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Applied Sciences

The Candle Flame

Measuring the temperature of a flame
according to the “three zones model”

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USA Standards Correlation

FRAMEWORK FOR K-12 SCIENCE EDUCATION © 2012

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

Dimension 1 Science and Engineering Practices	✓	Asking questions (for science) and defining problems (for engineering)		Use mathematics and computational thinking
	✓	Developing and using models		Constructing explanations (for science) and designing solutions (for engineering)
	✓	Planning and carrying out investigations	✓	Engaging in argument from evidence
	✓	Analyzing and interpreting data	✓	Obtaining, evaluating, and communicating information

Dimension 2 Cross Cutting Concepts	✓	Patterns	✓	Energy and matter: Flows, cycles, and conservation
	✓	Cause and effect: Mechanism and explanation		Structure and function
	✓	Scale, proportion, and quantity		Stability and change
	✓	Systems and system models		

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Dimension 3 Core Concepts	Discipline	Core Idea Focus
	Physical Science	PS3: Energy
		PS3.D: Energy in Chemical Processes and Everyday Life

NGSS Standards	Middle School Standards Covered	High School Standards Covered
	MS.PS-E: Energy	HS.PS-E: Energy

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Content Standards (K-12)			
✓	Systems, order, and organization		Evolution and equilibrium
✓	Evidence, models, and explanation	✓	Form and Function
✓	Constancy, change, and measurement		

Physical Science Standards Middle School		Physical Science Standards High School	
	Properties and Changes of Properties in Matter		Structure of Atoms
	Motion and Forces		Structure and Properties of Matter
✓	Transfer of Energy	✓	Chemical Reactions
			Motion and Forces
			Conservation of Energy and Increase in Disorder
		✓	Interactions of Energy and Matter

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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 Globisens Labdisc thermocouple sensor.

Time Requirement:

60 – 90 Minutes

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Objective

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 Labidsc thermocouple sensor.

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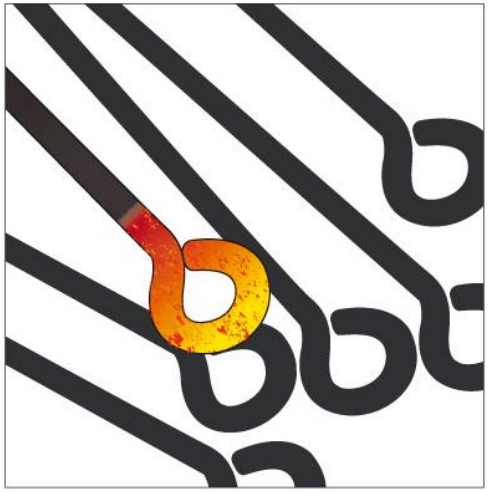
Introduction and theory

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 to its intensity.



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Introduction and theory

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 you'll be able to answer the following question:

Are the colors of a flame related to the temperature gradient along it?

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Introduction and theory

Theoretical

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 capillarity and is vaporized.

The color gradient 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.

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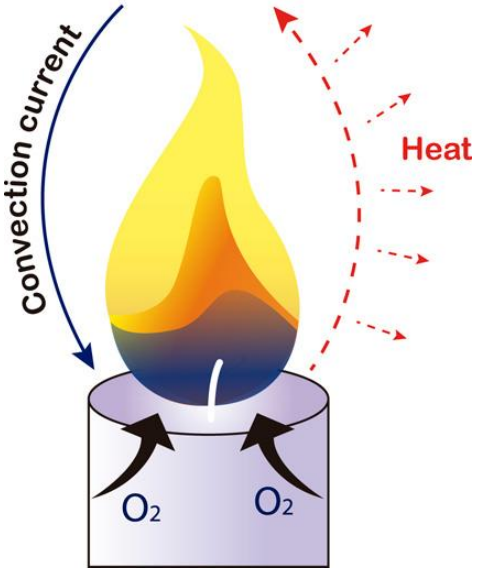
Introduction and theory



The flame of a candle has a structure comprised of three areas, showing colors near to the infrared spectrum the higher the temperature is:

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.

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Introduction and theory

Now students are encouraged to raise a hypothesis which must be tested with an experiment.

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?

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Activity description

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

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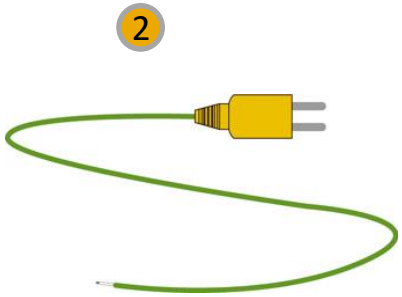
Resources and materials

1. Labdisc
2. Thermocouple
3. Candle
4. Matches



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Using the Labdisc

Labdisc configuration

To collect measurements with the Labdisc and thermocouple sensor, the Labdisc must be configured according to the following steps:

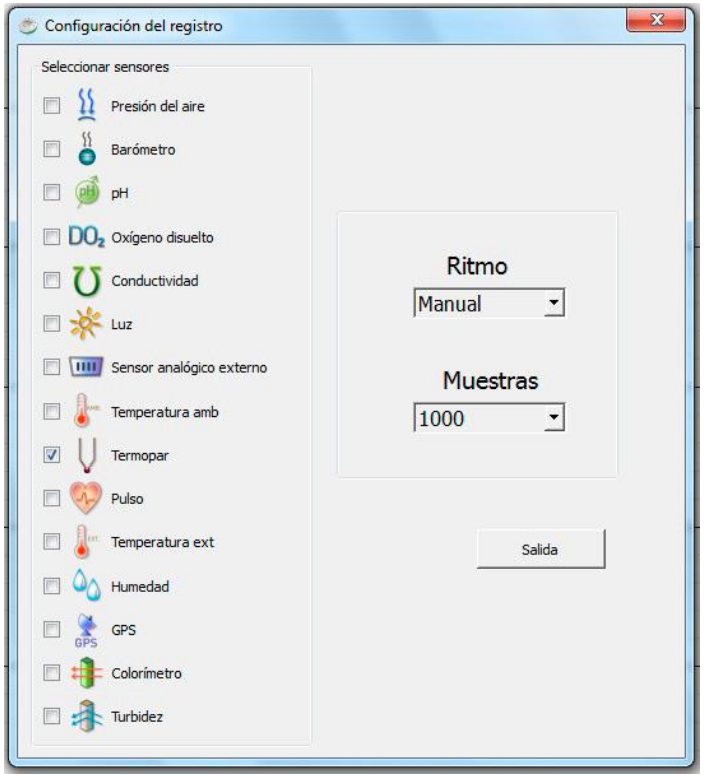
1. Open the GlobiLab software and turn on the Labdisc

2. Click on the Bluetooth icon in the bottom right corner of the GlobiLab screen. Select the Labdisc you are using currently. Once the Labdisc has been recognized by the software, the icon will change from a grey to blue color 

. If you prefer a USB connection follow the previous instruction clicking on the USB icon. You will see the same color change when the Labdisc is recognized 

.

3 Click on  to configure the Labdisc. Select thermocouple in the "Logger Setup" window. Enter "Manual" for the sampling rate.



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4. Once you have finished the sensor configuration start measuring by clicking 

5. Once you have finished measuring stop the Labdisc by clicking 

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Experiment

1. Light a candle and wait one to 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 sample make sure the thermocouple tip is soot-free.

Be careful:
The thermocouple isolation is easily burnt when it is close to fire.

4 Once you have finished measuring stop the Labdisc

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Results and analysis

1. Select a bar graph  from the GlobiLab menu to show the experiment 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 statistics tool  from the menu and calculate the difference between the extreme temperatures.

3. Observe the table data by clicking on  and compare the average value with the central temperature of the flame.

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Results and analysis

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?

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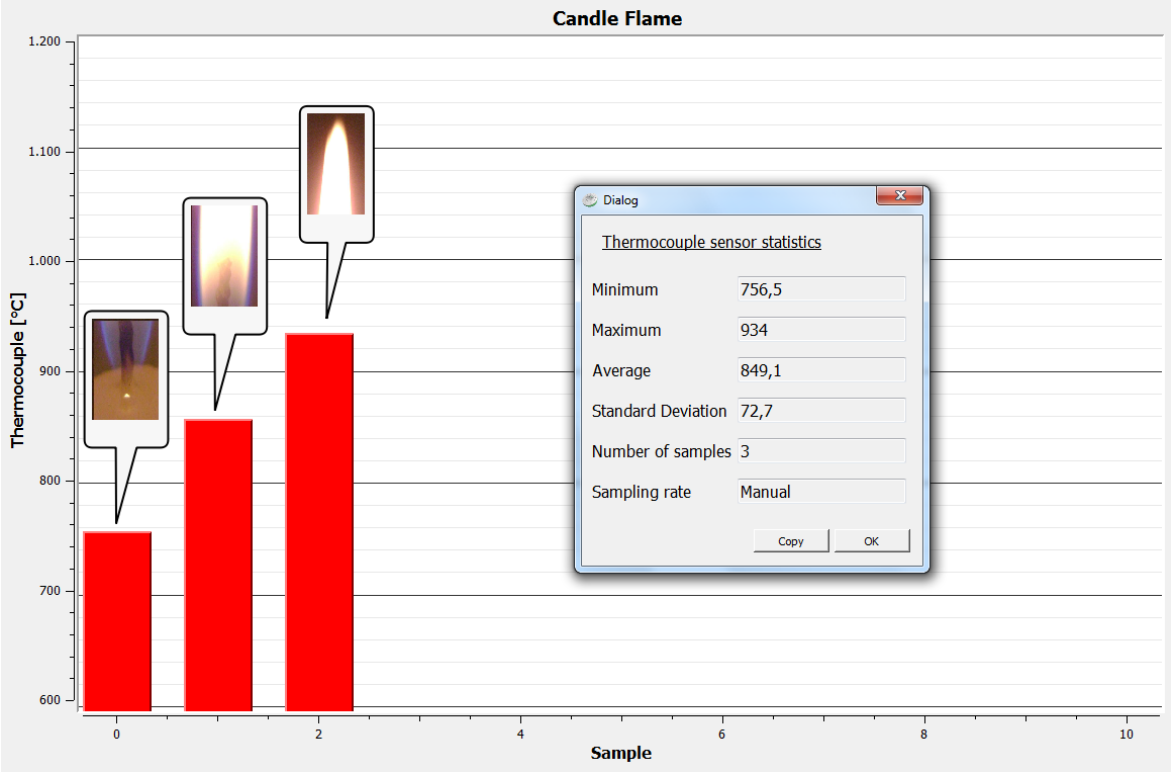
Results and analysis

The graph below should be similar to the one the students came up with:



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What variables are correlated in this experiment?

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

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.

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Conclusion

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

Students should remember from the theoretical background that the carbon particles are heated by the exothermic energy. The carbon then becomes incandescent and emits light near to the infrared spectrum.

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Activities for further application

In what position should the ring of a Bunsen burner be located to heat a beaker with the least amount of soot? Why?

Students should point out that the most important condition is to allow the greatest possible amount of oxygen to enter. In this way a complete combustion reaction is reached which produces a low soot concentration.

If you wanted to know the approximate mean temperature of a steel nail 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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