MATERIALS™ EXPLORERS

THE LIGHT ENERGY BEHIND LIGHTSABERS

How realistic is one of the most iconic fictional weapons of all time? This chapter explores some of the scientific concepts that relate to making a real life lightsaber and asks whether it will ever be possible to replicate it.

In this module students will be able to:

- Discuss the duality of light
- Explain how different colors of light are emitted by different elements
- Define plasma
- Develop a procedure for identifying unknown salts based on the color of light they emit
- Explain the relationship between energy, wavelength, and frequency
- Investigate how lasers are created and their uses in industry

Class Activity

THE COLOR OF A LIGHTSABER

Background:
Imagine if all the neon lights of Las Vegas were the same color. It wouldn't be very interesting, but it would be the reality if they were all truly made of neon. Different elements emit different colors, so the lights that you see are actually made up of any number of different substances.

The **electromagnetic spectrum** consists of all the forms of electromagnetic radiation arranged according to frequency and wavelength. From the electromagnetic spectrum, it can be inferred that energy is directly related to frequency while frequency is inversely related to wavelength.

In the early 1900s scientists conducted two experiments involving interactions of light and matter that could not be explained by the prevailing view of light as a wave: the photoelectric effect and the emission spectrum of hydrogen. Einstein explained the results of these two experiments through what he termed "the duality of light." Einstein proposed that light behaves like a wave when traveling through space and it acts like a stream of particles called **photons** when it interacts with matter.

Elements emit light when there is a continuous and sufficient source of energy. The atoms of the element absorb the energy and the electrons are excited to a higher energy. The electron will emit energy in the form of light called a photon as it returns to a lower energy level or its ground state. The energy of the photon is equal to the energy difference between the atom's excited state and lower energy state and corresponds to a specific color of light. Electrons can be excited through various forms of energy such as electrical or heat. When enough energy is applied to a gas, some electrons can break free from atoms, creating **plasma**.

Light energy, its colors, and its power have made the lightsaber of the *Star Wars*™ universe one of science fiction's most iconic weapons. Lightsabers can cut through virtually anything and can only be blocked by a material that conducts energy, some rare metals, or another lightsaber. Lightsabers employ many of the concepts mentioned above, although they are described as having plasma blades powered by fictional kyber crystals.

Class Activity

Could lightsabers ever cross the line from science fiction to science reality? Crystals really do influence the color of light emitted and plasma really can cut through anything. However, light and plasma simply can't stop one another the way two lightsabers can when they clash. Similarly, the very idea of a blade of plasma just isn't physically possible without some kind of containment. Given this, it seems that the creation of real lightsabers is still far, far away.

Problem

Although lightsabers owe their iconic colors to the kyber crystals that power them, the crystals appear colorless until first discovered by their destined Jedi. The Jedi Council wants to know if it is possible to predict the color of a crystal before it is obtained by a Jedi youngling, using small powdered samples of different crystals to test that colors they emit.

Task:

You must create a procedure to distinguish the various kyber powders based on their color. The following materials are at your disposal:

- Bunsen burner
- Striker
- Wooden splints
- Distilled water
- Stirring rod
- Beakers
- Powdered samples A through F
- Petri dishes

Requirements:

1. Safety goggles and an apron must be worn at all times.
2. Long hair must be pulled back.
3. Closed toe shoes must be worn.
4. Procedures must be approved by the teacher before beginning.




Class Activity

Questions

1. Create a data table including the columns “Unknown Sample,” “Color Emitted,” “Chemical Identified”, and “Character(s)” based on the information below:

Lightsaber Color	Character(s)
Blue/Green	Luke Skywalker, Qui-Gon Jinn, Rey, and Yoda
Red	Darth Vader, Darth Maul, Darth Sidious, Count Dooku, Inquisitors, and Kylo Ren
Violet/White	Mace Windu and Siths-turned-Jedi
Yellow	Jedi Temple Guard
Orange	Jedi Temple Guard

2. List the colors observed in the lab in the following orders:
   - **i.** From highest energy to lowest energy
   - **ii.** From highest frequency to lowest frequency
   - **iii.** From shortest wavelength to longest wavelength
3. What is the relationship between energy, frequency, and wavelength?
4. Given that the Sith are associated with red and the Jedi are associated with blue or green, would you theorize that the Jedi or Sith lightsabers are more powerful? Justify your response using your answer to Question 2 above.
5. What does it mean to “excite” electrons? How were electrons “excited” in this experiment?
6. Explain why different chemicals emit different colors of light using the Bohr model of the atom.
7. While lightsabers are fictional, where have you encountered colorful light emissions? Provide two examples.

Definitions

Electromagnetic Spectrum
The electromagnetic spectrum includes all of the forms of electromagnetic radiation. All forms of electromagnetic radiation are arranged according to frequency and wavelength on the spectrum.

Photon
A photon is a light particle.

Plasma
A state of matter created when enough energy is applied to a gas causing some electrons to break free from atoms.

Teacher Resources & Answer Key

Standards:	NGSS	HS-PS4-3	HS-PS4-4

Notes:

1. Teachers must approve student procedures before they begin. An appropriate procedure would be as follows:
   - i. Soak wooden splints in distilled water.
   - ii. Dip a wooden splint in an unknown sample. Remind students that only a little powder is needed. If too much powder is on the wooden splint it may fall into the burner, skewing further results.
   - iii. Set up Bunsen burner so that an inner blue cone appears.
   - iv. Hold wooden splint at the tip of the inner blue cone and observe the color.
   - v. Repeat until all unknowns have been tested.
   - vi. NOTE: For best results turn off lights and close classroom blinds.
2. Students should follow all safety procedures at all times including wearing goggles and aprons, pulling long hair back, no baggy articles of clothing or dangling jewelry.
3. The easiest method for students to access the unknowns is to pour a small amount into a petri dish.
4. The suggested unknowns are: **Sample A:** copper (II) chloride, **Sample B:** lithium chloride, **Sample C:** potassium chloride, **Sample D:** sodium chloride, **Sample E:** strontium chloride, and **Sample F:** calcium chloride.
5. Used wooden splints can be disposed of in garbage cans. Any remaining unknowns can be added to water to create a solution and be disposed of down the drain if the school drains are connected to a sanitary sewer system.

Answer Key

Unknown Sample	Color Emitted	Chemical Identified	Character(s)
A	Blue/Green	CuCl2	Luke Skywalker, Qui-Gon Jinn, Rey, and Yoda
B	Red	LiCl	Darth Vader, Darth Maul, Darth Sidious, Count Dooku, Inquisitors, and Kylo Ren
C	Violet/White	KCl	Mace Windu and Siths-turned-Jedi
D	Yellow	NaCl	Jedi Temple Guard
E	Red	SrCl2	Darth Vader, Darth Maul, Darth Sidious, Count Dooku, Inquisitors, and Kylo Ren
F	Orange	CaCl2	Jedi Temple Guard

Teacher Resources & Answer Key

1. **List the colors observed in the lab in the following orders:**
   - a. **From highest energy to lowest energy**
   - b. **From highest frequency to lowest frequency**
   - c. **From shortest wavelength to longest wavelength**

   For all three, the order is Violet, Green, Yellow, Orange, Red.

2. **What is the relationship between energy, frequency, and wavelength?**

   The shorter the wavelength, the higher the frequency, and the higher the energy.

3. **Given that the Sith are associated with red and the Jedi are associated with blue or green, would you theorize that the Jedi or Sith lightsabers are more powerful? Justify your response using your answer to Question 2 above.**

   In theory, the Jedi's lightsabers would be more powerful than those of the Sith because the colors of their lightsabers are associated with high energy while those of the Sith are associated with low energy.

4. **What does it mean to "excite" electrons? How were electrons "excited" in this experiment?**

   Exciting electrons means that electrons are absorbing energy. Electrons were "excited" in this experiment through the heat energy supplied by the flame of the Bunsen burner.

5. **Explain why different chemicals emit different colors of light using the Bohr model of the atom.**

   The distances between energy levels are different for different types of atoms. The color of light emitted depends on the distance the electron "falls" between energy levels.

6. **While lightsabers are fictional, where have you encountered colorful light emissions? Provide two examples.**

   Student answers will vary but may include neon signs, fireworks, rainbows, etc.

Extension Activity

BUILDING A BETTER (OR AT LEAST REALISTIC) LIGHTSABER

In the *Star Wars™* universe, the lightsaber is the symbolic embodiment of The Force and the strength and character of the Jedi (or Sith) who wields it. In *The Force Awakens*, Rey is able to defeat the highly trained Kylo Ren in lightsaber combat once she has accepted and submitted to her considerable Force-sensitive abilities. The lightsaber she uses is actually the one that Luke Skywalker famously lost in *The Empire Strikes Back* when Darth Vader cuts off his right hand, sending it and the lightsaber tumbling down an air shaft in Cloud City. And, Vader should know a thing or two about the power of that particular lightsaber, since it's the same one that Obi-Wan Kenobi takes from Anakin Skywalker as he leaves him to die on Mustafar in *Revenge of the Sith*—and then 20 years later gives it to an inexperienced Luke in *A New Hope*.

While the movies don't give much detail about how a lightsaber is actually made, the expanded *Star Wars* universe has fleshed out a fairly rich mythology as to how this weapon is forged, so to speak. According to the *StarWars.com* databank, a Jedi lightsaber is powered from a Kyber crystal mined from the ice caves of Ilum and then attuned and connected to the Force sensitivity of a particular Jedi knight. The business end of the weapon is a shaft of pure energy that can cut through anything except another light saber or a material that conducts energy.

Mystical crystals aside, could a light saber actually be built in the world as we know it, or are its origins purely the domain of exciting, but improbable, science?

In her book, *The Science of Star Wars*, Jeanne Cavelos, an astrophysicist who worked in the astronaut-training division of NASA's Johnson Space Center, tried to imagine what kind of energy would be contained in such a weapon. It could not be a laser for several reasons. For example, a laser beam would only be visible in air dense with dust, and the beam would travel in a straight line until it was absorbed, reflected, bent, or scattered by some obstruction. Her alternative is plasma—a gas that has been heated to extremely high temperatures. Plasma can be powerful, but containing it to a particular shape, such as the confines of the lightsaber shaft, would pose some hurdles science has not yet overcome. The high-powered plasma would also burn the hands holding the weapon, Cavelos learned in her research.

"In that case, perhaps Luke would prefer to . . . activate it by remote control," she wrote.

These hard science facts might suggest that building a light saber for real would be out of reach for mere mortals who do not channel The Force. When that question was put to a few materials scientists and engineers, they met the challenge with some creative ideas of their own for somewhat bending the laws of physics to build a light saber that could, at least theoretically, work. Read on to see what they proposed and decide for yourself if in some world not too far, far away, the science of *Star Wars* could actually exist.

A New Element for a New Weapon

Joseph F. AuBuchon, Applied Materials, and Joel Hollingsworth, Lam Research, recognized that the right element to make their lightsaber simply doesn't exist. So, they tackled the lightsaber challenge by inventing a fictional element of their own that had the properties they needed to make the blade work.

Master Obi-Wan Kenobi described

Extension Activity

a lightsaber as "an elegant weapon for a more civilized age." Contrary to what the name might imply to the uninitiated, the deadly blade of a lightsaber is not actually made up of pure light. By consulting with official records, we see that a lightsaber blade performs feats that no mere beam of light is capable of: parrying similar blades, casting shadows, and stopping in mid-air a short distance from its source (Figure A).

Lightsaber blades actually have solid metal cores. This central part of the formidable weapon is made of a single element, metachlorium (Me), number 138 on the periodic table, whose discovery shattered all materials records for melting point and cohesive energy. An energy cell powers three pumping lasers that are focused onto a coupling crystal at the base of the blade core, allowing a unique electromagnetic frequency to travel along the blade core as surface plasmons. Waste heat causes the blade core to rapidly expand by a factor of four or more, until it reaches its full size.

Magnetic suspension (which produces the weapon's characteristic hum) physically isolates the Me rod, containing the intense surface oscillations safely on the blade exterior. Some electromagnetic energy escapes as light in a color corresponding to coupling frequency, but the core contains almost all of it until coupled to another object, at which time plasmon energy and blade heat enables it to slice through steel like a knife through butter.

Don't Forget Proper Disposal

Wayne Reitz, Talbott Associates, Inc., sought inspiration for his lightsaber design in a plasma based blade which relied on a nuclear power source.

Model this new design from a flashlight, except the light beam would be a high-energy plasma that operates in air and is contained by a magnetic field. All components operate from within the hilt of the saber.

The plasma has the ability to degrade the structure and mechanical properties of any material it contacts. The power source would be nuclear, albeit a small reactor; the by-products of the nuclear reaction is the plasma source. Obviously, proper disposal is required. Otherwise, the garbage could become "mixed waste."

Too Hot to Handle

Iver E. Anderson, Ames Laboratory, drew on his experience with lasers to design his lightsaber.

From my own experience with lasers, the more powerful ones are also much bigger.

A key question is how much laser power is needed? Also, what laser wavelength would be preferred to allow maximum coupling to body parts and assorted weapons that are anticipated?

After knowing the power and wavelength, an optimum laser system (crystal or ionized gas) must be identified. A decision must be made between continuous wave or pulsed operation mode. A pulsed mode would allow higher operation power with a lower cooling requirement. This would also help in portability.

If the invention of a new laser system is required to achieve the optimum wavelength,for example, a long research period may be needed to select and optimize the output power.

If an existing laser system could be used, the packaging of the system for optimum portability will be the next huge challenge. The key is to reduce the weight of the power supply or to figure out how to transmit the power without an umbilical from a base supply to the battlefield. This may be done by microwaves. Also, the high

Extension Activity

power level would probably need a large cooling capacity, probably needing a gas-turbine-powered cooling fan.

In the end the toughest thing might be to get a volunteer to hold the saber that has a red hot handle and a small jet engine attached to the end; all the while keeping a microwave receiver dish pointed to the power supply that is sending a megawatt beam at him or her.

Any takers?

Parts excerpted from "The (Mostly Improbable) Materials Science and Engineering of the Star Wars Universe" by Maureen Byko, published in JOM, *May 2005, Volume 57, Issue 5, pp 12-18.*

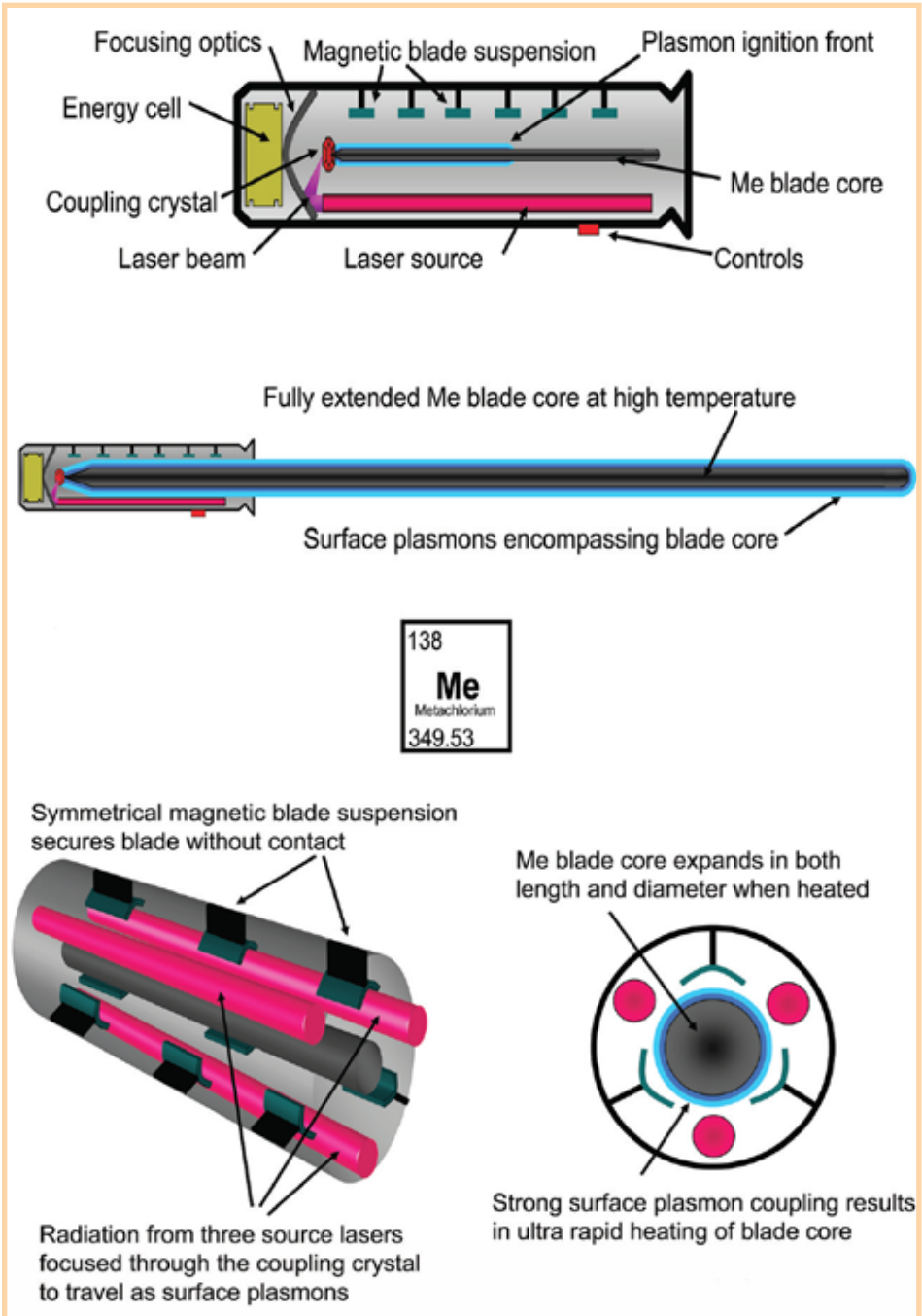
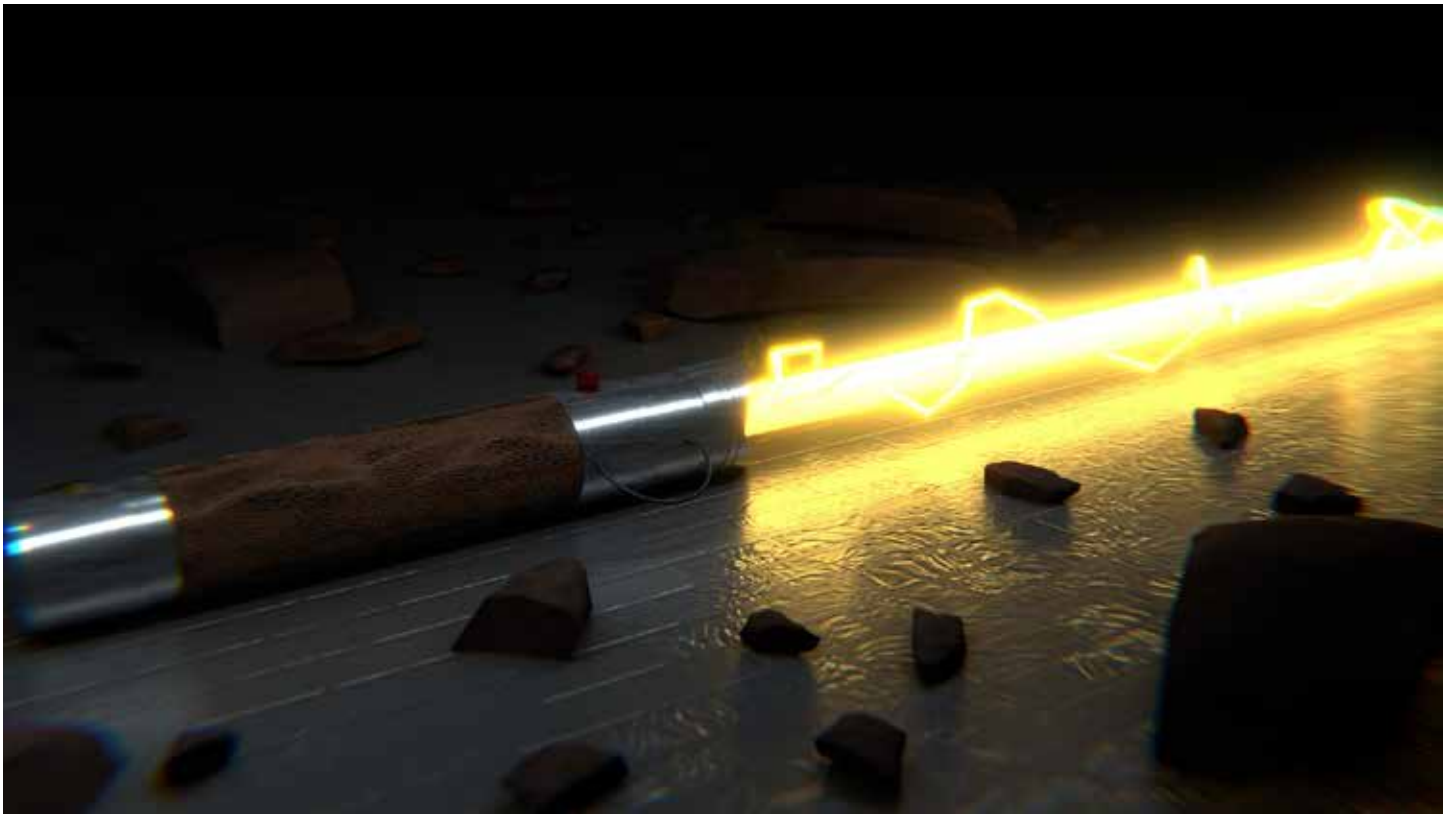


Figure A (a) A schematic drawing of a lightsaber during the plasmon-initiation process. (b) A schematic of the fully extended lightsaber. (c) Element 138 on the periodic table (filled5g shell). (d) A three-dimensional schematic of lightsaber interior when weapon is off. (e) A schematic of the lightsaber cross section.

Extension Activity

Questions

1. What is plasma?
2. What does laser stand for?
3. How is a laser created?
4. What are lasers used for in industry?
5. Figure A illustrates a metachlorium blade core. While metachlorium is a fictitious element, what properties might it need in order to work as the core of a lightsaber?
6. Based on the commentaries provided, how would you construct a lightsaber?



Extension Activity Answer Key

1. **What is plasma?**

   A state of matter created when enough energy is applied to a gas causing some electrons to break free from atoms.

2. **What does laser stand for?**

   Laser stands for light amplification by stimulated emission of radiation.

3. **How is a laser created?**

   A laser is created when billions of atoms produce trillions of photons at once and the photons line up to form a concentrated light beam.

4. **What are lasers used for in industry?**

   Student answers will vary but some examples include repairing detached retinas, reading product codes on groceries, recording and playing CDs and DVDs, cutting materials, transmitting phone calls and data, surveying roads, identifying molecules or viruses, measuring airplane velocity, cleaning diamonds and art relics, and guiding missiles

5. **Figure A. illustrates a metachlorium blade core. While metachlorium is a fictitious element, what properties might it need in order to work as the core of a lightsaber?**

   Metachlorium would need to be solid at room temperature with a high melting and boiling point, and would need to be a good conductor of heat and electricity.

6. **Based on the commentaries provided, how would you construct a lightsaber?**

   Student answers will vary.

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