Heat Transfer

Directions and Suggestions for Teacher

Purpose:

This lab is designed to give students an understanding of the connection between the thickness of a barrier between two rooms with different temperatures and the rate at which heat moves through the barrier..

Virtual Part:

(https://thephysicsaviary.com/Physics/Programs/Labs/HeatTransferGasesWithPredictionLab/)

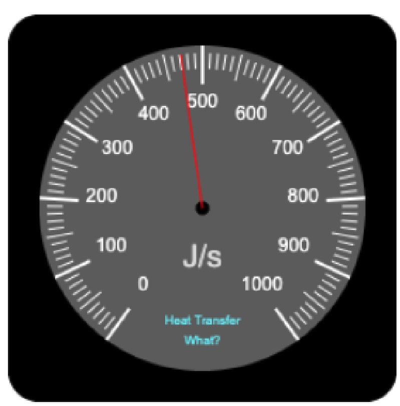
This lab can easily paired with a live lab that examines some factor that affects heat transfer through a barrier that separates two different temperature environments.

Measuring Thickness:

The program gives a digital readout of the thickness of the barrier separating the two different temperature environments. Thickness should be measured and graphed in mm.

Measuring Rate of Heat Transfer:

Students will be estimating the rate of heat transfer through the barrier using an analog display. The estimation should be made to the nearest Joule. In the display shown below an estimate of 471 J to 473 J would be appropriate.



This lab was created by Frank McCulley for thephysicsaviary.com.

Working Through the Lab:

Students will be clicking on the barrier to change the thickness. Although there are ten different thickness levels on the virtual program, students need not do all levels. I would not suggest less than 5 levels as it is a good practice to collect more data to have greater confidence in your results. The program will randomize the material of which the barrier is constructed as well as the temperatures of the two chambers being separated by the barrier, so all students will get different results. Students should not refresh the website while working or it will generate new values and thus make all the old data irrelevant.

Below is a sample of what potential data might look like.

Data:

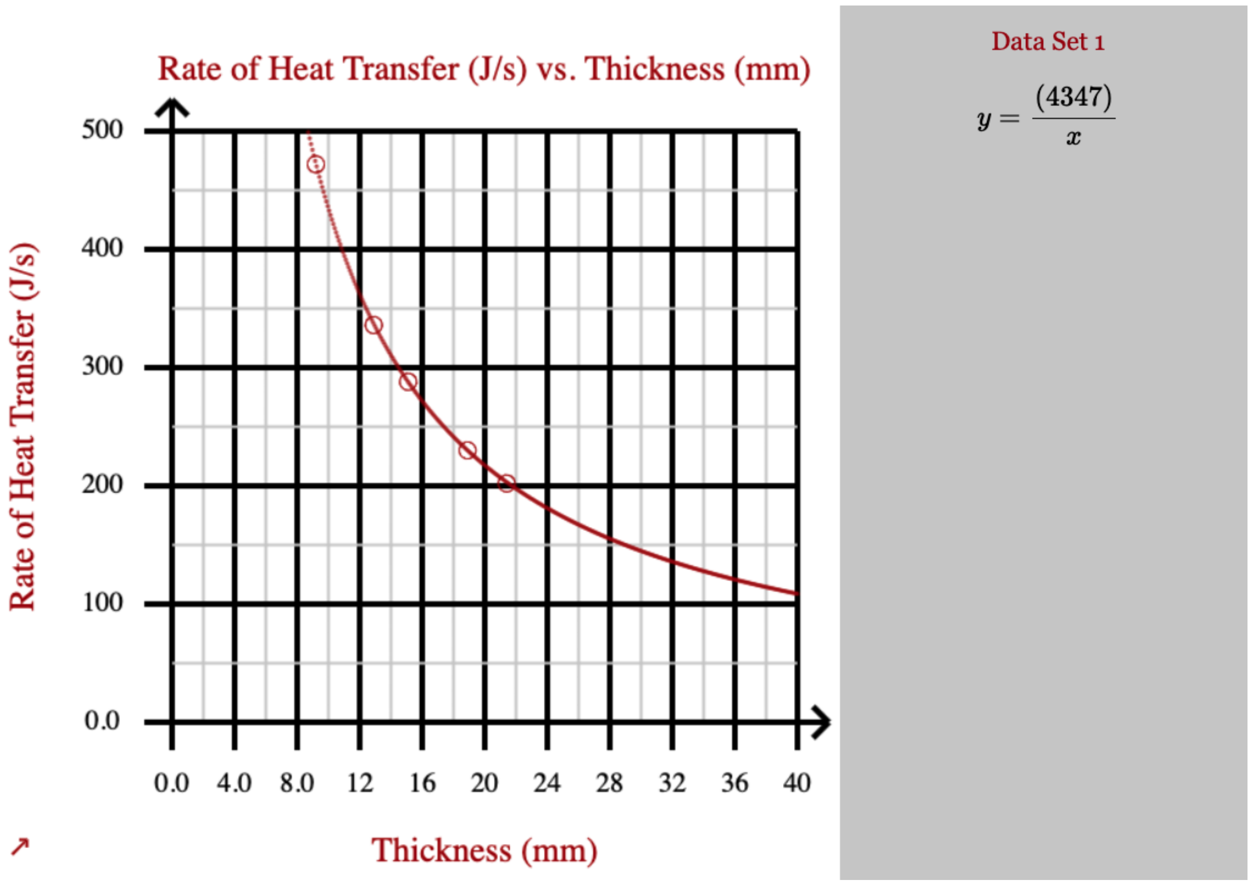
Thickness (mm)	Rate of Heat Transfer (J/s)
9.2	472
12.9	336
15.1	288
18.9	230
21.4	202

Graphing Data:

(https://www.thephysicsaviary.com/Physics/Programs/Tools/Graphing/)

Once students have finished collecting data, they should graph it and find a relationship between the variables. The thickness of the barrier in mm is the independent variable and should be placed on the x-axis and the rate of heat transfer in J/s is the dependent variable and should be on the y-axis.

I prefer always having the students transfer their graph onto their lab sheet by hand.



Equation:

For this graph students get an inverse relationship between the variables. This indicates to them that a thicker barrier will cause a lesser rate of heat transfer. Students should probably already understand intuitively that if they want to stay warmer, thicker clothes will be preferred to thinner ones. This experiment now will lead them to understand that doubling the thickness of the clothes, without changing any other variable, will cut the rate of heat transfer in half.

The equation for an inverse relationship is given below.

$$y = (\text{graph constant})/(x)$$

We want to continue to emphasize to them the idea that each of these letters has real physical significance. Looking at the axes, they should see that the y is the rate of heat transfer in J/s and the x is the thickness in mm. So the equation becomes:

$$Q/t = (\text{graph constant})/(\text{thickness})$$

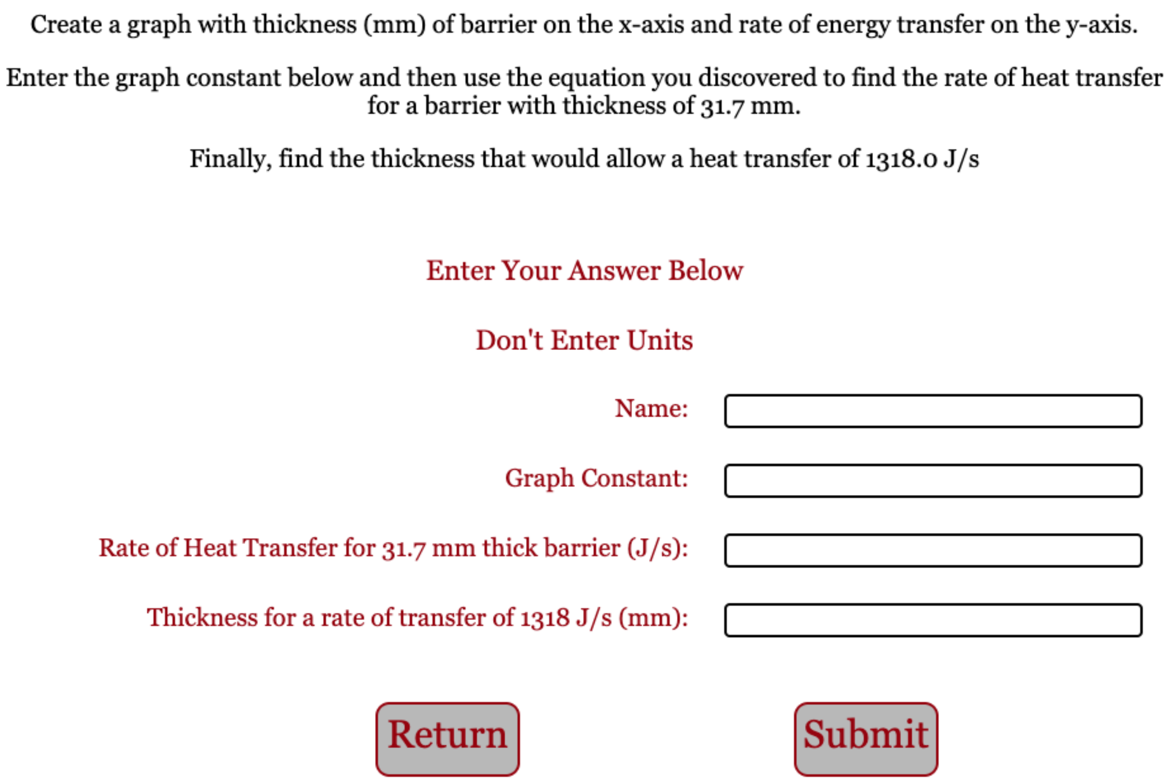
We then want students to think about the significance of the graph constants. Prompt them by asking what other things they could change besides the thickness that would have changed the rate of heat transfer through the barrier. Hopefully, they will come up with things like what the barrier is made out of, the area of the barrier, and the temperature difference between the two sides of the barrier.

I have found that students have the hardest time coming up with the area of the barrier as being one of the factors. I have them visualize a pint of Ben and Jerry's ice cream that they are grabbing with their hand. Heat will move from their hand into the ice cream and the ice cream will start to melt. Have them think about holding the ice cream with their entire hand vs. supporting it with just the tips of their fingers. They will see that the more area of the hand that is in contact with the cardboard barrier holding the ice cream, the faster the ice cream will melt.

Checking their work:

Once the students have reached the point where they have graphed and created an equation, they will then be able to check their work. They should simply hit “Finished” on the program to be brought to a form they can fill out to see if they did everything correctly. Remind students that they all will be getting different answers and that they shouldn’t worry if their answers differ from those of their classmates.

The first thing they will be entering is the graph constant of their graph. Make sure they graphed with the thickness in mm or their constant will not match what is expected by the program. Next they will use their equation to calculate the rate of heat transfer for a thickness that they didn’t collect. Finally, they will use their equation again to find the thickness required to produce a rate of heat transfer that they didn’t measure in their experiment.



Create a graph with thickness (mm) of barrier on the x-axis and rate of energy transfer on the y-axis.

Enter the graph constant below and then use the equation you discovered to find the rate of heat transfer for a barrier with thickness of 31.7 mm.

Finally, find the thickness that would allow a heat transfer of 1318.0 J/s

Enter Your Answer Below

Don't Enter Units

Name:

Graph Constant:

Rate of Heat Transfer for 31.7 mm thick barrier (J/s):

Thickness for a rate of transfer of 1318 J/s (mm):

Return

Submit

I would normally offer a small amount of extra credit added to the lab grade if they get all their answers correct. I would have them show me their completion certificate so I could record that they earned the extra credit. If a student doesn’t get everything correct, you can have them redo the lab by refreshing their page if time permits.

Live Part:

There are lots of options for a live part for this experiment. I would probably have the students test how a different factor affects heat transfer rather than the one they tested in the virtual part of this lab. One of the easiest things to test is the relationship between the difference in temperature between the two sides of the barrier and the rate of heat transfer.

I would do this by having the students set up a system where a small cup of hot water of known mass is placed in a bath of ice water. I would have a temperature probe continuously measure the temperature of the water in the small cup. I would have students graph this temperature and continually swirl the water so that the temperature remains fairly the same throughout the small cup.

After about ten minutes of the probe collecting data, I would have them analyze what has happened. I will have them record the temperature of the water in the cup at the start of each new minute. I will have them record the temperature of the water in the cup again after exactly 10 seconds have passed from the start of the new minute. I will have them figure out how much energy the water in the cup has lost in the first ten seconds of each minute using $Q = mC\Delta T$, where m is the mass of the original hot water in kg, C is the specific heat of water, and ΔT is the temperature change over the first ten seconds of each new minute. They will then divide this heat loss by 10 seconds to get an approximate rate of heat loss at the start of each new minute. A sample of what this could look like is shown below:

Minute #	Initial Water Temp (°C)	Temp after 10 s (°C)	Q Lost (J)	Q/t (J/s)
0	85.0	80.0	2095	209.5
1	72.3	68.7	1508	150.8
Up to 10				

They should then have the difference in temperature between the two sides of the cup at the start of each new minute (remember the ice bath should have a temperature of 0°C) and they should have the approximate rate of heat transfer occurring at that temperature difference. This data would look something like this:

Difference in Temperature (°C)	85.0	72.3	Continue for 10 readings
Rate of Heat Transfer (J/s)	209.5	150.8	Continue for 10 readings

Conclusion:

I personally like to have students write out a conclusion by hand after they are done with the entire lab.. Some things you can have students include in the conclusion.

1. **Restatement of the purpose.**
    a. This is a great way to open the conclusion
    b. It helps to reinforce the reason we were doing the lab.
2. **Brief Summary of the steps**
    a. I don't want too much here but I do want students to transition from the purpose to the results with a sentence or two summary of the steps.
    b. This part of the conclusion should paint with a very broad brush what type of data we were collecting and what remained constant when collecting data.
3. **Results**
    a. I want students to clearly state what type of relationship existed between the two variables we were examining.
    b. I want them to clearly explain what this means in simple to understand terms.
    c. Basically, they will be making sense of the equation they have discovered in the lab.
4. **Error**
    a. They should talk about their percentage of error from the lab.
    b. They should brainstorm at least one possible source of that error and how it can be minimized if they redid the lab.
5. **Limitations to the model**
    a. Whenever possible I want them to think about when the mathematical model for the lab would break down and no longer apply.
    b. For instance, with this lab, we assumed that the temperature at the location of the barrier was the same as the temperature measured for the room. In reality, the room temperature will not be uniform unless steps are taken to make sure air is continually circulating to keep things the same in all parts of the room.

Going Further

If you have the time, you could challenge the students with the following types of things.

1. Ask the students what they think would happen to the graph constant if the barrier was made from a more insulating or conductive material. You could have them sketch an approximate line on their graph for what that would have looked like in comparison to the material that they tested.

2. You can have students test different water bottles to find the rate of heat transfer through them. Some students will spend a lot of money to get a good water bottle and they might like to know how quickly the heat is escaping from their bottle compared to a cheaper bottle.