**5.2 Lab: Optics 1**

**Part 1: Blackbody Radiation and the Greenhouse Effect**

Much of the light we see comes from atoms and molecules, which are so hot they vibrate and collide with high-energy motion. Every time an atom changes the direction it is moving, the acceleration of electrons at the exterior of the atom causes light to be emitted. Objects at temperatures like the surface of the sun emit light in the visible part of the spectrum.

For a better understanding of what blackbody radiation is, read section 8.6 of the textbook (pp. 310–313), paying particular attention to the formula for the wavelength that is given the maximum power (p. 311) and example 8.4 which uses it.

A good basic video explanation can be found in [Why Do Hot Objects Glow? - Black Body Radiation](https://www.youtube.com/watch?v=Mj2QOpQkSfI&ab_channel=ButWhy%3F).

Two equations link Electromagnetic Energy (*E*) to Photon Frequency (*f*).

To explain the relation between the blackbody spectrum and temperature (which remember is related to the amount of internal energy in a body), the energy of light had to be quantized using the equation: . This led to the recognition that while light is a wave it also has properties similar to particles. A particle of light is called a photon and it is localized in space as it moves at the speed of light ().

The letter *h* stands for Planck’s Constant and is a fixed number given as or sometimes given with the unit *Js*. This is the energy in Joules of a photon with a frequency of 1 Hz. Higher frequencies have proportionately higher energies.

Since the energy of photons is so small (even high energy gamma rays have energies that are still a tiny fraction of a Joule), a smaller energy unit is often used, called an *electronVolt* (*eV*), meaning the KE energy of a single electron accelerated by a 1 Volt electric field. Plank’s Constant in *eV* is .

The second important equation is the relation between the wavelength of light that is most commonly emitted from a blackbody at a particular Kelvin temperature.

If we use the relationship between wavelength, frequency, and the speed of light   
() to express this as a frequency of peak emitted photons:

Solving the right side for the frequency, we get

From this we see that the hotter the object, the higher the peak photon frequency.

Traditionally, blackbody radiation charts have the photon wavelength along the horizontal axis, so higher energy light is on the left side.

The textbook also gives an equation that shows that the power of the radiated light (the energy emitted per second) is proportional to the area of the object and to the Kelvin temperature to the 4th power.

To see the relationship between temperature and frequency of sunlight and light emitted by the earth itself, **open the simulation** [**Blackbody Spectrum**](https://phet.colorado.edu/sims/html/blackbody-spectrum/latest/blackbody-spectrum_en.html):

The graph shows the distribution of light in terms of wavelength. In this chart, the farther to the left, the higher the frequency and energy of photons emitted. The vertical direction represents intensity of light. (See Figure 8.38 on p. 312.)

**Check the boxes labeled “Graph Values” and “Labels” to see the specific wavelength of the peak intensity and in what part of the electromagnetic spectrum the wavelength falls.**

**Set the temperature slider so the temperature is 5800 K**, about the temperature of the surface of the sun. This should be the default temperature when the simulation opens. If you’ve set the “Graph Values” check box, the simulation should identify the wavelength of the peak intensity *along the horizontal axis*. We can also calculate this wavelength: .

**Record the wavelength of the peak intensity here.**

Make sure you’ve recorded the value along the horizontal axis, not the vertical axis!

|  |  |  |  |
| --- | --- | --- | --- |
| Sun @ 5800 K | *λ* = |  | *µm* |
| Convert to meters | *λ* = |  | *m* |

Use scientific notation for the wavelength in meters.

Note: the symbol *e* to stand for is not proper in expressing measurements in scientific notation except in calculators and spreadsheets.

Incorrect 3e8; correct 3×10^8.

Unit conversion:

1 *µm* = , so to convert *µm* to *m* replace the micrometer unit with .

Example: an incandescent light bulb has peak wavelength of 0.966 *µm* so converted to *m* this would be . For reference, 1 *µm* is about the size of a speck of dust or a bacterium.

**Use this to calculate the frequency of the light**: ; If wavelength is in meters, frequency should come out in Hertz (Hz).

Example: the peak frequency of the light bulb example would be   
.

|  |  |  |
| --- | --- | --- |
| Frequency | f = |  |

Use scientific notation for frequency in standard units.

If you have checked the “labels” checkbox on the simulation graph, it shows the parts of the electromagnetic spectrum along the top. Use that information to answer the next question.

|  |  |  |
| --- | --- | --- |
| In what part of the electromagnetic spectrum is the peak of the graph? | | |
|  | a | Radio |
|  | b | Microwave |
|  | c | Infrared |
|  | d | Visible |
|  | e | Ultraviolet |
|  | f | X-Ray |
|  | g | Gamma Ray |

**Adjust the temperature to 300 K, ground temperature on a warm day.**

At first glance, it appears nothing is graphed for this low temperature. But if you **adjust the scale of the graph**, you can see the curve. At the bottom right of the graph are two magnifying glass icons, one + and one -. **Click on the “minus magnifier” three times. Then click on the “plus magnifier” at the upper left of the graph until you can see the curve clearly (9 times)**.

**Record the wavelength and calculate the frequency as before**.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Earth @ 300 K | *λ* = | |  | *µm* |
| Convert to meters | *λ* = | |  | *m* |
| Frequency | | f = |  | |

Use scientific notation for quantities in standard units.

|  |  |  |
| --- | --- | --- |
| What part of the electromagnetic spectrum is the peak of the graph? | | |
|  | a | Radio |
|  | b | Microwave |
|  | c | Infrared |
|  | d | Visible |
|  | e | Ultraviolet |
|  | f | X-Ray |
|  | g | Gamma Ray |

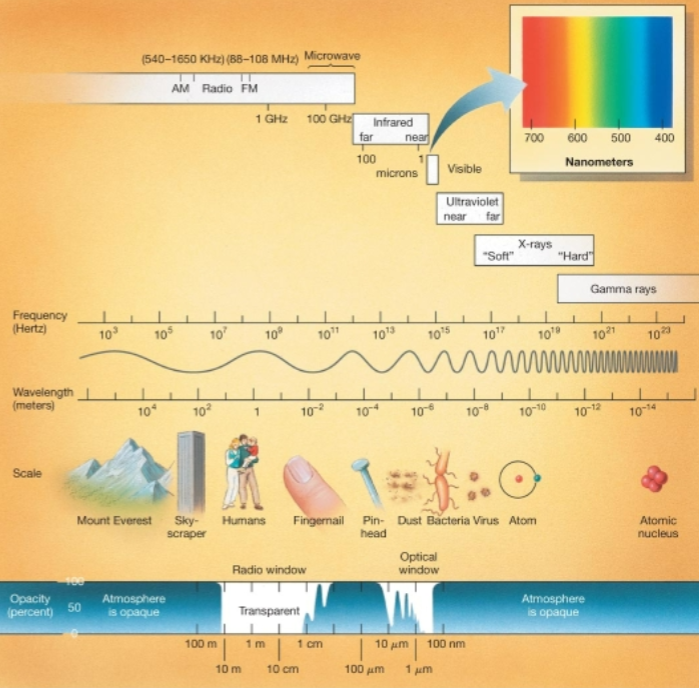
Note: the usual wavelength ranges of visible light and infrared light are given in the table below, following the usual frequency ranges. Check your calculated wavelength and frequency values to be sure you are in the right range.

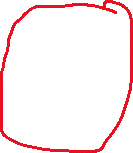
|  |  |  |
| --- | --- | --- |
| Type of radiation | Low wavelength | High Wavelength |
| Visible | 0.4 *µm* | 0.8 *µm* |
| *m* | *m* |
| Infrared | 0.8 *µm* | 1000 *µm* |
| *m* |  |
|  |  |  |
|  | Low Frequency | High Frequency |
| Visible |  |  |
| Infrared |  |  |

If your values in the table on page 2 and 3 do not fit with the regions of the spectrum indicated on the simulation graph, check your math.

The X-ray and Gamma Ray parts of the spectrum are higher in frequency than visible light and shorter in wavelength. Few objects in the universe are hot enough to emit these types of radiation except in supernova explosions and other violent stellar events. Radio and Microwave radiation are only emitted by very cool objects and have low frequencies and long wavelengths compared to IR, visible, and UV light.

Review the infographic on the next page. The entire spectrum is depicted, with illustrations as well, indicating their wavelengths when compared to physical objects. Also note the illustration indicating the regions of spectrum to which the atmosphere is mostly transparent but also to which it’s opaque (at the bottom). **[See next page.]**





Electromagnetic Spectrum: The entire electromagnetic spectrum, running from long-wavelength, low-frequency radio waves to short-wavelength, high-frequency gamma rays. (Chaisson, 20130909, p. 66)   
**See area circled in red at the bottom to answer questions on the next page.**

Opacity is the opposite of transparency. The effect of atmospheric opacity is that there are only a few windows at certain points in the EM spectrum where Earth’s atmosphere is transparent. Component gases that make up parts of the Earth’s atmosphere absorb radiation very efficiently at some wavelengths. Water vapor (H2O) and carbon dioxide (CO2) are strong absorbers of infrared radiation. (Chaisson, 20130909, p. 68)

For a simulation of the interaction of different kinds of light and important atmospheric gases, see this link: [Molecules and Light](https://phet.colorado.edu/sims/html/molecules-and-light/latest/molecules-and-light_en.html)

|  |  |  |
| --- | --- | --- |
| Is the atmosphere transparent to visible light? (see graphic on p. 5.) | | |
|  | | |
| The strongest wavelength of light from the earth is around 10 μm. Find that wavelength at the bottom of the chart on p. 5 and look at the transparency/opacity information just above that wavelength. Is the atmosphere primarily transparent for this wavelength or primarily opaque? | | |
|  | | |
| Use the [Molecules and Light](https://phet.colorado.edu/sims/html/molecules-and-light/latest/molecules-and-light_en.html) simulation to identify molecules that absorb infrared radiation. Set the light type to Infrared, click the green button on the flashlight, and then select each gas molecule at the right, observing if the molecule sometimes absorbs and reemits light energy. List those that do below. Be sure to watch multiple photons pass the molecule before deciding if it absorbs infrared light or not. | | |
|  | | |
| If the energy that infrared light would normally carry away from earth gets absorbed by these gases, this energy remains in the atmosphere. This should make the average temperature of atmosphere | | |
|  | a | go down. |
|  | b | stay the same. |
|  | c | go up. |

Something to consider before you finish.

Chart

Description automatically generated

This graph charts the change in ocean temperature, showing the ocean temperature in 2020 is about 0.8°C warmer than it was on average for the last three decades of the 1900s. This may not seem like a lot, but remember that water has an extremely high specific heat capacity, so it takes a lot of heat energy to raise the temperature of water compared to land or air.

Text

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Source: Woods Hole Oceanographic Institution

Let’s estimate how much mass has warmed just 1.5 °F (0.9 °C) and then use thermodynamics to calculate the heat needed to do that.

Surface area of oceans: 361 million km2 = .

Volume of top 700 meters:

Mass =

Specific Heat Capacity of Seawater:

Heat

For comparison, the energy released by all the nuclear tests as of 1996 was . So, the small temperature change masks a huge amount of energy absorbed by oceans over the past 2 decades.

This heat shifts to the atmosphere, which drives weather patterns. More energy in the atmosphere translates to more volatile weather, changes in flow of energy, moisture, ocean currents, and much more.

**Part 2 Optics of Curved Mirrors**

Open the PHET Simulation called Geometric Optics: <https://phet.colorado.edu/sims/html/geometric-optics/latest/geometric-optics_en.html>

* Click on the “Mirror” section (click twice).
* Start with the default settings:   
  Radius of Curvature = 180 cm, Diameter = 80 cm.
* Change the “Rays” setting to “Principal.”
* Click the box that says “Labels”
* Click on the horizontal ruler and drag it to the simulation and set it to measure the distance from the mirror to the focal Length (yellow x to the left of the mirror).
* Use the default mirror type, concave.

Diagram

Description automatically generated

Note that the focal length is half the Radius of curvature (ruler measures centimeters).

The principal rays shown in the simulation track the rays of light that allow us to locate where the light comes into focus, creating an image. Light moves from the image out so that if we look at the mirror from the left we see what we would see if there were an object at the image location radiating light.

1. A ray from the object that travels parallel to the optical axis reflects so that the ray goes through the focal point.
2. A ray that travels to the exact center of the mirror (where the optical axis passes through the mirror) reflects as for a flat mirror (angle of reflection equals angle of incidence).
3. A ray that travels through the focal point before reaching the mirror reflects so it goes parallel to the optical axis.

Note that all other rays that travel along other lines all reflect so they pass through the same points as the principal rays.

The image is referred to as a “real image” because the rays are actually traveling from the location of the image out away from the mirror.

* Place the ruler so the 200 cm mark is along the vertical grey line at the mirror’s location.
* Click and drag the object so the pencil point is 200 cm from the mirror.

Diagram

Description automatically generated

The simulation should now look like this.

The Mirror Equations describe the mathematical relationship between the following: Focal Length of the mirror: Distance from the mirror to the Focal Point.

Object Distance: Distance from the object to the mirror.

Image Distance: Distance from the mirror to the image.

Object Height: vertical height or size of the object.

Image Height: vertical height or size of the image.

The textbook uses the following variables to represent these measurements:

The magnification (*M*) is the ratio of the image height to the object height.

Note: other textbooks and web pages may use different letters for image and object distances.

In some cases, these quantities may be negative.

* Set the Radius of Curvature to 150 cm. This makes the focal length = 75.0 cm. For a concave mirror, focal length is positive.
* The object should be at 200 cm. This number is always positive when the object is to the left of the mirror.
* The image distance is always positive when the image is real. It should be at 120 cm.

See screen shot below for how the ruler is placed to measure the image distance.

A picture containing text, thermometer, device

Description automatically generatedA picture containing text, measuring stick

Description automatically generatedDiagram

Description automatically generated

* Measure the object height as the height of the frame around the object. It should be 102 cm. It is always positive.
* The image height should be 61 cm, but since it is inverted, we make it a negative number. Trial 1 values in the table below are already filled in.

Check the simulation and confirm that these measurements are correct. Ask questions if you do not understand how to measure any quantity.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trial | 1 | 2 | 3 | 4 | 5 |
| Units | cm | cm | cm | cm | cm |
| Focal length, f | 75 | 75 | 75 | 90 | –100 |
| Object distance, s | 200 |  |  |  |  |
| Image distance, p | 120 |  |  |  |  |
| Object height, h | 102 | 102 | 102 | 102 | 102 |
| Image height, j | –61 |  |  |  |  |

Formulas for calculating these values can be found following the instructions for the other trials (page 12–13). Check your measurements with the spreadsheet available for download on Canvas. Measured values should be within about 5 cm of the calculated value. Do not use the calculated values to fill the table above. All numbers should come from the ruler measurements in the simulation.

Trial 2: Move the object until the image and the object are the same distance from the mirror. Measure and record the values in the trial 2 column above.

Trial 3: Move the object so the image is taller than the object. Click on the icon showing a magnifying glass with a “–” sign in it to reduce the scale of the simulation view. Be careful reading the rulers. The ruler scale changes, so each tick-mark is 4 cm, not 2 cm as before. Record your values in the trial 3 column above.

Trial 4: Change the Radius of Curvature to 180 cm, which should make the focal length change to equal 90 cm. Move the object so it is between the focal length and the mirror. The image will be a virtual image (on the right side of the mirror). Adjust the object distance so you can use the vertical ruler to measure the image height. You may need to change the scale of the simulation. The image should be upright, so the image height is positive.

A virtual image appears to be behind the mirror (to the right) but we know that the rays are not coming from where the image is. Our eyes give us the illusion of the object behind the mirror because we mentally extend the rays reflecting off the mirror to come from the point where the extended rays would start.

When the image distance is to the right side of the mirror, it is given a negative value.

Trial 5: Make the following changes to the simulation settings:

* Change the type of mirror to convex (top center option).
* Change the radius of curvature to 200 cm. This should make the focal length –100 cm. Convex mirrors have negative focal lengths.
* Position the object so it is between the focal length and the mirror on the left side of the mirror.
* Measure the object distance, image distance, and image height, remembering to use the proper positive and negative signs.

**Sign convention reminders:**

Virtual images have negative image distances.

Inverted images have negative image heights.

The Mirror Equation

The Magnification Equation:

These equations can be used to predict the values of the measurements in problems.

The easiest way to calculate a value is to solve the equations for the value you want to calculate.

To test these equations, use the spreadsheet provided on Canvas which will apply these formulas for you.

The spreadsheet has different worksheets that calculate each quantity.

Entering the appropriate numbers in the cells with the yellow background will generate the quantities that can be calculated using the equation.

Do not enter numbers anywhere but the cells with the yellow background or you will remove the formulas.

Note: the simulation measurements may differ slightly from the calculated values due to difficulty measuring accurately.

We will look at videos giving a real view of concave mirrors.

**Part 3: Optics and Lenses**

A picture containing logo

Description automatically generated A picture containing logo

Description automatically generated

* Change the Simulation to show lenses.
* Use the default setting to keep the lens type Convex.
* Use the Principal Ray setting.
* Check the “Labels” box.
* Make the radius of curvature 60 cm.
* Leave the Index of Refraction 1.50 and the Diameter 80 cm.
* Position the object 260 cm from the lens.

A screenshot of a graph

Description automatically generated with medium confidence

Measurements and sign conventions for trial 1

* Objects on the left side of the lens have a positive object distance.
* Real images appear on the right side of the lens and have positive image distances.
* Virtual images appear on the left side of the lens and have negative image distances.
* The object height should be 102 cm.
* The image should be inverted, which means the image height is negative.
* Upright images have positive image heights.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trial | 1 | 2 | 3 | 4 | 5 |
| Units | cm | cm | cm | cm | cm |
| Focal length, f | 60 | 60 | 60 | 80 | –60 |
| Object distance, s | 260 |  |  |  |  |
| Image distance, p | 78 |  |  |  |  |
| Object height, h | 102 | 102 | 102 | 102 | 102 |
| Image height, j | –31 |  |  |  |  |

Trial 2

Move the object closer to the lens and find the position where the image is the same height (but inverted) as the object. Record the object and image distances.

Trial 3

Move the object so the image is taller than the object. Adjust the scale if necessary to measure the image height. The object distance should be greater than 80 cm but less than 110 cm. Record your values in the trial 3 column above.

Trial 4

Change the Radius of Curvature to 80 cm. Move the object so it is between the focal point and the lens. Measure and record the image distance and the image height. Review the sign conventions given above.

Virtual images with lenses appear to be on the left side of the lens. They can only be observed by looking through the lens from the right. In this case, you would see an upright enlarged image. This simulates using a magnifying glass to enlarge the view of something small.

Trial 5

A picture containing logo

Description automatically generatedChange the type of lens to concave.

Change the radius of curvature to 60 cm.

The focal length should be –60 cm.

Concave lenses have negative focal lengths.

Place the object between 260 cm and 200 cm from the lens (on the left).

Measure the image distance and image height, using the proper sign conventions.

As time allows we will observe the videos that show similar arrangements of lenses to objects, and the resulting images.