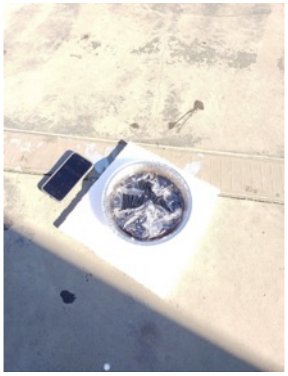


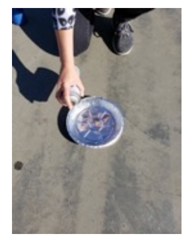
Watts Hitting the Earth

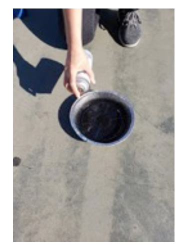
Pie Pan Solar Calorimeter

Finding out how much energy and power is delivered to the earth from our sun is a piece of cake (or Pie). Make and use a simple calorimeter to measure and calculate the number joules and watts of solar energy and power received per square meter on our planet's surface.

Tools and Materials:

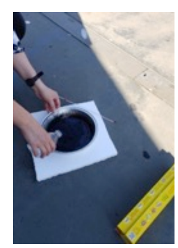
- A calm and cloudless day
- Large disposable aluminum pie pan (9 inches or larger)
- Black paint (paint and brush or spray can)
- Plastic or Cling wrap
- Quarter-liter (250ml) or half-liter bottle (500ml)
- A source of cool or room temperature water
- Thermometer
- Stopwatch
- Metric ruler
- Small sheet of Styrofoam (or other insulating material)





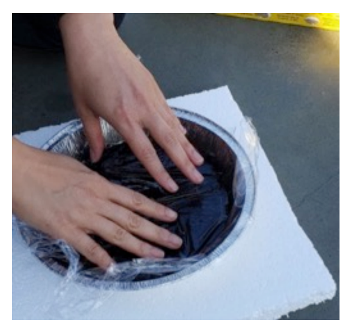
Assembly:

1. Paint the inside bottom (and only the bottom) of the pie pan black and let dry.
2. For a 9-inch pie pan use a 250ml bottle filled with water. For larger pans, use a half-liter bottle filled with water.
3. Find out when solar noon occurs at your location.
   Solar noon is the time when the sun is at its highest point in the sky in your area. This time may not coincide with 12:00pm. NASA has a good site to find this out at: https://www.esrl.noaa.gov/gmd/grad/solcalc/. Make sure you include Daylight Savings time (DST) if necessary.



To Do and Notice:

1. At solar noon, bring your supplies outside to a shady area that is next to a bright and sunny location.
2. Place the Styrofoam sheet flat on the ground in the shaded area with the painted pie pan on top.
3. Pour the water into the pan (record this amount in the worksheet below).
4. Immediately measure the temperature of the water (record this in the worksheet).
   Note: Tipping the pan to one side to increase the depth of the water will help get a better reading.
5. Place a piece of plastic or cling wrap on top of the surface of the water. This will help keep evaporation to a minimum as well as keep the absorbed heat in the water.



a. Cover all exposed water.
b. Make sure no bubbles of air are trapped under the plastic wrap.
c. Don't let excess wrap hang over the edge of the pie pan, it might get "picked-up" by any wind gusts.

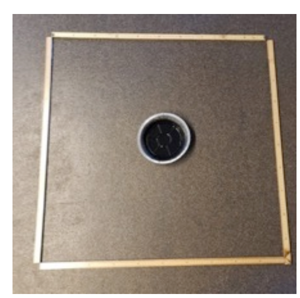
6. Move your set-up from the shade to a sunny area.
7. Start your timer.
8. Let your pie pan sit in the sun for 10 to 20 minutes.
9. Return to your device after the allotted time and immediately:
   a. Stop your timer (record this duration on the worksheet).
   b. Remove the plastic wrap and measure the temperature of the water (record this on the worksheet).
      i. Use the thermometer to do a quick stir of the water.
      ii. Tip the pan to one side to increase the depth of the water to get a better reading.
10. Empty your setup.

11. Measure the diameter of the bottom of the pie pan, i.e. the painted area (record this on the worksheet).
12. Do some calculations (see worksheet):
    a. Calculate the energy and power of your device.
    b. Extrapolate the energy and power of your device to the size of one square meter.

<u>What's Going On?</u>

You created a device called a solar calorimeter. Your device absorbed energy from the sun, a ball of blazing hot plasma, which radiated and sent energy across 93 million miles (150 million km) of space! The waves of energy arriving on the surface of the earth are about 54% infrared and 43% visible (the remainder is UV). [1] Your pie pan absorbed and transformed this radiant energy into thermal energy or heat.

Water has a known specific heat. A gram (or ml) of water will rise 1°C for every calorie or 4.2 joules of energy added to it. By doing the calculations, based on your collected data, you can figure out how much energy was absorbed by the water. Since you recorded the amount of time it took to absorb that energy, you can also calculate the power or rate at which the energy was transferred.



Once you know the power or rate of energy that your pie pan absorbed, you can extrapolate that area to one square meter by using a simple ratio.

Use the worksheet on the following page to solve the following:

- Energy transferred to pie pan
- Power or rate of energy transfer into the pie pan
- Power or rate of energy transfer into 1 m^2

Worksheet for Energy and Power

Data table

Volume of water used		in ml
Starting temperature of water (T_s)		in C˚
Final temperature of water (T_f)		in C˚
Duration		in minutes
Diameter of the painted bottom of the pie pan		in cm

Calculations for Energy transferred (in joules)

Here's the formula to use:

m·c·ΔT= **Energy**

m: the mass of the substance; in your case water, 1 ml =1 gram

m = ____________g

c: water's specific heat

4.18 joules/g·C˚

ΔT - the change in temperature

T_f - T_s = __________________ C˚

Energy: the amount of heat absorbed in joules (J)

Energy (into pie pan) = ________________joules

Calculation for Power or rate of energy transfer (in watts/ m^2)

Here's the formula to use :

Energy/ time = **Power**

Time (convert from minutes to seconds) = ____________s

Power (energy rate into pie pan)=________watts

Calculation for Power per square meter watts/:

Here's the formula to use:

1 m^2	=	watts per m^2 (this is what you're solving for)
Area of pie pan in m^2 (see below)		watts (energy rate into pie pan: from above)

Area of pie pan in m^2

Diameter of the painted bottom of the pie pan = ______________cm

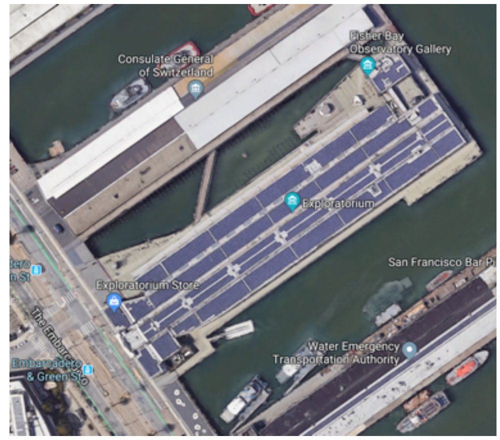
Convert from cm to m = ____________m

Radius (r)= Diameter/2 = __________ m

Area of pie pan = πr^2= __________m^2

Power = ___________watts / m^2

How does this value compare to the accepted value of power at the Earth's surface? Standard power on the earth's surface perpendicular to the Sun's rays at sea level on a clear day is approximately 1,000 W/m^2 [1].



The amount of energy hitting the surface of the earth every second is staggering and it's available to be converted to other forms of energy.

The Exploratorium, where this activity was developed has a roof with an area of about13,000 m² (see picture to the right).That means on a clear day at solar noon, there are over 13 megawatts of power hitting our roof. We placed solar cells on our roof to harvest this power. Our museum can produce up to 1.3 megawatts of power. Although that's only 10% efficient, our rooftop energy converters allow us to produce almost all our own electricity.

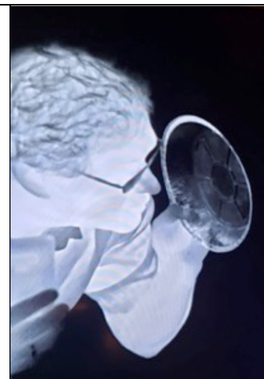
<u>Going further:</u>

- Can you answer these questions:
  - Can you design a better system that will capture even more energy?
  - How much energy could be harvested from your home or school's roof?
  - Try extending your calculations, see how much solar energy is received by the entire sun-exposed side of the earth.
  - Try estimating the total solar output of the sun with your results.
- Your calorimetric device was heated by radiation from the sun. However, all forms of energy are transformable. Could you use the sun's energy to make electrical energy? Mechanical energy? Chemical energy?

<u>Teaching tips:</u>

1. This is a great activity to begin a unit on the transformability of energy as well as introduce alternative energy systems.
2. Notice how the painted aluminum side of the pan feels cool, but as soon as you expose the black-coated side to the sun, it heats up. Use this activity to discuss reflectivity and absorption.
3. Explore how other wavelengths of light interact with various materials. If you have access to an infrared camera:
   a. How does the uncoated aluminum vs. the black painted side of the pie pan look?
   b. How does plastic wrap look in an IR camera?
   c. Look at IR interacting with other substances, like a standard plastic bottle.
   d. Does water absorb, reflect or transmit IR light?

   See below for images taken a the Exploratorium's camera

 Aluminum pie pan bottom. Note: Reflection of the IR light. Also note how opaque the plastic prescription glasses are.	 Black painted aluminum pie bottom Note: No reflections. It absorbs the light.	 Hand behind clear plastic wrap. Note: Very transparent to IR light
 Water inside a clear #1 two-liter plastic bottle. Note: The bottle opaque bottle		 Water at the bottom of a zip lock baggy. Note: The bag is clear, but the water absorbs and does not transmit IR light.

Reference:
[1]https://en.wikipedia.org/wiki/Sunlight#Composition_and_power

For another variation of this type of apparatus:
https://www.youtube.com/watch?v=12Zj7Bux5Bs