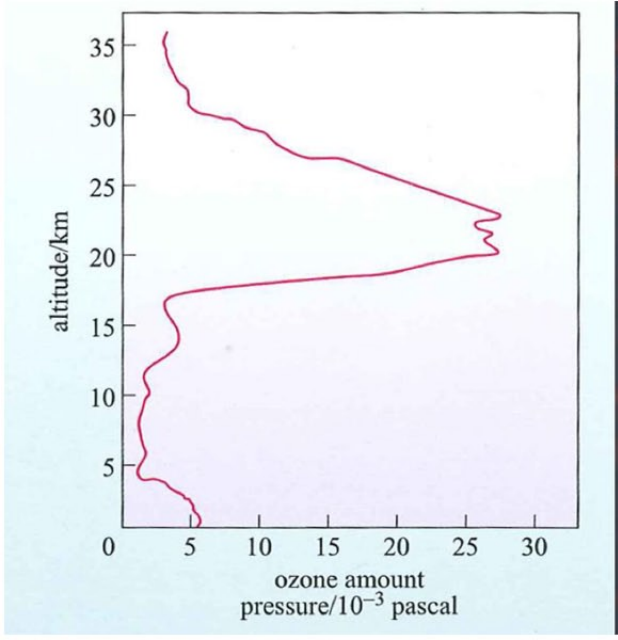
altitude/km
35
30
25
20
15
10
5
0
5
10
15
20
25
30
ozone amount
pressure/10^{-3} pascal


OZONE
LAYER
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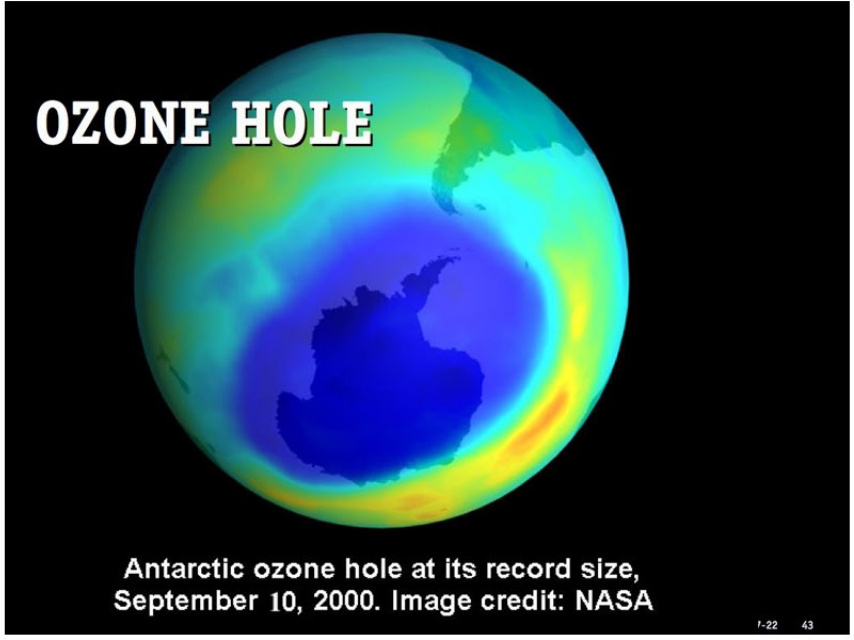
OZONE HOLE
Antarctic ozone hole at its record size,
September 10, 2000. Image credit: NASA
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