Hypersonics STEM Curriculum

Reflecting on Hypersonics

Grade	Time	Subject Area	Key Concepts
High School	45 min	Physics	Light Reflection - Mirrors

Lesson Overview

In this lesson, students will use a flat mirror and two markers to trace the path of light as it is reflected off a mirror and to an observer's eye. They will use their data to relate their diagram to the law of reflection. Students will also be asked to apply their understanding of reflection and the speed of light to viewing hypersonic vehicles.

This lesson is part of a series of high school physics lessons using hypersonics as a context to apply optics content.

NGSS Standards

HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

HS-PS4-3 Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

HS-PS4-5 Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Learning Objectives

By the end of this lesson, students will be able to:

- Draw a ray diagram for light reflected on a flat mirror.
- Label and measure the angle of incidence and angle of reflection on a ray diagram.
- Explain the relationship between the size of the mirror, the object distance, and how much of the object can be viewed in the mirror.
- Use the law of reflection to explain how a mirror works.

Essential/Overarching Question

How are images formed in mirrors?

Key Vocabulary

Speed – the rate at which an object is moving. Speed is calculated by dividing the distance travelled by the time it took to travel that distance.

Speed of Sound – the rate at which sound moves through a medium. The speed of sound depends on both the density and the temperature of the medium. The speed of sound through air at 20° C (68° F) at sea level is 343 m/s (767 mph).

Mach – the ratio of the speed of an object to the speed of sound or how many times the speed of sound an object is moving. It is often followed by a number indicating the ratio; for example: Mach 1 is the speed of sound, Mach 2 is twice the speed of sound, Mach 5 is five times the speed of sound.

Sonic – speeds equal to the speed of sound (Mach 1).

Subsonic – speeds smaller than the speed of sound (less than Mach 1).

Transonic – speeds near (Mach 0.8-1.2) the speed of sound where drag is highest (e.g. sound barrier).

Supersonic – speeds greater than the speed of sound (Mach 1 and greater).

Hypersonic – speeds greater than five times the speed of sound (Mach 5 and greater).

Fluid – a substance with no fixed shape; a liquid, gas, or plasma. A substance that flows when an external force is applied to it.

Flow – the motion of a fluid (liquid, gas, or plasma) when it experiences unbalanced forces.

Refraction – the redirection, or bending, of a wave as it passes from one medium to another caused by a change in speed.

Diffraction – the bending of a wave around the corners of an obstacle or the spreading of a wave through an aperture.

Reflection –the change in direction of a wave as it strikes the boundary between two different media so that the wave returns into the medium from which it originated.

Law of Reflection – when a light rays hits a smooth surface, the angle of reflection is equal to the angle of incidence.

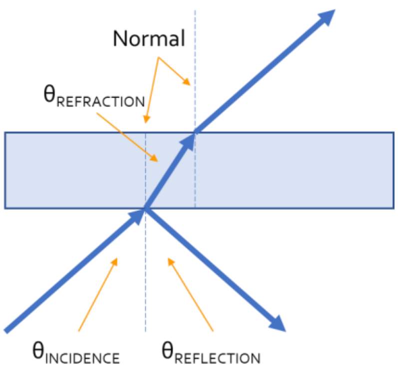
Angle of Incidence – the angle between a ray incident on a surface and the line perpendicular (at a 90-degree angle) to the surface.

Angle of Reflection – the angle between a ray reflected from a surface and the line perpendicular (at a 90-degree angle) to the surface.

Angle of Refraction – the angle between a ray refracted in a medium and the line perpendicular (at a 90-degree angle) to the surface.

Normal – the perpendicular line drawn to the reflecting surface.

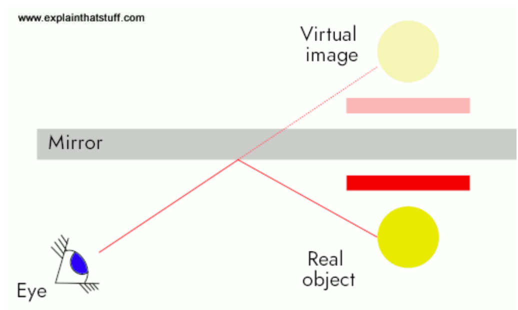
Science Concepts Overview



For you to see an object, light from the object must reach your eye. When you look into a mirror, light from the object reflects off the mirror and travels to your eye. The law of reflection states that the incident angle of a light ray is the same as the reflected angle. The angles of incident and reflection are measured from the normal to the surface – line perpendicular to the surface. Because your eye cannot process that the light changed direction, it thinks that the light came from “inside” the mirror – creating a virtual image.

A misconception that many people have is that if you want to see more of yourself in a mirror, you just need to move back. The truth is, as you move back, you are just changing the angle of the reflected light that meets your eye and you will see the exact same proportion of yourself in the mirror as you did closer up.

Additionally, with flat mirrors, the image you see is the same distance behind the mirror as the object is in front of the mirror. It is true that in mirrors on cars, objects in the mirror are closer than they appear because those are curved mirrors. While they follow the same law of reflection as flat mirrors, the curvature changes where the image is created.



Materials List

- ☐ Flat mirror roughly 8 cm x 16 cm – the markers should be taller than the mirror (one per student)
- ☐ Markers that will stand on their own (two per student)
- ☐ Protractors (one per student)
- ☐ Ruler (one per student)
- ☐ Reflecting on Hypersonics handout (one per student)
- ☐ Reflecting on Hypersonics Exit Ticket handout (one per student)

Lesson Preparation

Prior to the lesson, the instructor should gather materials and make copies of the Reflecting on Hypersonics and the Reflecting on Hypersonics Exit Ticket handouts.

Safety

Due to the nature of this lesson, it is recommended that the class take the following safety precautions:

- Participants should be reminded to be careful not to break the mirrors.
- Participants should be told the protocol in the case that a mirror breaks.

Procedure

Engage (10 minutes)

1. Have students answer questions 1-2 in the Looking into Mirrors section:
    - Taylor has a small flat mirror in their locker. When they are standing close to the mirror, they can see from their eyebrow to their chin. Taylor moves further away from the mirror. How much of their face can Taylor see in the mirror this time?
    - Explain your thinking. Describe your reasoning or any experiences you have had with mirrors that helped you choose your answer.
2. Have students share their ideas either within peer groups or as a class.
3. Have students find a mirror within the school and try what Taylor did.
4. Have students answer questions 3-5 in the Looking into Mirrors section:
    - Find a mirror in your school and try the same thing that Taylor did. As you move further away from a mirror, what did you see?
    - Did your prior understanding of mirrors align with what you just experienced? Why or why not?
    - What is something about mirrors and reflection that currently puzzles you?

Explore (20 minutes)

5. Students will work individually to trace the light path of light rays reflected on a flat mirror using the following directions:
    - Gather a flat mirror, two markers, a protractor, and a ruler.
    - Stand the mirror up along the mirror line in the diagram below. Make sure the reflective side of the mirror is facing the eye.
    - Stand one of your markers on the Object 1 circle.
    - Place a second marker behind the mirror. This is your image. Look in the mirror and locate the reflection in the mirror. Move the marker behind the mirror until the marker behind the mirror is exactly lined up with the reflection in the mirror. The marker is in the correct location when you can move your head from side to side and the marker behind the mirror is always exactly lined up with the reflection.
    - Trace a circle around the marker behind the mirror and label it Image 1.
    - Put a dot in the center of the object circle and the image circle.
    - Draw a line from the center of the image to the white spot on the eye.

- Locate the point where that line crosses the mirror. Draw a second line from this point to the center of the object.
- Draw a normal (perpendicular line) at the mirror where the two lines intersect.
- Label the angle of incidence (θi) and angle of reflection (θr).
- Measure and record the angle of incidence, angle of reflection, object distance to the mirror and image distance to the mirror on the data table.
- Repeat the steps for two other object locations of your choice.

Explain (5 minutes)

6. Students will be asked to explain their understanding of the law of reflection by answering questions 1-4 in the Reflecting on Mirrors section:
    - How do the angles of incident compare to the angles of reflection for each of your objects?
    - How do the object distances compare to the image distances for each of your objects?
    - How does your data compare to the law of reflection?
    - How does doing the activity change your answers to the Looking in Mirrors section? What makes you say that?

Elaborate (5 minutes)

7. Students will be asked to apply their understanding of the law of reflection to hypersonics by answering questions 5-6 in the Reflecting on Mirrors section:
    - One of the benefits of hypersonics vehicles is that they are hard to detect by ground radar systems due to the speed of the vehicles and the altitudes that they are able to travel. Radar uses reflected radio waves to measure an object's distance and velocity. What are different design ideas you have for hypersonic vehicles that would makes it harder to reflect radio waves off them, making it harder for ground radar to detect them?
    - For you to see a hypersonic vehicle, light is reflected from the vehicle and to your eye. The light is moving at 3×10^8 m/s, and a hypersonic vehicle travels at least 1,715 m/s. By the time the light reaches your eyes, will the hypersonic vehicle be where you saw it? Will it have moved a significant distance? How does this change how you perceive aircraft in the sky?

Evaluate (5 minutes)

8. Students will complete the Reflecting on Hypersonics Exit Ticket where they will be asked:
    - Rank the following images based on how much of their body each person will see in the mirror. If there are any ties, indicate that by circling the letters. Explain your reasoning below. (B=E=F, A=C=D)

STEM Career Connections

- Hypersonics engineering
- Aeronautical engineering
- Test engineering

- Systems engineering
- Physics
- Optics
- Manufacturing

Extensions

Students could be further *evaluated* on their understanding of the law of refraction by giving groups of students a laser, a series of flat mirrors, and a target somewhat surrounded by barriers. Students will need to figure out how to angle the mirrors and the laser so that the light beam is reflected onto the target.

Students could *elaborate* on their understanding of the law of reflection by creating their own explanation to the viral TikTok video that asks "How does the mirror know what's behind the paper?" In the video, one person is holding a pack of gum up against mirror with a piece of paper between the mirror and the gum while a second person filming pans out and is able to see the gum in the reflection in the mirror. You could do a demonstration of this for the students and ask them to use the law of reflection to answer their question.

Danny Nicholson: Think Bank Education. (2023, April 8). *How does the mirror know what's behind the paper. Explained!* [Video]. YouTube. https://www.youtube.com/watch?v=7wvkyAJS198

References & Resources

Danny Nicholson: Think Bank Education. (2023, April 8). *How does the mirror know what's behind the paper. Explained!* [Video]. YouTube. https://www.youtube.com/watch?v=7wvkyAJS198

Hieggelke, C., Maloney, D., & Kanim, S. (2012). *Newtonian tasks inspired by physics education research: nTIPERS*. Addison-Wesley.

Mathsphysicslovers. (2022, June 9). *Ray diagram of image formation by plane mirror/ how image formed in plane mirror* [Video]. YouTube. https://www.youtube.com/shorts/_8d_ROODvsc

Science Sauce. (2019, September 28). *Law of Reflection* [Video]. YouTube. https://www.youtube.com/watch?v=V0Z_nk5JS_E

SciShow. (2019, July 8). *A surprisingly simple secret to supersonic flight* [Video]. YouTube. https://www.youtube.com/watch?v=kGefMLHJBKA

Talented Tuber. (2017, April 11). *Difference between subsonic, supersonic and hypersonic speed* [Video]. YouTube. https://www.youtube.com/watch?v=LBJ3tXCjzN0

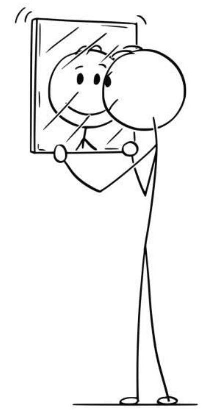
TED-Ed. (2013, September 19). *Light waves, visible and invisible - Lucianne Walkowicz* [Video]. YouTube. https://www.youtube.com/watch?v=O0PawPSdk28

TestTube 101. (2015, November 11). *Flying at hypersonic speeds* [Video]. YouTube https://www.youtube.com/watch?v=vL1qAfS0gic

Name: ____ Date: ___________________

Reflecting on Hypersonics

Looking into Mirrors



1. Taylor has a small flat mirror in their locker. When they are standing close to the mirror, they can see from their eyebrow to their chin. Taylor moves further away from the mirror. How much of their face can Taylor see in the mirror this time?
    a. They will see more of their face.
    b. They will see less of their face.
    c. They will see the same amount of their face.

2. Explain your thinking. Describe your reasoning or any experiences you have had with mirrors that helped you choose your answer.

3. Find a mirror in your school and try the same thing that Taylor did. As you move further away from a mirror, what did you see?
    a. More of my face.
    b. Less of my face.
    c. The same amount as my face.

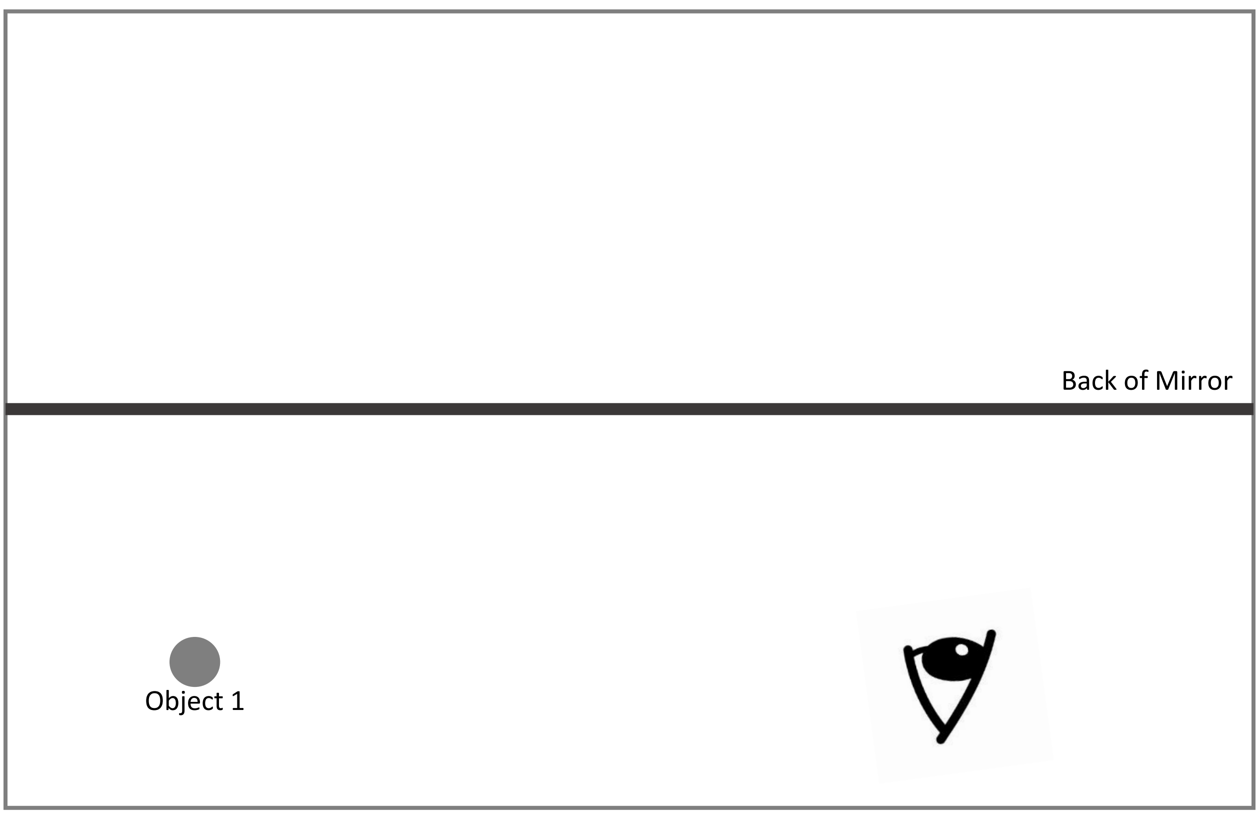
4. Did your prior understanding of mirrors align with what you just experienced? Why or why not?

5. What is something about mirrors and reflection that currently puzzles you?

Tracing Your Reflection

To better understand how light reflects off a mirror to create an image, we are going to trace the path of the light:

1. Gather a flat mirror, two markers, a protractor, and a ruler.
2. Stand the mirror up along the mirror line in the diagram below. Make sure the reflective side of the mirror is facing the eye.
3. Stand one of your markers on the Object 1 circle.
4. Place a second marker behind the mirror. This is your image. Look in the mirror and locate the reflection in the mirror. Move the marker behind the mirror until the marker behind the mirror is exactly lined up with the reflection in the mirror. The marker is in the correct location when you can move your head from side to side and the marker behind the mirror is always exactly lined up with the reflection.
5. Trace a circle around the marker behind the mirror and label it Image 1.
6. Put a dot in the center of the object circle and the image circle.
7. Use a ruler to draw a line from the center of the image to the white spot on the eye.
8. Locate the point where that line crosses the mirror. Use a ruler to draw a second line from this point to the center of the object.
9. Use a ruler and protractor to draw a normal (perpendicular line) at the mirror where the two lines intersect.
10. Label the angle of incidence (θ_i) and angle of reflection (θ_r).
11. Use a ruler and protractor to measure and record the angle of incidence, angle of reflection, object distance to the mirror and image distance to the mirror on the data table.
12. Repeat the steps for two other object locations of your choice.



Object	Angle of Incident	Angle of Reflection	Object Distance	Image Distance
1				
2				
3				

✈**Reflecting on Mirrors**

1. How do the angles of incident compare to the angles of reflection for each of your objects?

2. How do the object distances compare to the image distances for each of your objects?

3. How does your data compare to the law of reflection?

4. How does doing the activity change your answers to the Looking in Mirrors section? What makes you say that?

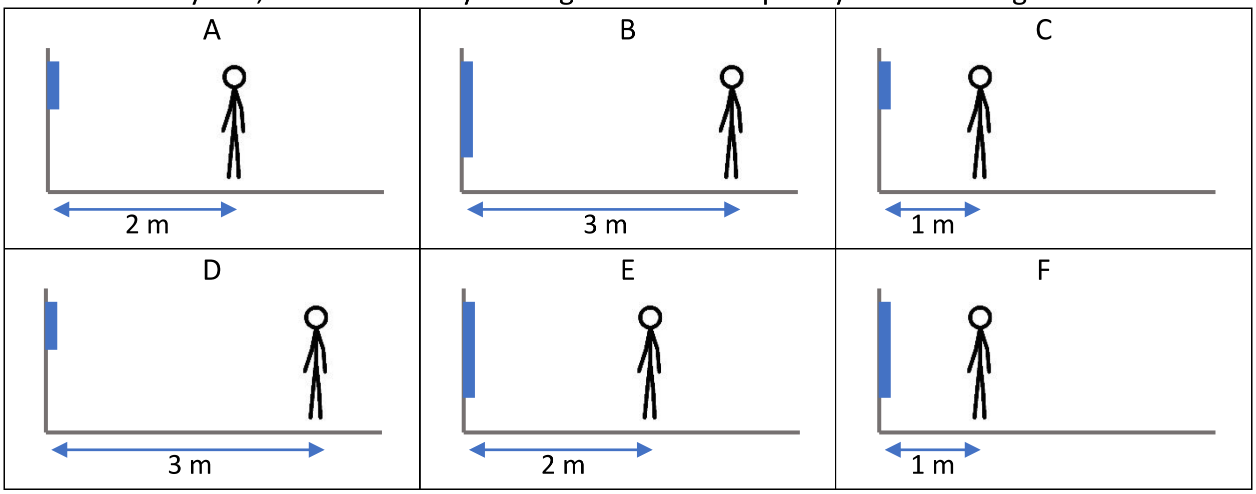
5. One of the benefits of hypersonics vehicles is that they are hard to detect by ground radar systems due to the speed of the vehicles and the altitudes that they are able to travel. Radar uses reflected radio waves to measure an object's distance and velocity. What are different design ideas you have for hypersonic vehicles that would makes it harder to reflect radio waves off them, making it harder for ground radar to detect them?

6. For you to see a hypersonic vehicle, light is reflected from the vehicle and to your eye. The light is moving at 3×10^8 m/s, and a hypersonic vehicle travels at least 1,715 m/s. By the time the light reaches your eyes, will the hypersonic vehicle be where you saw it? Will it have moved a significant distance? How does this change how you perceive aircraft in the sky?

Name: ____ Date: ____________________

Reflecting on Hypersonics Exit Ticket

Rank the following images based on how much of their body each person will see in the mirror. If there are any ties, indicate that by circling the letters. Explain your reasoning below.

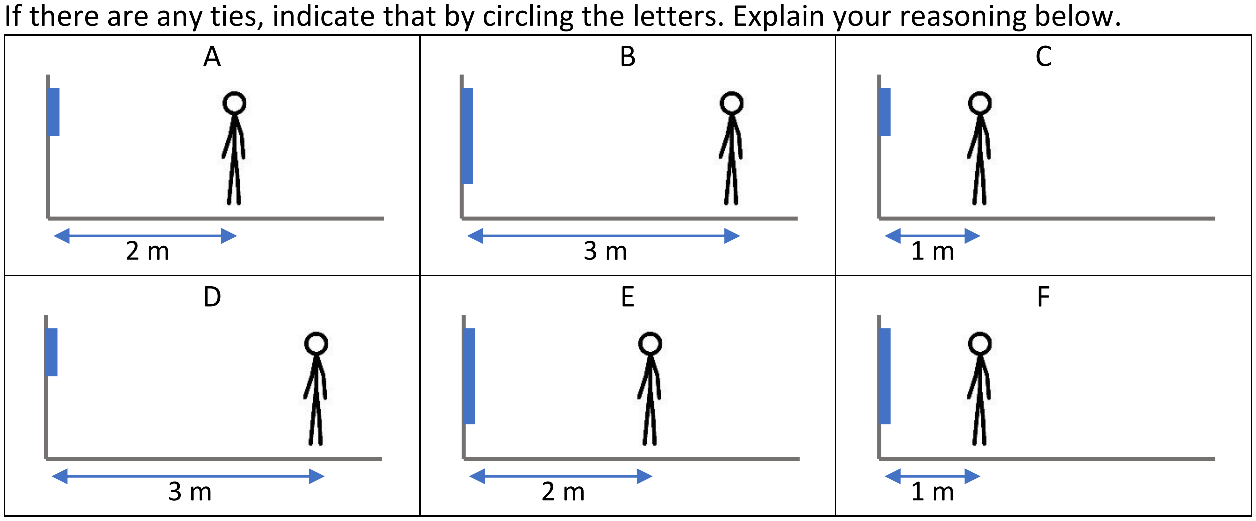


Largest _______, _______, _______, _______, _______ **Smallest**

Name: ____ Date: ____________________

Reflecting on Hypersonics Exit Ticket

Rank the following images based on how much of their body each person will see in the mirror. If there are any ties, indicate that by circling the letters. Explain your reasoning below.



Largest _______, _______, _______, _______, _______ **Smallest**