



Hypersonics STEM Curriculum



Hypersonic Units

Grade	Time	Subject Area	Key Concepts
6-8	45 min	Physical Science	Speed/velocity

Lesson Overview

In this lesson, students will convert the speed of objects moving at a wide range of speeds (a yacht, a school zone, sound, a North American X-15, and light) into units of miles per hour, kilometers per hour, meters per second, knots, and Mach number. By using a variety of objects and units, students will work to gain an understanding of the magnitude and equivalence of the different units.

Prior to this lesson, students should have learned how to do unit conversions and will now be able to apply their knowledge to the context of speed.

NGSS & CCSS Standards

MS-PS2-2 Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.

CCSS.MATH.CONTENT.7.RP.1 Compute unit rates associated with ratios of fractions, including ratios of lengths, areas and other quantities measured in like or different units.

CCSS.MATH.CONTENT.7.RP.2b Recognize and represent proportional relationships between quantities. Identify the constant of proportionality (unit rate) in tables, graphs, equations, diagrams, and verbal descriptions of proportional relationships.

Learning Objectives

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

- Convert speeds to different units.
- Explain the importance of using and understanding units.

Essential/Overarching Question

What are different ways of expressing how fast an object is moving?

Key Vocabulary

Units – a standard for making comparisons in measurements.

Unit Conversion – a statement or ratio that expresses how many of one unit are equal to another unit.

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.

Science Concepts Overview

Units are a critical aspect of measurements. Not only do units tell the reader how the quantity was measured, they also give clues to the magnitude of the measurement. For example, a distance of 10 centimeters is much smaller than a distance of 10 meters which is much smaller than a distance of 10 kilometers.

Speed has a wide range of measurements that are used in everyday life as well as in science contexts. Speed limits are frequently posted in miles per hour (mph) or kilometers per hour (km/h). The International System (SI) of Units for speed are meters per second (m/s). Boats and airplanes may use knots (kn) measure their speed. And objects that are traveling at very fast speeds often use a Mach number to represent their speed. Mach number is a ratio of the object's speed to the speed of sound.

Materials List

- Hypersonics Units handout (one per student)

- Calculators (one per student)
- Loose leaf paper (one per student)

Lesson Preparation

Prior to the lesson, the instructor should make copies of the Hypersonic Units handout and ensure that each student has access to a calculator.

Safety

There are no additional safety concerns beyond normal classroom procedures for this lesson.

Procedure

Engage (5 minutes)

1. Divide students into groups. Give the groups one to two minutes to answer the following questions on a whiteboard or large piece of paper to share with the class:
 - Name all of the units you can think of that measure speed.
 - How or when are those units used to measure speed?
2. Have each group share out their ideas.
3. Individually, or as a class, read the Introduction on the Hypersonic Units handout.

Explore (20 minutes)

4. Students will work individually, or in groups, to convert the speeds of the five objects into the other four units. They are provided a table with unit conversation factors to use as a reference. Students are asked to show all of their work on a separate piece of paper.
 - Yacht → 17.26 mph = 27.78 km/h = 7.72 m/s = 15 kn = Mach 0.023
 - School Speed Limit → 25 mph = 40.23 km/h = 11.18 m/s = 21.72 kn = Mach 0.033
 - Sound → 767.27 mph = 1234.8 km/h = 343 m/s = 666.74 kn = Mach 1
 - North American X-15 → 4,519.22 mph = 7,272.97 km/h = 2,020.27 m/s = 3,927.09 kn = Mach 5.89
 - Light → 6.71×10^8 mph = 1.079×10^9 km/h = 3.0×10^8 m/s = 5.83×10^8 kn = Mach 8.75×10^5

Example:

25 miles	1609.34 m	1 hour	1 min	= 11.18 m/s
hour	1 mile	60 min	60 sec	

Explain & Elaborate (10 minutes)

5. Students will elaborate on their understanding and apply their knowledge further by answering the following questions on the Hypersonic Units handout:
 - Why is it important to label measurements with units?
 - For objects moving at large speeds, such as supersonic and hypersonic vehicles, what units do you think are the most useful? What makes you say that?

- For objects moving at smaller speeds, such as animals and bicycles, what units do you think are the most useful? What makes you say that?
- It was estimated on one online forum that hyperspace, the unit of measurement for speed used in Star Wars, was equal to 25,000 light years per day or 6.12×10^{15} mph. What is the Mach number for the Millennium Falcon when it is traveling at hyperspace?

Evaluate (10 minutes)

6. Divide the 20 conversions up between groups of students. Each group should share the work and solutions for their assigned conversions with the class.

STEM Career Connections

- Aerospace engineering
- Physicist
- Testing engineer
- Pilots
- Mechanical engineer

Extensions

To further **explain** their understanding of units and unit conversions, students could each make up their own unit for speed and create conversion factors between their unit and the five units used in this lesson. Students will also need to explain when (the magnitude) it would be appropriate to use their new unit.

References & Resources

- Anil Kimar. (2016, September 9). *Convert units for velocity km per hour to meter per sec* [Video]. YouTube. <https://www.youtube.com/watch?v=0o4OCrn3e5Q>
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- Talented Tuber. (2017, April 11). *Difference between subsonic, supersonic and hypersonic speed* [Video]. YouTube. <https://www.youtube.com/watch?v=LBJ3tXCjzN0>
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- UVA Engineering. (2021, September 27). *"Need for speed: A hypersonics lecture"- Need for speed video contest* [Video]. YouTube. <https://www.youtube.com/watch?v=at2v5LJ0SUU>

Dr. Lori M. Stiglitz
JHTO Workforce Development Lead

Dr. Stephanie Stehle
Curriculum Specialist

Name: _____ Date: _____

Hypersonic Units

✦ Introduction

Different objects move at different speeds. With such a large possible range of object speeds, there is a variety of ways to measure speed. Speed limits are frequently posted in **miles per hour** (mph) or **kilometers per hour** (km/h). The International System (SI) of Units for speed are **meters per second** (m/s). Boats and aircrafts use **knots** (kn) to measure their speed. Objects traveling at very fast speeds often use a **Mach number** to measure their speed.






Unit Conversions Factors		
60 s = 1 min	1 m = 1000 km	1 kn = 1.15 mph
60 min = 1 h	1 mile = 1609.34 m	Mach 1 = 343 m/s

Mach number is a ratio of an objects speed to the speed of sound (the speed a sound wave moves from a source to a receiver). The Mach number, which can be a whole number (Mach 3) or a decimal (Mach 0.6), is calculated by dividing the speed of an object by the speed of sound.

The speed of sound depends on the medium the sound wave is traveling through (air, water, metal, etc.), the medium's density, and temperature. The speed of sound of air at 20° C (68° F) is 343 m/s. Speeds are categorized based on their Mach number. Speeds less than Mach 1 are **subsonic**, greater than Mach 1 are **supersonic**, and greater than Mach 5 are **hypersonic**.

✦ Unit Conversions

Use the unit conversion factors above to express the speeds of a yacht, a school zone speed limit, sound, North American X-15, and light in terms of miles per hour, kilometers per hour, meters per second, knots, and Mach number. Show all of your work on another piece of paper and attach it to this handout when you are finished.

	Miles per hour (mph)	Kilometers per hour (km/h)	Meters per second (m/s)	Knots (kn)	Mach number
				15 kn	
	25 mph				
			343 m/s		
					Mach 5.89
		1.079 x 10 ⁹ km/h			

★ Analysis Questions

1. Why is it important to label measurements with units?
2. For objects moving at large speeds, such as supersonic and hypersonic vehicles, what units do you think are the most useful? What makes you say that?
3. For objects moving at smaller speeds, such as animals and bicycles, what units do you think are the most useful? What makes you say that?
4. It was estimated on one online forum that hyperspace, the unit of measurement for speed used in Star Wars, was equal to 25,000 light years per day or 6.12×10^{15} mph. What is the Mach number for the Millennium Falcon when it is traveling at hyperspace?