Redistribution of Heat Energy

Heating the Earth

Sunlight is responsible for warming earth materials, but not all materials are warmed directly by sunlight. In fact, sunlight does not have a temperature. It's impossible for sunlight to have a temperature because temperature is an indication of the average motion of the particles in a sample of matter and sunlight is not made of matter. Heat energy is the kind of energy that a material has because of its particle motion. Knowing that Earth's energy is derived from the Sun is only part of the equation in understanding how Earth gets its temperature. In order for a material to warm, energy must be transferred to it by **conduction**, **convection**, or **radiation**. The sun transfers its energy to us via radiation, which warms Earth's surface. In turn, Earth's surface then transfers its energy to the surrounding air (ex. Ground warms air, water warms air).

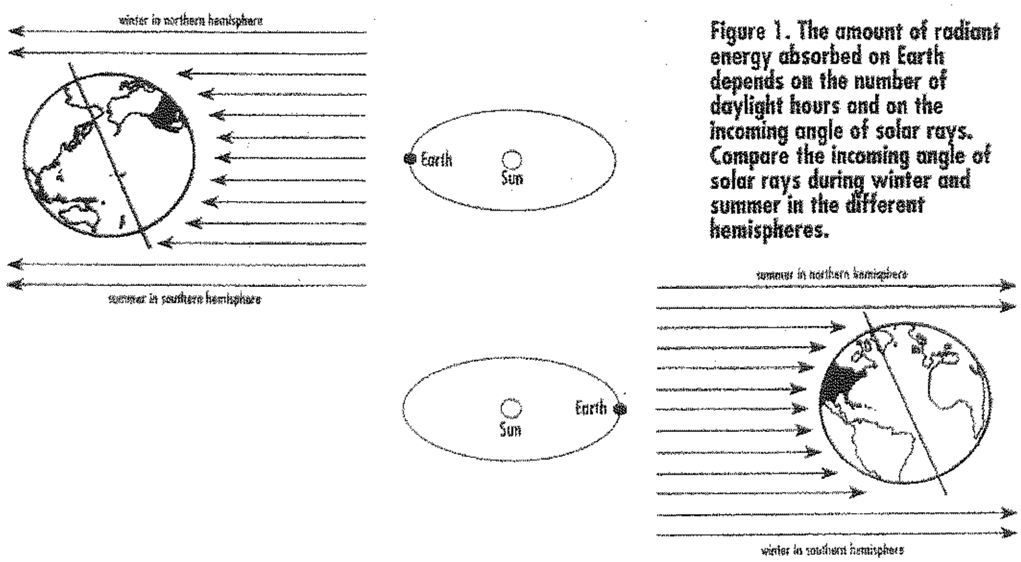

Figure 1. The amount of radiant energy absorbed on Earth depends on the number of daylight hours and on the incoming angle of solar rays. Compare the incoming angle of solar rays during winter and summer in the different hemispheres.

For all practical purposes we can say that Earth receives nearly a constant rate of radiant energy from the sun. This energy, however, is not uniformly distributed throughout the planet.

Heating the Earth

The 23.5 degree tilt in Earth's axis causes maximum intensities of solar radiation to strike the northern hemisphere during the middle months of the year and the southern hemisphere during the beginning and ending of the year (See Figure 1).

In addition, the curvature of Earth's surface affects the distribution of solar energy. At the equator, the sun's rays fall most nearly perpendicular. This transmits the highest amount of solar radiation because those rays strike a smaller surface area than do rays striking near the poles. This concentrating effect means that the amount of energy per square unit of surface area is greater near the Equator than near the poles. (See Figure 2)

The atmosphere is transparent to most incident solar radiation. However, some radiation is absorbed, scattered, or reflected by the atmosphere, depending on its wavelength. Radiation of some wavelengths is absorbed by water vapor, ozone, and dust particle; other wavelengths are scattered by air molecules; still others are reflected by

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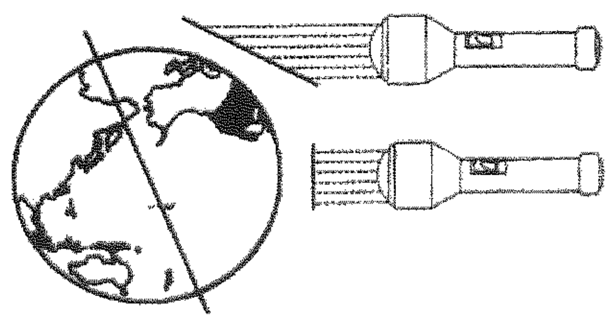
Figure 2. Earth's shape affects how its surface heats. More heat is transferred where the sun's rays strike Earth directly (near the equator) than where they strike Earth slanted (near the poles). Slanted rays transfer less heat largely because they are dispersed over a much larger area than are direct rays. This principle is demonstrated by measuring the area covered by a flashlight's beam on perpendicular and slanted surfaces.

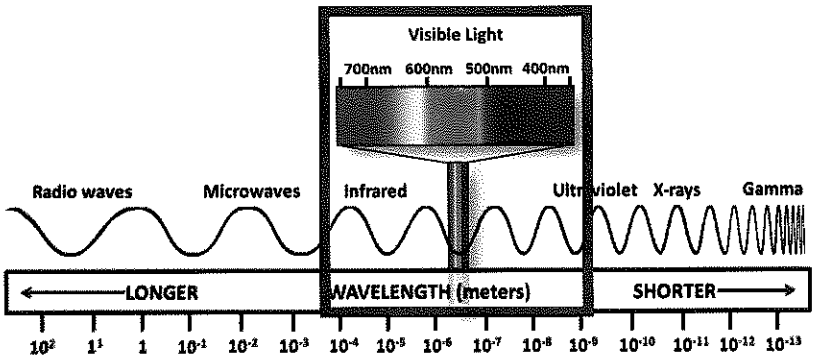


clouds. A large portion of the total solar radiation reaching Earth passes through the atmosphere and reaches the ground, where it is either reflected or absorbed. Some land materials- e.g. rocks, snow, sand, soil-readily reflect most of the sun's radiation. In contrast, bodies of water absorb, rather than reflect, most of the radiation they receive.

What happens when sunlight strikes Earth?

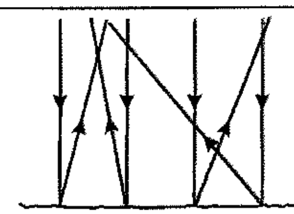
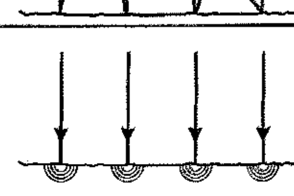
The sun emits a mix of many wavelengths of electromagnetic waves, but not all of them reach Earth. The following diagram (see below) shows the full spectrum of electromagnetic waves with the bold black section showing the range of the wavelengths of sunlight that reach Earth.

Infrared light waves are the range of wavelengths detectable by night-vision goggles. All objects emit infrared light waves. Visible light waves are the range of wavelengths that our eyes perceive. Red light has the longest wavelength, and vilolet the shorte. Utraviolet light waves have short wavelengths, which can cause sunburns and mutations in DNA.



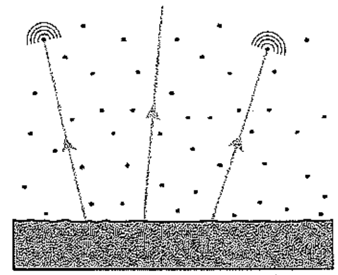
As sunlight waves travel through the vacuum of space, they remain relatively unchanged. When sunlight waves reach matter (ex. Air, land, water), they are transmitted, reflected, and/or absorbed. Note: sunlight waves are shown as straight lines, with arrows indicating the direction the wave is travelling- often referred to as rays of sunlight.

Light Wave Behavior

Transmission	**Transmission** occurs when rays of sunlight reach a boundary and pass through the boundary completely unchanged.	
Reflection	**Reflection** occurs when sunlight rays reach a boundary, bounce off, and change direction. Though the rays change direction, there is no other change (i.e., no change in energy level or wavelength).	
Absorption	**Absorption** occurs when sunlight rays reach a boundary and enter the new material, but do not pass through. Instead the material disrupts the wave and transfers its light energy into heat energy.	

Radiation

Radiation is the spontaneous emission of electromagnetic waves from objects. All objects above the temperature of absolute zero radiate electromagnetic waves. Because we don't typically see electromagnetic waves, it's easy to forget that everything around us is emitting them. The frequency of the wave varies and is determined by the temperature of the object. Hotter objects radiate shorter wavelengths of electromagnetic waves. Most earth materials (and organisms) emit the longer wavelengths of infrared light.



Longer-wave infrared light is absorbed by air particles

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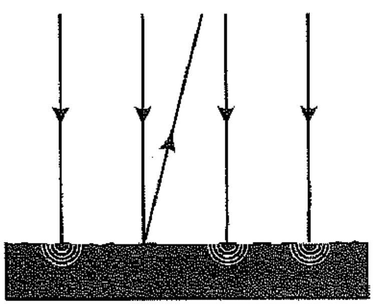
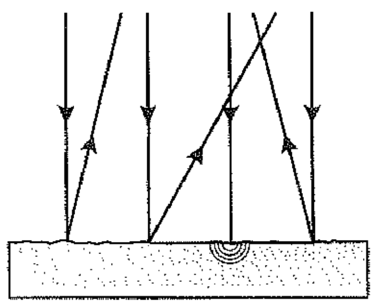
Infrared light waves behave like other waves—they travel unhindered through a vacuum, but can be absorbed, reflected, and transmitted when they interact with matter. Longer-wave infrared rays are readily absorbed by the gases in Earth's atmosphere. As atmospheric gases absorb these longer wave infrared waves, they warm because light energy is transferred to heat energy.

Reflectivity and Albedo

Most materials don't just transmit, just reflect, or just absorb sunlight – they do a little of this and a little of that. Objects such as trees and soil absorb some sunlight and reflect the rest. The amount that is reflected is determined by the material's reflectivity—by its **albedo** (pronounced all-bee-dough). Albedo is measured on a relative scale from 0-1.0 – 0% reflection to 100% reflection. An albedo of 0.0 would mean no light waves are reflected off an object – the object would be invisible to us. There has to be some light reflected back to our eyes in order for us to see an object. Dark materials (chalkboards, asphalt) absorb most of the light wave that strikes them –meaning they have a low albedo. Mirrors, snow, and white paper reflect most of the sunlight that strikes them. They have a high albedo. For example, the dark material above and to the left has a lower albedo (0.25), meaning it reflects 25% of the rays that strike it. The pale material has a higher albedo (0.75), meaning it reflect a lot more sunlight (75% of the rays).



Albedo = 0.25
(25% reflected, 75% absorbed)

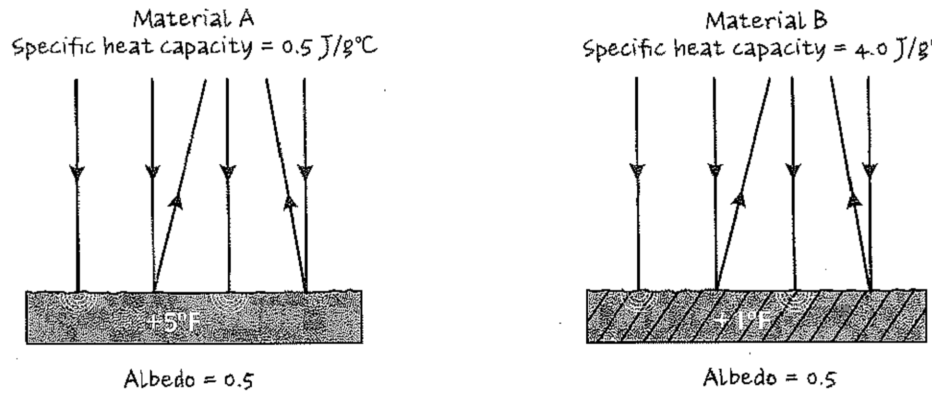


Albedo = 0.75
(75% reflected, 25% absorbed)

Average Albedos of Common Earth Materials

Material	Average albedo	% Light reflected
Snow	0.85	85%
Ice	0.60	60%
Concrete	0.55	55%
Sand	0.40	40%
Grass	0.25	25%
Soil	0.17	17%
Forest floor	0.15	15%
Asphalt	0.04	4%

What is specific heat capacity?



When materials absorb light waves, their temperature goes up, but not always by the same amount. This is because materials vary in their **specific heat capacity**. Specific heat capacity is the amount of heat energy needed to raise the temperature of 1 gram of a material by 1 degree Celsius.

The specific heat capacity of a material depends on its molecular makeup. It's an intrinsic physical property, like color, density, and melting point. The specific heat capacity of a material is a constant that doesn't change unless the material changes chemically or changes from one stat of matter to another (ex. Solid to liquid, liquid to gas). The following diagram illustrates the role of specific heat capacity in warming. Both materials acquire the same amount of light energy because their albedos are identical. However, Material A has a low specific heat capacity and thus warms more than Material B.

How do warm objects warm other objects?

Overall, Earth's atmosphere transmits, scatters, and reflects more radiant energy from the sun than it absorbs. Earth's surface, on the other hand, absorbs more solar energy on average than it reflects. On knowing only these facts, one might expect the atmosphere to be cooling while the surface. However, this is not the case because that imbalance is counteracted by the transfer of heat energy from the surface back to the atmosphere.

This transfer of heat occurs primarily through two different but interactive mechanisms: **sensible heating** and **latent heating**. Sensible heating involves the processes of conduction and convection. It accounts for about 23 percent of the overall heat energy transferred into the atmosphere from Earth's surface. Latent heating involves the transfer of heat as a consequence of changes of phases of water. This kind of heating accounts for about 77 percent of the heat transferred from Earth's surface to the atmosphere.

One mechanism of sensible heating, **conduction** is the spontaneous transfer of heat energy that occurs whenever two objects of different temperatures (be they solid, liquid, or gas) come in direct contact with each other. Even the slightest temperature differences between touching objects will trigger this transfer of energy. During conduction, there is a net directional transfer of heat energy from the hotter object to the colder object. For example, when a particle of cool air collides with warm sand, heat energy is transferred from the sand particle to the air particle. This energy causes the air particle to move and thus increases its heat energy. The temperature of the air increasing is evidence of this transfer of heat energy.

When the average heat energy of the particles that make up each object are the same (i.e. their temperatures are the same), conduction stops. Particles continue to collide and hotter particles transfer heat energy to colder particles, but because the average motion of the particles in each material is the same, there is no net transfer of heat energy. Heat energy comes and goes between the objects with every collision, but the transfer is random and doesn't proceed primarily in one direction.

Conduction is the principle underlying why the handle of a fireplace poker becomes hot when just the tip is left in the fire. Heat energy is transferred from the fire to the tip of the poker, and the metal in the poker transfers (conducts) the heat energy away from one end to the other. If you lay on a sandy beach on a sunny day, the sand feels warm. This is because the warm sand is transferring heat energy to your body by **conduction.** The warm sand is also radiating infrared light waves-and anything that absorbs these infrared light waves warms. Within the atmosphere, conduction is significant only in a very thin layer of air that is in immediate contact with Earth's surface.

Convection, on the other hand, is the process of heat distribution within a fluid (such as air or liquid water), achieved through movement of the fluid itself. Convection is an important process in atmospheric heating. It results from density differences between parcels of air with differing temperatures. The process of atmospheric convection begins when a parcel of air near Earth's surface is warmed. Warmer air is less dense than cooler air, thus it rises away from the surface. As it rises, it is replaced by cooler air underneath. That cooler air may, in turn, be warmed by the surface, become less dense and rise, repeating the process. As the warm air rises, it expands and cools, becoming more dense and sinking. Convection currents or cells are established through this process of heating and cooling. This circulation transports heat energy into the atmosphere. The principle of convection is used in home heating systems, with heaters or air vents usually placed at floor level rather than near the ceiling.

The convection process is facilitated by changes in air pressure. As war air rises, its pressure decreases, causing the air to expand and cool. As cool air sinks, its pressure increases and it is compressed and warmed. The expansional cooling and compressional warming mechanisms are important aspects of the atmospheric convection process.

How do thermometers work?

An increase in temperature is our indicator that an object has had an increase in heat energy. So it's helpful to think a bit about how thermometers actually work.

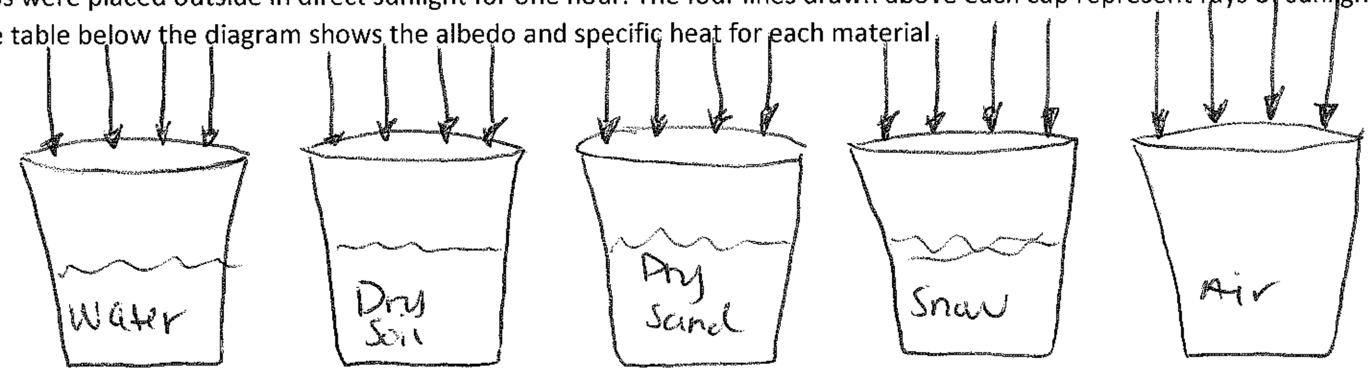
A bulb thermometer (ex. Classic mercury or alcohol) is one of the most common ways to measure temperature. When bulb thermometers come in direct contact with warm surfaces, liquids, or air particles, the heat energy from these materials is transferred by conduction to the glass and then to the liquid within the thermometer. The motion of the particles in the liquid increases, and the liquid expands up the thermometer tube. The level of liquid in the tube is an indication of the average heat energy of the particles in the material that the thermometer is touching.

When you take an air temperature with a bulb thermometer, you should take them temperature in the shade. Otherwise, the thermometer will absorb sunlight waves, which adds heat energy to the thermometer beyond what is transferred by conduction form the surrounding air particles.

An infrared thermometer does not come into direct contact with materials. Instead, infrared thermometers essentially take a picture of the infrared light waves radiating from an object and then calculate the temperature based on that data. They are similar to the night vision goggles used by the military. These thermometers only tell you the surface temperature of an object. They do not tell you anything about the object's internal temperature. For example, the sand on the beach on a sunny day may have a surface temp of 93 and an internal temp of 65. (think about what happens when you dig down and burry your feet). Because of this, geoscientists often indicate whether temperatures are surface temperatures or internal temperatures.

Check Your Understanding. Answer the following questions on a separate sheet of paper using complete sentences:

Use the diagrams below to help you answer the following questions. Each cup contains a different earth material. The cups were placed outside in direct sunlight for one hour. The four lines drawn above each cup represent rays of sunlight. The table below the diagram shows the albedo and specific heat for each material.



	Water	Dry soil	Dry Sand	Snow	Air
Albedo	0.06	0.17	0.40	0.85	N/A
Specific Heat capacity (J/g°C)	4.2	0.80	0.29	2.1	1.01

1. Draw each cup on your own sheet of paper. Draw each ray of sunlight as shown above. Then use the light wave behavior diagram to show what happens when sunlight strikes the material.

2. Imagine each ray has 2 joules of light energy. Based on how you drew the rays, record how much energy you predict will be transferred to each cup.

	Water	Dry Soil	Dry Sand	Snow	Air
Predicted amount of energy transferred to each material					

3. Which matter would you expect to increase the most in temperature? Rank the cups in terms of what you predict their temperature increases will be.

	Water	Dry Soil	Dry Sand	Snow	Air
Predicted temperature increase (rank most to least)					

4. In all of the demonstrations you have observed in class and we have discussed, thermal energy is transferred from a warmer object to a cooler one. Explain how heat energy cannot be transferred from a cooler object to a warmer one. Draw particle diagrams to help you explain your answer.