Lesson Plan
Katherine Clerk Maxwell and Color Mixing of Light

Katherine Clerk Maxwell (right) with her husband James Clerk Maxwell (left) and their dog Toby.

*Image courtesy of the Cavendish Laboratory, Cambridge University.*
*This image is under a Creative Commons Attribution-NonCommercial 3.0 Unported License (CC BY-NC 3.0).*

---

1 Maxwell and his Wife, Katherine Mary Dewar, P1180, Cavendish Laboratory, Cambridge University, [https://cudl.lib.cam.ac.uk/view/PH-CAVENDISH-P-01180/1](https://cudl.lib.cam.ac.uk/view/PH-CAVENDISH-P-01180/1).
Example images of color mixing with light.
Images courtesy of Karyn Tripp from the ‘Teach Beside Me’ lesson plan blog²

<table>
<thead>
<tr>
<th>Grade Level(s): K-1</th>
<th>Subject(s): History, Art, Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplements: Color Mixing, Additive Properties of Color</td>
<td></td>
</tr>
<tr>
<td>This teaching guide introduces and enriches the concepts of primary and secondary colors of light, as well as the color mixing theory of light. Students do not need background information on the primary and secondary colors to be able to participate in the lesson. A supplemental activity introduces students to color mixing in pigments.</td>
<td></td>
</tr>
<tr>
<td>In-Class Time: 35 minutes</td>
<td>Prep Time: 5-10 minutes</td>
</tr>
<tr>
<td>Materials</td>
<td></td>
</tr>
<tr>
<td>Three strong flashlights</td>
<td></td>
</tr>
<tr>
<td>Red, blue, and green cellophane</td>
<td></td>
</tr>
<tr>
<td>3 rubber bands</td>
<td></td>
</tr>
<tr>
<td>A light whiteboard or wall</td>
<td></td>
</tr>
</tbody>
</table>

Objective

This lesson introduces Katherine Clerk Maxwell, emphasizing her involvement in color theory and teaching students light color mixing. The teacher will demonstrate mixing colors using lights, calling up students to help participate in activities which they will demonstrate to the class. Students will be able to identify the primary colors of light, understand how they mix to create secondary colors, and learn about what Katherine and James Clerk Maxwell discovered involving color mixing: that mixing red, green, and blue creates white light.

Introduction

Katherine Clerk Maxwell is most known as the wife of James Clerk Maxwell, who is famous for his many notable discoveries such as his work with electromagnetic radiation, color vision, Saturn’s rings, and the kinetic theory of gasses. Katherine is known to have served as an assistant and as the subject of James’ experiments, working to help run some of his more tedious or laborious work. Although records of her role have been largely lost, it seems as though she had a large involvement in running experiments on color vision and gasses.

Katherine is a prime example of a spouse to a prominent physicist, who is known to have helped in many experiments, but whose involvement is not well documented and not often credited.

Katherine Clerk Maxwell was born as Katherine Mary Dewar in Glasgow, Scotland in 1824. As a woman in the early to mid-1800s, much of Katherine’s life is known only in the context of her father and husband. Because of this, not much is known about her early life. She was the daughter of Susan Place and Daniel Dewar. Her father was a prominent figure: a Presbyterian reverend with a Doctorate of Divinity, working as the principal of Marechal College Aberdeen. Likely because of her parents, Katherine was raised in a very religious setting, and remained pious throughout her life.

In terms of education, Katherine likely received an early education to learn women’s obligations and religion. She was able to get much of her schooling because of her father’s social class, likely learning more of literacy and numeracy than typical women of her time. It was not until 1889 that Scottish universities allowed female students in higher education. However, the universities of Edinburgh, Aberdeen, Glasgow, and St. Andrews were involved in the 18th century Scottish enlightenment in education, which particularly impacted the upper-classes (which Katherine’s father was part of).

Katherine met James Clerk Maxwell through her father when James was working as a professor of Natural Philosophy at her father’s institution, Mariscal College at the University of Aberdeen. (The University of Aberdeen where both her husband and father worked did not allow women until 1892.) Katherine and James married on June 2, 1858, and they remained married until James’s premature death. Katherine did not remarry. Katherine and James never had children, enjoyed riding horses, and were extremely devout in their shared Presbyterian religion and dedication to each other. James’s friends described their bond as “unexampled devotion.” James Maxwell enjoyed writing poetry as a hobby, with the subject of many of his poems being devoted to his wife: “I, drinking deep of thy rich love, / Thou feeling all the strength of mine, / Our souls will rise in faith above / The cares which make us pine.” Letters from their friends remarked that James’s “one and only care was for his wife,” with James writing to his Aunt that “we are quite necessary to one another, and understand each other

---

7 “History,” The University of Aberdeen, University of Aberdeen, accessed 16 June 2022, https://www.abdn.ac.uk/about/history/our-history.php#:~:text=A%20separate%20science%20faculty%20%2D%20also,a%20quarter%20of%20the%20faculty.
10 Campbell and Garnett 139.
11 Campbell and Garnett 304.
better than most couples I have seen." Both Katherine and James had their fair share of illnesses, seemingly trading off taking care of each other. For example: “… Maxwell suffered from two severe illnesses… in both of them he was nursed by Mrs. Maxwell… his wife was left quite alone with him—the servants only coming to the door of the sick-room. He has been heard to say that by her assiduous nursing on this occasion she saved his life." James lost his battle with stomach cancer on November 4, 1879.

In a letter to his aunt announcing their soon-to-be marriage, James mentioned Katherine's support of his physics endeavors, writing that "she certainly won't stop the mathematics." This proved to be true later, when it has been confirmed that Katherine served as a research assistant to his work.

Katherine’s main involvement with her husband’s work was on his color vision and gas studies. Many of these experiments were done in their shared home. Maxwell’s biography (written by two of his friends, Lewis Campbell and William Garnett) states:

“Maxwell resided at 8 Palace Gardens Terrace, Kensington, where he carried on many of his experiments in a large garret… which ran the whole length of the house. When experimenting at the window with the colour-box (which was painted black, and nearly eight feet long), he excited the wonder of his neighbours, who thought him mad to spend so many hours in staring into a coffin. This was also the scene of his well-known experiments on the viscosity of gases at different pressures and temperatures.”

As these experiments were performed in the privacy of their home, much of the extent of Katherine’s involvement in the work was unrecorded in history. Much of the evidence revealing her involvement has only been found in correspondence or notes from James’ friends, rather than in published scientific papers.

In the color vision experiments, Katherine acted as a research subject, as we know from the record of measurements of her responses to color mixing and color blindness tests. In his 1860 paper “On the theory of compound colours, and the relations of the colours of the spectrum” James Maxwell wrote down the observations of “observer J. (myself)” to represent himself on page 70. However, on the same page, there is a second observer listed as “another observer (K.)” Though there is no name tied directly to observer K, correspondence between James and his close friend Lewis Campbell reveal that it is Katherine.

In this experiment, they built a box which used mirrors, prisms and diffraction of light in order to allow adjustable amounts of the three primary colors of light to be shown onto a white wall inside the box. Volunteers such as Katherine and James were then employed to look into the box, adjusting different amounts of each color and recording their visual observations. This color box experiment was performed in their home, looking at the additive and subtractive aspects of light. Working with Young’s theory of light (revolving around using three primary colors that mix to form any other color), they...
mathematically showed how much of each primary color of light (red, green, blue) needed to be mixed to make virtually any color. As an observer, Katherine determined when certain amounts of the red, green, and blue mixed to form very specific variations of color. Below is a diagram containing the additive and subtractive color models, where the additive model pertains to light and the subtractive model relates to pigment. When mixing the three primary colors of light, Katherine and James would have seen the additive color model in action.

![Color Models Diagram](image)

The three primary colors of light (red, blue, and green) differ from the three primary colors of pigment (red, yellow, and blue), because of additive and reflective properties of light. In the case of light, white light is formed when all colors are mixed together, but in a physical medium like pigmented paint, dark colors are created when all colors are mixed together. The Maxwells also applied theories of color to investigate the cause of color-blindness, theorizing that it may be because an individual could lack certain color receptors, as the eye has red, green, and blue receptors.

Katherine also acted as a lab assistant or technician in James’ experiments on gasses, as revealed through two sources of correspondence with James’ friends: in an 1877 postcard to Peter Guthrie Tait and in a biography on James written by two of his friends (Lewis Campbell and William Garnett) published in 1882. James was studying the viscosity of gasses, eventually producing “On the viscosity or internal friction of air and other gases” in 1886. These experiments required a considerable amount of manual effort to produce steam and maintain different required temperatures. A fire had to be kept going for many days in some experiments, with ice employed to keep it cool in others, and “Mrs. Maxwell acted as stoker, which was very exhausting work when maintained for several consecutive hours.” James also wrote to Peter Guthrie Tait “my better 1/2, who did all the real work of the kinetic theory is at present engaged in other researches. When she is done I will let you know her answer to your enquiry.” James thus reveals the physical work that Katherine put into the experiment, although Tait’s original enquiry, as well as following correspondence, has been lost.

Unfortunately, records of any other involvement that Katherine had in her husbands’ work have not yet been found, if they exist. It is suspected that she had a hand in far more of his work than was

---

18 Cotnoir, Leigh, “Primary Colors of Light and Pigment,” [learn](https://learn.leighcotnoir.com/artspeak/elements-color/primary-colors/).
19 Campbell and Garnett, 158.
recorded, as the couple were life partners in many ways and much of James’s work was done at their home.

After James passed away, Katherine served as an executor to her husband, managing his personal papers. She sorted through his records and correspondence, donating most of his records to the Cavendish Laboratory Archives at Cambridge University, and to two of his friends (Lewis Campbell and William Garnett) who published a biography about James in 1882. However, Katherine decidedly did not donate personal letters or those pertaining to herself. These records relating to Katherine are presumably lost, as with much of the paper trail of her life.

There are no apparent records of Katherine’s life after her husband’s passing. Katherine passed away on December 12, 1886 and is buried with her husband and his parents.21

<table>
<thead>
<tr>
<th>Instructions/Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engage: 2 Minutes</strong></td>
</tr>
<tr>
<td>Teachers will introduce students to Katherine Clerk Maxwell and her involvement with color theory by showing photos of Katherine and James and discussing their work.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>What is the teacher doing?</th>
<th>What are the students doing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introducing students to the basics of who Katherine Clerk Maxwell was, emphasizing the importance of collaboration in science (as in Katherine assisting James), and their role in discovering important ways to mix color. Main Discussion Points and Photos for the teacher to reference are listed below and in supplemental materials for this discussion plan.</td>
<td>Become acquainted with Katherine Clerk Maxwell and color mixing theory through the presentation.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engage: 2-3 Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next, teachers will go from explaining who Katherine was to explaining what she helped discover. This will involve a short introduction to primary and secondary colors. The teacher will show a quick musical video describing what primary and secondary colors are, stopping the video early.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>What is the teacher doing?</th>
<th>What are the students doing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show the ‘Primary Colors and The Formation of Secondary Colors’ video from Knowledge Platform (link found here and in Required Resources). The teacher will stop the video at the 1:46 second timestamp.</td>
<td>Become acquainted with what the primary and secondary colors are through the video.</td>
</tr>
</tbody>
</table>

---

Explain: 3-5 Minutes

The teacher will lead students in a class-wide exchange, where students are asked review questions pertaining to the primary and secondary colors of light that were described in the previous video. The teacher should also specifically clarify that there are different primary colors pertaining to light versus pigment.

What is the teacher doing?
The teacher will lead the class in reviewing what was said in the video. Teachers can ask students questions based on ‘Discussion I’ from the discussion sheet below and in the teaching guide’s supplemental materials. Students will be told that there is a surprise reward for participation in the discussion. This reward will be involvement in using the flashlights in the light demonstration in the next section. Teachers will also clarify that there are different primary colors of light versus pigment. Teachers may show the image below to demonstrate, where the additive color model relates to light in the video students just watched, and the subtractive color model may relate to mixing something that they have seen before such as paint or markers.

What are the students doing?
Discuss answers to the review questions asked by the teacher.

Explore: 10-15 Minutes

The teacher will lead a class demonstration, asking questions and experimenting with the flashlights while involving participation with the students that participated in the review questions. This will be a demonstration of color-mixing with primary colors.
### What is the teacher doing?
The teacher will lead a demonstration using the cellophane-colored lights to show how the colored lights mix. This will involve shining the lights on a whiteboard or light-colored wall with the lights off. Teachers will invite students up to hold the red, blue, and green flashlights, emphasizing that they are the primary colors of light. They will show that these lights mix to form the secondary colors of cyan (or blue-green), magenta (or purple) and yellow. Teachers will engage students by asking what they think will happen when combining each of the colors before each step, asking them what they believe will happen before demonstrating it. Students can switch out taking turns holding the flashlights, exploring different color combinations, and guessing what they think the results will be. Students will also be given time to experiment with combining any colors they choose. Teachers should also emphasize that combining green, blue, and red will form white light in the experiment. Example questions for the teacher to ask students during the demonstration are listed in ‘Discussion II’ questions below and in the supplemental materials for this lesson plan.

### What are the students doing?
Students will answer questions asked by the teacher while watching and participating in the flashlight color demonstrations. They will be free to explore any combinations of the colored lights that they want, making guesses of which colors they think will turn off. While experimenting with these color combinations, students will see what Katherine saw when she was working on these experiments with James!

---

**Explore: 7-10 Minutes**

After establishing the previous step’s basis of primary and secondary color mixing, the teacher will direct the class back to Katherine and James’s work. The teacher will emphasize that this is what Katherine saw, describing that Katherine’s job was to replicate very specific colors. The teacher will call students up to replicate certain colors of their choosing.
### What is the teacher doing?
The teacher will emphasize Katherine’s role to the students. They will explain that Katherine had to mix specific amounts of the colors to match a certain color. They will then call up volunteers to attempt to recreate colors of objects around the room of the student’s choosing. Students will be asked to describe the colors that they are recreating. [For example, students may be asked to attempt to replicate the color of a chair in the classroom, with students holding the lights and a volunteer working together and pointing to where on the board of colored light matches the objects color]

### What are the students doing?
Student volunteers with replicate what Katherine had to do, by attempting to work together to recreate the color of certain objects around the room. A student will be called up to point to the closest color-match to the object that is shown on the board, while other students hold the flashlights. Students will be asked to describe the color that they are replicating. In this way, students must work together and have the opportunity to further experiment on their own.

### Required/Recommended Reading and Resources

**Video**
  - This is a quick instructional video describing the primary colors of light, and how they mix to form all other colors, including white.

**Readings**
  - The present lesson plan is adapted from this “Color Mixing with Light” lesson idea by Karyn Tripp, a former teacher.
  - This source presents an explanation of the primary colors of light versus pigment for further clarification on the topic.

### Main Discussion Points and Photos

Main Discussion Points can also be found in the Supplemental Materials to this lesson plan.

### Main Points of Katherine Clerk Maxwell

- She lived in Europe (the United Kingdom) during the 1800s.
• She helped to assist her husband in his physics experiments.
• She and her husband worked to research colored light, and how certain colors of light can mix together to create other colors.

Many photos and primary sources of Katherine and James, as well as their correspondence and experiments, can be found at the Cambridge Digital Library. This library database includes a large collection of primary sources from James Clerk Maxwell. It holds original photos pertaining to him and Katherine’s lives, as well as photos of his actual letters, experiments, and apparatus they used in their research. If students are interested, teachers may show them these photos:


Katherine Clerk Maxwell (right) with her husband James Clerk Maxwell (left) and their dog Toby.  
Image courtesy of the Cavendish Laboratory, Cambridge University.  
This image is under a Creative Commons Attribution-NonCommercial 3.0 Unported License (CC BY-NC 3.0).

Katherine Clerk Maxwell (right) with her husband James Clerk Maxwell (left) and their dog Toby.  
Image courtesy of the Cavendish Laboratory, Cambridge University.  
This image is under a Creative Commons Attribution-NonCommercial 3.0 Unported License (CC BY-NC 3.0).

22 Maxwell and his Wife, Katherine Mary Dewar, P1180, Cavendish Laboratory, Cambridge University,  
https://cudl.lib.cam.ac.uk/view/PH-CAVENDISH-P-01180/1.


Evidence of Katherine’s participation in James’s gas viscosity experiments, eventually producing “On the viscosity or internal friction of air and other gases” in 1886.9


Discussion Questions

Discussion Questions can be found with a corresponding Answer Key in the Supplemental Materials to this lesson plan.

Discussion I

The following are possible questions that the teacher may ask students to review the primary colors of light from the ‘Primary Colors and The Formation of Secondary Colors’ video made by Knowledge Platform. Teachers may use these as example questions, picking any to engage the students.

1. How many primary colors of light are there?

2. What are the primary colors of light?
3. What is special about the primary colors of light?
4. What color is light from the sun?
5. Are the primary colors of light and primary colors of materials (like mixing paint) different?
6. What color would you get if you mixed red and yellow paint? Is this different from if you were to mix red and yellow light?

Discussion II

The following are possible questions that the teacher may ask students while demonstrating light color mixing using flashlights and calling up volunteers to experiment.

1. What color do you think is created when we mix [color 1] and [color two]? For example: What color do you think is created when we mix [red] and [blue]?
2. What will happen if we mix all the colors of light? Will they all mix to form black?
3. [To ask the class, and invite students to participate in holding the flashlights] What color combinations do you want to try?

Further Reading and Additional Resources

  - This source is the biography of James Clerk Maxwell, as created by two of his close friends. The biography includes more detailed information of his personal life and experiences, with references to Katherine.
  - This is James Clerk Maxwell’s original published paper on color theory, where he and Katherine used the color box to experiment. Katherine’s observations are recorded on page 70.
  - This is a lesson plan on the primary colors of physical materials, such as paint. If desired, this lesson demonstrates a possible method of teaching the physical aspects of primary colors, rather than the primary colors of light.
  - This source is a short review of the Maxwell’s color experiments and background. Explanations of the light box that Katherine helped with on page 1693.
  o This video includes a demonstration of a color mixer kit. This is designed to show clearer and more precise color mixing. If funding allows, this could be an example demonstration to delve further into the details of color mixing for higher grade levels.
  o This is a short and fun educational video on the primary colors. This video pertains to the physical primary colors (red, yellow, blue), rather than the primary colors of light (red, green, blue), and could be used in a lesson plan on color mixing utilizing paint.
  o This is Katherine Clerk Maxwell’s Wikipedia page, for background and context on her life.
  o This library database includes a large collection of primary sources from James Clerk Maxwell. It holds original photos pertaining to him and Katherine’s lives, as well as photos of his actual letters, experiments, and apparatus they used in their research. If students are interested, teachers may show them the photos.

**Extensions**

**Science Activity**
Students may be given small balls of red, yellow, and blue play dough. They could then be asked to mix certain amounts of the play dough to replicate the color of an object of their choosing (such as an eraser, colored pencil, or piece of construction paper). Students will be asked to present their created color and the object that they matched the color to during class the next day.

**Related AIP Teacher’s Guides on the History of the Physical Sciences:**
• Laura Bassi’s School of Experimental Physics
• The Night Sky by Another Name Grades 1-3
• The Gravity of Emilie du Chatelet

**Common Core Standards**

<table>
<thead>
<tr>
<th>Speaking &amp; Listening</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CCSS.ELA-LITERACY.SL.1.1</strong></td>
</tr>
<tr>
<td>Standard</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>CCSS.ELA-LITERACY.SL.1.3</td>
</tr>
<tr>
<td>CCSS.ELA-LITERACY.SL.K.1</td>
</tr>
<tr>
<td>CCSS.ELA-LITERACY.SL.K.2</td>
</tr>
<tr>
<td>CCSS.ELA-LITERACY.SL.K.3</td>
</tr>
<tr>
<td>CCSS.ELA-LITERACY.SL.K.4</td>
</tr>
<tr>
<td>CCSS.ELA-LITERACY.SL.K.6</td>
</tr>
<tr>
<td>Reading: Literature</td>
</tr>
<tr>
<td>CCSS.ELA-LITERACY.RL.1.2</td>
</tr>
<tr>
<td>CCSS.ELA-LITERACY.RL.K.2</td>
</tr>
<tr>
<td>Mathematics: Measurement &amp; Data</td>
</tr>
<tr>
<td>CCSS.MATH.CONTENT.K.MD.A.2</td>
</tr>
</tbody>
</table>

Next Generation Science Standards


Physical Sciences

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-PS1-1 Structure and Properties of Matter</td>
<td>Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties. Grade: K-2</td>
</tr>
</tbody>
</table>

All content in this and other AIP Teaching Guides is subject to usage conditions due to copyright and/or other restrictions and may only be used for personal, educational, and other non-commercial uses consistent with the principles of fair use under Section 108 of the U.S. Copyright Act.