

b) What kind of geologic structure is this? What are the features labeled A and B?

This is an impact crater, judging by the fact that it is very nearly circular, and has a central peak (feature A) and rayed ejecta blanket (feature B).

3. [6 Points] Escape from Venus.

a. Calculate the escape velocity from the top of Venus's atmosphere (about 200km above the surface).

$$\begin{aligned}V_{esc} &= \sqrt{2GM/R} = \sqrt{2GM/(R_p + h)} \\&= \sqrt{2(6.67 \times 10^{-11} \text{ m}^3/\text{kg/s}^2)(4.87 \times 10^{24} \text{ kg}) / (6.051 \times 10^6 \text{ m} + 2 \times 10^5 \text{ m})} \\&= \mathbf{10,200 \text{ m/s} = 10.2 \text{ km/s}}\end{aligned}$$

b. Calculate and compare the *most probable* thermal velocities of hydrogen and deuterium atoms at Venus's exospheric temperature of 350 K [Hint: look at Mathematical Insight 10.2]. The mass of a hydrogen atom is 1.67×10^{-27} kg, and the mass of a deuterium atom is about twice the mass of a hydrogen atom.

$$\begin{aligned}\text{Hydrogen: } V_{thermal} &= \sqrt{2kT/m} = \sqrt{2(1.38 \times 10^{-23} \text{ J/K})(350 \text{ K}) / (1.67 \times 10^{-27} \text{ kg})} \\&= \mathbf{2,410 \text{ m/s} = 2.41 \text{ km/s}}\end{aligned}$$

$$\begin{aligned}\text{Deuterium: } V_{thermal} &= \sqrt{2kT/m} = \sqrt{2(1.38 \times 10^{-23} \text{ J/K})(350 \text{ K}) / (2 * 1.67 \times 10^{-27} \text{ kg})} \\&= \mathbf{1,700 \text{ m/s} = 1.70 \text{ km/s}}\end{aligned}$$

c. Would you expect *any* of the atoms in Venus's atmosphere to escape? What do these calculations tell us about whether Venus has lost large quantities of water? [Hint: the fraction of deuterium atoms to hydrogen atoms in Venus's atmosphere today is about 100 times higher than on Earth]

*If the thermal velocity of a particular type of particle is more than a few percent of the escape velocity—i.e., more than a few hundred meters per second, for an escape velocity of ~10 km/s—then we would expect significant loss of that species over time (as described on page 315 of your text). In Venus' atmosphere, both hydrogen and deuterium satisfy this condition, according to the results of 3b. Thus, both species should have suffered significant loss due to thermal escape. Furthermore, $V_{thermal}$ for hydrogen is greater than 20% of the escape velocity ($0.20 * 10.2 \text{ km/s} = 2.04 \text{ km/s}$), which means that virtually all hydrogen should have been lost via thermal escape after a few billion years, whereas $V_{thermal}$ for deuterium is less than 20% of V_{esc} , which explains why more deuterium has survived to the present day. Much of the hydrogen lost by Venus throughout its history was likely originally present in water molecules.*

4. [1 Point] Why is the surface of Mars red?

The martian surface is red because of the high abundance of oxidized (“rusted”) iron-bearing minerals on the surface.

5. [2 Points] List 3 conditions necessary for a planet to have a magnetic field. Why does Venus not have a magnetic field?

To have a global magnetic field, a planet needs:

- 1) An electrically conducting fluid in its interior—often an iron-rich core, but in principle this could be another liquid or gas.*
- 2) Convection in that fluid*
- 3) Fairly rapid rotation of that fluid*

Although Venus probably has a molten core layer analogous to that of Earth (thus satisfying condition (1)), Venus is rotating quite slowly, with a 243-day rotation period, which is probably too slow to satisfy condition (3). We do not know whether condition (2) is satisfied on Venus.

6. [3 Points] The book mentions the *Venus Express* mission which reached Venus in 2006. What is the current status of the mission? Mention some aims of the mission, what it plans to study, and whether it has made any major discoveries. [Hint: You can search for news stories about *Venus Express* on the internet, but make sure to put your answer in your own words]

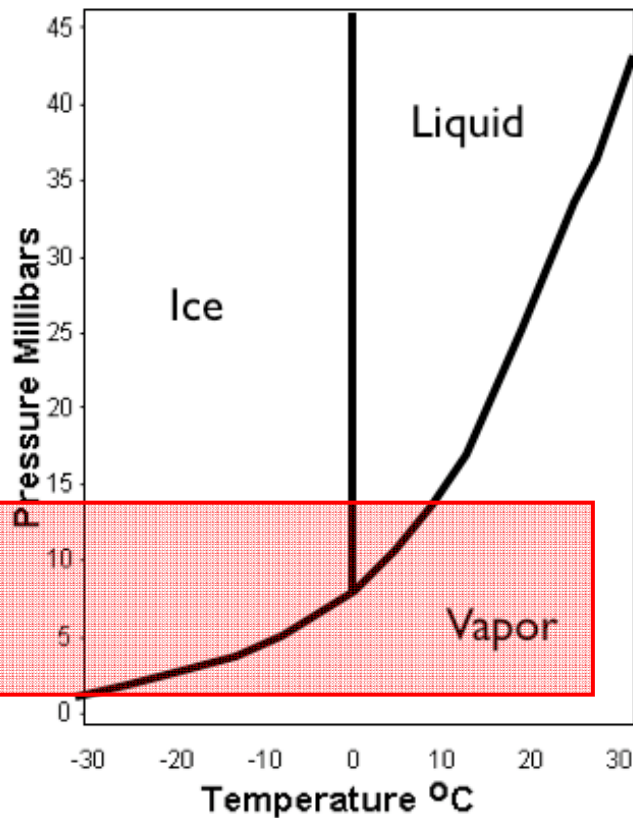
Venus Express is a European Space Agency (ESA) mission; its website is: <http://sci.esa.int/venusexpress/>

As the above site describes, Venus Express is currently nearly six months into its “Extended Mission” at Venus, having successfully completed its “Nominal Mission” of 500 Earth days in its current orbit around Venus. The spacecraft orbits Venus every 24 hours, a period selected for the convenience of the spacecraft operators on Earth!

Unlike NASA’s Magellan mission, which mapped 98% of the surface of Venus using RADAR sounding, Venus Express carries no RADAR instruments; rather, its objectives center around developing a better understanding of the venusian atmosphere. Specific mission goals include understanding the super-rotation of Venus’ upper atmosphere, as well as the general circulation, composition, and chemistry of the atmosphere, including the role played by what little water is there, and how the greenhouse effect has affected the planet throughout its history. With an instrument (VIRTIS) that detects infrared radiation, Venus Express may also be able to measure hot spots on the planet’s surface due to ongoing volcanic activity, if there is any.

No evidence for active volcanism has been seen to date, but Venus Express has detected strong evidence for lightning in the venusian atmosphere, which seems to occur approximately as often there as it does on Earth. Venus Express has also determined the global atmospheric circulation at a wide range of latitudes and heights within the atmosphere, including spectacular “double vortex” formations above the north and south poles. Finally, by measuring the current rate of escape of ions including hydrogen and oxygen, and also detecting deuterium-bearing “heavy water” in the upper atmosphere, Venus Express has provided new constraints on how abundant water may once have been on Venus early in the planet’s history. These and other scientific results were reported in a special section of the journal Nature (Vol. 450, pp. 629-662).

7. [3 Points] Below is a phase diagram for water (a plot that shows the temperature and pressure ranges where water is stable as a liquid, solid, and gas). Show where the range of Mars's surface temperatures and pressures lies on this diagram. What can you conclude about the stability of liquid water on Mars today?



At midday during summer in the southern hemisphere on Mars, surface temperatures reach as high as 300 K (27 °C) at some locations (M. Carr, 2006; The Surface of Mars, Cambridge Univ. Press). But during winter at the poles, the surface can get down to 150 K (-123 °C), at which point CO₂ freezes out of the atmosphere. Total atmospheric pressure ranges from 0.7 mbar at the summit of Olympus Mons, to 14 mbar at the bottom of the Hellas impact basin (Carr, 2006).

For most of the year, and across most of the surface of Mars, temperatures never exceed 0 °C; even when they do, much of the martian surface has an atmospheric pressure less than 6.1 mbar, the minimum value for liquid water to be stable even transiently. In the few places where both the temperature and pressure are occasionally high enough for liquid water to be stable, it will still evaporate rapidly due to the low partial pressure of water vapor in the atmosphere on Mars. In short, liquid water cannot exist stably for any significant period of time anywhere on Mars today.