Lecture
Surface Temperature of Planets

Objectives
• Effective temperature of a planet
• Greenhouse effect on surface temperature of terrestrial planets
• Surface temperature of giant planets

Notes

• What determines the effective temperatures of a planet
For the terrestrial planets, the source of most of the energy reaching the atmosphere and the surface is the Sun (342 Wm^{-2}); Relatively little energy comes from the planet's interior (about 0.06 Wm^{-2}). The incident solar radiation is either reflected or absorbed by the atmosphere and surface. The net energy input to the planet is the solar radiation absorbed by the atmosphere and surface. The planet radiates according to its temperature. This radiation is the net energy output from the planet.

Once a planet reaches thermal equilibrium (the energy input to the planet and the energy output from the planet are balanced, at least on a short-term), then there is no net cooling or net heating. Its temperature does not change with time. This temperature, called effective temperature, can be calculated using an established formula.

The effective temperature of a planet is determined by the solar radiation absorbed by its atmosphere and surface, which in turn is determined by the area of absorption, solar flux density and albedo.

The effective temperature of Venus, Earth, and Mars are 227 K, 255 K, and 217 K, respectively. The effective cloud-top temperature for Jupiter, Saturn, Uranus and Pluto are 120, 89, 53, 54, respectively.

Note that the effective temperature of a planet does not have to, and usually does not, equal to its surface temperature.

• What is the greenhouse effect? What are the most common greenhouse gases in the atmosphere of terrestrial planets? What are the magnitudes of greenhouse effects on Venus, Earth, and Mars?
At a given effective temperature, a planet with an atmosphere containing greenhouse gases radiates the absorbed solar energy back into space less efficiently than a planet with no atmosphere. Therefore, its surface temperature must rise to achieve a new energy balance at a higher temperature. In this way, the atmosphere acts like the glass in a greenhouse, allowing solar radiant energy to pass through from outside but trapping heat inside. This is known as the greenhouse effect.

The electromagnetic spectrum ranges from long wavelength radio waves through microwaves and infrared radiation, across the various colors of visible light (from about 400 nm to 700 nm), and on to short wavelength ultraviolet (UV) radiation, X-rays, and gamma-rays.

The light emitted by a black body (albedo=0, reflect nothing, absorbs everything) is called black-body radiation. A black-body radiation spectrum (an intensity versus energy curve) depends on the temperature of the body. The black-body spectra at the Earth's surface temperature and the

Sun's surface temperature, 288 K and 5770 K, respectively, are shown in Figure 5.22a. The Sun radiates in the infrared, UV and the visible range. The Earth's surface radiates in the infrared range.

The absorption spectrum of the Earth's atmosphere is shown in Figure. 5.22b. The atmosphere is nearly transparent in the visible region, so that if not scattered by clouds, most of the visible radiation reaches the surface where it is absorbed. The surface radiates at infrared wavelengths, and this energy is absorbed by molecules such as CH_4, CO_2, H_2O, N_2O, O_3 in the atmosphere, thereby raising its temperature.

The high surface temperature of Venus (500 K higher than its effective temperature) can be attributed to the greenhouse effects from CO_2 and H_2O. The tenuous Martian atmosphere does n does not provide sufficient greenhouse effect (surface temperature of Mars is only a few K higher than the effective temperature of the planet). The Earth has just the right amount of greenhouse effects (about 30 K) to support life. However, it has been demonstrated that the level of CO_2 in the Earth's atmosphere is rising as a result of Industrial Revolution. Other greenhouse gases (for example, CFC-chloroflurocarbon, CH_4) have also been added to the Earth's atmosphere through industrial and agricultural activities. The enhanced greenhouse effect may lead to global warming. Currently there is much concern about the environmental impacts of these changes.

• ***Where are the surfaces of giant planets? What are the surface temperatures?***
None of the four giant planets has an accessible surface (if they have any surface at all). The base of the atmosphere is often defined at the 1 bar pressure level (1 bar being approximately the pressure of the Earth's atmosphere at sea-level). This level corresponds roughly to the base of the directly observable layers of the planets.

The temperature at the 1 bar pressure are 165 K, 135 K, 75 K, and 70 K for Jupiter, Saturn, Neptune and Pluto, respectively. They are higher than the effective cloud-top temperature

Suggested research paper topic: Why are 1 bar temperatures higher than cloud-top effective temperatures? Can you account for the differences quantitatively?