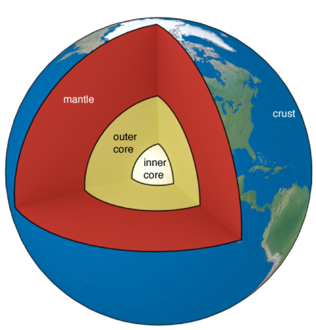
Inner Solar System

1. The Earth

1.1 Earth Structure



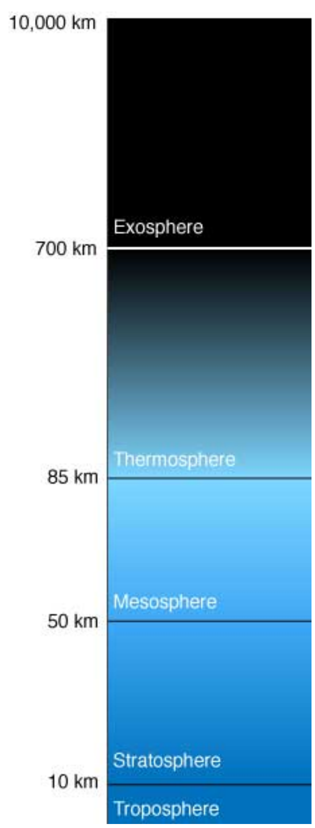
A schematic drawing of the major sections inside the earth

Region	Thickness	Constituents
Inner core	1300 km	Solid Iron & Nickel
Outer core	2250 km	Liquid Iron & Nickel
Mantle	2900 km	Rocky (heavy elements)
Crust	8-40 km	Rocky (lighter elements)
Atmosphere	16 - 480 km	Gasses

Deepest Hole: 12km. Kola Superdeep Borehole

1.2 Earth Atmosphere

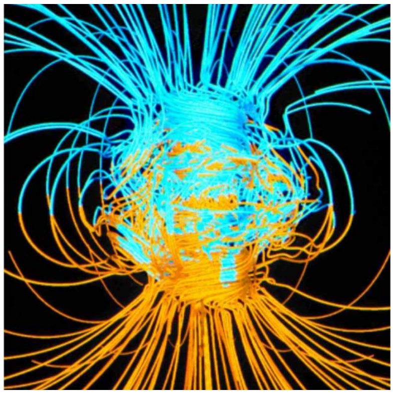
Fraction (by mass)	Fraction (by number)	Species
75.5 %	78.1 %	N_2
23.1 %	20.9 %	O_2
1.3 %	0.93 %	Ar
0.05 %	0.04 %	CO_2
trace	trace	Ne, He, CH_4, Neon, He, Methane, Krypton



The Atmosphere of the Earth

1.3 Earth Magnetosphere

Origins of the Magnetosphere



Simulation of the geo-dynamo fields

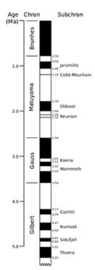
Contemporary Physics, 1997, **38** 4, Glatzmaier, G. and Roberts, P. http://dx.doi.org/10.1080/001075197182351

The Dynamo Theory: Moving charges.

1. Why is the Earth magnetic?
2. Why has its magnetic field existed over at least 70% of geological time?
3. Why is it predominantly dipolar?
4. What determines its strength?
5. Why does its strength vary, but by so little?
6. Why does the magnetic compass needle point approximately North?
7. Why does the averaged geomagnetic axis coincide with the geographical axis?
8. Why does the polarity of the Earth's field reverse?
9. What happens to the geomagnetic field during a reversal and why?
10. Why does the frequency of reversals vary so greatly over geological time?
11. Why is neither polarity of field favored over the other?
12. What causes the slow secular change of the field?
13. What is the significance of the westward drift?
14. Can a single mechanism explain why other planets and satellites are magnetic too?

Convective Motions + Coriolis forces cause motion of charges within the molten outer core.

The Earth's Magnetic field



Magnetic field flips

USGS

Strength: 25 to 65 microteslas (0.25 to 0.65 gauss).

The north magnetic pole is in Greenland

It flips sometimes. (Last time was about 780,000 years ago.)

What does it do?

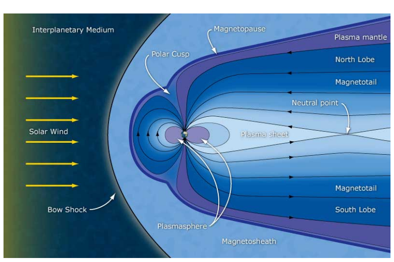
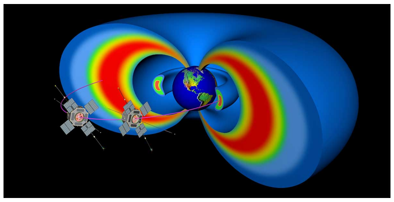


Illustration of Earth's magnetic field

ESA/C. T. Russel

Van Allen Radiation Belts



Van Allen Probes

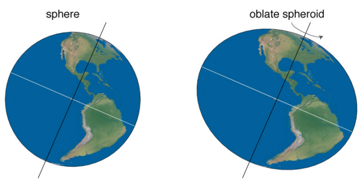
Johns Hopkins University Applied Physics Laboratory

The radiation belts are two donut-shaped regions of high-energy particles, mainly protons and electrons, trapped by the magnetic field of the Earth. These belts are often referred to as "The Van Allen Belts" because they were discovered by James Van Allen and his team at the University of Iowa. This scientific discovery was a first for the space-age.

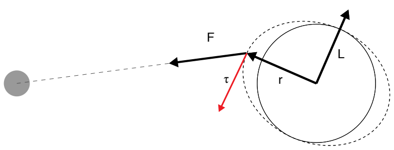
The inner belt reaches from 1000 km to 6000 km. It is comprised of high concentrations of electrons in the range of hundreds of keV and energetic protons with energies exceeding 100 MeV,

The outer belt goes from 13,000 to 60000 km. Mostly contains high energy (0.1–10 MeV) electrons

1.4 Earth's shape

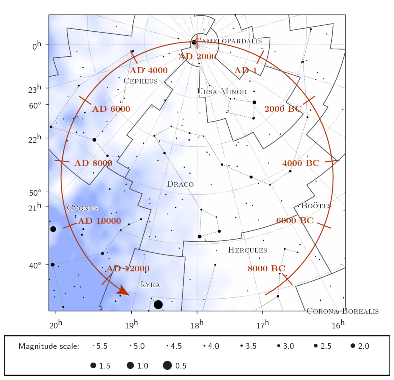


Precession



The spheroid allows for a torque, which leads to a precession.

Precession



The North Celestial Pole

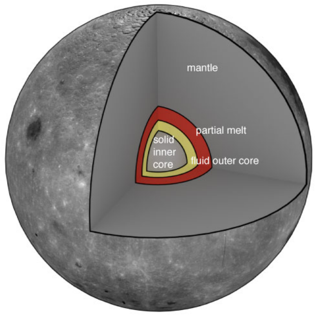
https://in-the-sky.org/article.php?term=precession_of_the_equinoxes

The North Pole Star changes! Just very slowly.

2. The Moon

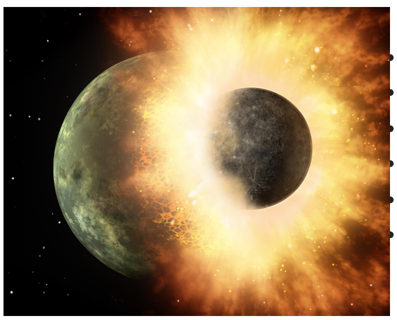
2.5 Moon Structure

Recent results have challenged the previous views. Seismic Detection of the Lunar Core



Lunar internal structure

2.6 Formation



Giant-impact hypothesis

- Earth's spin and moon's orbit have similar orientations
- Moon samples indicate that the Moon's surface was once molten.
- The Moon has a relatively small iron core.
- The Moon has a lower density than Earth.
- Evidence exists of similar collisions in other star systems (that result in debris disks).
- The stable-isotope ratios of lunar and terrestrial rock are identical, implying a common origin.

Moon Formation

By NASA/JPL-Caltech -
http://www.nasa.gov/multimedia/imagegallery/image_feature_1454.html,
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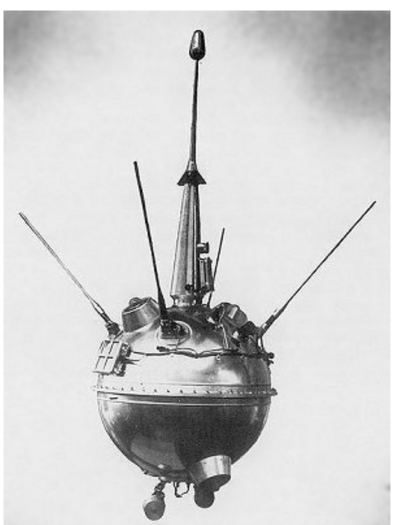
curid=8626942

2.7 Explorations

First Touch



Luna 2: Soviet Moon Probe, September 12, 1959

By NASA - http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1959-014A, Public Domain, https://commons.wikimedia.org/w/index.php?curid=16509292

2.8 Apollo Program

On the lunar surface

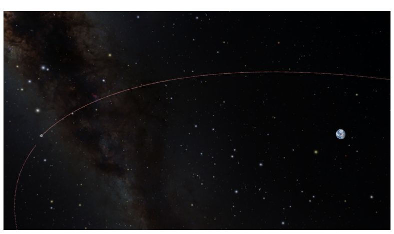
NASA: flickr album

- 1961 to 1972
- First manned flight: 1968
- First landing: Apollo 11, July 1969
- Last landing: Apollo 17, Dec 1972
- Missions brought back 842 lbs of rocks
- Left several science experiments
- Installed Retro-Reflectors

1969 events

1. Vietnam War
2. Mets win WS
3. Jet's win SB
4. Stonewall riots
5. Woodstock
6. Bread: $0.23
7. Minimum Wage: $1.60 per hour

3. Earth Moon System

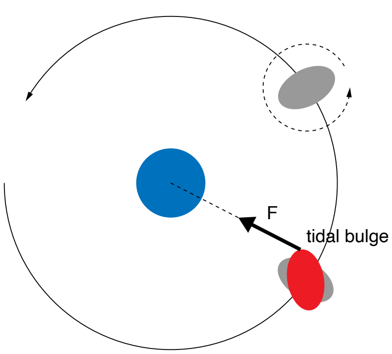


Scale Image of Earth and Moon

3.9 Tides

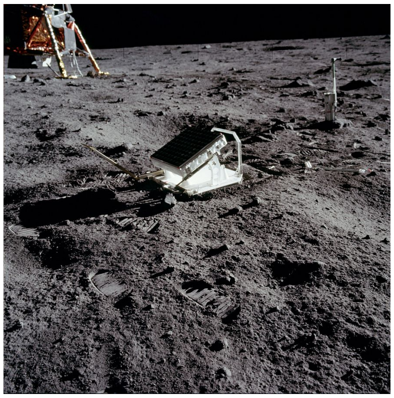
Tidal Forces Sim

3.10 Tidal Locking



A torque will arise if the two angular velocities are different, due to the tidal bulge.

3.11 Moon is leaving

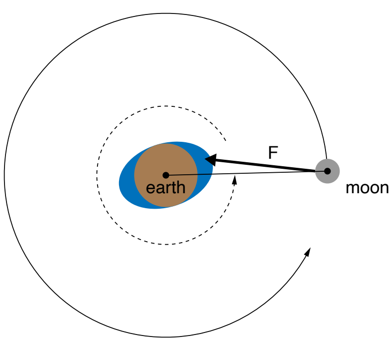


3.8 cm/year

Lunar Laser Ranging Experiment with the stereo camera in the background (NASA image number AS11-40-5952). This Retroreflector was left on the Moon by astronauts on the Apollo 11 mission. Astronomers all over the world have reflected laser light off the reflectors to measure precisely the Earth-Moon distance.

NASA
https://www.hq.nasa.gov/office/pao/History/alsj/a11/AS11-40-5952.jpg

Tidal Braking



Tidal Braking

Over time, the tidal bulge will create a counter-torque to the rotation. This will cause the central object to rotate just a little bit slower. We can measure this:

$$\frac{dP_{\text{rot}}}{dt} = 0.0016 \text{ s/ century} \tag{1}$$

But this implies a change in L! Where does it go?

Let's start with the angular momentum L of the moon in orbit around the earth. It depends on the mass of the moon, its speed and its distance from the center of rotation.

$$L_{\text{orbit}} = M_{\text{moon}} v r = M_{\text{moon}} \left(\frac{GM_{\text{E}}}{r}\right)^{(1/2)} r = \left(GM_{\text{E}} M_{\text{moon}}^2 r\right)^{(1/2)} \tag{2}$$

Consider the change in angular momentum as a function of time:

$$\frac{dL_{\text{orbit}}}{dt} = \left(GM_{\text{E}}M_{\text{moon}}^2\right)^{(1/2)} \frac{1}{2} r^{-1/2} \frac{dr}{dt} \tag{3}$$

If the earth and moon are considered the only two bodies in the system, then any change in ang. momentum of the moon will have to be balanced by a change in angular momentum of the earth, i.e. the earth's rotation speed.

$$\frac{dL_{\text{orbit}}}{dt} = -\frac{dL_{\text{rot}}}{dt} \tag{4}$$

For a rotating body, the angular momentum is a product of the moment of inertia, I, and the angular velocity, ω:

$$L_{\text{rot}} = I\omega \tag{5}$$

Considering the earth a sphere:

$$I = \frac{2}{5} M_{\text{E}} R_{\text{E}}^2 \tag{6}$$

which leads to:

$$L_{\text{rot}} = \frac{2}{5} M_{\text{E}} R_{\text{E}}^2 \left(\frac{2\pi}{P_{\text{rot}}}\right) \tag{7}$$

where P_{rot} is the rotational period. Considering the first time derivative:

$$\frac{dL_{\text{rot}}}{dt} = \frac{4\pi M_{\text{E}} R_{\text{E}}^2}{5} \left(-\frac{1}{P_{\text{rot}}^2} \frac{dP_{\text{rot}}}{dt}\right) \tag{8}$$

Using (3), and the conservation of angular momentum, we obtain:

$$\frac{\left(GM_{\text{E}}M_{\text{moon}}^2\right)^{1/2}}{2r^{1/2}} \frac{dr}{dt} = \frac{4\pi M_{\text{E}} R_{\text{E}}^2}{5P_{\text{rot}}^2} \frac{dP_{\text{rot}}}{dt} \tag{9}$$

Rearranging for dr/dt:

$$\frac{dr}{dt} = \frac{8\pi}{5} \left(\frac{M_{\text{E}} r}{G}\right)^{1/2} \frac{R_{\text{E}}^2}{M_{\text{moon}} P_{\text{rot}}^2} \frac{dP_{\text{rot}}}{dt} \tag{10}$$

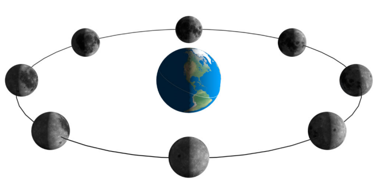
dP/dt is measurable:

$$\frac{dP_{\text{rot}}}{dt} = 0.0016 \text{ s/ century} \tag{11}$$

Putting this into (10) yields a rate of motion as:

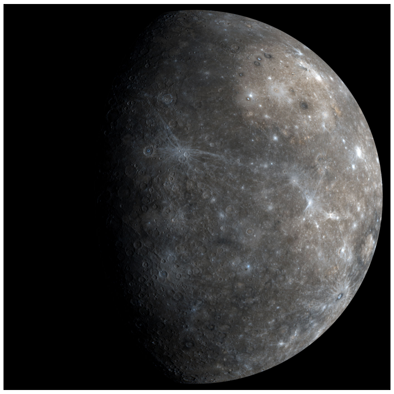
$$\frac{dr}{dt} \approx 4 \text{ cm/ yr} \tag{12}$$

3.12 Moon Phases



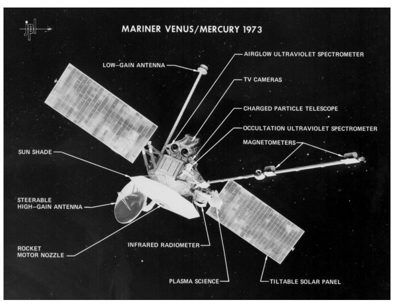
The moon in orbit showing its phases.

4. Mercury



This high-resolution mosaic of WAC images shows Mercury as it appeared to MESSENGER as the spacecraft departed the planet following the mission's first flyby of Mercury.

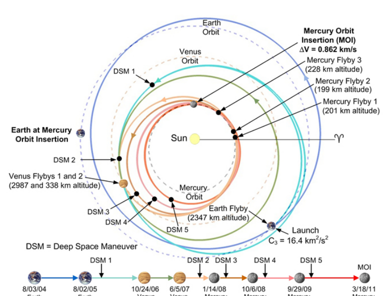
Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington



Mariner 10 spacecraft - launched November 3, 1973, Mercury 1st flyby March 1974

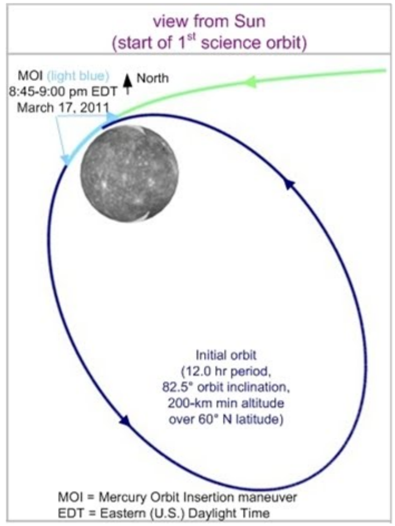
By NASA / Jet Propulsion Laboratory - http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=1563http://www.nasa.gov/multimedia/imagegallery/image_feature_1483.html, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1182348

4.13 The Messenger Mission



It's not hard to get to Mercury, but it's hard to slow down and stop there. It takes less energy to leave the solar system all togethers than it does to get to mercury and slow down enough to get into orbit.

The complicated trajectory to get to Mercury.

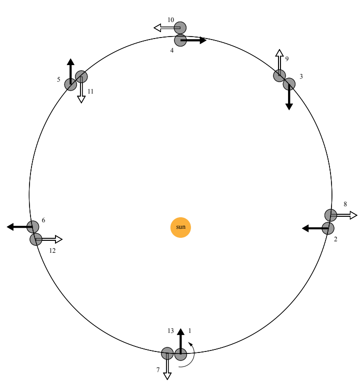


The 1st science orbit

By NASA, Jet Propulsion Laboratory, Applied Physics Laboratory - MESSENGER Website, Public Domain, https://commons.wikimedia.org/w/index.php?curid=15235525

4.14 Mercury - stats

- Atmosphere: None!
- Temperature
    1. Daytime: 700 K at equatorial noon
    2. Nighttime: 100K at polar regions
- Interior:
    1. Little is known (hard to get to)
    2. Probably has iron-rich interior
    3. Probably has very thin silicate crust
    4. Probably has some molten material in core – observed magnetic field is weak



Mercury rotates 3 times during 2 orbits.

Orbital and Rotational Periods	
Orbital Period	87.969 Earth Days
Rotation Period	58.646 Earth Days

The Ratio of Orbit to Rotation is

$$\frac{87.969}{58.646} = 1.5 \tag{13}$$

Phase locked due to solar "tidal" effect. The eccentricity of Mercury makes the ratio 3:2 as opposed to 1:1 like the moon.

Half a mercurial day lasts one Mercurial Year

A day on Mercury

5. Venus

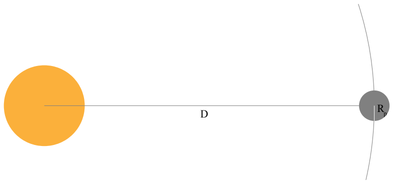
NASA/Goddard Space Flight Center
Scientific Visualization Studio.

Physical Parameters		
Mass	4.867×10^{24} kg	$0.815 M_{\mathrm{E}}$
Radius	$6,051.8$ km	$0.9499 M_{\mathrm{E}}$
Year	224.701 days	0.615 years
Rotation	once every 243 Earth days	Clockwise!
Eccentricity	0.006772	(nearly circular)
Magnetic Field	None	(due to slow rotation)

Venus is very much like the earth in its basic physical properties (mass, radius). However, that's where the similarity ends. Its temperature is much hotter, atmosphere much thicker, rotation speed much slower. No moon. Nearly spherical due to slow rotation speed. No magnetic field

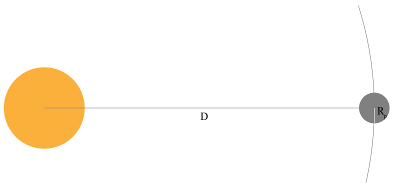
5.15 Greenhouse Effect

How hot would a planet be, if it didn't have an atmosphere?



A planet is located a distance D away from an energy source.

a is the albedo, or how much energy is reflected.
(1 = all of it, 0 = none of it.)



A planet is located a distance D away from an energy source.

The Luminosity of the sun is:

$$L_{\text{Sun}} = 4\pi R_{\text{Sun}} \sigma_{\text{SB}} T_{\text{Sun}}^4 \tag{14}$$

Now consider a planet a distance D away from the sun. The power received by the planet would just be the ratio of its cross section to a sphere of radius D. The energy received per second will be

$$P_{\text{in}} = L_{\text{Sun}}(1-a)\left(\frac{\pi R_p^2}{4\pi D^2}\right) \tag{15}$$

If the planet radiates as a blackbody, then:

$$P_{\text{out}} = 4\pi R_p^2 \sigma_{\text{SB}} T_p^4 \tag{16}$$

In thermodynamic equilibrium: $P_{\text{out}} = P_{\text{in}}$

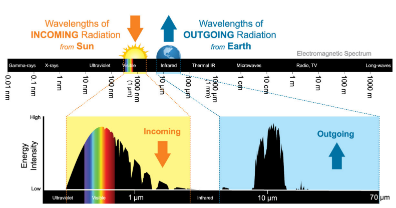
Thus, we can say:

$$L_{\text{Sun}}(1-a)\left(\frac{\pi R_p^2}{4\pi D^2}\right) = 4\pi R_p^2 \sigma_{\text{SB}} T_p^4 \tag{17}$$

Solving for T_p

$$T_p = T_{\text{Sun}}(1-a)^{1/4}\sqrt{\frac{R_{\text{Sun}}}{2D}} \tag{18}$$

Putting number relevant to the Earth and Sun in to this equation, yields a temperature for the earth equal to 255K = -19° C=-1° F. Obviously, we're missing something from this analysis: the greenhouse effect. Take away: the greenhouse effect is *real*.



https://www.weather.gov/jetstream/absorb

5.16 Venus' Atmosphere

- Top of clouds is 250 K, however, at the surface the temperature is 750 K, above the melting point of Lead.
- Atmospheric Carbon Dioxide prevents outgoing infrared radiation.
- Pressure at the surface is about 90 atm.

The Soviet Union's Venera 14 probe captured two color panoramas of Venus's surface in 1982. This panorama came from the rear camera. Russian Academy of Sciences / Ted Stryk

https://www.planetary.org/space-images/venus-surface-panorama-from-venera-14-camera-2

5.17 Venus' Volcanos

- More volcanos than any other object in the solar system. (>1500 major)
- Unclear if they are active or not.

6. Mars

Mars, from space. Mosaic of the Valles Marineris hemisphere of Mars projected into point perspective, a view similar to that which one would see from a spacecraft. The distance is 2500 kilometers from the surface of the planet, with the scale being .6km/pixel.

Physical Parameters		
Mass	6.42×10^{23} kg	$0.107 M_{\mathrm{E}}$
Radius	3397 km	$0.533 M_{\mathrm{E}}$
Year	686.9 days	1.8807 years
Rotation	24 h 37 min 22.6 s	
Eccentricity	0.0934	
Magnetic Field	Weak	Probably larger in the past

6.18 Mars' Atmosphere

The atmosphere of Mars is mainly composed of carbon dioxide (95 %). It contains only 2 % nitrogen and 0.1–0.4 % oxygen.

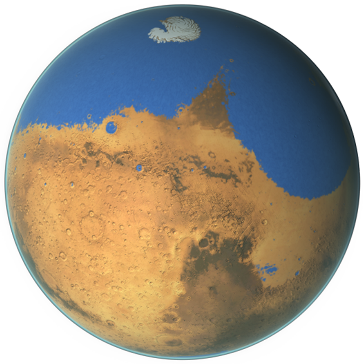
The air pressure is only 5–8 mbar. Much has been lost. No greenhouse effect.

6.19 Mars' Surface

It's red: Iron Oxide aka rust.

Polar Caps: water ice and CO_2

Indications are that water has flowed on Mars in the past. Geologic features like river beds and other erosion indicators suggest this. No liquid water has been found on the surface. Too cold and the pressure is too low.



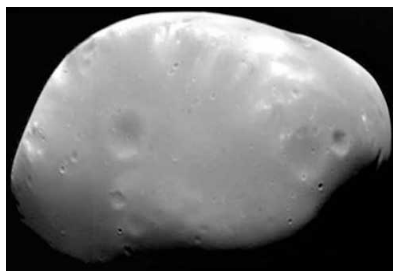
Mars may have had oceans

NASA's Goddard Space Flight Center

6.20 Mars' Moons

Mars' Larger moon Phobos

European Mars Express Mission



The small moon Deimos

European Mars Express Mission

Two relatively small moons: Phobos and Deimos

The size of Phobos is roughly 27 km× 21 km × 19 km, and the orbital period around Mars is only 7 h 39 min.

Deimos is smaller. Its diameter is 15 km × 12 km × 11 km. The orbital period of Deimos is slightly over 30 hours.