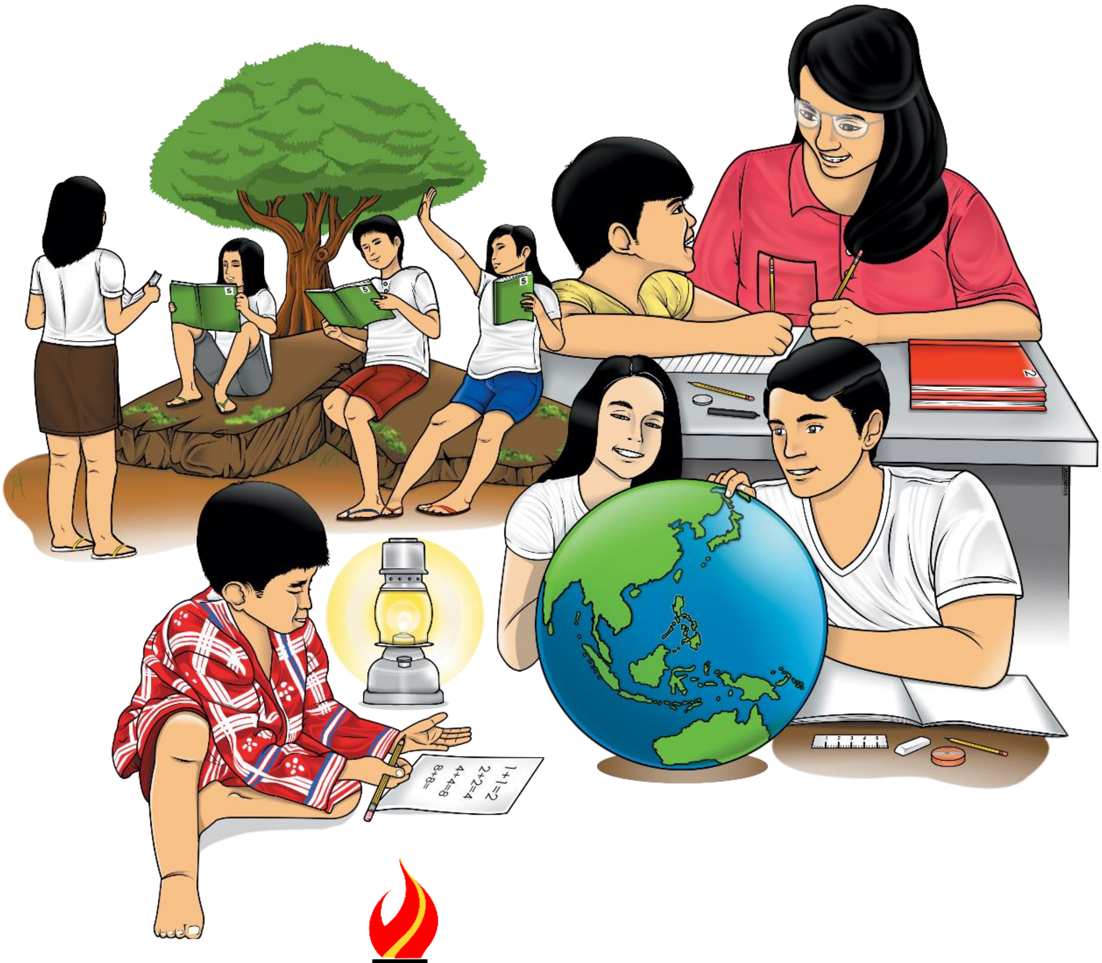
Senior High School

Physical Science

Quarter 2 – Module 6:

General Relativity



ALTERNATIVE DELIVERY MODE

ADM

Physical Science
Alternative Delivery Mode
Quarter 2 – Module 6: General Relativity
First Edition, 2020

Published by the Department of Education
Secretary: Leonor Magtolis Briones
Undersecretary: Diosdado M. San Antonio

Development Team of the Module

Authors: Vea Marie V. Ibardolaza

Editors: Joey H. Villanueva, Arlene C. Malaybalay

Reviewers: Tommy R. Rico, Emiterio D. Macarubbo, Maricris N. Surigao

Illustrator: Vea Marie V. Ibardolaza

Layout Artist: Justine C. Montoya

Management Team: Wilfredo E. Cabral, Director IV
Jennifer F. Vivas, CLMD Chief
Dennis M. Mendoza, Regional EPS in-charge of LRMS
Micah S. Pacheco, Regional ADM Coordinator
Jocelyn M. Aliñab, CID Chief
Tommy R. Rico, Division in-charge of LRMS
and Division ADM Coordinator

Department of Education – National Capital Region

Office Address: Misamis St., Bago Bantay, Quezon City

Telefax: 02-929-0153

E-mail Address: depedncr@deped.gov.ph

Senior High School

Physical Science

Quarter 2- Module 6:
General Relativity

DEPARTMENT OF EDUCATION

Introductory Message

For the facilitator:

Welcome to the Physical Science 11 Alternative Delivery Mode (ADM) Module on General Relativity!

This module was collaboratively designed, developed and reviewed by educators to assist you, the teacher or facilitator in helping the learners meet the standards set by the K to 12 Curriculum while overcoming their personal, social, and economic constraints in schooling.

This learning resource hopes to engage the learners into guided and independent learning activities at their own pace and time. Furthermore, this also aims to help learners acquire the needed 21st century skills while taking into consideration their needs and circumstances.

In addition to the material in the main text, you will also see this box in the body of the module:

Notes to the Teacher

This contains helpful tips or strategies that will help

As a facilitator you are expected to orient the learners on how to use this module. You also need to keep track of the learners' progress while allowing them to manage their own learning. Furthermore, you are expected to encourage and assist the learners as they do the tasks included in the module.

For the learner:

Welcome to the Physical Science 11 Alternative Delivery Mode (ADM) Module on General Relativity!

Our hands are the most represented parts of the human body. It is often used to depict skill, action, and purpose. With our hands, we create, accomplish and learn. Hence, you are capable and empowered to successfully achieve the relevant competencies and skills at your own pace and time. Your academic success lies in your own hands!

This module was designed to provide you with fun and meaningful opportunities for guided and independent learning at your own pace and time. You will be able to process the contents of the learning resource while being an active learner.

This module has the following parts and corresponding icons:

What I Need to Know	This will give you an idea of the skills or competencies you are expected to learn in the module.
What I Know	This part includes an activity that aims to check what you already know about the lesson to take. If you get all the answers correct (100%), you may decide to skip this module.
What's In	This is a brief drill or review to help you link the current lesson with the previous one.
What's New	In this portion, the new lesson will be introduced to you in various ways such as a story, a song, a poem, a problem opener, an activity or a situation.
What is It	This section provides a brief discussion of the lesson. This aims to help you discover and understand new concepts and skills.
What's More	This comprises activities for independent practice to solidify your understanding and skills of the topic. You may check the answers to the exercises using the Answer Key at the end of the module.
What I Have Learned	This includes questions or blank sentence/paragraph to be filled in to process what you learned from the lesson.
What I Can Do	This section provides an activity which will help you transfer your new knowledge or skill into real life situations or concerns.

Assessment

This is a task which aims to evaluate your level of mastery in achieving the learning competency.

Additional Activities

In this portion, another activity will be given to you to enrich your knowledge or skill of the lesson learned. This also tends retention of learned concepts.

Answer Key

This contains answers to all activities in the module.

At the end of this module you will also find:

References

This is a list of all sources used in developing this module.

The following are some reminders in using this module:

1. Use the module with care. Do not put unnecessary mark/s on any part of the module. Use a separate sheet of paper in answering the exercises.
2. Don’t forget to answer *What I Know* before moving on to the other activities included in the module.
3. Read the instruction carefully before doing each task.
4. Observe honesty and integrity in doing the tasks and checking your answers.
5. Finish the task at hand before proceeding to the next.
6. Return this module to your teacher/facilitator once you are through with it.

If you encounter any difficulty in answering the tasks in this module, do not hesitate to consult your teacher or facilitator. Always bear in mind that you are not alone.

We hope that through this material, you will experience meaningful learning and gain deep understanding of the relevant competencies. You can do it!

What I Need to Know

This module will help you understand space-time warping and determine the consequences of General Relativity. This module will provide you with discussions and learning activities designed in such a way that students can easily understand.

CONTENT STANDARD: The learners demonstrate an understanding of Relativity and the Big Bang.

PERFORMANCE STANDARD: The learners should be able to create a video presentation that details the impact of the Theory of Relativity to human.

LEARNING COMPETENCIES: The learners must explain the consequences of the postulates of General Relativity (eg. correct predictions of shifts in the orbit of Mercury, gravitational bending of light, and black holes)

CODE:S11/12PS-IVi-j-71

- Lesson 1 – The Modern Theory of Gravitation

After going through this module, you are expected to:

1. Describe gravity based on General Relativity.
2. Explain the consequences of the postulates of General Relativity.
3. Determine how General Relativity can be observed in real life situations.

What I Know

Direction: Read each question carefully. Choose the letter of the best answer. Write your answer on a separate sheet of paper.

1. What planet in the solar system is most affected by the sun's warping of space-time?
   a. Mercury
   b. Venus
   c. Earth
   d. Mars

2. How does General Relativity view gravity?
   a. Gravity warps space and time.
   b. Gravity is the curvature of space-time.
   c. Gravity warps mass.
   d. Gravity is a force.

3. Which is true about time according to general relativity?
   a. Time slows down with gravity.
   b. Time accelerates with gravity.
   c. Time is pulled down by gravity.
   d. Time can't be changed by gravity.

4. How does the curvature of space-time affect the light from distant stars?
   a. The curvature of space-time reflects light passing through it.
   b. The curvature of space-time bends light passing through it.
   c. The curvature of space-time does not allow light pass through it.
   d. The curvature of space-time absorbs the light passing through it.

5. Which is an application of the concepts of Einstein's General Theory of Relativity?
   a. using an electromagnet
   b. adjustments made in Global Positioning System or GPS
   c. presence of light
   d. all of the above

6. What must be the velocity of an object to escape a black hole?
   a. less than c
   b. zero
   c. equal to c
   d. greater than c

7. How does mass affect the warping of space-time?
    a. The greater the mass of an object, the space-time around it becomes more distorted.
    b. The greater the mass of an object, the space-time around it becomes less distorted.
    c. The lesser the mass of an object, the space-time around it becomes more distorted.
    d. The mass of an object does not affect the warping of space-time.

For nos. 8 and 9, refer to the table below:

Planet	**Mass** (10^{24}kg)	**Diameter** (km)
Venus	4.87	12,104
Earth	5.97	12,756
Jupiter	1898	142,984
Uranus	86.8	51,118

8. Based on the data, what planet can warp space-time the most?
    a. Venus
    b. Earth
    c. Jupiter
    d. Uranus

9. Based on the data, what planet can warp space-time the least?
    a. Venus
    b. Earth
    c. Jupiter
    d. Uranus

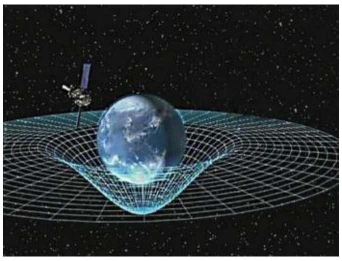
10. What is an example of a non-inertial frame of reference?
    a. a stationary frame
    b. moving frame
    c. Earth
    d. a rotating frame

Lesson 1 The Modern Theory of Gravitation

Albert Einstein's happiest thought of his life

Photo Credits: Vea Marie V. Ibardaloza, 2020

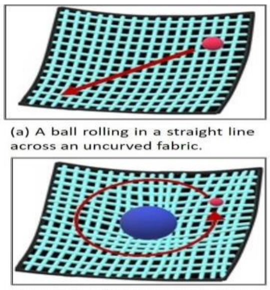
In 1907, while Albert Einstein was sitting in the patent office, he envisioned a person falling from the roof of a building. He later considered this idea as "the happiest thought of his life, because he was imagining that as the person was falling, he became weightless. That by going free fall, there will be no gravitational force. This idea refers to Einstein's **Principle of Equivalence,** which states that gravity is equivalent to a uniformly accelerated reference frame and served as the backbone of his General Theory of Relativity.



https://upload.wikimedia.org/wikipedia/commons/thumb/d/d1/GPB_circling_earth.jpg/800px-GPB_circling_earth.jpg

General Relativity, deals with non-inertial or *accelerating frames of reference*. In this theory, Einstein did not consider gravity as a force but a product of the warping or curving of space-time. This idea is contrary to Isaac Newton's Law of Universal Gravitation, in which gravity is viewed as a force of attraction between objects due to their masses.

Space-time is a four-dimensional continuum composed of the three dimensional space and one dimension of time.



(a) A ball rolling in a straight line across an uncurved fabric.

(a) A ball rolling in a curved path due to the distortion created by the heavier and larger ball placed at the middle of the fabric.

Photo Credits: Vea Marie V. Ibardaloza 2020

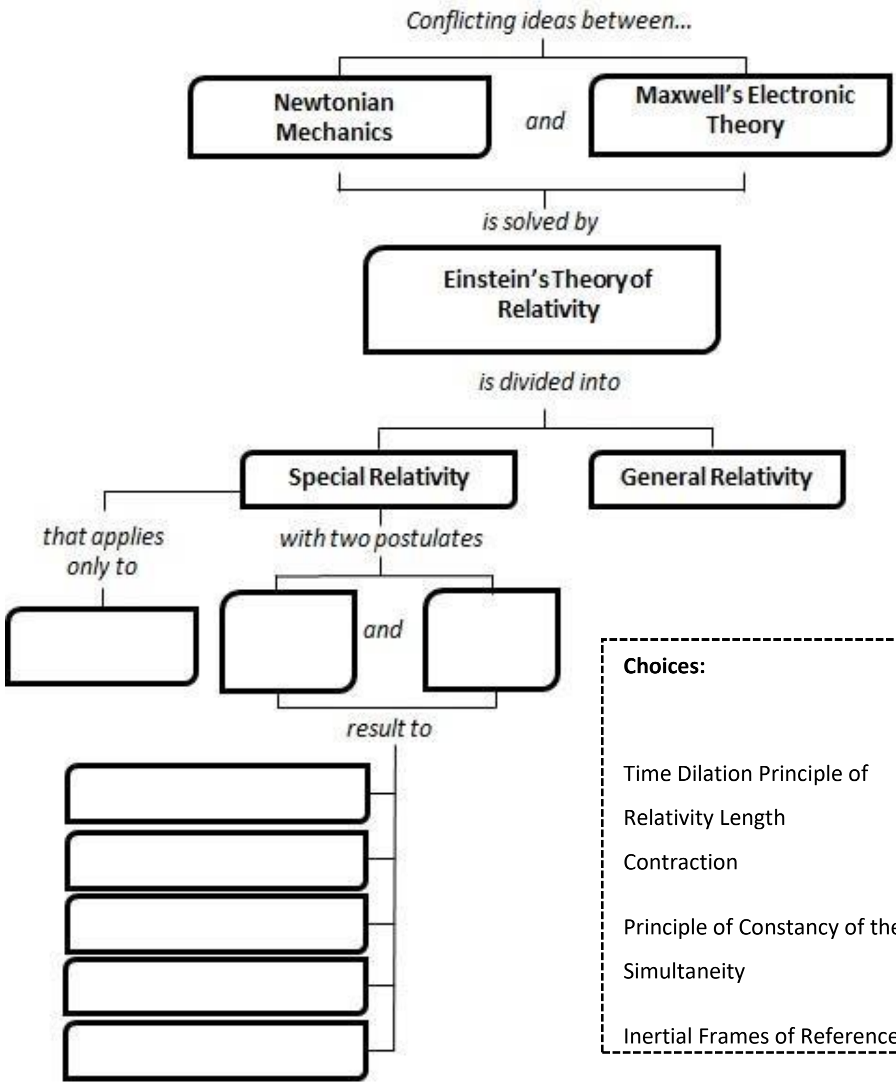
Warping or curving of space-time can be simulated with the use of a fabric. Rolling a ball across the fabric makes it move in a straight line motion. But if you place a heavier ball or object at the center, the fabric it will become distorted. Once you roll a ball again, it will no longer move in a straight line. Hence, it will follow a curved path around the heavier ball at the middle and that is how warping of space-time happens.

This fabric analogy helps us visualize the warping of space-time. Space-time is like a fabric that can be deformed. It is uncurved or flat at any region away from a massive cosmic body. But in the presence of a massive cosmic body such as stars, the space-time will be distorted creating a depression. If another cosmic body is near the warped space time, it will move around the larger body instead of falling straight down the center of the curvature.

Moreover, General Relativity explains the warping of space-time quantitatively defining how the mass and energy of a cosmic body determines the shape of the space-time. The greater the mass of a cosmic body, the greater the distortion it will create in the space-time.

What's In

Complete the concept map by putting the correct terms inside the boxes. Choose your answer from the box below:



Choices:

Time Dilation Principle of

Relativity Length

Contraction

Principle of Constancy of the Speed of Light Relativity

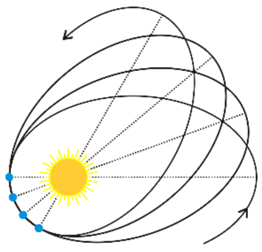
Simultaneity

Inertial Frames of Reference

What's New

The Peculiar Orbit of Mercury

You have learned from the previous modules that a *perihelion* is a point in a planet's orbit closest to the sun, while the aphelion is the point farthest from the sun. Based on the illustration at the right, you will notice that the perihelion of Mercury advances periodically. What causes the shifting of Mercury's orbit?



Wikimedia Commons user Mpfiz https://miro.medium.com/max/1400/0*Gx00 TqPPdoo-0q98.png

The table below shows how other planets contribute to the shifting of Mercury's orbit. Study the table and answer the questions below.

Planet	Newtonian Calculation of the Effects of Planets in Mercury's Perihelion in seconds of arc per century
Venus	277.9
Earth	90.0
Mars	2.5
Jupiter	153.6
Saturn	7.3
Uranus	0.14
Neptune	0.04

E. Siegel (2016) https://medium.com/starts-with-a-bang/when-did-isaac-newton-finally-fail-1d80e4fc54e6

1. What planet greatly affects the orbit of Mercury?
2. What planet affects Mercury's orbit the least?
3. Explain why Jupiter affects Mercury more considering that Earth is nearer to it?

Based on Newtonian Gravitation, Mercury's perihelion advances by about ***531*** *seconds of arc (arcsec) per century* due to the motion of other planets. However, in the 19th century, it was observed that the actual advancement is ***574*** *arcsec per century*.

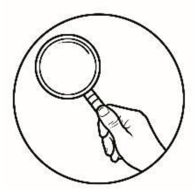
4. What is the difference of the observed actual advancement (574 arcsec per century) from Newtonian calculation (531 arcsec per century)?

Another table at the right shows the precession of each planet. Study and answer the questions below.

Planet	Distance from the Sun (km)	GTR Precession Value (arsec per century)
Mercury	57,900,000	43.0
Venus	108,900,000	8.6
Earth	149,600,000	3.8

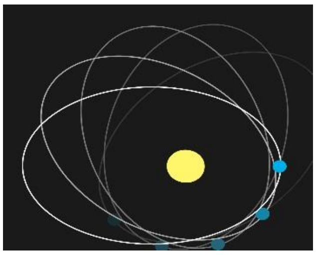
https://nssdc.gsfc.nasa.gov/planetary/factsheet/

5. Does your computed discrepancy in question no. 4 matches the precession of Mercury in the table above? Yes or No?
6. How will you compare the GTR (General Theory of Relativity) precession value of Mercury to Venus and to Earth?
7. How will you relate the distance of a planet to the Sun to the value of its GTR precession?
8. Among the planets in the solar system, why is Mercury affected by the warping of space-time caused by the Sun?



What is It

The Various Evidence for General Theory of Relativity



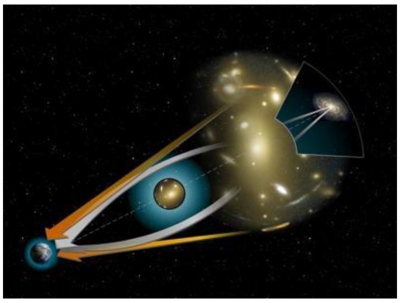
https://upload.wikimedia.org/wikipedia/commons/1/19/Apsidendrehung.png

The Correct Prediction of Shifts in the Orbit of Mercury

On the previous lesson, you have learned that there is a large shift in the orbit of Mercury compared to the other planets in the solar system. Its perihelion advances two degrees per century. *Perturbation* or the effects of nearby planets is accounted to 531 arcsec per century shift which is calculated using Newtonian Gravitation. However, there is a 43 arcsec per century discrepancy from the actual computation during the modern times. This discrepancy lead to Einstein's explanation of perihelion shift and that shifting is a result of the warping of space-time.

Mercury, as the innermost and the nearest planet to the sun is the most affected by the sun's warping of space-time.

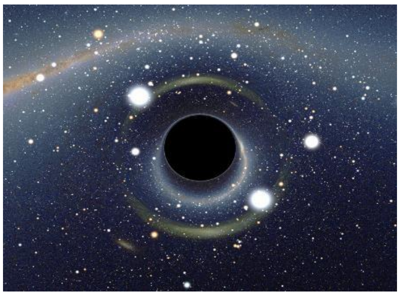
❖ Gravitational Bending of Light



https://upload.wikimedia.org/wikipedia/commons/0/02/Gravitational_lens-full.jpg

Gravitational lensing happens as light emitted by distant stars or galaxies bends following the curvature of space-time created by a massive object in the universe.

Arthur S. Eddington, a British astronomer conducted two expeditions in 1919 to measure the gravitational deflection of light passing near the sun. He followed Einstein's suggestion that photographic observations can be done during a solar eclipse. The two expeditions are both successful, revealing the stars near the sun were indeed displaced.

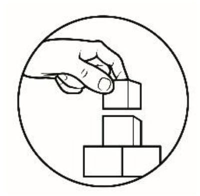


https://upload.wikimedia.org/wikipedia/commons/5/5e/BH_LMC.png

❖ Black Hole

German astronomer, Karl Schwarzschild was the first to use the general relativity in predicting that a sufficiently massive body can deform space-time and that lead to his idea of the existence of black holes. Black holes are extremely dense collapsed star that not even light can escape from its gravitational field. Anything must surpass the escape velocity of the black hole in order to free itself from the gravitational attraction and escape into space.

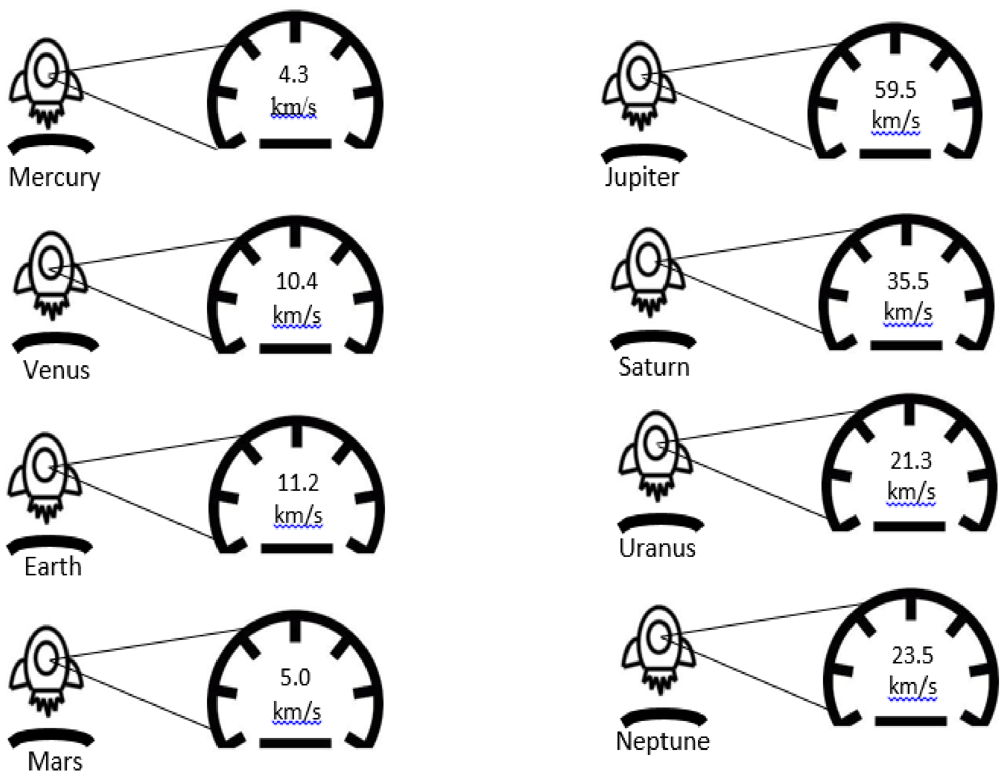
A dense neutron star has an escape velocity equal to *c* or the *speed of light*. This means that not even light can escape the gravitational pull of the cosmic body.



What's More

Activity 1. Quest for Escape

The speedometer readings in every spacecraft show the escape velocities of each planet. Study and analyze the illustrations and determine whether the statements below are true or false.



https://nssdc.gsfc.nasa.gov/planetary/factsheet/
Photo Credits: Vea Marie V. Ibardaloza 2020

TRUE or FALSE

1. A spacecraft must attain a speed of 11.2 km/s to leave the Earth's surface.
2. It is easier to leave the surface of Jupiter than Earth.
3. Escape velocity is affected by the planet's mass.
4. Mars has smaller escape velocity than Venus and Earth because it is farther from the sun.
5. The escape velocity of a planet is not affected by the sun's warping of space-time.

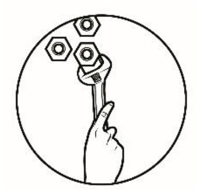
What I Have Learned

To check your understanding of the lesson, complete the sentences below. Choose your answer inside the box.

space-time	accelerating	star	mass
gravity	escape velocity	sun	velocity
43	black holes	lensing	

1. General relativity deals with________________________________frames of reference.
2. General relativity considers____________________________as a product of warping of space-time.
3. ___________________________ is a four-dimensional space composed of a three dimension of space and one dimension of time.
4. The____________________of a cosmic body is proportional to the distortion it can create in space-time.
5. General relativity like the special relativity has consequences such as: ____________________perihelion shift; gravitational_______of light and the existence of__________.
6. Mercury as the nearest planet to the_______________________is greatly affected by the sun's warping of space-time.
7. About_*arcsec per century* discrepancy in Mercury's perihelion shift was calculated using the general relativity. This value is equivalent to the difference in the observed procession in the 19th century and the precession calculated using Newtonian gravitation.
8. Gravitational______________________________happens when light emitted by distant stars or galaxies bends due to the curvature of space-time created by a massive object in the universe.
9. Black holes are extremely dense collapsed________________________that not even light can escape from its gravitational field.
10. _____________________________is the speed an object must attain to escape a massive body.

What I Can Do



https://upload.wikimedia.org/wikipedia/commons/8/8d/GPS_Satellite_ NASA_art-iif.jpg

Global Positioning System or GPS, originally known as NAVSTAR GPS, was invented by Dr. Ivan Getting and the US Department of Defense.

It was designed for military navigation and it is composed of 24 satellites orbiting the Earth at 4000 meters per second (m/s). Each of the 24 satellites carries a highly stable and synchronized atomic clocks. Each clock measures the time for radio signals to travel from the satellite to a receiver on Earth.

Nowadays, GPS is widely used in cars and cellular phones as it gives accurate readings of position and speed. Due to the satellites' constant motion relative to the observers on Earth and time runs slower wherever gravity is strongest, clocks were corrected for effects predicted by the special and general theory of relativity.

Answer the questions below. Limit your answers in 3 to 5 sentences only.

1. What will happen if the clocks of GPS are not corrected using the predicted effects of special and general theory of relativity?

2. Relate the phrase "time runs slower wherever the gravity is strongest" to the warping of space-time.

Assessment

DIRECTIONS: Read each question carefully. Choose the letter of the best answer. Write your answer on a separate sheet of paper.

1. Which is viewed as distortion of space-time?
   a. mass
   b. time
   c. gravity
   d. force

2. What happens to light as it travels along a massive cosmic body?
   a. it bends
   b. it reflects
   c. it bounces
   d. it disappears

3. What cosmic body can distort space-time the most?
   a. Sun
   b. Moon
   c. Earth
   d. Jupiter

4. What force is explained by general relativity?
   a. Weak nuclear force
   b. Strong nuclear force
   c. Electromagnetic force
   d. Gravitational force

5. What is the minimum velocity needed for a spacecraft to leave the Earth?
   a. less than Earth's escape velocity
   b. greater than Earth's escape velocity
   c. equivalent to Earth's escape velocity
   d. equivalent to the speed of light

6.Which of the following is an accelerating frame of reference?
   a. a moving car at constant speed
   b. a building
   c. free falling object
   d. a stationary bus

7. How does special relativity differs from general relativity?
   a. Special relativity applies only to moving frames while general relativity applies only to stationary frames.
   b. Special relativity applies only to stationary frames while general relativity applies only to accelerating frames.
   c. Special relativity applies only to stationary or moving frames while general relativity applies only to accelerating frames.
   d. Special relativity applies only to accelerating frames while general relativity applies only to stationary or moving frames.

8. What is space-time?

a. Space-time is a combination of three-dimensional space with time.
b. Space-time is a time an object takes to travel in space.
c. Space-time is a gravitational field.
d. Space-time is a two-dimensional space and time.

9. What can best explain the unusual orbit of Mercury?

a. Perturbation
b. Sun's warping of space-time
c. gravity
d. both a and b

10. Why do GPS clocks need to be corrected using the General Theory of Relativity?

a. because they are far away from Earth
b. because they are stationary
c. because they are orbiting the Earth
d. because they are affected by the Earth's warping of space-time

Additional Activities

A. Explain the statement of John Wheeler below. Limit your answer into five (5) to ten (10) sentences only. Write your answer on another sheet of paper.

"Space-time tells matter how to move; matter tells space-time how to curve."

B. Create a video presentation that details the impact of the Theory of Relativity to human.

Answer Key

What I Know	What's More	Assessment
6. A	1. True	1. C
7. B	2. False	2. A
8. A	3. True	3. A
9. B	4. True	4. D
10. D	5. False	5. C
11. D		6. C
12. A		7. C
13. C		8. A
14. A		9. D
15. D		10. D

References

Benett, Donahue, Schneider, Voit, 2017, The cosmic perspective: spacetime and gravity, Pearson Education, Inc., Retreived from https://www.pearson.com/store/p/cosmic-perspective-the/P100001061998

Christopher McFadden, 2016, 10 ways you see Einstein's theory of relativity in real life, Retreived from https://interestingengineering.com/10-ways-can-see-einsteins-theory-relativity-real-life-keyword-theory-relativity

David R. Williams, 2019, Planetary fact sheet-metric, NASA Goddard Space Flight Center Greenbelt, MD 20771, Retrieved from https://nssdc.gsfc.nasa.gov/planetary/factsheet/

Elizabeth Landau, 2019, 10 things Einstein got right, Retrieved from https://solarsystem.nasa.gov/news/954/10-things-einstein-got-right/

G.G.Nyambuya, 2010, Azimuthally symmetric theory of gravitation – I on the perihelion precession of planetary orbits, Retrieved from https://www.researchgate.net/publication/229570285_Azimuthally_Symmetric_T h eory_of_Gravitation_I_On_the_Perihelion_Precession_of_Planetary_Orbits

Karen S. Santiago, Angelina A. Silverio, 2016, Exploring Life Through Science Series Physical Science for Senior High School, 257-259, Phoenix Publishing House, Inc.

NASA, 2008, MIME type: image/jpeg 1,200 x 900 pixels, Artist concept of Gravity Probe B orbiting the Earth to measure space-time, a four-dimensional description of the universe including height, width, length, and time https://commons.wikimedia.org/w/index.php?curid=4072432

Alain r, 2006, MIME type: image/jpeg 2,560 × 2,048 pixels, Simulated view of a black hole in front of the Large Megallanic Cloud https://commons.wikimedia.org/wiki/File:BH_LMC.png

Benutzer:Rainer Zenz, 2007, MIME type: image/png 1,900 × 1,900 pixels, Perihelion Rotation https://commons.wikimedia.org/wiki/File:Apsidendrehung.png

Ethan Siegel, 2016, the overall precession of an object orbiting a central, large mass, greatly exaggerated in magnitude, Image credit: Wikimedia Commons user Mpfiz https://miro.medium.com/max/1400/0*Gx00TqPPdoo-0q98.png

NASA, http://hubblesite.org/newscenter/archive/2000/07/image/c Gravitational_lens MIME type: image/jpeg 702 × 531 pixels, https://commons.wikimedia.org/wiki/File:Gravitational_lens-full.jpg#filehistory

NASA, http://www.navcen.uscg.gov/ftp/gps/ggeninfo/gps-iif.tif Artist's conception of GPS Block II-F satellite in Earth orbit, MIME type: image/jpeg 1,006 × 806 pixels https://upload.wikimedia.org/wikipedia/commons/8/8d/GPS_Satellite_NASA_art-iif.jpg

For inquiries or feedback, please write or call:

Department of Education - Bureau of Learning Resources (DepEd-BLR)

Ground Floor, Bonifacio Bldg., DepEd Complex
Meralco Avenue, Pasig City, Philippines 1600

Telefax: (632) 8634-1072; 8634-1054; 8631-4985

Email Address: blr.lrqad@deped.gov.ph * blr.lrpd@deped.gov.ph