

Chapter 11 Comparative Planetology

As we think about the planets in our solar system, it is worthwhile to compare and contrast their features. To do this, we will be dividing them into obvious big categories. As a start, we can deal with the Terrestrial Planets and our Moon, Jovian Planets, and Icy Moons.

Terrestrial Planets and Earth's Moon all have densities indicative of rock or rock and an iron core. They all have solid surfaces that have been at least partly resurfaced since the objects were formed. As we compare and contrast the surface features of these objects, it is useful to examine both what they have and why they might be the same or different'

	Earth	Moon	Mercury	Venus	Mars
Atmosphere					
Folded Mountains					
Magnetic Field					
Plate Tectonics					
Active Volcanoes					
Water (running?)					
Sedimentary layers					
Impact Craters					
Resurfaced after formation?					
Iron Core					
Valleys?					
Cause(s) of valleys					

As we compare the terrestrial planets, we think that all of them have experienced collisions and formed craters, but today they don't all have the same number of craters. Venus is partly protected against impact craters by its thick atmosphere, as is Earth to a lesser degree. Craters on Venus, Mercury and the Earth are covered over by lava flows and on the Earth are eroded by the wind and weather. Some parts of Mars are covered with loose soil, so we don't know anything about what might be below.

We think that all these terrestrial bodies started out hot, both from impacts releasing kinetic energy and from radioactive decay. Their own gravity compresses them and heats them further. Early in the histories of these planets, the heat was sufficient to melt each of these objects and allow its densest materials to sink to the center. As time goes on, heat from the planets' interiors works its way out. Radioactive decay continues, but the overall rate of energy released decreases as radioactive nuclei decay into stable ones. Small objects like the Moon, asteroids and possibly Mars have had enough time to solidify all the way through. Once the object has completely solidified, we do not expect to see volcanic events or new folded mountains. You might call these cooled off bodies "dead". Earth and Venus are so large that their interiors are still molten.

Some terrestrial objects have atmospheres. We are not sure about the source of gas for these atmospheres. Some elements, like hydrogen and oxygen, can come both from within the refractory original materials and from impacts by icy bodies like comets. Even when no crater is formed, the materials from small meteors and comets can be accreted and incorporated into the mass associated with the planet or moon. As you read this, there are many tiny meteors hitting the Earth. They are stopped by our atmosphere, but they bring us material without leaving any crater.

Even if all the terrestrial objects once had atmospheres, they don't all have gas today. Whether an object can hold onto an atmosphere depends on whether the individual atoms or molecules of gas reach escape velocity. Escape velocity comes from the same formula you have already

learned, $V_{\text{escape}} = \sqrt{\frac{2G(m_1 + m_2)}{r}}$. Here one of the masses is the mass of the planet, and the other is the mass of the atom or molecule. The distance is the distance from the center of the planet or moon to the molecule. The mass of the molecule is definitely negligible compared to the mass of the planet. But the mass of the atom or molecule matters a lot determining whether it will HAVE the velocity escape.

Temperature measures the energy of random motion of free particles, like those in an atmosphere. The higher the temperature, the higher the average kinetic energy, but all different types of motion have the same average kinetic energy.

As you have learned, kinetic energy is given by the formula $KE = \frac{1}{2}mv^2$. Since the average kinetic energy of motion for every molecule is the same, the more massive molecules have smaller velocities. The less massive ones move faster.

Which is the most massive molecule N_2 , CO_2 , H_2O , or O_2 ? To decide, you add up the masses of the atoms (one unit for each proton or neutron) in the molecule. For CO_2 you would have one carbon atom at 12 units, and 2 oxygen atoms at 16 units each. That is a total of 44 units, making it the most massive of these molecules. Since CO_2 is the most massive, it will usually have the lowest velocity and be less likely to escape. Water vapor has mass only 18 units, so it would have a higher velocity than the other molecules and be more likely to escape. The average velocity does not need to exceed escape velocity for a gas to escape eventually. Some of the molecules have higher than average velocity and others lower. The highest velocity molecules can escape even if the average velocity molecules cannot.

Mercury, the Moon, and Mars have small masses and have the least success retaining atmospheres. Mars, being the most massive and the coldest, has retained some of its atmosphere. The Moon and Mercury have nearly nothing.

In the case of Earth and Venus, both have extensive atmospheres, but Venus has over 90 times as much total gas as the Earth. How did this come to be?

We think that the terrestrial planets started with some hydrogen and helium from the solar nebula. Some of these gasses would have been attracted as the planets formed. But both hydrogen and helium are very light molecules and largely escape.

Volcanoes on Venus, Earth and Mars probably create secondary atmospheres. Based on current measurements, volcanoes expel water vapor (mostly) and carbon dioxide, as well as melted rock. These eruptions lead to atmospheres with lots of water vapor and some carbon dioxide.

Venus' high temperature probably caused water vapor to rise to the top of the atmosphere where the molecules were broken up by ultraviolet light from the Sun. The hydrogen atoms could easily escape at the high temperatures in Venus' atmosphere. Venus' atmosphere may still have the bulk of the carbon dioxide that has ever been expelled by its volcanoes.

As we know, water can exist as solid, liquid or gas on Earth's surface. The large amounts of water vapor from volcanoes condensed to form oceans early in our history. Much of the carbon dioxide dissolved in the oceans and some of the carbon was used to make seashells. The carbon in the shells didn't necessarily return to the atmosphere. The shells get compacted to limestone and removed from the atmosphere. In some cases plate tectonics drag the limestone (with its carbon) back into Earth's interior. Estimates of the total amount of gas above that has EVER been part of Earth's atmosphere indicate amounts comparable to the amount that Venus has.

We think that the Oxygen molecules in Earth's atmosphere are at least partly the result of life. Oxygen molecules (O_2) react readily. If it were not always being renewed by plants and bacteria,

we expect that the oxygen would react with the surface and would no longer be present in the atmosphere.

The mass of Mars is only about 11% as large as Earth's and its radius is about half as large. Combining these effects, the escape velocity leads to an escape velocity only about 47% as large as on the Earth. The lower temperature at Mars' distance helps it to retain some of its atmosphere.

Jovian planets are distinguished by the predominance of gases and volatiles in their makeup. Starting with Jupiter and progressing to Neptune, they progress from Jupiter with nearly solar abundances of the elements to Neptune with decreasing percentages of hydrogen and increasing percentages of rock and ice.

As we go further out in the solar system from Jupiter's distance, the total amount of material in the original gas cloud seems to have decreased, resulting in less massive planets. Due to the lower total masses, highly compressed forms, like metallic hydrogen are not found in Uranus and Neptune.

All of the Jovian planets except Uranus have substantial amounts of internal energy. Jupiter, for example, produces nearly twice as much energy from its hot interior as comes from the Sun. We expect that Jovian planets will all have internal heating due to gravitational compression. Why Uranus does not show more heating is the open question. (There probably isn't a large enough percentage of radioactive materials in the cores of these planets to cause substantial heating),

Icy moons of Saturn and Uranus seem to form a family of icy-rocky bodies. This family may include some of the smaller moons of Jupiter and of Neptune, but we do not yet have enough information about their surfaces or compositions. The family certainly includes Mimas, Enceladus, Tethys, Hyperion, Ariel, Umbriel, Titania and Oberon. It probably includes Rhea, Dione, and Iapetus.

These moons show varying numbers of impact craters on surfaces largely composed of ice. The surfaces typically have parts with few craters. These are probably places where the surface has been cleaned up by out flowing water. They typically have areas that look like cracks or riverbeds. Probably their surfaces have cracked open and allowed water to flow out, covering over the earlier craters. These moons are probably not hot enough to melt rock and cause volcanic flows with magma. Since the water stands in lieu of the melted rock, these processes are often called icy vulcanism.

All of these icy-rocky moons have densities between 1 and 2 g/cm³, indicating that there is a large percentage of ice. Other moons, like Ganymede and Callisto probably have a larger percentage rock than do some of the moons that are more distant from the Sun. Miranda shows signs of icy vulcanism, but the surface includes such different large landforms, that there is more going on than on other moons.

Questions (Read the textbook and come to lecture. Fill in the table at the start of the chapter to solidify your knowledge, then try the questions)

- 1) You want to visit a moon where you can see craters more than 4 billion years old. Where could you go? (There are lots of possibilities, see how many you can name)
- 2) What causes planets to have (ever) melted and allowed the denser materials to fall to the center?
- 3) What objects have atmospheres? Why don't all objects have them?
- 4) Where should you look for active volcanoes?
- 5) Aren't all planets and moons made of the same elements? If that is so, what causes some objects to have active volcanoes and others to have none?
- 6) Are all the Jovian planets the same except for mass? If not, what is different?