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The following unit covers key concepts in the Earth Science syllabus: electromagnetic spectrum, wavelength, insolation, the angle of insolation, the Greenhouse Effect, the solstices and equinoxes, absorption of light energy by color and texture, the First Law of Thermodynamics, specific heat, conduction, convection, radiation.

Integrated into this 11 page document are how the features of the pizza box solar ovens relate to these concepts and the directions for their construction. All materials needed to build the ovens can be purchased in a supermarket and/or stationary store with the exception of the pizza boxes themselves which can be obtained from a local pizza shop for a small fee (must be new and clean).

We have found that using the pizza box concept – and the corresponding tasty treats they produce – is key to involving young people in experiential learning that really has an impact. While concepts as listed above can seem abstract without context, seeing them in action inculcates the lessons and makes them more real and enduring.

The ideal time to employ the curriculum is when you have sufficient solar energy to power the pizza box ovens i.e. in the Northeast United States from April 1 through November 15 with the hottest months producing the quickest and most dramatic results. That said, we have seen ovens reach 275 degrees in 25-30 minutes in May making for exciting demonstrations and enthusiastic participants. In the past decade, GrowNYC has programmed this unit for over 6,000 students in NYC intermediate and high schools and Earth Science teachers have remarked about the positive impacts this experiential learning unit has on test scores and performance.

Solar Ovens and Earth Science

A. Introduction- Earth Science Background Information

Solar radiation is part of the broader **electromagnetic spectrum**, a scale of energy types that are given off as transverse waves. The strength and intensity of differing electromagnetic outputs vary due to wavelength and wave-frequency. **Wavelength** is the distance between two successive, identical points on a wave, i.e. one peak to the next. **Wave-frequency** is the rate at which it takes an entire wavelength to pass in one second. Length and frequency are inversely related, meaning as a wave's length gets longer its frequency is less. The greater a wave's frequency and shorter the wavelength, the more energy the wave carries. This is because short-wave radiation travels faster, carrying energy to a destination in less time (See Figure 1). (1)

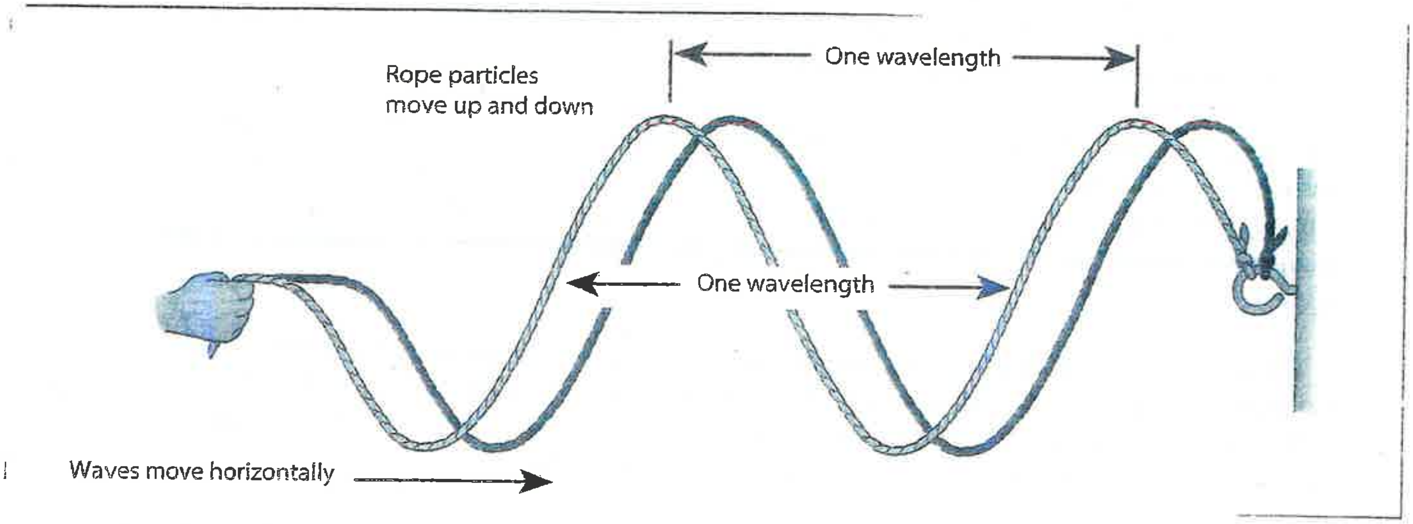

Figure 1: A transverse wave
Callister, Jeffrey C. *Earth Science: The Physical Setting*. Pearson Prentice Hall, 2006. Pg. 70

Note: Footnotes in Section A correspond to preceding diagrams and text

The Sun's rays are comprised of four different types of electromagnetic energy including X-rays, ultraviolet (UV) radiation, visible light, and infrared radiation. The strength and intensity of these different outputs vary because of their different wavelengths. Short-wave radiation, like X-rays and UV, carries more energy while the long-wave type, like visible light and infrared, carries less (See Figure 2). (2)

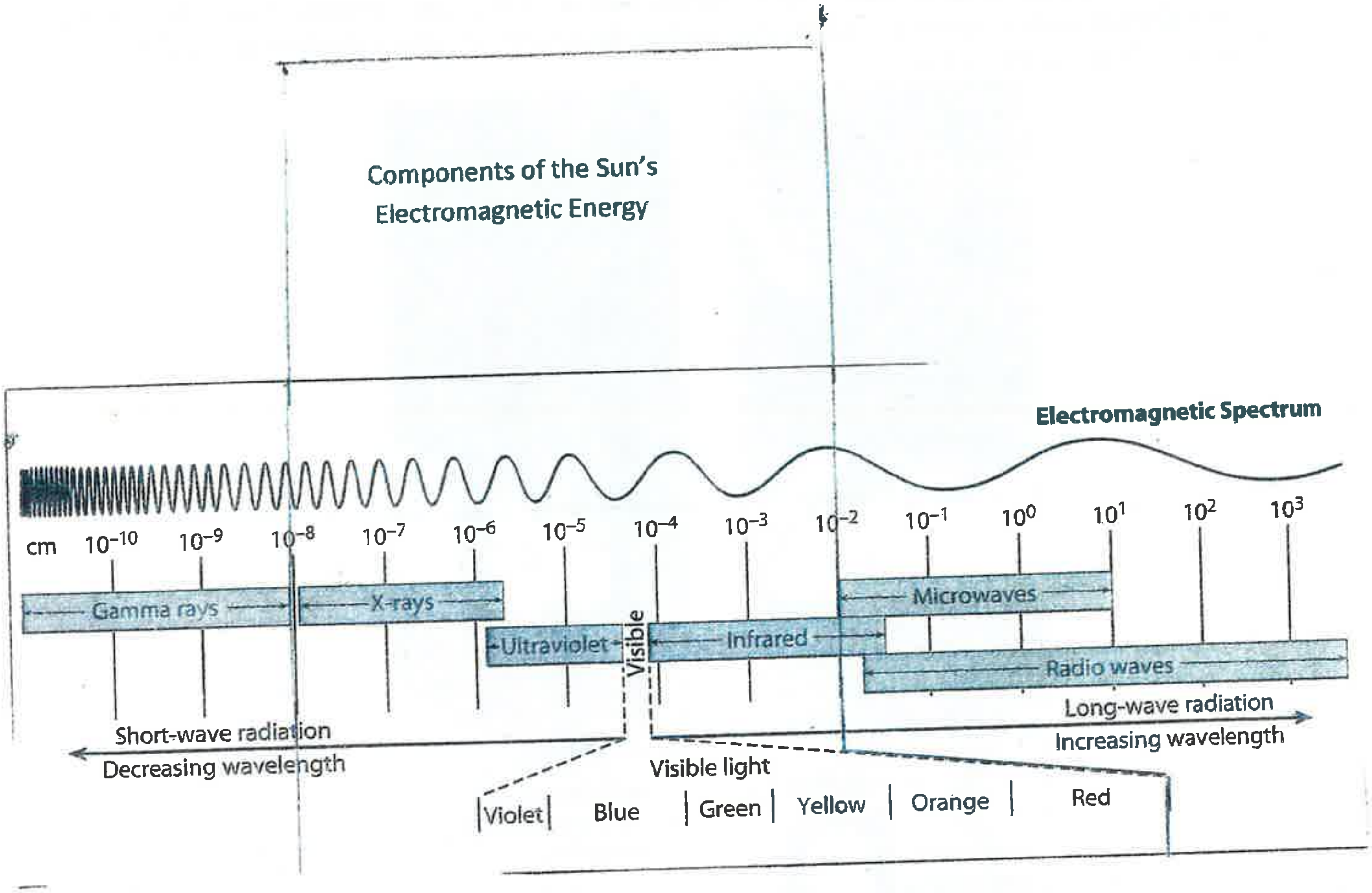

Figure 2: The electromagnetic spectrum. The components of solar radiation (X-rays, UV, visible, and infrared) are boxed in.

2. Ibid, Callister, pg. 71

2. Before solar radiation comes in contact with us living here on the Earth's surface, it must first pass through the atmosphere. **Insolation** is the amount of solar electromagnetic energy that hits Earth's outer atmosphere. It is comprised of 47% infrared radiation, 46% visible light, and 6% ultra violet radiation. Insolation is greatly altered by our atmosphere as only 50% actually makes it to Earth's surface. Most UV and other shorter wave radiation is absorbed in one of Earth's upper atmospheric layers (stratosphere) by an oxygen gas (ozone) that resides there (the ozone layer). Infrared and other short-wave radiation is also absorbed but by different atmospheric gases such as water vapor, carbon dioxide (CO_2), and methane. Insolation can also be reflected back to space by clouds, decreasing the amount of solar radiation we receive even further (See Figure 3). (3)

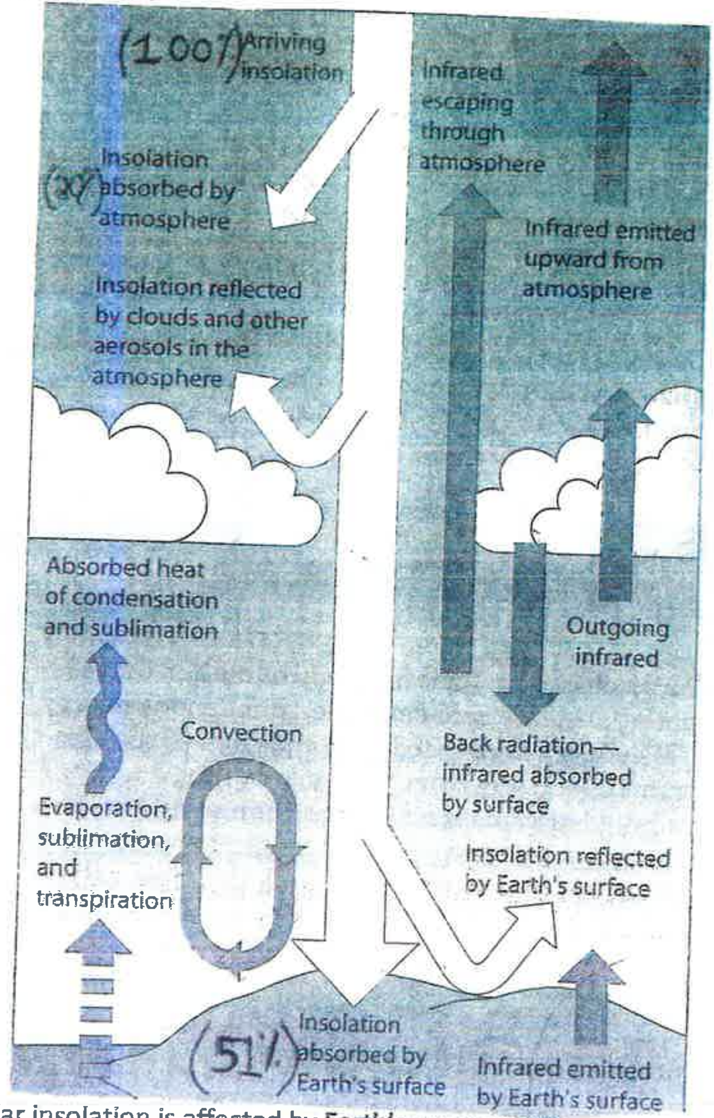

Figure 3: How solar insolation is affected by Earth's components.

Note: 19% of solar insolation is *absorbed* by the atmosphere, 4% is *reflected* by the atmosphere, 24% is *reflected* by clouds, 3% is *reflected* by Earth's surface, and 50% is *absorbed* by Earth's surface.

3. Ibid, pg. 86

The Greenhouse Effect is a natural atmospheric process that warms the Earth. When solar radiation hits Earth's surface some is reflected and some is absorbed, as we just discussed. The radiation that is absorbed heats up the ground and in order to balance its energy content, the Earth's surface radiates heat back up into the atmosphere in the form of long-wave radiation. The CO_2 and methane in the atmosphere absorb this infrared radiation and prevent the heat from returning to space, creating a hotter temperature for our planet. The Greenhouse Effect is an essential warming process that provides habitable conditions on Earth. If CO_2 levels continue to rise at the current rate, we can expect to experience a dangerously hot planet.

The amount of solar radiation that is absorbed or reflected at Earth's surface depends on two factors, the angle at which the rays strike the ground and the characteristics of the ground surface itself. Texture and color of the Earth's surface are very important in this regard. Smooth surfaces allow for more reflection as the solar waves are able to bounce off at a more direct angle. An object absorbs all colors of solar light except for the color pigment it contains. This color is instead reflected off the object and back to the human eye; i.e. we perceive a red apple as red because only red light is reflected off of it, while absorbing all other colors of the spectrum. For this reason, we can understand why white objects are best for reflection of light and why black objects are best for absorption of light. This is because white is a mixture of all color and thus all light is reflected off of it while black is the absence of all color and therefore absorbs all light.

Angle of Incidence, also called Angle of Insolation is the angle at which solar radiation strikes the Earth's surface. Different angles of incidence correspond directly to different intensities of solar radiation received by Earth's surface, altering the surface's capacity to either absorb or reflect energy waves. Simply put, the position of the sun in the sky affects how much solar radiation we receive and what happens to that radiation when we receive it. Insolation is greatest when the sun is overhead as the radiation beams down directly and concentrates the light to the smallest possible area. As the angle decreases, intensity of insolation decreases because the sun's rays become farther and farther spread out over Earth's surface. As a result, time of day is a very important factor with regards to intensity of insolation. At solar noon, 12 o'clock PM, one can experience the part of the day with the most direct sunlight. Angle of incidence is greatly affected by the seasonal patterns of the Sun. Ever wonder why it's hotter in the summer and colder in the winter? Our planet orbits around the Sun all year in an ellipse while tilted on an axis of 23.5 degrees. This combination creates a cycle of colder and warmer temperatures worldwide. We, living in the northern mid-latitudes, undergo summer weather when the northern hemisphere is tilted *towards* the Sun, increasing angle of incidence, intensifying solar insolation, and increasing temperature. June 21st, is a day we refer to as the **Summer Solstice** because the Northern Hemisphere is tilted towards the Sun at a maximum, creating the greatest angle of incidence we experience all year, around 71.5 degrees in New York at 12:00 noon. Conversely, we undergo winter weather when the Northern Hemisphere is tilted *away* from the Sun, decreasing angle of incidence, weakening solar insolation, and decreasing temperatures. December 21st is deemed the **Winter Solstice** as the Northern Hemisphere is tilted away from the Sun at a maximum, creating the smallest angle of incidence we experience all year, around 24.5 degrees in New York at 12:00 noon.

Our fall and spring seasons are determined by the time of year when the tilt of the Earth's axis is inclined neither away from nor towards the Sun. We call this occurrence an equinox and we undergo one on or around September 23rd, **Autumnal Equinox**, and one on or around March 21st, **Vernal Equinox**. At these times, New York experiences an angle of incidence around 50 degrees. In this way, we generally experience mild temperatures in the fall and spring as the solar insolation we receive is neither very strong nor weak. Since the Angle of Insolation is perpendicular to the equator during the equinoxes, the equator experiences its highest temperatures of the year. Located at the very middle of the Earth, the equator receives solar insolation at an optimizing angle of incidence at 90 degrees (See Figure 4). (4)

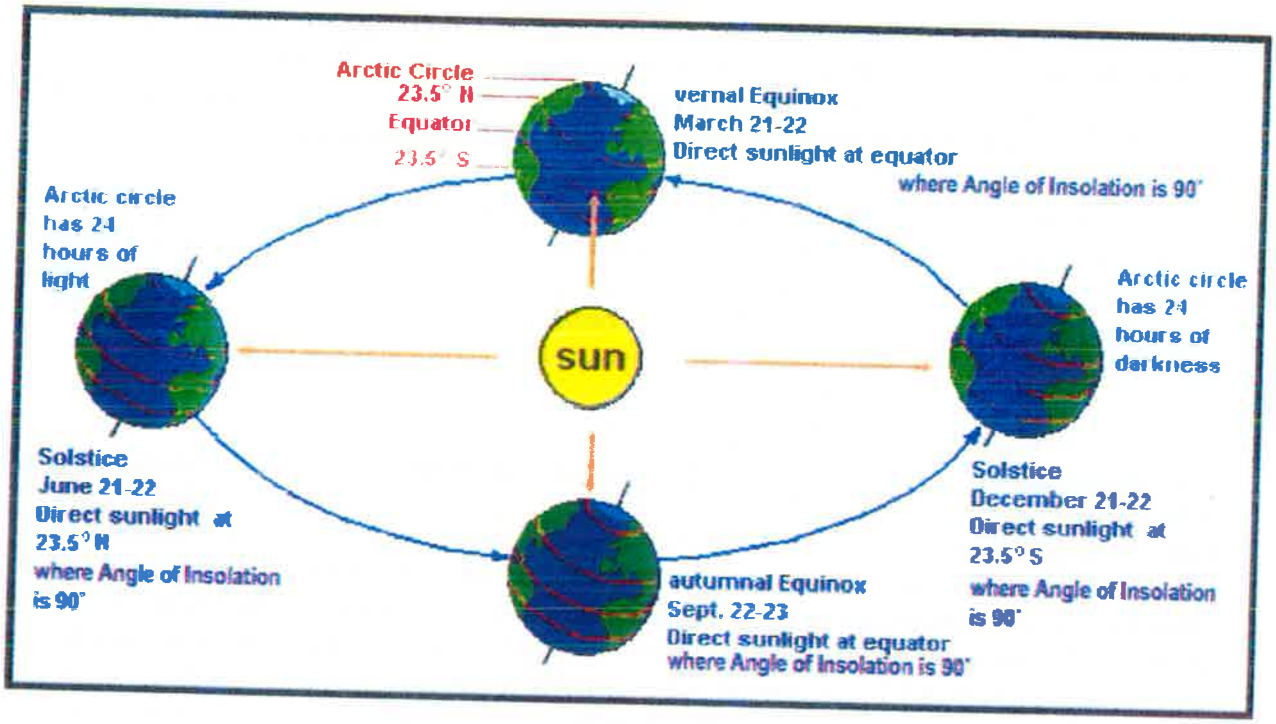

Figure 4: The rotation of Earth around the Sun and the seasonal angles of insolation it creates. **Note:** the Angle of Insolation is perpendicular (90 degrees) at the equator during the Equinoxes. The Angle of Insolation is also 90 degrees at 23.5 degrees N. and 23.5 degrees S. during the summer and winter solstices.

4. From Southeast Regional Climate Center of Columbia, South Carolina

The angle of incidence in a particular location decreases by one degree for each degree of latitude away from the point of perpendicular insolation. Conversely, the angle of incidence increases by one degree for every degree of latitude closer to the point of perpendicular insolation (See Table 1). (5)

Latitude	**Summer Solstice June 21**		**Equinoxes: March 21, September 23**		**Winter Solstice December 21**	
	Angle of Incidence at 12:00 Noon	**Duration of Insolation**	**Angle of Incidence at 12:00 Noon**	**Duration of Insolation**	**Angle of Incidence at 12:00 Noon**	**Duration of Insolation**
90° N	23½°	24 Hours	0°	12 Hours	—	0 Hours
80° N	33½°	24	10°	12	—	0
70° N	43½°	24	20°	12	—	0
66½° N	47°	24	23½°	12	0°	0
60° N	53½°	18½	30°	12	6½°	5½
50° N	63½°	16¼	40°	12	16½°	7¾
40° N	73½°	15	50°	12	26½°	9
30° N	83½°	14	60°	12	36½°	10
23½° N	90°	13½	66½°	12	43°	10½
20° N	86½°	13¼	70°	12	46½°	10¾
10° N	76½°	12½	80°	12	56½°	11½
0°	66½°	12	90°	12	66½°	12
10° S	56½°	11½	80°	12	76½°	12½
20° S	46½°	10¾	70°	12	86½°	13¼
23½° S	43°	10½	66½°	12	90°	13½
30° S	36½°	10	60°	12	83½°	14
40° S	26½°	9	50°	12	73½°	15
50° S	16½°	7¾	40°	12	63½°	16¼
60° S	6½°	5½	30°	12	53½°	18½
66½° S	0°	0	23½°	12	47°	24
70° S	—	0	20°	12	43½°	24
80° S	—	0	10°	12	33½°	24
90° S	—	0	0°	12	23½°	24

Table 1: Variation in insolation by latitude and season

5. From Earth Science: The Physical Setting, pg. 91

B. Integration- Earth Science and Solar Ovens

Today, it is important for our global community to come together under the realization that we must make a change in the way we use and think about energy. It is crucial that we begin to move away from our uses of emission-intensive fossil fuels and head towards an era of sustainable, clean energy sources. The Sun is an infinite natural resource that we as humans have yet to take full advantage of. If we look to and try to learn from the natural workings of our planet as an example, we can see that through photosynthesis, solar energy is used to power the complex, interconnected cycles that allow life to exist. If the Sun is capable of sustaining all life on Earth, it is certainly capable of meeting some of our energy needs.

In recent years, several organizations have set up solar ovens for many families in Africa, Asia, and Central and South America so people can begin to harness the natural and clean power of the Sun. Solar energy has significantly improved the lives of tens of thousands of people, allowing them to not only prepare nutritious food for their families but to purify drinking water, treat infectious diseases, and preserve food, without harming the environment!
The solar oven we plan to build has been adapted from many designs. The pizza box solar oven is capable of reaching temperatures of 275 degrees, hot enough to cook some food. Our ovens will be constructed from these materials: **a recycled pizza box, black construction paper, aluminum foil, clear plastic wrap, scissors, glue, and tape.** Our first step will be to construct the flap that will act as our solar collector. To do this, **draw a one inch border around all four sides of the top of the pizza box. Cut along three sides of this border, leaving an uncut line along the back of the box. Form the flap by gently folding back along the uncut line to form a crease** (See Figure 5). (6)

Figure 5: How to create the reflective flap for our oven.

6. Solarnow.org

Cut a piece of aluminum foil to fit on the inside of the flap. Smooth out any wrinkles and glue into place. We use aluminum foil because it has a reflectivity of 88% (shiny side up) meaning 88% of incident radiation that hits the foil is reflected off of it. We can use this reflected solar radiation to power our oven. In addition, aluminum foil is a product that can be recycled easily and efficiently. Remember, the smoother the surface the better the reflectivity so be sure to glue your foil on smoothly.

We can use our knowledge of solar angular incidence to optimize the amount of radiation our ovens receive. We always want to be gathering light at or around 12 o'clock noon in order to capture the strongest radiation of the day. For every minute before or after 12 noon, the Sun will be lower in the sky, creating a smaller angle of incidence, and weaker solar insolation. During the summer, we will achieve the greatest temperatures for our oven as the Sun reaches its highest angle, allowing us to capture more direct sunlight; while in the winter, we will record our lowest temperatures for the opposite reason. The fall and spring seasons will give us mid-range results. Due to the fact that we live in the northern hemisphere, we want to direct our ovens south. This is because the equator always receives the strongest insolation and it is located south of us (See Figure 6). (7)

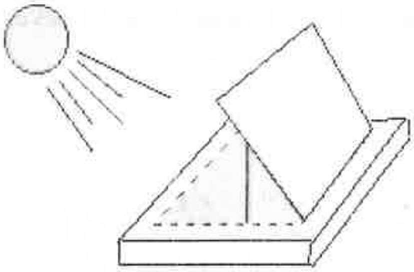

Figure 6: We position our ovens to maximize insolation collection.

7. Ibid, solarnow.org

Next, we want to create a base for our oven that will be able to get as hot as possible. **Cut out an additional piece of aluminum foil and line the bottom of the box with it using glue**; in addition**, lining the short sides of the box will increase heating area**.

On top of our aluminum lining, we want a material that will be able to absorb the solar radiation that reflects into our box. Here is where **we use black construction paper to cover the base of our ovens, using glue or tape**. We want to reflect as little solar radiation off the surface as possible while absorbing as much as possible in order to maximize the amount of heat we radiate. As we discussed earlier dark surfaces work best because they contain little or none of the color in visible light and therefore don't reflect and instead absorb the incoming light energy the best. In addition, **we can experiment with crinkling the black paper**; as we discussed earlier, rough surfaces do a better job of absorbing light. Once the light energy is absorbed it excites the molecules in the black paper which move faster and become hot. They absorb the light energy and rerelease it as longer wavelength infrared heat energy- an approximation of the process that occurs on the surface of the earth when absorbed light energy is rereleased as longer wavelength heat energy.

The first law of thermodynamics can help us understand how our oven works. This law states that energy cannot be created nor destroyed, however, its form can be changed. With our pizza box ovens, we are taking the energy from the sun and transforming it into heat.

We now need a way of trapping the heat from escaping our box. Next, **measure a piece of plastic wrap to fit over the opening you created while forming the flap. Cut the plastic**

larger than the opening so it can be taped to the underside of the flap. Also, be sure to tape the plastic to the inner sides of the top part of the box.

The oven will function like a greenhouse as solar radiation in the form of light energy goes through the plastic, turns to heat energy upon being absorbed by the black paper; the heat is then trapped by the plastic in the box.

However this is actually somewhat different than the Greenhouse effect mentioned above. When solar radiation hits the Earth's surface some is reflected and some is absorbed. The radiation that is absorbed heats up the ground and in order to balance its energy content, the Earth's surface radiates heat back up into the atmosphere in the form of long-wave radiation. The CO_2 and ethane in the atmosphere absorb this infrared radiation and prevent the heat from returning to space creating a hotter temperature for our planet.

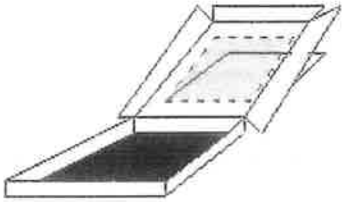

Figure 7: Our finished solar oven and its components.

8. Ibid, solarnow.org

It is important that we are able to minimize heat loss in our ovens as heat flows naturally from a warmer to a cooler space. This heat can be transferred through processes known as conduction, convection, and radiation. **Conduction** is the transfer of heat through a material by the transfer of kinetic energy from particle to particle, i.e. the flow of heat between two materials of different temperatures that are in direct physical contact. Much of our solar cooking will occur due to the conduction that results from the food plate we will use in our ovens. The latent heat will transfer from our black construction paper to the aluminum plate sitting on top of it. The hot plate will then heat up our food and help with the cooking process. **Convection** is the transfer of heat by means of air currents caused by differences in density. Warmer currents are less dense and rise above cooler currents. This results in a circulatory motion known as a convection current that transfers heat. The convection current will circulate around the inside of our ovens and increase the internal temperature. While working outside, we will need to be aware and careful to prevent the escape of our convection currents. The latent heat we create from our ovens will want to escape our pizza boxes and try to enter the cooler outside environment; therefore we need to make sure to secure our plastic wrap and create efficient insulation. **Radiation** occurs when an object emits heat; this heat then travels and eventually becomes absorbed by another object; radiation is ultimately how our oven works. Our black oven surface will radiate heat, our plastic covering will trap the heat from leaving, and our food will eventually absorb it and cook.

Other points to consider:

- How can we better insulate our ovens?
- Would extra reflective surface area help? How?
- Would more layers of plastic help? How?
- Should the shiny or dull side of the aluminum on the bottom face up, or does it matter?
- Is it better to prop the reflector up with a straw or dowel stick or to adjust it manually or does it matter?

Citations:
Callister, Jeffrey C. *Earth Science: The Physical Setting*. Boston: Pearson Prentice Hall, 2006. Print.
"Make a Pizza Box Solar Oven." *Solar Now, Inc.* 2003. Web. <http://www.solarnow.org/pizzabx.htm>.

Using the Solar Oven

These ovens will reach 275° in 25 minutes on a day when the Angle of Insolation is over 60° and can reach 200° even when the Angle is around 48° (at the equinoxes). S'mores cook quickly and effectively at these temperatures. As late as mid November around noon or as early in a calendar year as early March, at noon these ovens can reach 150°-175°. At the higher temperatures cheese, tomatoes, and basil will melt over English muffins to produce a little makeshift pizza. Vegan chocolates, no fat/low sugar graham crackers and rice marshmallows can also make a healthier version of s'mores.