29:52 Exploration of the Solar System
Class Notes for April 4, 2008
Planetary Atmospheres

One of the most basis facts about the solar system to date is that some solar system objects have atmospheres and others do not. The Earth and Venus have dense atmospheres, Mars has a tenuous one, and Mercury and the Moon lack atmospheres. Fairly simple physics principals explain a lot of this.

The material covered in this lecture is contained in Section 7.2 of the textbook.

A Tale of Two Speeds

One can understand the retention of planetary atmospheres by comparing two speeds. The first is a property of the planet, and is the *escape speed*. The escape speed is the speed that any object must have if it is to move away to an infinite distance from an object. The formula that defines it is

$$v_{es} = \sqrt{\frac{GM}{R}} \tag{1}$$

where G is the gravitational constant ($G = 6.673 \times 10^{-11}$ in SI units) M is the mass of the planet (in kilograms) and R is the radius (meters) of the planet.

If we substitute values for the Earth in this equation ($M = 5.97 \times 10^{24}$ kg, $R = 6.378 \times 10^{6}$ meters), we get $v_{esc} = 11.2 \times 10^{3}$ meters/sec, or 11.2 km/sec. That is about 7 miles per second. If we put the values for the Moon, we get a much lower escape speed of 2.4 km/sec.

The Average Molecular Speed

Atoms or molecules in a gas move with a range of speeds. We call this the *Maxwellian Distribution* of molecular speeds. A plot of it is shown in Figure 7.2 of the book. The average speed v_{av} is given by

$$v_{av} = \sqrt{\frac{8k_BT}{\pi m}} \tag{2}$$

where k_B is Boltzmann's constant, another fundamental constant of physics ($k_B = 1.38 \times 10^{-23}$ in SI units) T is the gas temperature (in Kelvins) and m is the mass of the molecule (kilograms). The mass of an O_2 molecule is 5.31×10^{-26} kilograms. For a temperature of 290 K, i.e. room temperature and a typical temperature in the Earth's atmosphere, the average speed of an oxygen molecule is 438 meters/sec, or *much less* than the escape speed of the Earth. This explains why the Earth has held on to its oxygen for billions of years.

Note from Figure 7.2 that there are many molecules moving faster than the average molecular speed, so for a planet to hold on to an atmosphere over geological time periods, it is necessary (roughly) that the escape speed be at least 6 times the average molecular speed.

To tell whether a planet can retain an atmosphere, take the escape speed and divide by 6. This speed can then be compared with the average speed of any molecule. The values of $v_{esc}/6$ for different solar system objects are given in Table 7.3. One can see that Venus and the Earth have high values, Mars has a middle value, and the Moon and Mercury have low values.

Because of the mass dependence of the average speed, a planet can retain some gases (large masses) and be unable to retain lighter gases (smaller masses). Thus the Earth can retain molecular oxygen and nitrogen, and water vapor, but cannot retain hydrogen (a good thing).

Jupiter and Saturn

We are now going to start talking about planets in the outer solar system, much further from the Sun than Mercury, Venus, the Earth, and Mars. We will start with the important planets Jupiter and Saturn.

Look at the vital characteristics of these two planets in Tables 12.1 and 12.2. The first characteristics to note are their distances from the Sun. Jupiter has a semimajor axis of 5.2 astronmical units, and Saturn has a semimajor axis of 9.5 a.u. Kepler's 3rd Law then says that their orbital periods (periods of revolution) are 11.9 and 29.5 years, respectively.