The Candle Flame: Measuring the Temperature of a Flame According to the “Three Zones Model” (Teacher’s Guide)
OVERVIEW

Students will study the relationship between the chromatic structure of a candle flame and the temperature of each area, calculating the magnitude of differences quantitatively. They will use tools for graph analysis to find out the results.

MATERIALS NEEDED

Ward's DataHub
USB Cable Connector*
Thermocouple
Candle
Matches

* – The USB connector cable is not needed if you are using a Bluetooth enabled device.

NUMBER OF USES

This demonstration can be performed repeatedly.
**FRAMEWORK FOR K-12 SCIENCE EDUCATION © 2012**

*The Dimension I practices listed below are called out as **bold** words throughout the activity.*

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<th>Dimension 1</th>
<th>Science and Engineering Practices</th>
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<tr>
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<td>Asking questions (for science) and defining problems (for engineering)</td>
<td>Use mathematics and computational thinking</td>
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<td>Developing and using models</td>
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<td>✓</td>
<td>Planning and carrying out investigations</td>
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<td>Analyzing and interpreting data</td>
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<td>Patterns</td>
<td>Energy and matter: Flows, cycles, and conservation</td>
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<td>✓</td>
<td>Cause and effect: Mechanism and explanation</td>
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<td>Scale, proportion, and quantity</td>
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<tr>
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**NATIONAL SCIENCE EDUCATION STANDARDS © 2002**

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<td>✓ Evidence, models, and explanation</td>
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<td>✓ Constancy, change, and measurement</td>
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<td>Motion and Forces</td>
<td>Structure and Properties of Matter</td>
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<tr>
<td>✓ Transfer of Energy</td>
<td>✓ Chemical Reactions</td>
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<td></td>
<td>Motion and Forces</td>
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<td>Conservation of Energy and Increase in Disorder</td>
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<tr>
<td>✓</td>
<td>Interactions of Energy and Matter</td>
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✓ Indicates Standards Covered in Activity
LEARNING OBJECTIVES

Core Objectives (National Standards):
• Develop the ability to refine ill-defined questions and direct to phenomena that can be described, explained, or predicted through scientific means.
• Develop the ability to observe, measure accurately, identify and control variables.
• Decide what evidence can be used to support or refute a hypothesis.
• Gather, store, retrieve, and analyze data.
• Become confident at communicating methods, instructions, observations, and results with others.

Activity Objectives:
The purpose of this activity is to relate temperature and color in a candle flame, create a hypothesis and proceed to test it using the Ward’s DataHub thermocouple sensor.

Time Requirement:
60–90 minutes
VOCABULARY

**Bunsen Burner:** A small adjustable gas burner used in laboratories.

**Capillary Action:** A phenomenon associated with surface tension and results in the elevation or depression of liquids in a narrow passage.

**Combustion:** The process of burning something. Rapid chemical combination of a substance with oxygen, producing heat and light.

**Convection Current:** The movement of molecules within liquids and gases.

**Flame:** A hot glowing body of ignited gas that is generated by something on fire.

**Heat:** The quality of being hot or having a high temperature.

**Hydrocarbon:** A compound of hydrogen and carbon, such as any of those that are chief components of petroleum and natural gas.

**Incandescent:** Emitting light as a result of being heated.

**Temperature:** The degree or intensity of heat present in a substance or object.

**Thermocouple:** A device able to measure very high temperatures more appropriately than a thermometer. The potential difference between a “couple” of dissimilar metals in the tip of the tool, is utilized to measure the temperature.
INTRODUCTION

Different materials change their appearance because of environmental influences. Heat is one of the most common environmental factors and it produces an easily recognizable change of color in matter when temperature is increased. An example of this phenomenon can be found in the metal industry where metals show a bright yellow color just before melting which is called incandescence. It is therefore clear that not only can we relate color to the temperature of matter, but also intensity.

• Why do you think we call some colors warm or cold? Think of examples.

• Have you ever seen the different colors of a candle flame? Have you felt the irradiated heat from the flame?

According to what we’ve discussed so far, a simple candle flame can make an interesting scientific study object and in this experiment we’ll try to discover all its complexity.

Carry out the experiment activity with your class so that at the end students will be able to answer the following question:

• Are the colors of a flame related to the temperature gradient along it?
A candle flame is produced by the combustion of wax, a hydrocarbon. Once the candle has been lit, the heat melts the wax which rises through the wick by capillary action and is vaporized.

The color gradient in a flame reveals the temperature increase from the base to the top of the flame, similar to the ignition of a metal. In this case, elemental carbon particles called soot are released from the incomplete combustion of the wax and are heated by the exothermic energy of this reaction - thus emitting light.

The flame of a candle has a structure comprised of three areas. The higher the temperature is, the closer the color gets to the infrared spectrum.

**Three Zones Model:**

*Blue Area:* Basal region of the flame where combustion is complete due to the richness of oxygen. Carbon particles are not present here.

*Orange/Brown Area:* The majority of oxygen is consumed in the blue area, therefore the combustion here is incomplete. Because of that, we can find a great concentration of carbon which is heated to temperatures ranging from 800 to 900 °C.

*Yellow Area:* The chemical conditions here are similar to the previous area; however the carbon particles have now reached higher temperatures.

Now students are encouraged to raise a hypothesis which must be tested with an experiment. Students may find it helpful to formulate their hypothesis as an answer to the following question.

- **If you measure the temperature of different areas of a candle flame, how do you expect the results to change when you measure from the lowest to the highest zone? Why?**
CONNECTING THE WARD’S DATAHUB TO A COMPUTER

If you are using a Bluetooth communication device:

Right-click on the Bluetooth icon in the lower right corner of the screen and select the Ward’s DataHub you are using. The icon will change from gray to blue, as shown at right, indicating that the Ward’s DataHub and the computer are now connected via Bluetooth.

If you are using a USB communication device:

In order to use USB communication, connect the Ward’s DataHub and the computer with the USB cable supplied. Click on the USB icon at the lower right corner of the screen. This icon will change from gray to blue, as shown at right, indicating that the Ward’s DataHub is connected to the computer via USB.

USING THE WARD’S DATAHUB

|= Select key  |= On/Off and Escape key  |= Scroll key |

To collect measurements with the Ward’s DataHub, it must first be configured as follows:

1. Turn on the Ward’s DataHub by pressing the On/Off/Esc key.
2. Go to setup by using the Scroll key; then select Setup by pressing the Select key.
3. Select the Set Sensors option by pressing the Select key.
4. If any sensor(s) appears on the screen, press the key representing that sensor to deactivate it. Once you have a blank screen, press the Thermocouple/Ambient Temperature Sensor key.
5. Press the On/Off/Esc key once to return to the setup menu.
6. Press the Scroll key to highlight the Sampling Rate and then press the Select Key.
7. Press the Scroll key until “Manual” is highlighted, then press the Select key.
8. Press the On/Off/Esc key to return to the setup menu.
9. Press the Scroll key to highlight the Number of Samples and then press the Select Key.
10. Press the Scroll key until “Manual” is highlighted, then press the Select key.
11. Press the On/Off/Esc key three times to return to the main operating screen. x 3
12. Press the Select key to start measuring. (You are collecting data when there is an icon of a Runner in the upper left hand corner of the screen.)
13. Once you have finished measuring, stop the Ward’s DataHub by pressing the Select key, followed by the Scroll key.
DID YOU KNOW?

If you light a candle and put a glass or jar over it, what happens to the flame? It goes out in a short amount of time, right? Well, this is because during the combustion process, the flame used up all of the oxygen that was present in the glass. Without oxygen there is no way for the combustion process to continue. Therefore, the process stops and the flame goes out.

ACTIVITY

1. Light a candle and wait one or two minutes. After this period, throw away the liquid wax and measure the flame height.

2. Identify the three separate areas in the flame. Start with the blue zone and move up the flame.

3. As you introduce the thermocouple to each of the three areas of the flame, measure the temperature. Before recording each new measurement, make sure the thermocouple tip is soot-free.

   **Be careful: The thermocouple insulation is easily burned when it is close to fire.**

4. Once you have finished measuring, stop the Ward’s DataHub.
DID YOU KNOW?

Our ancestors exploited the heat of flame for warmth and cooking since between 1 and 1.8 million years ago. Significant transitions in history, such as that between the Stone Age and the Bronze Age, have been determined by our ability to sustain a flame of a given temperature.

RESULTS AND ANALYSIS

1. Select the bar graph from the Ward’s DataHub software menu to show the experimental results. Then, add pictures of each bar to indicate the measured areas by clicking .

2. Get the average, maximum and minimum values of temperature using the statistic tool from the menu and calculate the difference between the extreme temperatures.

3. Observe the table data. Click on and compare the average value with the central temperature of the flame.
   - How do the results relate to your initial hypothesis? Explain.
   - What was the relationship between the color and temperature of the flame?
   - Where did you record the minimum and maximum temperature values? What was the average between these magnitudes? Was the average similar to the temperature in the second area (orange/brown)?
   - What was the magnitude of temperature range within the flame height? Did you expect this result?

The graph below should be similar to the one the students came up with.
CONCLUSIONS AND ASSESSMENTS

1. What variables are correlated in this experiment?

   Students should point out that the temperature increase is related to the spectral scale; “warmer colors” show the higher temperatures. Indirectly, the height of the flame could also be correlated with the temperature.

2. Why is the basal area of the flame blue?

   Students should mainly consider two reasons. This area has the higher oxygen concentration since it is the starting point of the gas that determines the complete combustion. As a result, the amount of carbon is not meaningful and therefore the ignition is practically nothing.

3. How are warm colors produced in the upper and middle areas of the flame?

   Students should recognize that the carbon particles are heated by the exothermic energy. The carbon then becomes incandescent and emits light closer to the infrared spectrum.
ACTIVITIES FOR FURTHER APPLICATION

The aim of this section is for students to extrapolate the acquired knowledge during this lesson through its application in different contexts and situations. Furthermore, it is intended that students question and present possible explanations to the experimentally observed phenomena.

1. In what position should the ring of the Bunsen burner be located to heat a beaker with the least amount of soot? Why?
   
   Students should point out that the most ideal position of the ring would allow the greatest possible amount of oxygen to enter. In this way, a complete combustion reaction is reached which produces a low soot concentration.

2. If you wanted to know the approximate mean temperature of a steel nail which is heated at its tip, what zone would you measure?

   Students should use the knowledge obtained during the class to suggest they could get an approximate value in the middle zone of the nail.
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According to the “Three Zones Model” 
(Student Guide)

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- Why do you think we call some colors warm or cold? Think of examples.
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3. How are warm colors produced in the upper and middle areas of the flame?
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4. Write a concluding paragraph describing what you observed during the experiment.
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