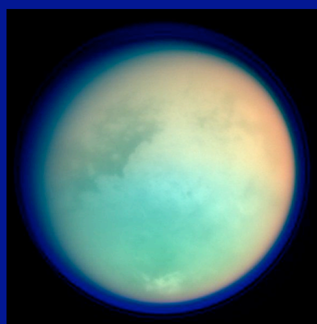
Atmospheres in the Solar System



From last time….

Whether a planet has an atmosphere or not depends on the relative magnitude of two speeds

- The speed at which molecules move around in the gas (thermal speed)
- The speed of escape from the planet (escape speed, depends on mass and radius of a planet)

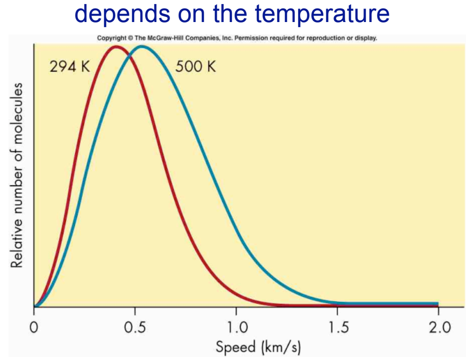
the gravitational escape speed from a planet

Result from Newton's theory of gravity. The escape speed is the speed necessary for a projectile to move an infinite distance from a planet. If the planet has mass M (kilograms) and radius R (meters), then the escape speed is

$$v_{esc} = \sqrt{\frac{2GM}{R}} \qquad (1)$$

where $G = 6.673 \times 10^{-11}$ (SI) units.
Work out the case for the Earth: $M = 5.97 \times 10^{24}$ kg, $R = 6378$ km $= 6.378 \times 10^{6}$ m, $v_{esc} = 11.2 \times 10^{3}$ m/sec $= 11.2$ km/sec.

The distribution of molecular speeds depends on the temperature



The higher the temperature of a gas, the faster its molecules (or atoms) move around, and the more momentum they impart to the walls surrounding them. This is the origin of pressure exerted by a gas

Demo last time, demo this time

the mean molecular speed in a gas

The average speed v_{av} of molecules in a gas is

$$v_{av} = \sqrt{\frac{8k_B T}{\pi m}} \qquad (2)$$

where k_B is a, the *Boltzmann constant*, $k_B = 1.38 \times 10^{-23}$ in SI units, T is the temperature in degrees Kelvin, and m is the mass of the molecule which makes up the gas.
The average temperature at the surface of the Earth is around 290K. The mass of molecule of oxygen (O_2) is 5.31×10^{-26} kg. Substituting these numbers into the equation for the average speed gives a value of 438 meters/sec, which is *much less* than the escape speed from the Earth. This explains why the Earth has been able to hold on to its oxygen atmosphere for 2 billion years.

It is obvious that to hold on to an atmosphere, escape speed > thermal speed, but

- It has to be the case that escape speed >> thermal speed
- Reason: when molecules in the "tail" disappear into space, the tail is "regenerated" (like a lizard)
- Atmosphere continues to lose particles, like a leak

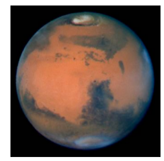
The criterion for hanging onto an atmosphere

- Depends on relative magnitude of escape speed and average molecular speed
- If molecular speed > about 1/6 of escape speed, atmosphere will "leak out" over a period of billions of years
- If molecular speed << 1/6 of escape speed, the planet should retain the atmosphere.

Above rule of thumb seems to roughly work (see Table 7.3), but there are some mysteries. Example: Mars and Titan

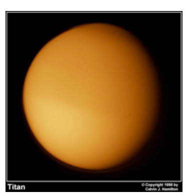
Can use equations above to calculate some numbers

Example 1: Mars



- Mass=0.103 Earth masses
- Radius=0.53 Earth radii
- Temperature at surface = 250K
- Molecule in atmosphere: Carbon Dioxide (44 atomic mass units)
- Escape speed=4.93 km/sec
- Thermal speed=0.346 km/sec
- Ratio=14.2

Example 2: Titan



- Mass=1.83 X mass of our Moon
- Diameter=5150km
- Temperature at surface=90K
- Molecule in atmosphere: nitrogen (28 atomic mass units)
- Escape speed=2.64 km/sec
- Thermal speed=0.260 km/sec
- Ratio=10.1

Why 28? Why not 14?

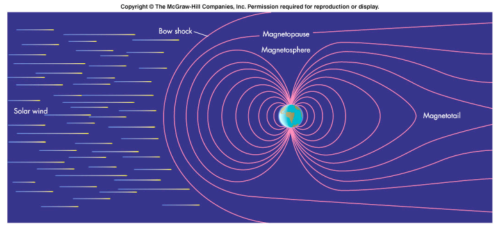
Based on this, you would expect…

- Mars and Titan to have similarly dense atmospheres, with Mars (maybe) in the lead.
- But, (as we have seen) Mars has a very tenuous atmosphere.
- As we will see, Titan has a very dense one, with pressure at the surface greater than that of Earth

What's going on?

- We don't know
- Maybe the atmosphere of Mars was "sandblasted" by the intense solar wind early in the history of the solar system (estimates that power in early solar wind 35X that at present)
- Maybe Titan has a huge, subsurface reservoir of frozen atmosphere that replaces that which leaks into space

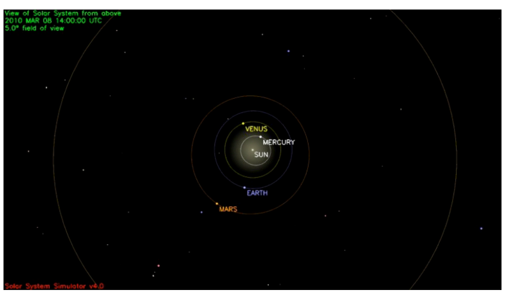
Why wasn't the Earth's atmosphere sandblasted too?



We are even closer to the Sun than Mars

The answer

Where we have been so far…the inner solar system and the **terrestrial planets**

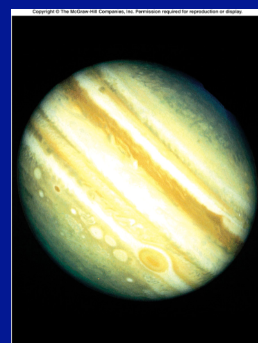


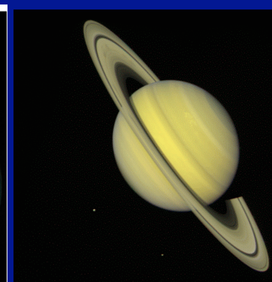
Now let's move out further in space…the outer solar system and the **Jovian planets**

What do Jupiter and Saturn look like?

- Jupiter is usually the brightest planet in the sky
- Saturn is always as bright as a “first magnitude” star
- Both are neat to look at in a small telescope

Our first look at Jupiter and Saturn





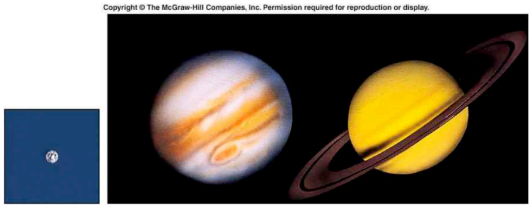
Question?

- Jupiter is almost always larger in angular size than Venus and Mars
- Right now, Venus and Mars have angular diameters of about 10 arcseconds, Jupiter is 33 arcseconds
- Saturn is about 19
- What does it mean?

Basic properties of Jupiter and Saturn

- Jupiter: 11.2 X diameter of Earth and 318 X mass
- Saturn: 9.5 X diameter of Earth and 95 X the mass
- Jupiter and Saturn: the “giant planets”
- Question: how do we know the masses of Jupiter and Saturn?

A visual comparison of Earth, Jupiter, and Saturn



Jupiter and Saturn are rapid rotators: 9.9 and 10.7 hours

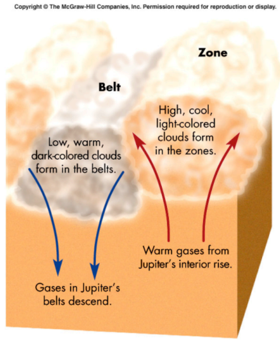
The Chemical Composition of Jupiter and Saturn

The densities of Jupiter and Saturn are about that of water (Jupiter is 1.33 grams/cc, Saturn is 0.69 grams/cc). Basic physics shows that objects with the mass, size, and density of Jupiter and Saturn must be made of very light elements. Specifically, they must be composed nearly completely of hydrogen and helium.

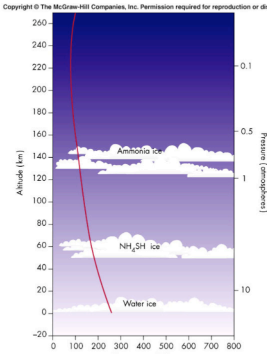
Although we reach this conclusion on the basis of theoretical physics, this conclusion is borne out by all observations. The spectrum of Jupiter shows absorption lines due to hydrogen-rich molecules such as ammonia (NH3), methane (CH4), and water, as well as others hydrocarbons such as acetylene, ethane, and propane. This chemical composition was also verified by the Galileo spacecraft probe, which descended into the atmosphere of Jupiter.

Read the quotation in the text about the fact that Jupiter and Saturn are nearly completely composed of hydrogen and helium. *In this, they have the same*

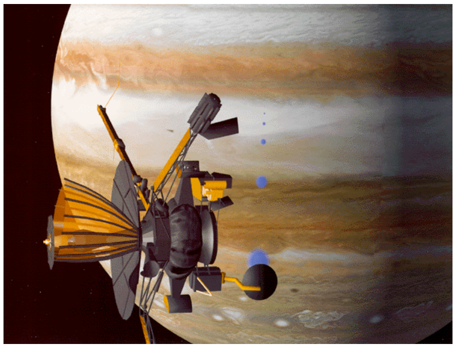
The cloud bands of Jupiter



The atmospheric structure of Jupiter



Exploration of Jupiter



The Galileo Probe