I. Objectives

1. Investigate basic principles of the transfer of radiation through Earth's atmosphere.
2. Distinguish the difference between incoming "short-wave" solar radiation and outgoing "long-wave" thermal radiation.
3. Investigate the relationship between infrared-absorbing gases and the fundamental cause of the atmospheric greenhouse effect.

II. Introduction

The main source of energy available on Earth is the electromagnetic radiation (E&M) emitted by the Sun. This solar E&M radiation consists mainly of wavelengths of light in the 'visible' portion of the spectrum. Because the sunlight incident on the Earth is not appreciably absorbed by gases in the atmosphere, "short-wave" solar radiation reaches the ground where some of it is absorbed, resulting in the heating of Earth's surface. The emitted "long-wave" thermal radiation from the warmed surface is sent back up into the atmosphere. Depending on the concentration of infrared-absorbing constituents (e.g., carbon dioxide and water vapor), the atmosphere will then re-radiate some of that absorbed infrared [IR] energy. A portion of the IR radiation is sent back down toward the surface, thereby increasing the temperature near ground-level above what it would be without the presence of "greenhouse" gases.

III. Prelab Definitions

1. electromagnetic radiation

2. wavelength

3. visible spectrum

4. infrared [IR] spectrum

5. Short-wave radiation

6. Long-wave radiation

7. absorption

8. emission

9. albedo

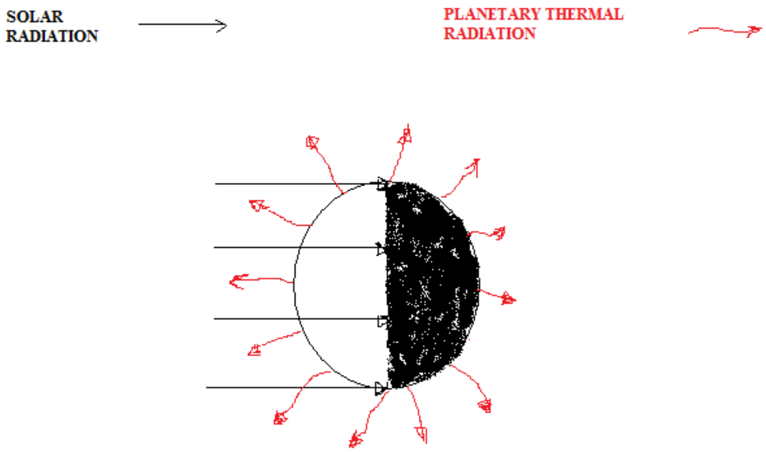
10. thermal equilibrim

11. blackbody

12. greenhouse gas

IV. Lab Procedure

The diagram below (prepared by Dr. D.X. Kerola) depicts the transfer of short-wave solar radiation to the Earth and the re-radiation of long-wave thermal radiation by the heated planet. Incoming sunlight (which illuminates only the sun-facing hemisphere) is indicated with the straight lines, while the outgoing planetary radiation is emitted in all directions to space.



For radiative equilibrium, the absorbed solar irradiance multiplied by the projected sun-facing circular area, must equal the outgoing thermal radiation ($F_{thermal}$) multiplied by the full surface area of Earth. Because our planet rotates, the incident sunlight will ultimately heat the entire earth surface in the course of a day.

The entire surface area of Earth is given as:

$$A_{earth} = 4\pi R_E^{\,2}$$

where R_E is the radius of the Earth

The projected circular area illuminated by the sunlight is:

$$A_{projected} = \pi R_E^{\,2}$$

Radiative balance requires:

$$(1-\alpha)\, S\, \pi R_E^{\,2} = F_{thermal}\, 4\pi R_E^{\,2}, \qquad \text{equation 1}$$

where S is the *solar constant* (1370 watts/m^2) and $\alpha = 0.30$ is the albedo (or reflectivity) of the Earth. The quantity $(1-\alpha)$ therefore represents the fraction of the incident sunlight *absorbed.*

1. Solve for the quantity $F_{thermal}$ in equation 1, above. [Hint: Divide both sides by $4\pi R_E^{\ 2}$]
Show your work and be sure to use the correct units.

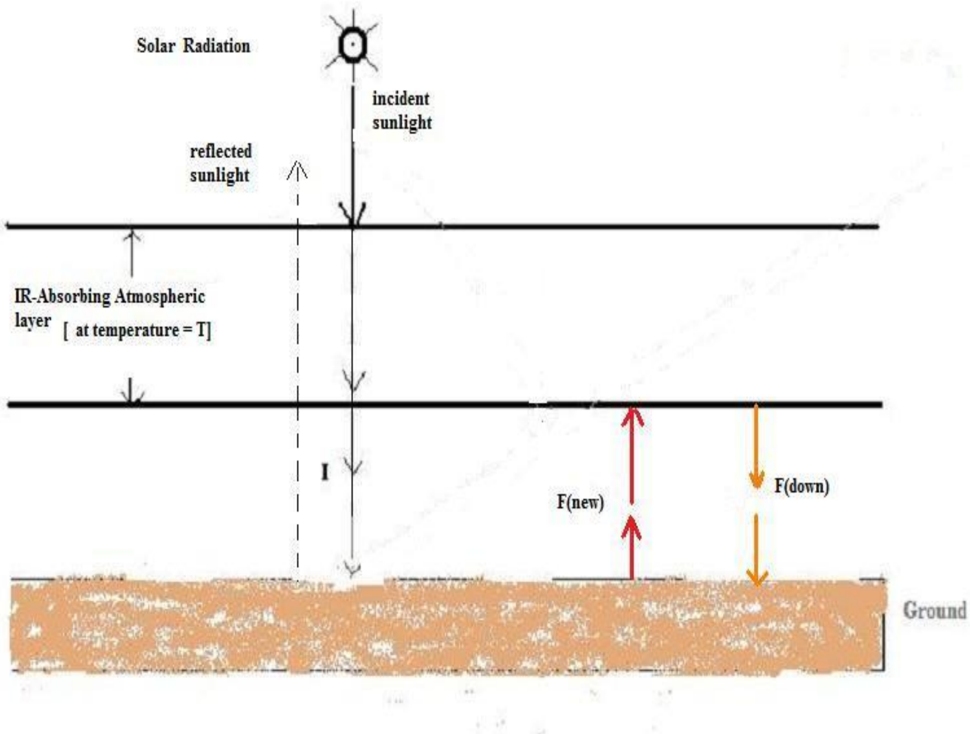
The outgoing thermal radiation from Earth that you determined in problem 1 is often referred to as *blackbody* radiation. A blackbody is an idealized perfect absorber and perfect emitter. The Stefan-Boltzmann Law relates the energy of a blackbody to its temperature. We express it as follows as it relates to the blackbody, or *equilibrium* temperature of earth's surface.

$$F_{thermal} = \sigma T_{equil}^{\ 4},$$

where $\sigma = 5.67 \times 10^{-8}$ Watts m^{-2} $°K^{-4}$

2. Solve for the equilibrium temperature. **Show your work and write your answer in kelvins.**

We insert now an idealized "atmospheric layer" into our model of radiative equilibrium. Gases which comprise the layer absorb strongly in the thermal IR, so a new situation arises depicted in the sketch below (courtesy D.X. Kerola)



Our model atmosphere will now radiate an amount of thermal energy back toward the ground, given by:

$$F_{thermal} = F_{down} = \sigma T_{equil}^{4}$$

So, now we can find a "new" elevated temperature *due to the greenhouse effect*.
The new thermal flux upward from the ground is twice what it was before the introduction of our ideal IR-absorbing atmospheric layer. We write:

$$F_{new} = 2F_{thermal},$$

or

$$\sigma T_{new}^{4} = 2\sigma T_{equil}^{4}$$

3. Compute the new, "greenhouse-caused" ground temperature, T_{new} . (Use the value T_{equil} you calculated in problem 2.).

4. What do you conclude based on your calculation in problem 3? By approximately how much has the insertion of an atmospheric layer raised the near-ground temperature above what it was without the layer?

V. Lab Discussion

The crude model presented in these lab problems vastly oversimplifies what atmospheric scientists have to account for in order to accurately determine the magnitude of global warming caused by the so-called greenhouse effect (or more realistically the "atmosphere effect"). Nevertheless, our present exercise serves to illustrate the physical elements of the problem.

1. What gases in the Earth's atmosphere are important in contributing to the greenhouse effect and to global warming?

2. In what portion of the E&M spectrum do these greenhouse gases have a majority of their absorption features [or absorption *bands*]?

3. Can you think of other non-gaseous components of Earth's atmosphere which might help contribute to the greenhouse effect? Explain.

Lab courtesy of Dr. Dana Kerola