

Gravitational Waves

Grades 11-12

Estimated class time 45 minutes.

Summary

The purpose of this lesson is to model for the students what a gravitational wave is and how it is created.

Objectives

- Students will be able to define and describe the characteristics of all waves
- Students will be able to describe and discuss on a conceptual basis how Einstein's theory of general relativity describes gravity.
- Students will be able to describe how a gravitational wave is created.
- Students will be able to compare the properties of gravitational waves with other waves

National Science Standards

- NS.9-12.1 SCIENCE AS INQUIRY
As a result of activities in grades 9-12, all students should develop
 - Abilities necessary to do scientific inquiry
 - Understandings about scientific inquiry
- NS.9-12.2 PHYSICAL SCIENCE
As a result of their activities in grades 9-12, all students should develop an understanding of
 - Motions and forces
 - Conservation of energy and increase in disorder
 - Interactions of energy and matter
- NS.9-12.4 EARTH AND SPACE SCIENCE
As a result of their activities in grades 9-12, all students should develop an understanding of
 - Origin and evolution of the earth system
 - Origin and evolution of the universe
- NS.9-12.7 HISTORY AND NATURE OF SCIENCE
As a result of activities in grades 9-12, all students should develop understanding of
 - Science as a human endeavor
 - Nature of scientific knowledge
 - Historical perspectives

Knowledge Prerequisite

Students should have a basic understanding of waves. They should also be familiar with Einstein's theory of general relativity.

Teacher Background

Throughout the lesson pay attention to the Teacher Note sections. These sections are for your benefit, with the information contained to be revealed to the students as you deem necessary. This lesson is formatted for students with a basic understanding of waves. Please feel free to modify if you deem appropriate.

Materials

- Plastic wrap
- Water
- Cups (Enough for class)
- Food Coloring
- Rubber bands (Enough for class)
- Marbles (Enough for two per student)
- Gravitational Wave Demonstrator (See Appendix for Construction Steps)
- A slinky or some other string like object that can be used to demonstrate basic wave properties.

Procedure:

I. Engagement

Have the students read the 1993 article “**Pulsar Gravitational Waves Win Nobel Prize.**” Discuss gravitational waves with the class. Lead them through a discussion about what a gravitational wave might be and how they might form.

II. Exploration

Teacher Note: Depending on the level of your students, the concept of a wave can be differentiated. Waves are created by the **accelerations** of particles, i.e. electrons creating electromagnetic waves, matter particles creating sound, etc. On a conceptual high school level, “**vibrations**” are a simplification that makes wave formation easier to grasp but the **acceleration** model is more accurate. This lesson has been created with the broader range of high school learners in mind. If you deem it appropriate for your students, feel free to substitute the **acceleration** explanation of wave creation for the “**vibrations**” method.

1. After the introduction, first conduct a basic review of wave properties. Start off with a partner and using the slinky demonstrate how to create a wave. The key ideas to discuss are that a vibration creates a wave and that the wave transports energy.
2. On the board, give the students the following notes:
 - a. All waves are created by vibrations
 - b. All waves transport energy from one location to another.
 - c. All waves with the exception of electromagnetic waves require a medium.

Teacher Note: Throughout your notes, describe various waves to the students. The key idea of this section is to make it clear to the students that waves, regardless of type, share similar properties and are created by similar processes. Talk about how water waves are created. Talk about how the “vibrations” of electrons create electromagnetic waves. But be sure to make clear to your students that although there are different types of waves, they are all similar in terms of their properties.

3. Now instruct the students about how to build their Gravitational Wave Demonstrator.

Teacher Note: Depending on class dynamics you may want to perform a demonstration instead of a student activity. You can use the gravitational wave demonstrator with an overhead. In this case use a clear plastic dish, like a pie plate or food container, to help with spilled water.

4. First place one marble on the Gravitational Wave Demonstrator. At this point a classic demonstration of Einstein’s Theory of General Relativity is presented. The Gridlines should appear warped. Placing the second marble on the demonstrator should simulate the effects of gravity.

Teacher Note: A complete lesson on Einstein Theory of General Relativity can be found with the lesson for the Cosmic Times 1919. This lesson can be used as a prior lesson or as a reference for expanding this section of this lesson. The key idea that needs to be addressed to the students is how Einstein’s Theory of General Relativity explains gravity.

5. Now have the students share with a partner what is necessary to create any wave. Then share with the class. *They should respond a vibration.*

6. Now place a moving mass in the Gravitational Wave Demonstrator. Students should notice ripples in the plastic wrap. These are gravitational waves.

III. Explanation

7. Now give the students more notes.

- a. Define gravitational waves: Disturbance in the curvature of space-time caused by the motion of matter.
- b. Gravitational waves are literally the vibration of space-time

8. Now discuss with the class how physicists originally believed that gravitational waves were a mathematical anomaly, that they couldn’t be real. What property of all waves would make gravitational waves seem improbable? *Answer: All waves transport energy. What is lost from the moving matter?*

9. Now relate back to the article. How did scientists prove the existence of gravitational waves? *Answer: The stars are part of a binary system and are in orbit about each other. They were found to be slowly spiraling in toward this other. This is caused by a loss of orbital energy. That energy is now going into gravitational waves, which is*

being generated by the motion of the stars around each other. The gravitational waves transport the energy out of the binary star system.

IV. Extension/Evaluation

10. Have the students finish either two ways
 - a. Develop an experiment for detecting gravitational waves. How could you notice or detect the existence of these ripples?
 - b. Write a summary of how gravitational waves are created. Answer the following points.
 - i. What do they have in common with other waves?
 - ii. How are they created?
 - iii. What is their medium?

Appendix

Gravitational Wave Demonstrator

1. Fill a cup with water to the brim. Add a little food coloring to aid with observing the medium. Prepare your demonstration area for a little spill over. A clear plastic container would be useful for an overhead.
2. Take plastic wrap and with a sharpie marker create a grid. Place on top of the cup and secure with a rubber band. Make sure the plastic wrap is tightly wrapped.
3. Place mass on top of the wrap to simulate the curvature of space-time. Moving masses create ripples. (Gravitational waves) The more mass the greater the effect.