

Bent Out of Shape Solar System

Universal Law of Gravity

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Published by *K20 Center*

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Grade Level	11th – 12th Grade	**Time Frame**	160 minutes
Subject	Science	**Duration**	3 class periods
Course	Physics		

Essential Question

Why do objects attract each other? What holds solar systems together? How does spacetime explain how gravity acts at a distance?

Summary

In this lesson, students examine how Einstein's spacetime is warped by mass, and they learn to use this idea to explain how gravity holds the solar system together. Students investigate spacetime being warped by using a Fabric of Spacetime Table and then apply Newton's Law of Gravitation to derive the equations for an object in orbit. By the end of the lesson, students will calculate the centripetal force, speed and period of an object in orbit. Students analyze the idea that spacetime is a real building block of the universe by examining how accelerating objects create gravitational waves.

Snapshot

Engage

Students listen to the sound of a gravitational wave to spark initial interest in the topic, make observations, and form questions about the topic.

Explore

Students observe and qualitatively explain the motion of marbles on a spandex table with a large mass in the middle as an analogy of how planets orbit the sun.

Explain

Students are introduced to the concept of spacetime in a reading, and they are asked to go back and evaluate how the concept fits in with the descriptions that they made of the spandex table, which is now referred to as the fabric of spacetime.

Students apply Newton's Law of Gravitation as the centripetal force for objects in orbit to construct equations of objects in orbit. Students make use of these equations to solve for centripetal force, orbital speed, and period.

Extend

Students analyze the information in videos to explain how the detection of gravitational waves is evidence for the existence of spacetime.

Evaluate

Students demonstrate conceptual understanding of how warping spacetime causes objects to orbit by applying the concept to black holes to explain why even light cannot escape the black hole. This is a new application, and so it requires the students to adapt what they know about centripetal motion and spacetime.

Students demonstrate quantitative proficiency of the concept through deriving and solving the equations that were introduced in the explain section.

Standards

Next Generation Science Standards (Grades 9, 10, 11, 12)

HS-PS2: Motion and Stability: Forces and Interactions
HS-PS2-4: Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
HS-ESS1: Earth's Place in the Universe
HS-ESS1-4: Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

Attachments

- Einstein's Spacetime Reading—Bent Out of Shape Solar System - Spanish.docx
- Einstein's Spacetime Reading—Bent Out of Shape Solar System - Spanish.pdf
- Einstein's Spacetime Reading—Bent Out of Shape Solar System.docx
- Einstein's Spacetime Reading—Bent Out of Shape Solar System.pdf
- Exit Ticket Solution Key - Bent Out of Shape Solar System.docx
- Exit Ticket Solution Key - Bent Out of Shape Solar System.pdf
- Fabric of Spacetime Setup Directions - Bent Out of Shape Solar System.docx
- Fabric of Spacetime Setup Directions - Bent Out of Shape Solar System.pdf
- Fabric of Spacetime Teachers Guide - Bent Out of Shape Solar System.docx
- Fabric of Spacetime Teachers Guide - Bent Out of Shape Solar System.pdf
- Fabric of Spacetime—Bent Out of Shape Solar System - Spanish.docx
- Fabric of Spacetime—Bent Out of Shape Solar System - Spanish.pdf
- Fabric of Spacetime—Bent Out of Shape Solar System.docx
- Fabric of Spacetime—Bent Out of Shape Solar System.pdf
- Gravitational Waves Teacher's Guide - Bent Out of Shape Solar System.docx
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- Gravitational Waves—Bent Out of Shape Solar System.pdf
- Gravity Holds Solar System Together Teachers Guide - Bent Out of Shape Solar System.docx
- Gravity Holds Solar System Together Teachers Guide - Bent Out of Shape Solar System.pdf
- Gravity Holds Solar System Together—Bent Out of Shape Solar System - Spanish.docx
- Gravity Holds Solar System Together—Bent Out of Shape Solar System - Spanish.pdf
- Gravity Holds Solar System Together—Bent Out of Shape Solar System.docx
- Gravity Holds Solar System Together—Bent Out of Shape Solar System.pdf
- Lesson Slides - Bent Out of Shape Solar System.pptx

Materials

- Lesson Slides (attached)
- Fabric of Spacetime Setup Directions (attached)
- Fabric of Spacetime handout (attached, 1 per student)
- Einstein’s Spacetime Reading handout (attached, 1 per student or posted online)
- Gravity Holds Solar System Together (attached, 1 per student)
- Gravitational Waves handout (attached, 1 per student)
- Gravitational Waves Teacher’s Guide (attached)
- Exit Ticket Solution Key (attached)
- Butcher paper (one piece per group)
- Materials required per Fabric of Spacetime Table:
    - 4 - Insert Female Tee with ½” barb x ½” barb x ½” FPT

    - 4 - ¾" PEX Pipe 46" long
    - 4 - ½" PVC Tee
    - 1 - ½" PVC Cross
    - 8 - ¾" J-Hook Pipe Hanger
    - 4 -½" PVC Adapter
    - 4 - ½" PVC Pipe 22" long
    - 4 - ½" PVC Pipe 30.5" long
    - 1 spandex fabric 1.75m x 1.75m
    - 1 1kg weight
- Approximately 20 marbles
- Notebook paper
- Pencil

20 minutes

Engage

Teacher's Note: Lesson Preparation

In advance of teaching the lesson, build the Fabric of Spacetime Tables using the **Fabric of Spacetime Setup Directions**. Before the lesson, practice the demonstrations to help guide students about what to do during the lesson. View the video below for a demonstration of using the tables with students. Ideally two tables are preferred but adjust the number of tables based on your classroom and students.

Embedded video

https://youtube.com/watch?v=MTY1Kje0yLg

Use **Lesson Slides** to guide the lesson. Display **slides 3 and 4** to review the essential questions and learning objectives with students. Have students take out a piece of notebook paper. Move to **slide 5** and introduce the I Notice, I Wonder strategy to students. Display **slide 6** and provide the information on the slide to students which provides context for the video they are going to watch.

Next, move to **slide 7** and play **The Sound of a Gravitational Wave** video. Move to **slide 8** and give students 3-5 minutes to individually write down two things they noticed and two things they wonder about from the video.

Place students in groups of 4-5 and give each group a piece of butcher paper. Display **slide 9** and give students about ten minutes to discuss their responses and record the highlights for the group on the butcher paper.

Have students hang up their butcher paper around the room. The main objective is to spark student interest and to bring up questions. It is okay if they do not have many answers at this point. Throughout the unit, have students re-visit the butcher paper and add answers to their questions.

Teacher's Note: Technology Integration

An alternative to the butcher paper could be to have the groups post their responses on a class discussion board such as Padlet or shared Google document.

30 minutes

Explore

Give each student the attached **Fabric of Spacetime** handout. Display **slide 10** and have students stand around the Fabric of Spacetime Table(s). Ask students to complete the tasks on the handout by having students take turns at the table(s). Monitor students as they complete the tasks, providing help and guidance when needed. See the attached **Fabric of Spacetime Teachers Guide** which provides more information about the way the marbles interact with the table.

Teacher's Note: Technology Integration

All student handouts can be posted online instead of printing, and students could record their responses in their notebook or on notebook paper.

55 minutes

Explain

Have students return to their seats. Display **slide 11**, and pass out the attached **Einstein's Spacetime Reading** handout. Introduce the CUS and Discuss strategy to students. Provide time for students to read the handout silently. After reading, pair students up and have them discuss what they circled, underlined, and starred.

Tell students to pair up and revisit their notes on the Fabric of Spacetime handout and re-answer question 2 again using the idea that mass bends spacetime. Ask a few groups to share what they have written down for question 2 now that they have learned about spacetime.

Display **slide 12** and pass out the attached **Gravity Holds Solar System Together** handout. Have a class discussion over questions 1-6 by asking students to explain each question to you with words and equations using their prior knowledge of centripetal force and Newton's Laws to justify why the objects are behaving like they do. Use the attached **Gravity Holds Solar System Together Teacher's Guide** to facilitate the discussion. For question 7, complete the question as a class and prompt students to explain each step of the question. Then move to **slide 13** and have students work in partners to complete question 8. Display **slide 14** and tell students to respond to question 9 using the Claims, Evidence, Reasoning (CER) strategy. Slide 14 has instructions for how to write a CER.

Teacher's Note: Writing a Claim, Evidence, Reasoning

If students are not familiar with CER, consider showing this video to students:

Embedded video
https://youtube.com/watch?v=JGOxVIgmGWE

Teacher's Note: Equation Explanation

In regards to the **Gravity Holds Solar System Together** handout, Treating /r/ as one value for the whole sun works because the sun has a spherical mass distribution. If the mass were spread out differently, the equation needs to take the different distances for different pieces of mass into account.

35 minutes

Extend

Display **slide 15** and pass out the attached **Gravitational Waves** handout. Place students into groups of two to three. Tell students they are to watch two videos and should work together to add what they notice and what they wonder to their handout after each video. Display **slide 16** and play the **Gravitational Waves Explained** video.

Embedded video
https://youtube.com/watch?v=4GbWfNHtHRg

Have students add notes from the video to their handout. Move to **slide 17,** and play the **Brian Greene Explains Discovery of Gravitational Waves** video. Have students add notes from the video to their handout.

Embedded video
https://youtube.com/watch?v=s06_jRK939I

Teacher's Note: Solutions Guide

See the attached **Gravitational Waves Teacher's Guide** for sample answers as well as more information about the discussion of gravitational waves. Information about interferometer and links are also provided for more information.

After students have added notes from the videos, have them pair up and review what they have written down with another student. Then, ask for several pairs to share what they took away from the video. Use this time to clarify any misconceptions or answer questions students might have.

20 minutes

Evaluate

Display **slide 18** and divide the students into groups of 2-3. Have the students look at the questions on the butcher paper around the room from the Engage section earlier in the lesson. On a group sheet of notebook paper that students will turn in, have students record the answers for 3 of the questions on the butcher paper posted around the room, and write down 1 question they still do not know the answer to. At a later time, review the questions students have written that they could not answer.

Display **slide 19** and have students individually answer the two questions on notebook paper and turn it in before leaving the classroom for the day. Review students' papers to assess understanding of the lesson content. See the attached **Exit Ticket Solution Key** for answers to the questions.

Resources

- K20 Center. (n.d.). Claims, evidence, reasoning (CER). Strategies. https://learn.k20center.ou.edu/strategy/156
- K20 Center. (n.d.). I notice, I wonder. Strategies. https://learn.k20center.ou.edu/strategy/180
- YouTube. (11 February 2016). Brian Greene Explains the Discovery of Gravitational Waves. Video. https://www.youtube.com/watch?v=s06_jRK939I
- YouTube. (1 February 2016). Gravitational Waves Explained. Video. https://www.youtube.com/watch?v=4GbWfNHtHRg
- YouTube. (3 November 2020). Sound of the first detected gravitational wave!! https://youtu.be/Nvl89a46Ogw