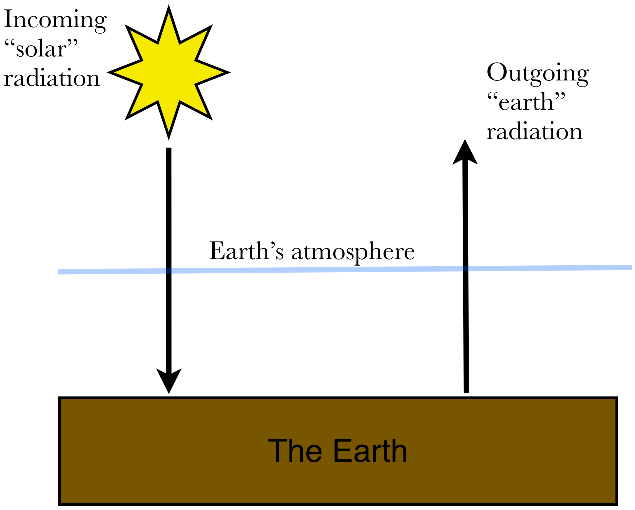
Calculating a Planet's Temperature:

Student Worksheet

A laboratory experiment from the Little Shop of Physics at Colorado State University

Learning Objective:

The rate at which energy leaves the planet depends on its' temperature. A stable temperature of a planet is a result of balancing the energy. The temperature of the Earth depends on the balance between energy coming in and energy leaving the atmosphere to space. If the incoming heat in the atmosphere is increased, the planet's temperature will increase until it emits enough outgoing radiation to balance the incoming radiation.



If Energy In = Energy Out, energy is balanced and temperature will remain constant.

If Energy In > Energy Out, temperature will increase until energy out is equal to energy in.

If Energy In < Energy Out, temperature will decrease until energy out is equal to energy in.

Questions:

1. The average temperature of the Earth has been relatively stable for the last 10,000 years. What factors do you think influence our planet's temperature?

2. What are some of the underlying forces that could cause a planet's average temperature to change (including both cooling and heating effects)?

Activity: Calculate planetary temperature using energy balance

Step 1 - Gaining and losing energy

A. Energy IN:

On average, the rate at which radiation reaches the earth's surface is **364 J/s/m2**.

Joules are units of energy.

Watts (W) are units that describe the flow of energy in joules per second (J/s). W=J/s

Energy flows into and out of the earth as W/m2 - the flow of energy coming in or going out of each square meter on earth.

Therefore, we can say **Energy IN$_{\text{earth}}$ = 364 J/s/m2, or 364 W/m2**

B. Energy OUT:

The rate at which the planet radiates energy back to space depends on the Stefan-Boltzmann constant (using the Greek symbol sigma) multiplied by the avg. temperature of the planet in Kelvins to the fourth power.

Therefore, **Energy OUT** = σT^4

= (Stefan-Boltzmann constant) (avg Temp$_{\text{planet}}$ in Kelvins to the fourth power)

= $(5.67 \times 10^{-8} \text{J/s/m}^2\text{/K}^4)\ T^4$

To calculate Energy OUT, we need to know the average temperature of the planet. Let's start with an **average T** of the earth's surface, which is **283K**.

1. **Calculate the rate at which the energy leaves the earth.**

Energy OUT = σT^4

=

=

A. Incoming radiation (W/m2)	B. Outgoing radiation (W/m2)

2. **Is there an energy imbalance? Circle the correct symbol.**

Energy IN >, <, = Energy OUT

C. Will the planet warm or cool to adjust?

Incoming - Outgoing = Net radiation

Circle the correct statement:

Net Radiation is positive, Temp will increase

Net radiation is negative, Temp will decrease

Net Radiation is balanced, Temp will be stable

D. Calculating the temperature change due to energy imbalance

The change in temperature depends on the balance between the rate of incoming radiation and the rate of outgoing radiation. It also depends on the heat capacity of the planet which is how quickly it heats up (wood heats up slower than metal due to different heat capacities).

The heat capacity of the earth = 4×10^8 J/K/m^2 (Translation: it takes 4×10^8 Joules to raise the temperature of 1 m^2 by 1 K)

[Note: To keep track of units, if W = J/s; **J = Ws**]

1. **Calculate the temperature change**

TEMP Change (in Kelvins) = (IN - OUT) x TIME (seconds in a year) / HEAT CAPACITY

=

=

E. Calculating the ***new*** global temperature

1. **Calculate the new global temperature at the end of one year:**

NEW TEMP = OLD TEMP + TEMP CHANGE

=

=

Step 2 - We have completed the first row together. Now, continue, but with a new scenario - this will teach you how scientists can predict temperature change and how climate change really works.

<u>Scenario</u>: Incoming radiation increases by 5%. Record the new value in Column A, "Incoming Radiation" for Year 1. (Instead of using a 5% increase, students may want to research the literature for an estimated value of incoming radiation increase based on a predictions for a doubling of CO2 in the atmosphere.)

A. Record the new rate of "Incoming Radiation" in Column A - this will be the same value for each year starting at Year 1.

B. Calculate "Outgoing Radiation." In this calculation, always use the previously calculated "Temp of Planet" from Column E (refer to Step 1: B)

C. Calculate Net Radiation - difference between IN - OUT (refer to Step 1: C)

D. Calculate the "Change in Temp" (refer to Step 1: D)

E. Add the new temp to the old temp for the "Temp of Planet" - Column E (refer to Step 1: E)

F. Convert from Kelvin to Celsius - Column F

Time (years)	**A. Incoming Radiation (W/m2)**	**B. Outgoing Radiation (W/m2)**	**C. Net Radiation Incoming - Outgoing Radiation**	**D. Change in Temp (K)**	**E. Temp of Planet (K)**	**F. Temp of Planet (°C)**
0 (present)	364	363.8	0.2	0.024	283.024	9.87
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

The "Net Radiation" of Column C is an important indicator of energy balance. When radiation IN - OUT begin to oscillate at zero, you have created at a new equilibrium energy balance - at a new stable temperature for the planet!

Step 3 - Input your data into a graphing software such as Excel. Make three graphs.

A. Incoming and Outgoing Radiation (W/m2) vs. Time

B. Incoming - Outgoing Radiation vs. Time

C. Temp (C) vs. Time

Step 4 - Questions:

- **What was the starting temperature (in degrees C)? ___________________________**
- **What was the final temperature (degrees C)? ____________________________**
- **How long (in years) did it take for the energy to balance? ______________________**
- **The outgoing radiation increased each year, but why did the increases get smaller each successive year? ___________________________________**