

# OpenStax Astronomy, Ch.10: WS Solutions (Apr-2021)

## Solutions

1. List several ways that Venus, Earth, and Mars are similar, and several ways they are different.

Venus, Earth, and Mars are similar in that they consist of rock and metal for the most part; they are terrestrial planets, closer in to the Sun than the jovian planets; all have atmospheres (although they are of different constituents and with different pressures); all have volcanic activity on their surfaces; and all have or have had some kind of greenhouse effect change their surface temperatures. The three planets are different in many ways, among them: their size (Mars is significantly smaller); their atmospheres (Mars and Venus is dominated by CO<sub>2</sub>, while Earth's is dominated by nitrogen (and has a significant amount of oxygen)); the presence or absence of liquid water on their surfaces today; the major way that their surfaces undergo large-scale changes (plate tectonics on Earth, blob tectonics on Venus, impacts and wind action on Mars); whether they are now or have been in the past suitable for life.

2. Compare the current atmospheres of Earth, Venus, and Mars in terms of composition, thickness (and pressure at the surface), and the greenhouse effect.

Earth's atmosphere is about 4/5 nitrogen and 1/5 oxygen; Venus' atmosphere is mostly carbon dioxide, with a pressure about 90 times higher than Earth; Mars' atmosphere is also mostly carbon dioxide, with a pressure only about one hundredth that of Earth. Venus has had an ongoing runaway greenhouse effect, leading to extraordinarily high surface temperatures. Earth is presently seeing the greenhouse effect increase with higher levels of carbon dioxide in the atmosphere. Mars has had a "runaway refrigerator" effect leading to a thinner atmosphere and colder temperatures over time.

3. How might Venus' atmosphere have evolved to its present state through a runaway greenhouse effect?

There may have been carbon dioxide in the Venus atmosphere to begin with. But however large that initial supply was, heat from the Sun could have evaporated water from the surface of Venus, releasing carbon dioxide absorbed in the water. The carbon dioxide in the atmosphere prevented infrared radiation from escaping the planet, leading to a rise in temperatures and further loss of water and release of carbon dioxide. Sunlight would break up water vapor molecules higher in the atmosphere into hydrogen, which escaped the planet, and oxygen, which combined with surface rocks. The loss of water reduces the planet's ability to absorb carbon dioxide.

4. Describe the current atmosphere on Mars. What evidence suggests that it must have been different in the past?

The martian atmosphere consists mostly of carbon dioxide, but is very thin, less than 1% of Earth's atmosphere. However, the strong evidence of water on Mars in the past that our missions have found means that the atmosphere must have been thicker and warmer, or water would have evaporated away very quickly.

5. Explain the runaway refrigerator effect and the role it may have played in the evolution of Mars.

Martian gravity is not strong enough to hold a gaseous atmosphere over a long period of time, so the atmosphere would have gotten thinner as gas escaped. This would



lead to lower temperatures, and more gas would have frozen and deposited out of the atmosphere, lowering temperatures still further. The thinner atmosphere and colder temperatures would lead to the loss of most water from the planet, except for water ice, permafrost ground deposits, and perhaps underground saltwater.



6. What evidence do we have that there was running (liquid) water on Mars in the past? What evidence is there for water coming out of the ground even today?

Images from orbiting spacecraft of runoff channels and outflow channels all show evidence of formation by running water. Several dry basins contain minerals that only form with water and indicate extensive lakes in the past. In 2015, some dark streaks (recurring slope lineae or “gullies”) that got longer over the course of several days showed spectra of hydrated salts, and may be evidence of saltwater on Mars today.

7. What evidence is there that Venus was volcanically active about 300–600 million years ago?

While small impactors burn up in Venus’ thick atmosphere, larger chunks from space make craters on Venus’ surface, as they do on other worlds. Do counts of larger craters on Venus can be compared to counts of such craters elsewhere in the solar system. Such crater counts on Venus show that its surface is about 300–600 million years old. Nothing older appears on the venusian surface. The implication is that the surface consists of lava flows from that time that covered older surface features, showing only more recent ones.

8. Why is Mars red?

Winds on Mars are strong enough to blow surface dust all over the planet. This dust contain iron oxide, which gives it the rusty red color.

9. What is the composition of clouds on Mars?

Clouds on Mars are of three types: dust clouds; water-ice, like those on Earth; and clouds of frozen carbon dioxide crystals (dry ice).

10. What is the composition of the polar caps on Mars?

Seasonal ice caps are made up of dry ice, or crystals of frozen carbon dioxide; the northern residual cap is water ice, whereas the southern permanent ice cap is made predominantly of water ice with a covering of carbon dioxide ice.

11. Describe two anomalous features of the rotation of Venus and what might account for them.

Venus has retrograde rotation about its axis, opposite to the direction of spin of most other planets; also, its rotational period is longer than any other planet’s. It is in fact longer than its orbital period, so its day is longer than its year. Astronomers think Venus suffered a collision with another large body during the formation period of the solar system, changing its rotational motion in both these ways.

12. How was the *Mars Odyssey* spacecraft able to detect water on Mars without landing on it?

*Odyssey* used a gamma-ray spectrometer to detect hydrogen below the martian surface. Analysis of the signals indicated that the hydrogen was probably from water molecules in ice frozen below the surface.

13. Venus and Earth are nearly the same size and distance from the Sun. What are the main differences in the geology of the two planets? What might be some of the reasons for these differences?

Venus and Earth are similar in having geology driven by mantle convection currents, which have brought hot lava near the surface and generate volcanic eruptions. These convection currents also placed stress on the crust and produced widespread tectonic features on both planets. Both have mountains, mountain ranges, and valleys.



However, Venus also has unique features such as the coronae, and Earth has unique features such as the deep ocean trenches. Like Earth's surface, the surface of Venus is relatively young by solar system standards, less than a billion years. However, the geology of Earth is dominated by plate tectonics, whereas there is no indication of plate motions on Venus. Instead, Venus has "blob tectonics," where the rising of hot material from within plays a dominant role in sculpting its surface. In addition to the absence of plate tectonics, Venus is also different from Earth in having a much lower level of erosion, presumably because there is no precipitation and surface wind speeds are very low.

14. Why is there so much more carbon dioxide in the atmosphere of Venus than in that of Earth? Why so much more carbon dioxide than on Mars?

On Earth, much of the carbon dioxide originally in the atmosphere dissolved in the ocean water and is now found in sea sediments. Venus has no such sink for its carbon dioxide. Mars is smaller than Earth and Venus, and so the escape velocity for carbon dioxide on Mars is smaller than on Venus, both now and in the past.

15. Is it likely that life ever existed on either Venus or Mars? Justify your answer in each case.

Venus is too hot and dry for life, and there is no evidence that it once had a more comfortable climate. Mars, in contrast, is known to have had a wetter, warmer surface between 3 and 4 billion years ago. At just the time life was forming on Earth, the conditions on Mars were apparently rather similar to those on our own planet. Thus, it is widely speculated that Mars may have developed an independent life at that time, although the issue of whether any of that life survived to the present is much more problematic. There is also the interesting possibility that Mars and Earth have exchanged biological materials over their history, and thus that Mars could have been seeded with terrestrial life, or that Earth has been the recipient of martian microbes.

16. We believe that Venus, Earth, and Mars all started with a significant supply of water. Explain where that water is now for each planet.

On Earth, the water is still in the oceans and ice fields. Mars, which has significantly less gravity than Earth or Venus, gradually lost much of its original atmosphere. As the pressure decreased, liquid water could no longer remain liquid and either froze as temperatures dropped or evaporated. In the upper atmosphere, with no ozone layer, ultraviolet radiation from the Sun tore apart the molecular bonds of H<sub>2</sub>O and the lighter hydrogen was lost to space. The water that was left is frozen, in the polar caps, and (mostly) deeply buried in permafrost. On Venus, which began hotter since it was closer to the Sun and got hotter because of the greenhouse effect, water quickly became water vapor. This was lost into space when ultra-violet broke the water into H and O and lighter elements escaped from the top of the atmosphere.

17. One source of information about Mars has been the analysis of meteorites from Mars. Since no samples from Mars have ever been returned to Earth from any of the missions we sent there, how do we know these meteorites are from Mars? What information have they revealed about Mars?

Gas trapped in bubbles in the meteorites matches what we know of the martian atmosphere. Most of the martian meteorites are volcanic basalts; most of them are also relatively young—about 1.3 billion years old. We know from details of their composition that they are not from Earth or the Moon. There was no volcanic activity on the Moon to form them as recently as 1.3 billion years ago. It would be very



difficult for ejecta from impacts on Venus to escape through its thick atmosphere. By the process of elimination, the only reasonable origin seems to be Mars, where the Tharsis volcanoes were active at that time.

18. Near the martian equator, temperatures at the same spot can vary from an average of  $-135\text{ }^{\circ}\text{C}$  at night to an average of  $30\text{ }^{\circ}\text{C}$  during the day. How can you explain such a wide difference in temperature compared to that on Earth?

The thin martian atmosphere does not shield the surface from sunlight during the day and does not retain heat to keep the surface warm at night. Therefore, the surface is exposed to extreme temperatures relative to those on Earth.

19. At its nearest, Venus comes within about 41 million km of Earth. How distant is it at its farthest?

Venus and Earth have a semimajor axis of 108.2 and 149.2 million km from the Sun, respectively. When Venus is at inferior conjunction, which means that Venus is between Earth and the Sun, this is when Venus is nearest to Earth at a distance of  $149.2 \text{ million km} - 108.2 \text{ million km} = 41.4 \text{ million km}$  (or about 41 million km as already noted). When Venus is at superior conjunction, which means that the Sun is between Earth and Venus, this is when Venus is farthest from Earth at a distance of  $149.2 \text{ million km} + 108.2 \text{ million km} = 257.8 \text{ million km}$  (so about 258 million km).

