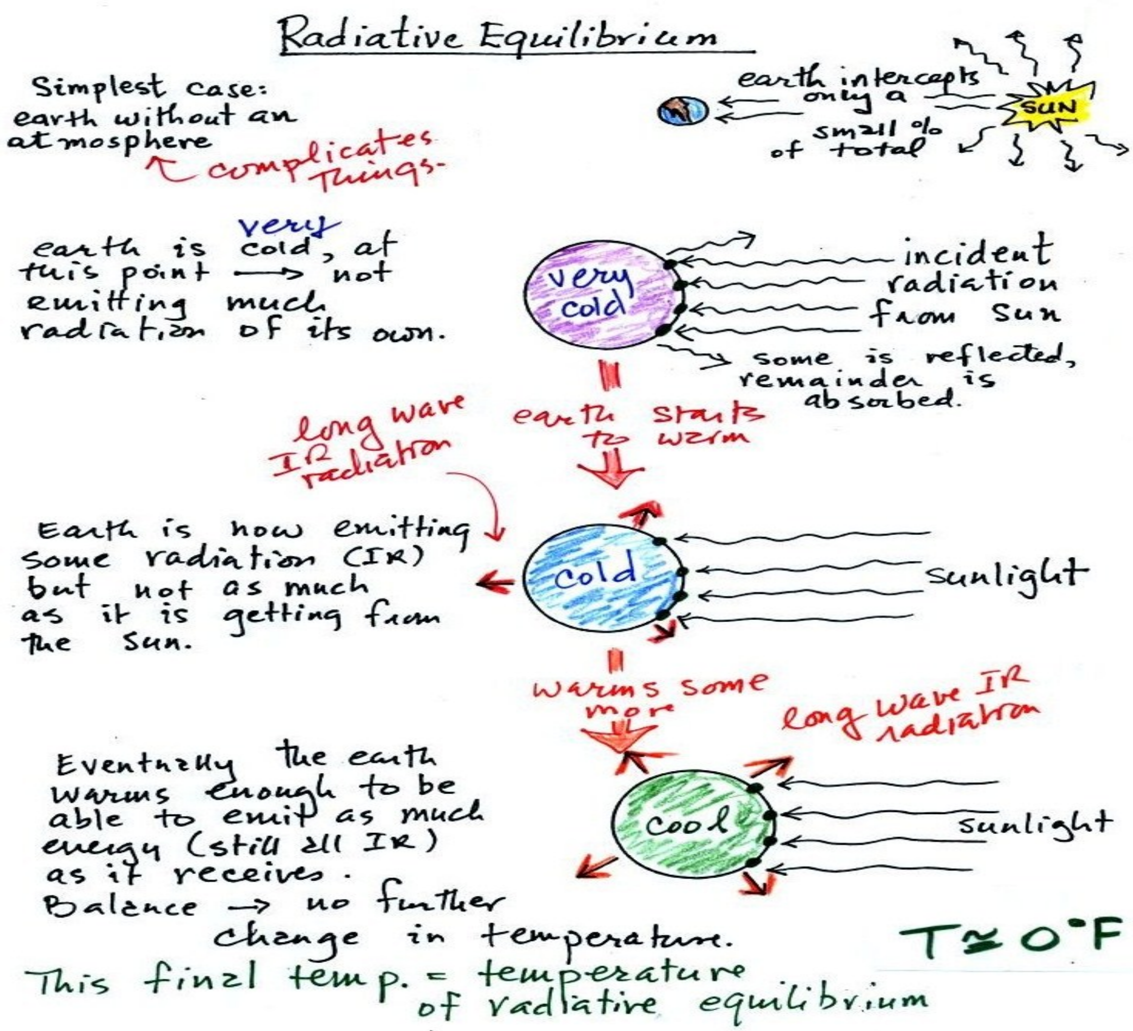
Module 5 - Lecture 14

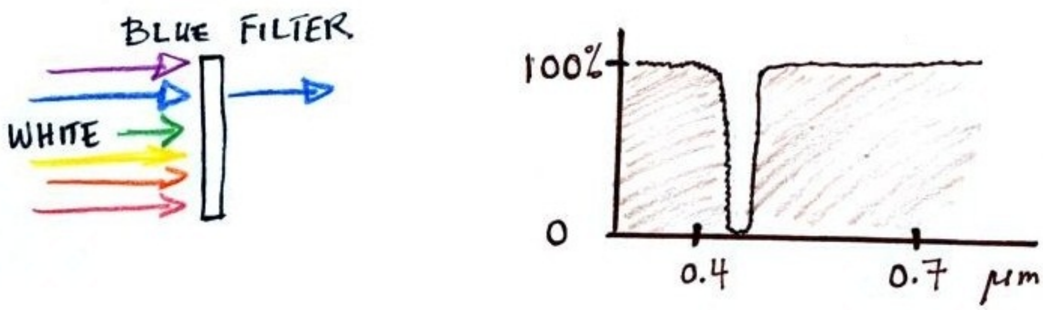
You might wonder how the sun could possibly be in energy balance with the earth. The sun has an average temperature of 6000^0K and emits 160,000 times more energy than the earth. The answer is that the earth is located about 90 million miles from the sun and only absorbs a very small fraction of the total energy emitted by the sun. To be in energy balance, the earth only needs to emit the same amount of energy it absorbs from the sun.

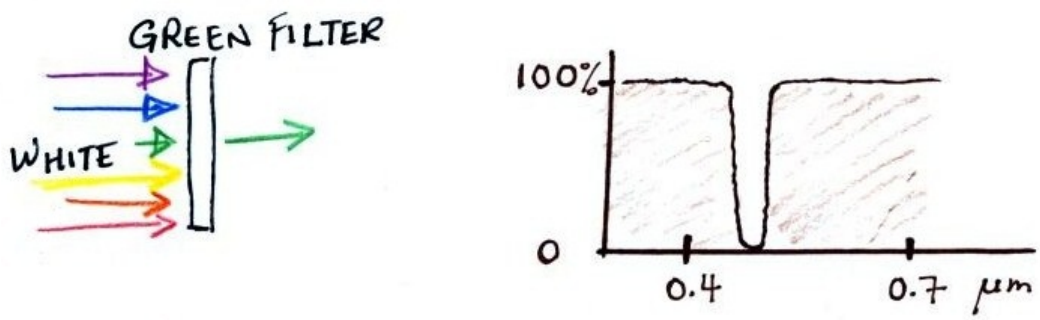
We will look at the simplest case first, the earth without an atmosphere (or at least an atmosphere without greenhouse gases). In the figure below, we start by imagining that the earth has a temperature of absolute zero (0^0K) and is not emitting any EM radiation at all (the purple earth in panel 1). As the earth absorbs sunlight, it begins to warm (the blue earth in the middle panel) and emit EM radiation. At this point, the earth continues to become warmer because it is still absorbing more energy from the sun then it is emitting. Eventually the earth warms to the point where it is emitting as much EM radiation as it is absorbing (the green earth in the bottom panel). The temperature at which this occurs is about 0^0F or 255^0K. This is called the ***temperature of radiative equilibrium***. This would be the average surface temperature of the earth if there were no greenhouse gases.

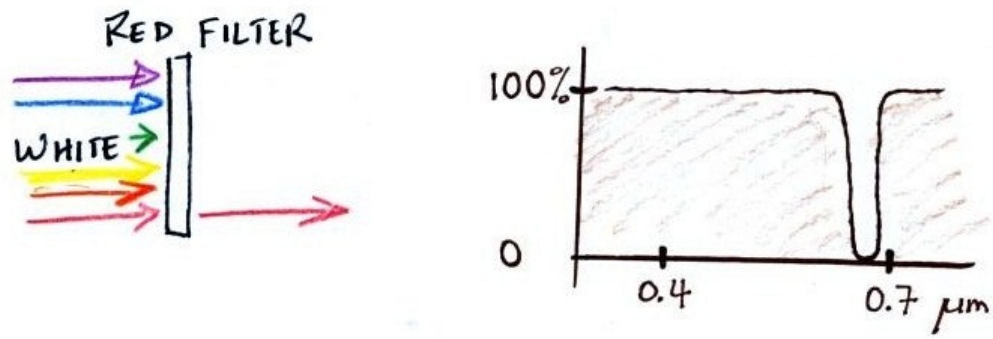


Before we start to look at the radiant energy balance on the earth with an atmosphere, we need to learn about filters. The atmosphere will filter sunlight as it passes through the atmosphere toward the ground. The atmosphere will also filter infrared radiation emitted by the earth as it tries to travel into space.

We will first look at how simple blue, green, and red glass filters affect visible light. In this way, we will become familiar with filter absorption graphs. If you shine white light (a mixture of all the colors) through a blue filter, only the blue light passes through. The filter absorption curve shows 100% absorption at all but a narrow range of wavelengths that correspond to blue light. Similarly the green and red filters only let through green and red light.

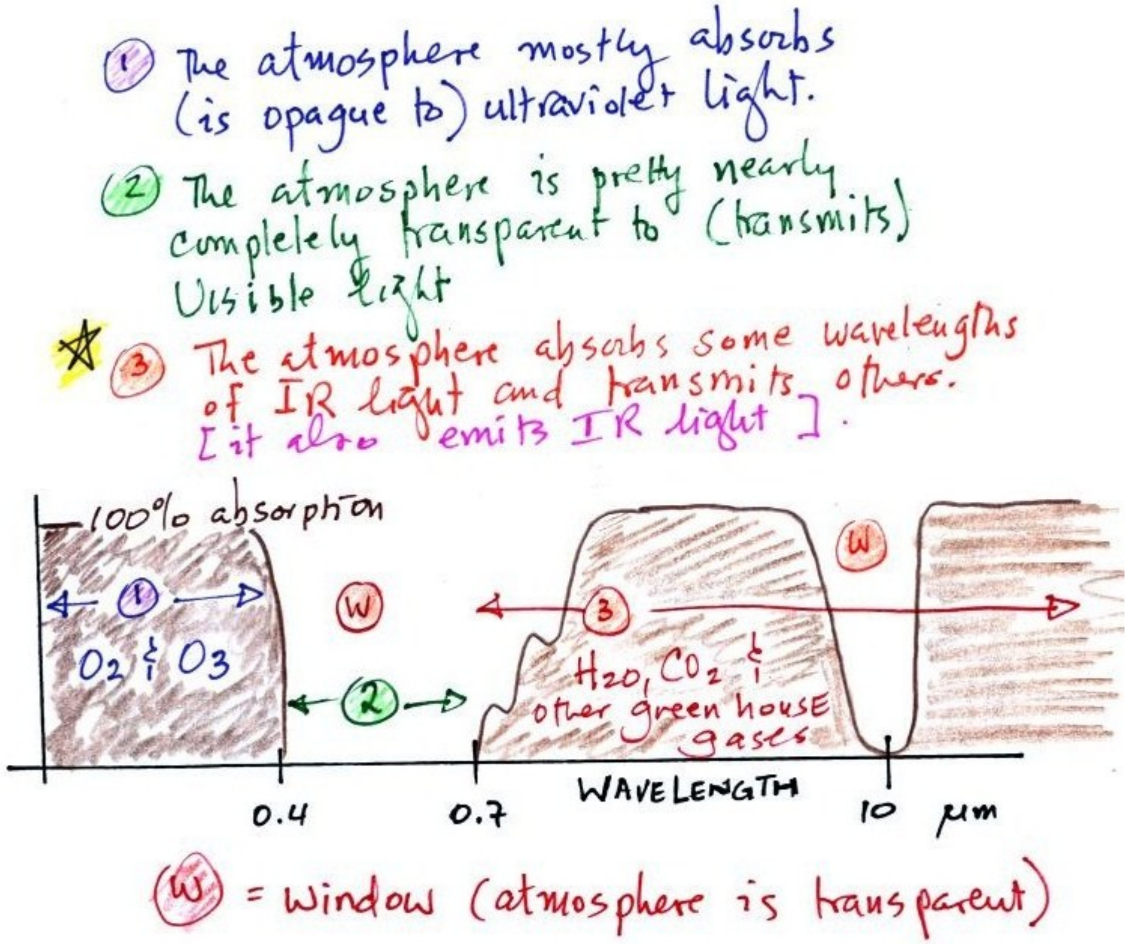




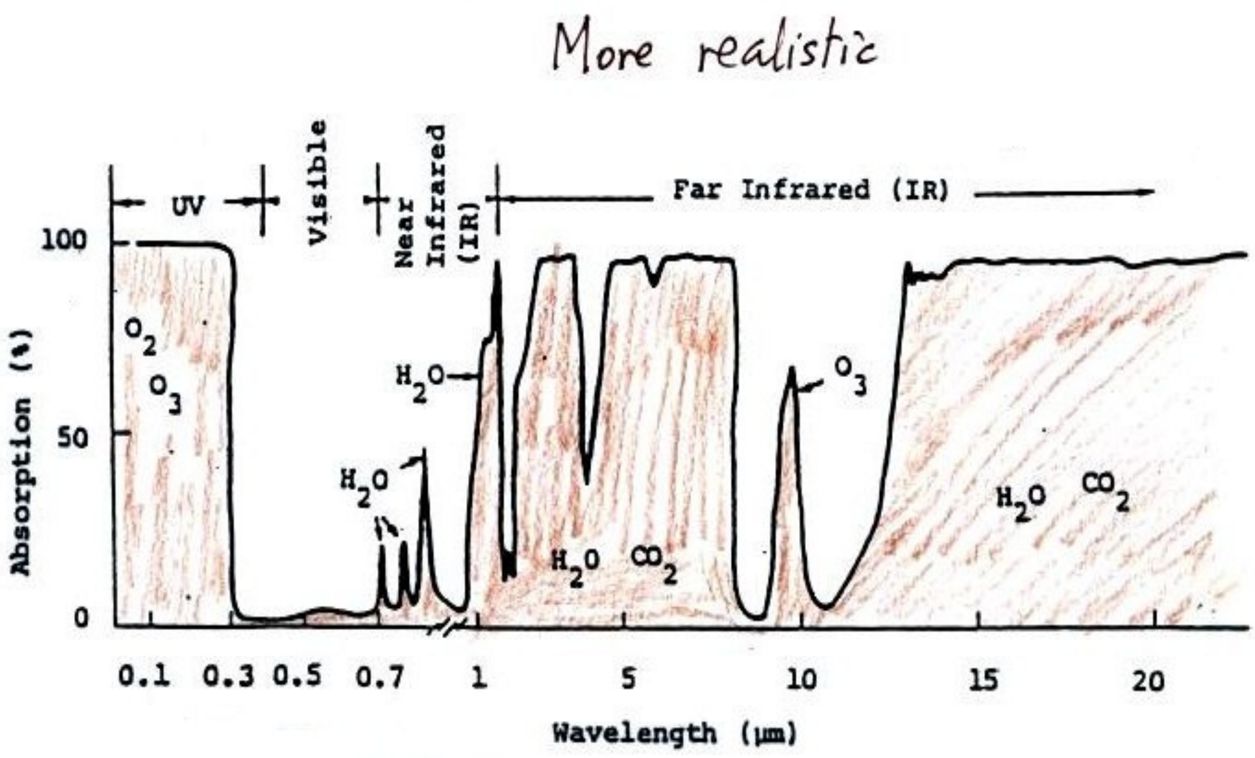


The following figure is a <u>simplified</u> filter absorption curve for the atmosphere on ultraviolet, infrared and visible light. You already know from your own observations that air is clear to visible light. In other words, the atmosphere transmits visible light. Oxygen and ozone reactions in the stratosphere make the atmosphere almost completely opaque to ultraviolet light. We will assume that the atmosphere absorbs all incoming ultraviolet light and that no ultraviolet light reaches the ground. This is, of course, not entirely accurate. Greenhouse gases make the atmosphere a selective absorber of infrared light; the atmosphere absorbs certain infrared wavelengths and transmits others. It is the atmosphere's ability to absorb (and also emit) certain wavelengths of infrared light that produces the greenhouse effect and warms the surface of the earth.

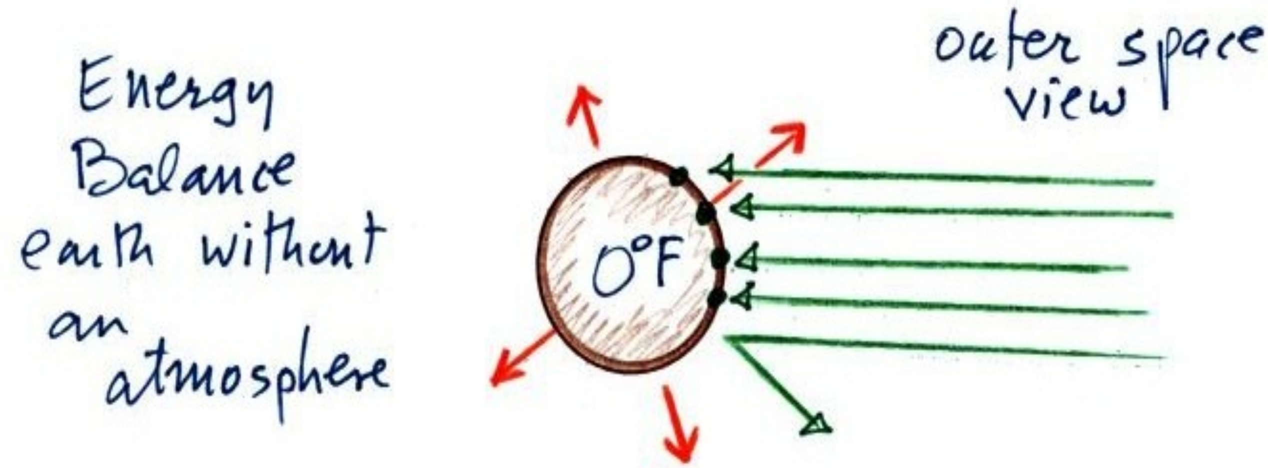
Note the "atmospheric window" centered at 10 micrometers. Light emitted by the earth at this wavelength (and remember 10 um is the wavelength of peak emission for the earth) will pass through the atmosphere. Another transparent region, another window, is found in the visible part of the spectrum.



A more realistic picture of the atmospheric absorption curve is shown below. The simplified version above will work well for us.

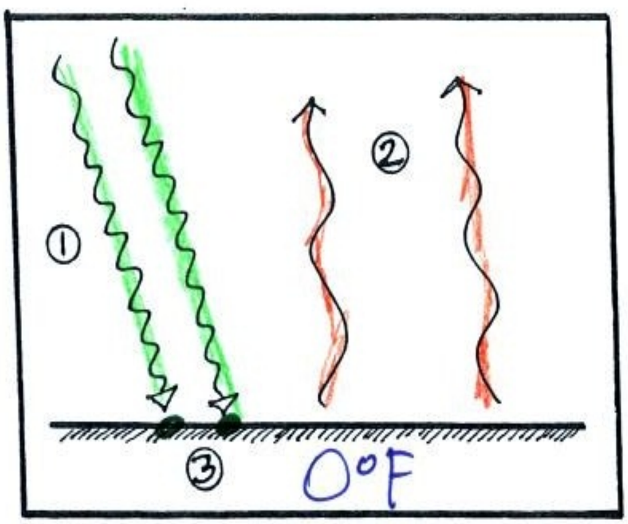


Now we will discuss radiative equilibrium. The figure below shows the outer space view of the earth without an atmosphere. The important thing to note is that the earth is absorbing and emitting the same amount of energy (4 arrows absorbed balanced by 4 arrows emitted).



The next figure shows the earth without an atmosphere from the vantage point of the earth's surface. Do not let the fact that there are four arrows are being absorbed in the previous figure and two arrows absorbed and emitted in this figure concern you. The important thing is that there are equal amounts being absorbed and emitted in both cases.

Radiative equilibrium on the earth **without** an atmosphere



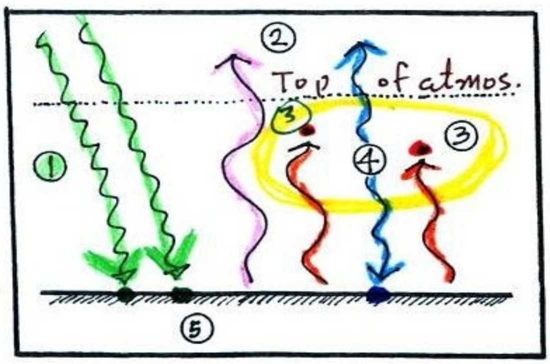
① 2 arrows of incoming sunlight absorbed by the ground.

② 2 arrows of IR light being emitted by the ground – they go back out into space.

③ Temperature of radiative equilibrium = 0°F

The next step is to add an atmosphere. The figure below is a **simplified version** of radiative equilibrium on the earth with an atmosphere. The radiative equilibrium temperature of the earth with an atmosphere is 60^0F or 289^0K. This is the temperature of the atmosphere is compared to the 300^0K which is the average temperature of the surface of the earth.

Radiative equilibrium on the earth with an atmosphere that contains greenhouse gases. "Simplified version"



① 2 arrows of incoming sunlight it's all transmitted by atmosphere.

② IR light emitted by the ground at a wavelength that passes through the air without being absorbed and goes out into space.

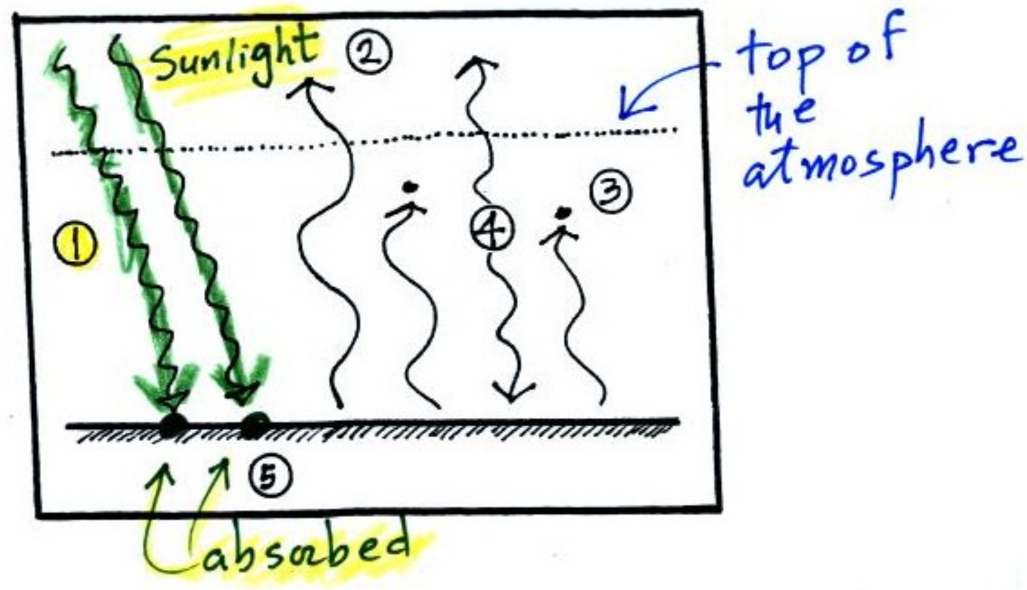
③ IR light emitted by the ground that is absorbed by greenhouse gases in the air

④ IR light emitted the atmosphere. There are 2 arrows: one goes up and into space, the other goes down & gets absorbed by the ground.

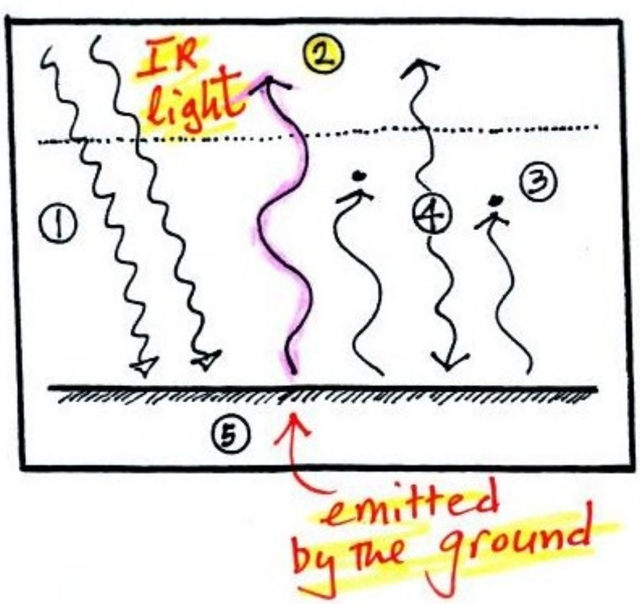
⑤ Temp at which this balance occurs ~ 60 °F.

check for energy balance at ground ✓ in the atmosphere ✓ and above the atmosphere. ✓

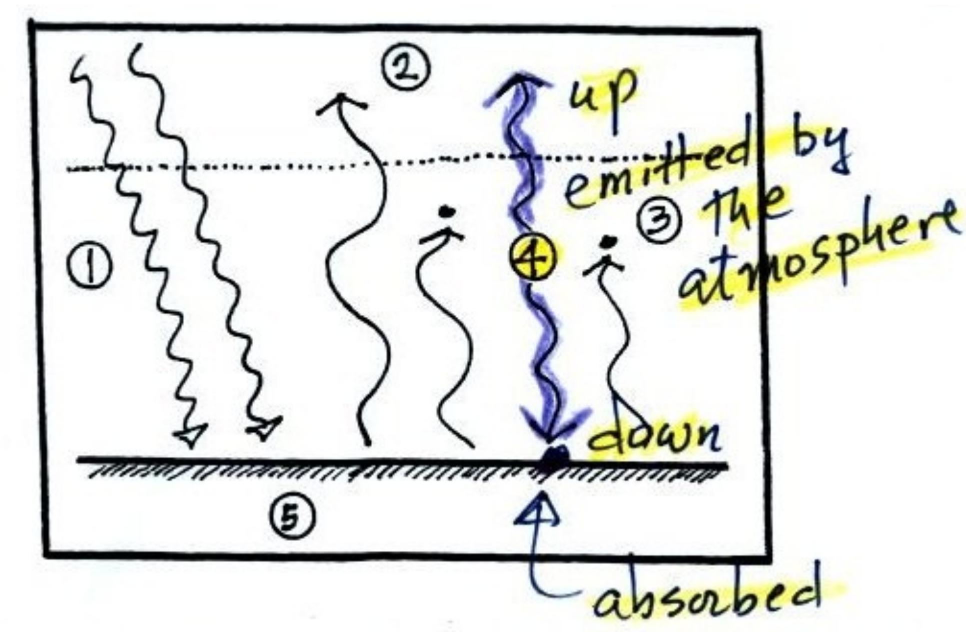
We will now examine various parts of the previous figure individually. This figure illustrates how visible light is transmitted through the atmosphere and is absorbed by the ground. The figure shows two rays of incoming sunlight that pass through the atmosphere, reach the ground, and are absorbed. All of the incoming sunlight is assumed to be transmitted through the atmosphere. This assumption is not true because sunlight is about half IR light and some of that is going to be absorbed.



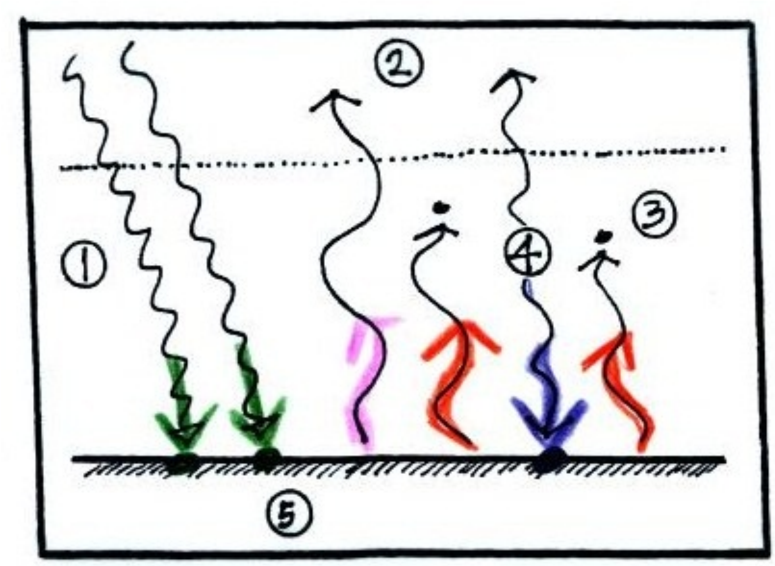
The ground is emitting three rays of infrared radiation. One of these (pink arrow) is emitted by the ground at a wavelength that is NOT absorbed by greenhouse gases in the atmosphere. This radiation passes through the atmosphere and goes out into space. The other two units of infrared radiation emitted by the ground are absorbed by greenhouse gases is the atmosphere.



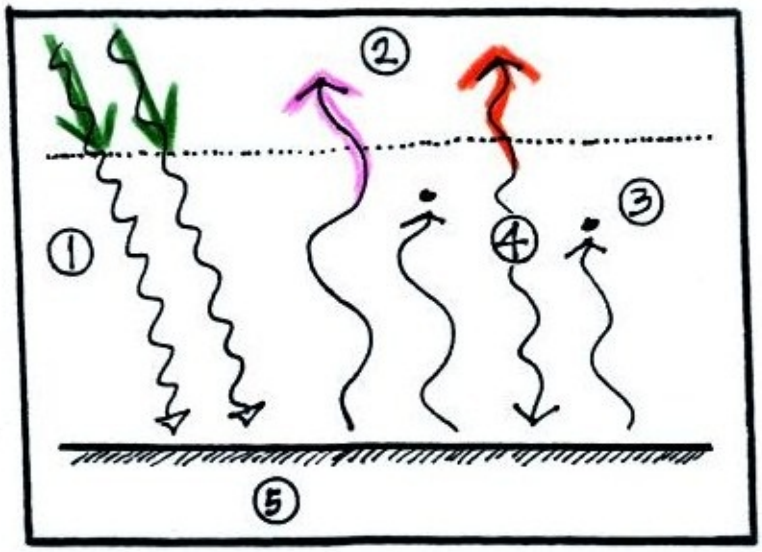
The atmosphere is absorbing two units of radiation.   In order to be in radiative equilibrium, the atmosphere must also emit two units of radiation. One unit of infrared radiation is sent upward into space and one unit is sent downward to the ground where it is absorbed.



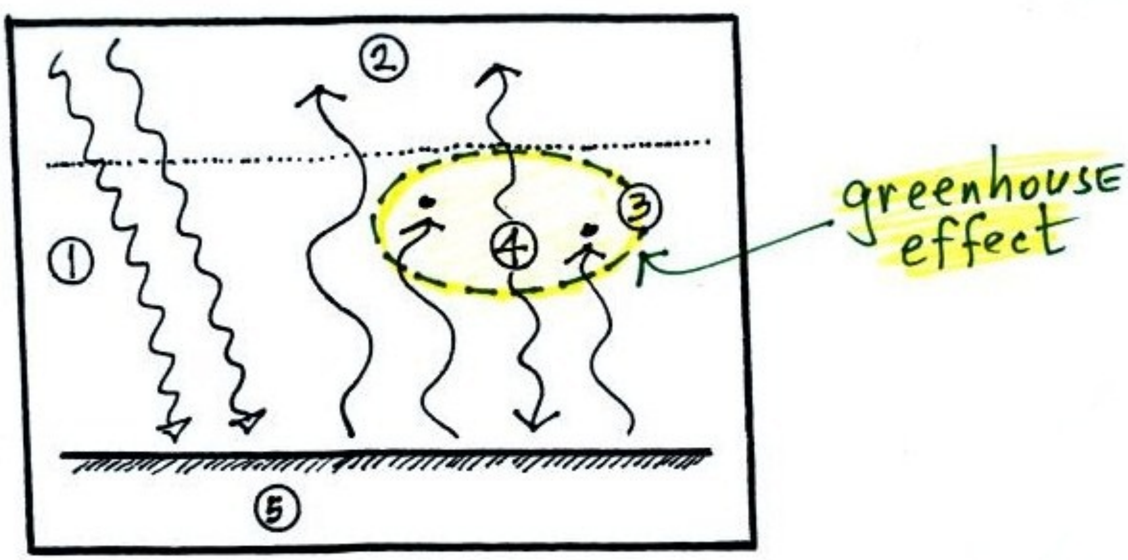
Before we go any further we will check to be sure that every part of this picture is in energy balance. The ground is absorbing 3 units of energy (2 green arrows of sunlight and one bluish arrow coming from the atmosphere) and emitting 3 units of energy (one pink and two red arrows).



The atmosphere is absorbing 2 units of energy and emitting 2 units of energy.



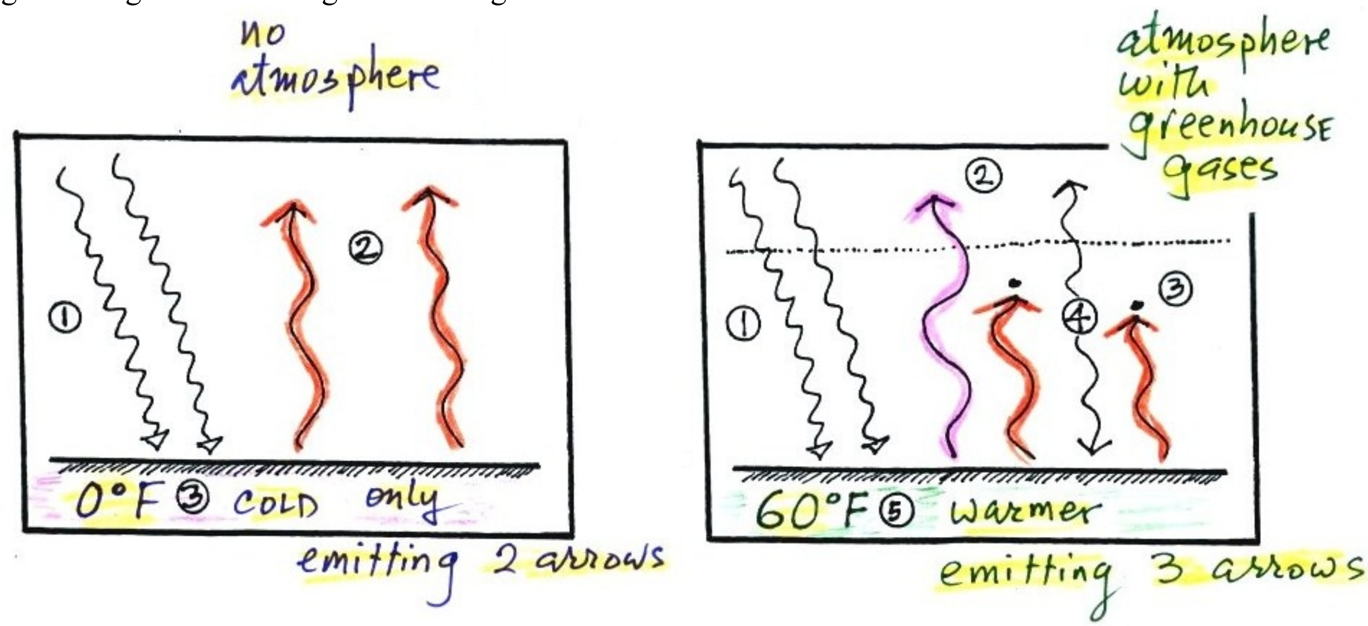
2 units of energy arrive at the earth from outer space, 2 units of energy leave the earth and head back out into space.



The greenhouse effect is found in the absorption and emission of IR radiation by the atmosphere. Here's how you might put it into words:

Greenhouse Effect
Some of the IR radiation emitted by the earth's surface is absorbed by greenhouse gases (rather than passing through the atmosphere and going into space). The atmosphere then emits IR radiation upward & downward. The ground effectively gets back some of what it would otherwise have lost.

The greenhouse effect warms the surface of the earth. The figure below shows the energy balance without an atmosphere (left) and the energy balance with an atmosphere that contains greenhouse gases (right). At left the ground emits two units of energy, but with greenhouse gases the ground at the right is emitting three units.



We know from the Stefan-Boltzmann Law that the amount of energy emitted by an object depends on its temperature. Because the ground in the right picture emits three arrows instead of two arrows, it must be warmer. Why is do greenhouse gases make the surface warmer? The greenhouse gases radiate energy back to the ground. In effect, the ground receives three units of energy instead of two and the ground becomes warmer. Without greenhouse gases, the earth would be a frozen ball of ice instead of a hospitable 60^0F.