Investigating Planets Name:_______________________________________Block:______ **E1:R6**

FYI: Planetary Temperatures and Atmospheres

Read FYI: *A Planet's Temperature, The Importance of an Atmosphere,* and *The Greenhouse Effect* As you read answer the following questions about the readings:

Word/Term	Definition
Temperature	
Heat	
Albedo	
Reflection	
Absorption	
Transmission	
Visible Light	
Infrared radiation	
Greenhouse gases	

1. How are temperature and heat different?

2. What three main factors determine a planet's temperature?

3. How does a planet's atmosphere protect the planet?

4. How do greenhouse gases act to warm a planet?

FYI A Planet's Temperature

A planet's temperature is an important characteristic related to many factors, such as how much electromagnetic radiation reaches the planet from the sun, how much of that electromagnetic radiation is reflected by the planet and how much is absorbed, and if/how the absorbed energy is trapped and distributed.

Temperature, heat, and electromagnetic radiation are related but different concepts.

- **Temperature** is a measure of the average energy of the particles (atoms and/or molecules) in objects or systems. This energy is in the form of the motions of those particles. In an object with higher temperature—a hotter object—the particles move extremely fast. In an object with a lower temperature—a colder object—the particles move more slowly. The temperatures need to be close to absolute zero, which is as cold as it gets, in order for us to directly observe the motions.
- **Heat** is a form of energy directly related to the internal energy of an object or system—to the motion of the atoms and molecules that make up the object or system. (An **atom** is a building block for all matter. It is the smallest unit of an element, such as hydrogen (H) or helium (He), that retains the properties of that element. A **molecule** is the smallest particle of a substance, such as water (H_2O), that retains all the properties of the substance. A molecule is composed of two or more atoms.). As an object or system receives heat, its temperature rises. Similarly, as an object or system loses heat, its temperature decreases.
- **Electromagnetic radiation** is a form of energy that propagates through space at the speed of light. **Visible light**, which we refer to simply as "light," is the form of electromagnetic radiation that we see with our eyes.

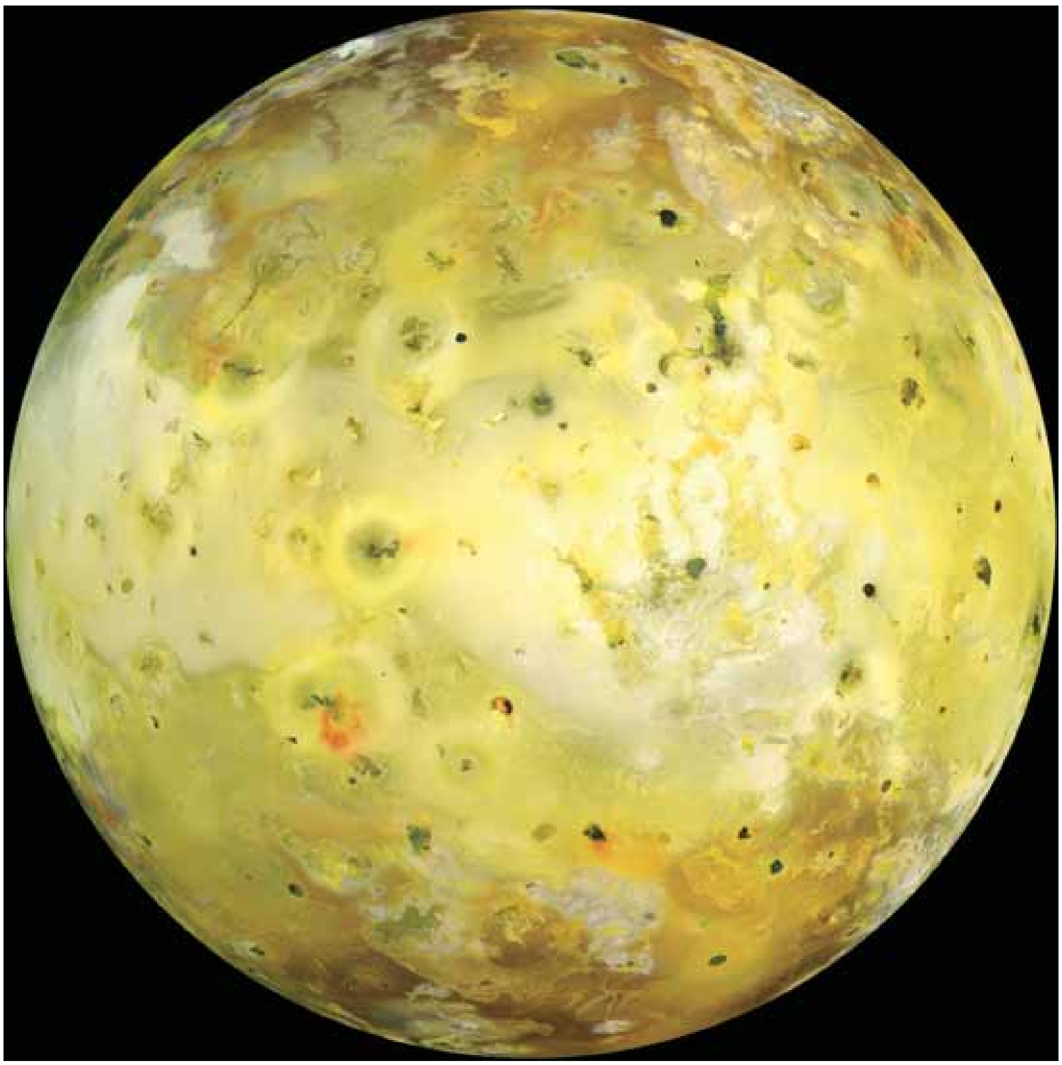
When electromagnetic radiation from the sun reaches a planet (or moon), some of the energy from the sun is absorbed by the planet. This absorbed energy becomes part of the planet's energy and helps determine the temperature of the planet. The more energy a planet absorbs from the sun, the higher that planet's temperature.

The amount of energy available for absorption is not the same for each planet, however. The amount of electromagnetic radiation reaching a planet decreases rapidly as distance from the sun increases. As a result, the amount of energy available for absorption is much lower for planets and moons farther from the sun. This means that, all else being equal, the farther a planet is from the sun, the lower that planet's surface temperature.

In fact, "all else" is not equal. Not all planets are equally able to absorb and trap electromagnetic radiation from the sun. Other factors, such as a planet's albedo and a planet's atmosphere (if any), also influence a planet's temperature. A planet's albedo determines how much of the electromagnetic radiation reaching the planet is actually absorbed. **Albedo** is a measure of the reflectivity of a planet. More specifically, it is the fraction or percentage of incoming radiation that is reflected by the atmosphere and/or the surface of a planet. The higher the albedo, the more radiation is reflected. For example, ice, which is highly reflective, has an albedo about 0.8, or 80%. Earth, with its oceans and clouds, has an albedo of 0.37, while the moon has an albedo of only 0.11.

In addition, not all planets are equally able to hold on to the energy they absorb from the sun's electromagnetic radiation. An atmosphere plays a major role in how much heat a planet can retain, the range of temperatures experienced by a planet, and the distribution of temperatures across a planet. (See FYI: *The Importance of an Atmosphere*.) We talk about a planet's average temperature, minimum temperature, and maximum temperature.

Finally, planets and moons do have other sources of energy that can contribute to their temperatures. For example, there are internal sources of heat, such as volcanism.



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FYI The Importance of an Atmosphere

An **atmosphere** is the layer of gases that may surround a planet or moon. There is no definite boundary between the atmosphere and outer space. Instead, the atmosphere simply becomes thinner and thinner as it gets farther from the world's surface.

Venus, Earth, Mars, Pluto, and one moon of Saturn, called Titan, all have significant atmospheres. Some of the moons in the solar system, such as Jupiter's Europa and Ganymede, have very thin atmospheres, called exospheres, that are almost, but not quite, a vacuum. For the gaseous planets, such as Jupiter, it is difficult to distinguish between what is planet and what is atmosphere. In fact, gaseous planets don't have a surface, their atmospheres just get denser toward the center of the planet until a solid state is reached.

Whether or not a world has an atmosphere is dependent on a number of factors, including surface gravitation. The gas that makes up the atmosphere has mass, and so it is attracted to the mass of Earth by gravitational force. The gravitational force on Jupiter is strong enough to hold really light gases, such as hydrogen or helium. The gravitational force on Earth is strong enough to hold on to an atmosphere, though one made primarily of the heavier gases nitrogen and oxygen. The gravitational force on Titan is very low; however, the temperature of this outer-world moon is also very cold. As a result, the gases in Titan's atmosphere have very little thermal energy and are moving slowly. Their velocity (speed with a direction) is low enough that they can't escape the gravitational force of their moon.

Atmosphere Affects a Planet's Temperature

A world's atmosphere reflects, absorbs, and transmits electromagnetic radiation.

- **Reflection** is the process of changing the direction of the electromagnetic radiation. The atmosphere reflects the electromagnetic radiation, meaning that it takes radiation that is entering the atmosphere and returns or gives back that radiation to space.
- **Absorption** is the process by which electromagnetic radiation is taken up or in by another entity, such as the gases of an atmosphere. The atmosphere absorbs the electromagnetic radiation, meaning that it takes in the radiation.
- **Transmission** is the process of passing electromagnetic radiation through a substance. The atmosphere transmits electromagnetic radiation, meaning that it allows the radiation to travel through to the world's surface.

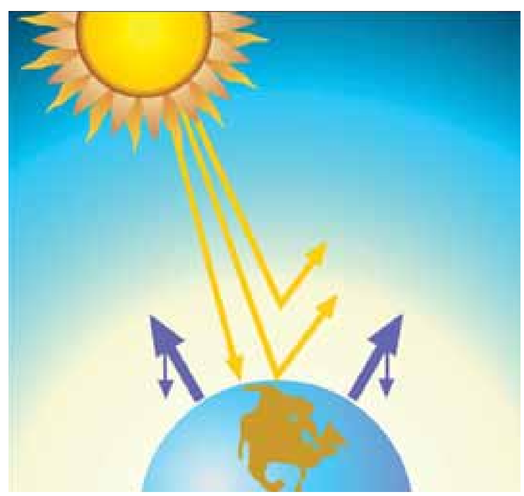

Figure 1-19: Diagram showing the greenhouse effect

When an atmosphere absorbs electromagnetic radiation from the sun, it is absorbing energy. This energy directly relates to the temperature of the world. The more energy that is absorbed, the higher the temperature. The greenhouse effect is the process by which the electromagnetic radiation absorbed and trapped by a planet's atmosphere heats the planet. Thus, an atmosphere affects the temperature of a world by absorbing energy from the sun.

Much of the light reaching a world from the sun is visible light. On Earth, this light warms the surface, which reradiates much of this heat back toward space. However, the surface reradiates this heat as **infrared radiation**.

While visible light passes easily through Earth's atmosphere, infrared light does not. An atmosphere absorbs about 90% of the infrared light emitted by the surface. Thus, the nature of the atmosphere affects how much and what types of radiation are reflected, absorbed, and transmitted.

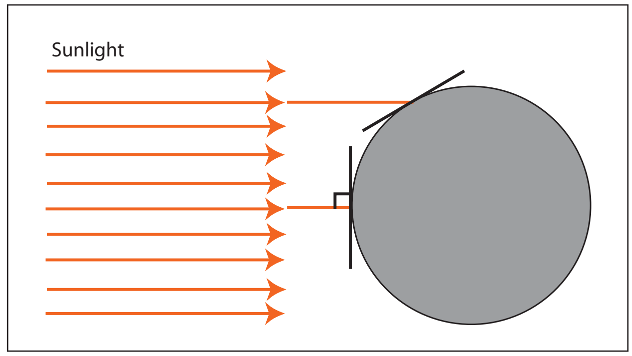

Figure 1-20: Diagram showing the angles at which sunlight reaches a world's surface. A world without an atmosphere or with only a very thin atmosphere will be hotter at the location where the sunlight is coming straight down, at a right angle to the surface, than at the locations where the sunlight is reaching the surface at a lower angle.

An atmosphere also affects the temperature of a world by reducing the temperature extremes. If a world doesn't have an atmosphere to absorb and hold energy from the sun, the side of that world that is toward the sun is much hotter than the side that is away from the sun. Also, if a world doesn't have an atmosphere, the temperature near the part of the world where the sun is directly overhead is much greater than at the parts of the world where the sun can never be directly overhead. Because of a world's spherical shape, the energy available per unit area decreases from the parts of the world where the sunlight comes straight down from directly overhead (such as near the equator on Earth) to the parts of the world where the sunlight comes in at a low angle (such as at poles on Earth). (See Figure 1-20.) Atmospheric gases can move, so an atmosphere is able to take energy from the warmer places to the cooler places, reducing the temperature differences. For example, the temperatures on Mercury range from about 467 °C near the planet's equator on the side facing the sun to about -183 °C near the poles and on the side of the planet away from the sun. In contrast, the temperatures on the surface of Venus are only a few degrees warmer at the equator than at the poles.

Other Features of a Planet's Atmosphere

In addition, an atmosphere helps protect a world's surface from dangerous electromagnetic radiation. Some forms of electromagnetic radiation can be harmful. For example, ultraviolet radiation causes sunburns, which are damaging to human skin. An atmosphere doesn't absorb or reflect all types of electromagnetic radiation equally—Earth's atmosphere transmits almost all the light from the sun but only some of the ultraviolet radiation. Thus, by reflecting and absorbing some of the electromagnetic radiation from the sun, an atmosphere can protect a world's surface.

An atmosphere also helps protect a world's surface from asteroids, meteoroids, and other bits and pieces of rock and materials traveling through the solar system. If a world has an atmosphere, this space debris may burn up in that atmosphere and never reach the surface. The thickness of the world's atmosphere, along with the size and nature of the debris, determines whether or not the debris burns up before reaching the surface. For example, little pieces burn up easily in Earth's atmosphere, resulting in meteors, which are commonly (though incorrectly) called falling or shooting stars. However, objects larger than a few meters in diameter zip almost unaffected through Earth's atmosphere. Even Venus's dense atmosphere only burns up objects less than 100 or so meters in diameter. Larger stuff goes right through. When pieces do reach the surface due to a thin or nonexistent atmosphere, the result is a **crater**, a circular depression or lowered area on a surface. In general, the larger the piece hitting the surface, the larger the crater. Therefore, a world without an atmosphere or with an insubstantial atmosphere will have many more small craters on its surface.

Finally, an atmosphere directly affects the surface of a planet or moon. For example, movement of the atmosphere, or wind, causes erosion— a wearing away or slow destruction of the surface. Wind also carries materials such as dust across a world's surface. An atmosphere therefore moves materials from one location to another.

FYI The Greenhouse Effect — Venus, Earth, and Mars

Greenhouse Gases

In the news, we often hear about **greenhouse gases**. These gases are made of molecules that can store considerable amounts of energy. The bonds holding a molecule's atoms together are not rigid; they can twist, lengthen, and shorten, allowing the atoms to move slightly. When a molecule absorbs energy, its atoms move more, storing the energy in the molecule's flexing bonds. In general, the more bonds a molecule has, the more energy it can store. The stored energy increases a substance's temperature.

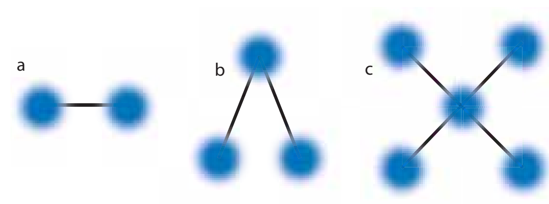

Figure 1-21: Diagrams showing the number of bonds and atoms in various atmospheric gases—(a) model of a nitrogen (N_2) or oxygen (O_2) molecule; (b) model of a carbon dioxide (CO_2), water (H_2O), or ozone (O_3) molecule; (c) model of a methane (CH_4) molecule

Any gas molecule with three or more atoms is a greenhouse gas. Thus, carbon dioxide (CO_2), water (H_2O), and ozone (O_3) are greenhouse gases. Each of them has two bonds holding their three atoms together (Figure 1-21b). When these molecules absorb energy, the atoms move more, flexing the bonds and storing the energy. The more bonds a gas molecule has, the more heat energy it can store. For example, methane (CH_4), with its four bonds (Figure 1-21c), holds 60 times as much heat energy as carbon dioxide does!

Compare this to how non-greenhouse gases, such as nitrogen (N_2) and oxygen (O_2), behave when absorbing energy. Nitrogen and oxygen have only one bond connecting the two atoms (Figure 1 - 21a). This bond cannot store as much energy. When nitrogen and oxygen are heated, the pair of atoms just spins end over end, with little energy being stored in the bond between them.

The Atmospheres of Venus and Mars

The atmospheres on both Mars and Venus are about 95% carbon dioxide, a greenhouse gas. One would think that both Mars and Venus would, therefore, be hot planets. However, the composition of an atmosphere is only one factor. The total amount of atmosphere a planet has and the albedo of that atmosphere are also important.

Venus has an extremely thick atmosphere, about 92 times thicker than that of Earth. This thick CO_2 atmosphere causes a strong greenhouse effect, absorbing and trapping heat on the planet. As a result, the average temperature on Venus is about 457 °C. This means that, on average, Venus is much hotter than Mercury, even though Mercury is closer to the sun.

This very high planetary temperature is even more remarkable when another aspect of Venus's atmosphere is considered. In its upper atmosphere, Venus has a layer of thick clouds. These clouds have a high albedo, reflecting over half of the sunlight that reaches them. What this means is that while Earth is farther from the sun than Venus is, Venus's surface actually receives less sunlight. As a result, without the runaway greenhouse effect of its atmosphere, the temperatures on the surface of Venus would actually be about the same as those on the surface of Earth.

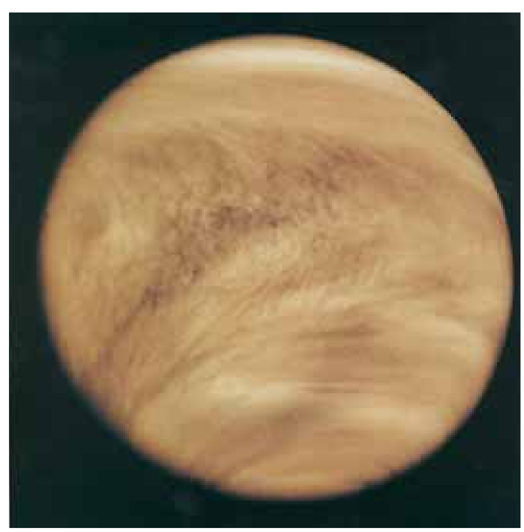

Figure 1-22: Image of Venus with its thick, reflective layer of clouds

Mars has a thin atmosphere, about 170 times thinner than that of Earth. The thinness of this CO_2 atmosphere means that, despite the high concentration of greenhouse gas, the temperatures on Mars are low and vary widely.

The Atmosphere of Earth

In contrast, Earth's atmosphere is mostly made of non-greenhouse gases. Nitrogen and oxygen make up 99% of Earth's atmosphere. If these were greenhouse gases, Earth's average temperature would be several hundred degrees Celsius, instead of 15°C.

However, Earth's atmosphere is not devoid of greenhouse gases. For example, the greenhouse gas carbon dioxide is a small (0.04%) but vital part of Earth's atmosphere. There is carbon dioxide in Earth's atmosphere as part of natural processes, such as photosynthesis, but there is also carbon dioxide in the atmosphere because of human activities. In particular, the burning of fossil fuels such as gasoline, coal, and oil add carbon dioxide to the atmosphere. In this way, humans are increasing the ability of Earth's atmosphere to absorb and store energy. It is becoming increasingly clear that the increase in greenhouse gases and the subsequent warming of our planet is due to human activity. Some scientists think that global warming could occur due to a natural solar cycle, with the sun radiating more energy now than in the recent past. Regardless of the cause, the consequences of this heating worry many people. Recent trends include melting ice caps, rising sea levels, changing climates, decreased rainfall, and increased evaporation, which, in turn, adds more water vapor to the atmosphere and accelerates the heating.

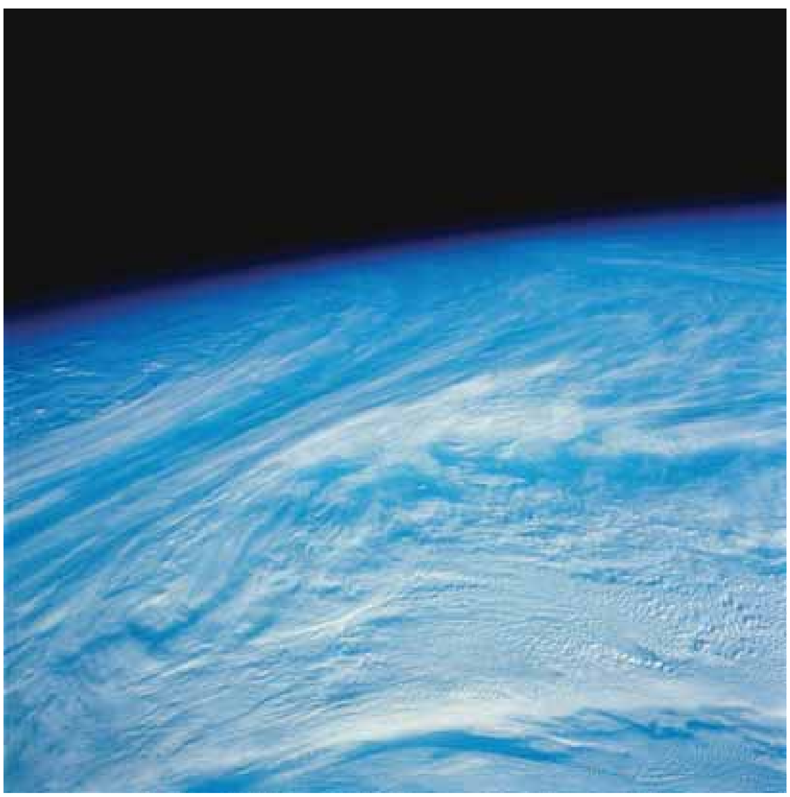

Figure 1-23: Photograph of Earth and its atmosphere taken from space