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Summary

THE BIG IDEA **Everything pulls on everything else.**

13.1 The Falling Apple

Newton reasoned that the moon is falling toward Earth for the same reason an apple falls from a tree—they are both pulled by Earth's gravity.

- Newton understood the concept of inertia, that without an outside force, moving objects continue to move at constant speed in a straight line. He knew that if an object undergoes a change in speed or direction, then a force is responsible.

13.2 The Falling Moon

The moon is actually falling toward Earth but has great enough tangential velocity to avoid hitting Earth.

- Newton reasoned that the moon must be falling *around* Earth. The moon falls in the sense that it falls beneath the straight line it would follow if no force acted on it. He hypothesized that the moon was a projectile circling Earth under the attraction of gravity.
- Newton compared the motion of the moon to a cannonball fired from the top of a high mountain. If the cannonball were fired with enough speed, its path would become a circle and the cannonball would circle indefinitely.
- Both the orbiting cannonball and the moon have a component of velocity parallel to Earth's surface. This sideways or *tangential velocity* is sufficient to ensure nearly circular motion *around* Earth rather than *into* it.
- Newton reasoned that the mass of the moon should not affect how it falls, just as mass has no effect on the acceleration of freely falling objects on Earth. How far the moon falls should relate only to its *distance* from Earth's center.

13.3 The Falling Earth

Newton's theory of gravity confirmed the Copernican theory of the solar system.

- The planets don't crash into the sun because they have tangential velocities. If the tangential velocities of the planets were reduced to zero, their motion would be straight toward the sun and they would indeed crash into it. Any objects in the solar system with insufficient tangential velocities have long ago crashed into the sun.

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13.4 Newton's Law of Universal Gravitation

Newton discovered that gravity is universal. Everything pulls on everything else in a way that involves only mass and distance.

- Newton's **law of universal gravitation** states that every object attracts every other object with a force that for any two objects is directly proportional to the mass of each object.
- The law of universal gravitation can be expressed in equation form: $F = G\,(m_1 m_2/d^2)$, where m_1 and m_2 are the objects' masses, and d is the distance between their centers of mass.
- The **universal gravitational constant,** G, in the equation describes the strength of gravity. In scientific notation, $G = 6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$. The value of G tells us that the force of gravity is a very weak force. It is the weakest of the presently known four fundamental forces.

13.5 Gravity and Distance: The Inverse-Square Law

Gravity decreases according to the inverse square law. The force of gravity weakens as the square of distance.

- When a quantity varies as the inverse square of its distance from its source, it follows an **inverse-square law.** For example, the inverse square of 3 is $\left(\frac{1}{3}\right)^2$, or $\frac{1}{9}$.
- This law applies to all cases where the effect from a localized source spreads evenly throughout the surrounding space, such as the weakening of gravity with distance. Other examples are light, radiation, and sound.

13.6 Gravitational Field

Earth can be thought of as being surrounded by a gravitational field that interacts with objects and causes them to experience gravitational forces.

- A **gravitational field** occupies the space surrounding a massive body. A gravitational field is an example of a *force field,* for any mass in the field space experiences a force.
- Iron filings sprinkled over a sheet of paper on top of a magnet reveal the shape of the magnet's magnetic field. The pattern of filings shows the strength and direction of the magnetic field at different locations around the magnet. Earth is a giant magnet and, like all magnets, is surrounded by a magnetic field.
- The strength of Earth's gravitational field, like the strength of its force on objects, follows the inverse-square law. Earth's gravitational field is strongest near Earth's surface and weaker at greater distances from Earth.

13.7 Gravitational Field Inside a Planet

☑ The gravitational field of Earth at its center is zero!

- The gravitational field of Earth exists inside Earth as well as outside.
- If you traveled through an imaginary hole drilled completely through Earth, you'd gain speed as you fell from the North Pole toward the center of Earth, and lose speed moving away from the center toward the South Pole.

13.8 Weight and Weightlessness

☑ Pressure against Earth is the sensation we interpret as weight.

- The force of gravity, like any force, causes acceleration. Because we are almost always in contact with Earth, we think of gravity primarily as something that presses us against Earth rather than as something that accelerates us.
- If you stand on a scale, gravity pulls you against the supporting floor and scale, and the floor and scale push upward on you. This pair of forces compresses a spring-like gauge inside the scale. The weight reading on the scale is linked to the amount of compression.
- **Weightlessness** is not the absence of gravity; rather, it is the absence of a support force. Astronauts in orbit are without a support force and experience weightlessness.

13.9 Ocean Tides

☑ Newton showed that the ocean tides are caused by *differences* in the gravitational pull of the moon on opposite sides of Earth.

- The moon's gravitational attraction is stronger on Earth's oceans closer to the moon, and weaker on the oceans farther from the moon. This difference causes the oceans to bulge out on opposite sides of Earth. Because Earth spins, a fixed point on Earth passes beneath both bulges each day, producing two high tides and two low tides.
- A **spring tide** is a high or low tide that occurs when the sun, Earth, and moon are all lined up. The tides due to the sun and the moon coincide, making high tides higher than average and low tides lower than average. Spring tides occur during a new or full moon.
- A **neap tide** occurs when the moon is halfway between a new moon and a full moon. The pulls of the moon and sun are perpendicular to each other. As a result, the solar and lunar tides do not overlap, so the high tides are not as high and low tides are not as low.

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13.10 Black Holes

When a massive star collapses into a black hole, there is no change in the gravitational field at any point beyond the original radius of the star.

- Two main processes occur continuously in stars like our sun: gravitation, which tends to pull solar material inward, and thermonuclear fusion, which blows material outward.
- If the fusion rate increases, the sun will get hotter and bigger; if the fusion rate decreases, the sun will get cooler and smaller.
- When the sun runs out of fusion fuel (hydrogen), gravitation will dominate and the sun will start to collapse. The collapse will cause helium to fuse into carbon, and the sun will expand into a *red giant*. When the helium is used up, the sun will collapse into a *black dwarf*.
- For stars more massive than the sun, once thermonuclear fusion ends, gravitational collapse will take over, eventually forming a **black hole.** The density of a black hole is so great that its enormous gravitational field prevents even light from escaping. The gravitational field beyond the original radius of the star is no different after the collapse than before.

13.11 Universal Gravitation

The formulation of the law of universal gravitation is one of the major reasons for the success in science that followed, for it provided hope that other phenomena of the world might also be described by equally simple and universal laws.

- Earth is round because of gravitation. Earth attracted itself together before it became solid. Any "corners" of Earth have been pulled in so that Earth is a giant sphere.
- The solar system began when a slightly rotating ball of interstellar gas contracted due to mutual gravitation. To conserve angular momentum, the rotational speed of the ball of gas increased, causing the particles to sweep out into a disk shape.
- The deviation of an orbiting object from its path around a center of force caused by the action of an additional center of force is called a **perturbation.**
- The planet Neptune was discovered when a perturbation in the orbit of Uranus led scientists to conclude that a disturbing body beyond the orbit of Uranus was the culprit.
- According to current scientific understanding, the universe originated and grew from the explosion of a primordial fireball some 13.7 billion years ago. This is the "Big Bang" theory of the origin of the universe. All the matter of the universe was hurled outward from this event and continues in an outward expansion.
- More recent evidence suggests the universe is not only expanding, but *accelerating* outward. It is pushed by an antigravity *dark energy* that makes up an estimated 73 percent of the universe. Twenty-three percent of the universe is composed of the yet-to-be discovered particles of exotic *dark matter.* Ordinary matter makes up only 4 percent.

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Exercises

13.1 The Falling Apple (page 233)

1. Describe the legend of Newton's discovery that gravity extends throughout the universe.

_____

_____

_____

2. Newton understood the concept of _____, developed by Galileo, that without an outside force, moving objects continue to move at constant speed in a straight line.
3. Is the following sentence true or false? Circular motion is accelerated motion, which requires a force. _____

13.2 The Falling Moon (pages 233–235)

4. Newton realized that the moon must be falling _____ Earth.
5. Is the following sentence true or false? The moon falls beneath the straight line it would follow if no force acted on it. _____
6. Newton compared motion of the moon to a cannonball fired from the top of a high mountain. Describe the possible paths for the cannonball proposed by Newton.

_____

_____

_____

_____

7. Circle the letter of the word that best describes the tangential velocity that prevents the moon from hitting Earth.

a. upward b. sideways

c. downward d. backward

8. Is the following sentence true or false? Newton believed that the mass of the moon affects how it falls. _____
9. Explain Newton's calculation that the moon falls 1.4 millimeters each second.

_____

_____

_____

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13.3 The Falling Earth (page 236)

10. Is this sentence true or false? Newton's theory of gravity confirmed the Copernican theory of the solar system. _____

11. Circle the letter of the sentence that describes the motion of a planet if its tangential velocity were reduced to zero.

    a. It would drift in space.

    b. It would continue in orbit at a slower speed.

    c. It would crash into the sun.

    d. It would spin away from the solar system.

12. Why are there no large objects in the solar system today with very low tangential velocities?

    _____

13.4 Newton's Law of Universal Gravitation (pages 237–239)

13. Is the following sentence true or false? Isaac Newton discovered gravity.

    _____

14. State Newton's law of universal gravitation using words.

    _____

    _____

    _____

15. What is the equation for universal gravitation?

    _____

16. The constant G in this equation is called the _____ and describes the _____.

17. The English physicist _____ first measured G.

18. Is the following sentence true or false? The force of gravity is the strongest of the presently known four fundamental forces. _____

19. Is the following sentence true or false? At the top of a mountain, your weight is slightly less than at ground level. _____

13.5 Gravity and Distance: The Inverse-Square Law (pages 240–241)

20. Express the inverse square law in words.

    _____

    _____

21. Circle the letter of the inverse square of 9.

    a. $\frac{1}{3}$

    b. $\frac{1}{81}$

    c. 3

    d. 81

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Match each change with the effect it would have on the force of gravity between two objects.

Change	Effect
_____ 22. The mass of one object doubles.	a. The force is divided by 2.
_____ 23. The mass of one object decreases by half.	b. The force is divided by 4.
_____ 24. The distance between the objects' centers of mass doubles.	c. The force is multiplied by 2.
_____ 25. The distance between the objects' centers of mass decreases by half.	d. The force is multiplied by 4.

26. Is the following sentence true or false? The gravitational influence of every object is exerted through all space. _____

13.6 Gravitational Field (pages 242–243)

27. The pulls that Earth and the moon exert on each other is action at a distance because the bodies interact without _____.

28. Define *gravitational field*.

_____

_____

29. Earth's gravitational field interacts with objects by causing them to experience _____.

30. Field lines show the _____ and _____ of a force field.

31. Field lines are closest together where a field is _____.

32. How are gravitational field lines related to the acceleration of an object around Earth?

_____

_____

13.7 Gravitational Field Inside a Planet (page 244)

33. Circle the letter that identifies the location where Earth's gravitational field is zero.

a. in a plane above Earth's surface
b. at Earth's surface
c. between Earth's surface and its center
d. at Earth's center

34. Is the following sentence true or false? The weight of a rock at Earth's center is zero. _____

13.8 Weight and Weightlessness (pages 245–246)

35. Why are people often unaware that gravity accelerates us?

_____

36. Pressure against Earth is the sensation we interpret as _____.

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Match each position or movement of an elevator with your weight if you stepped on a scale in the elevator.

Elevator Position or Movement	Weight Reading
_____ 37. sitting still	a. no weight
_____ 38. accelerating downward	b. normal weight
_____ 39. accelerating upward	c. greater weight than usual
_____ 40. falling freely	d. less weight than usual

41. Rather than define your weight as the force of gravity that acts on you, it is more practical to define weight as

_____

42. Is the following sentence true or false? Weightlessness is the absence of gravity. _____

43. Explain why rotating giant wheels will likely be used as space habitats in the future.

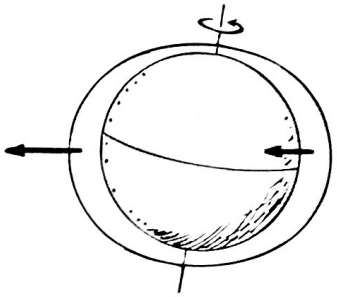
_____

_____

13.9 Ocean Tides (pages 246–248)

44. How often does a high tide occur? _____

45. Is the following sentence true or false? The pull of the moon and Earth on each other causes them both to be slightly elongated rather than spherical. _____



46. The figure shows the moon near the spinning Earth. Use the figure to explain the cause of ocean tides on Earth. In your explanation, describe why the arrows in the figure are different lengths.

_____

_____

_____

47. Circle the letter of the fraction that compares the sun's contribution to ocean tides to the moon's contribution.

a. one sixteenth b. one fourth

c. one eighth d. one half

48. The sun's pull on Earth is _____ times greater than the moon's pull on Earth.

49. Write *spring* or *neap* on each line to indicate whether the description matches a spring tide or a neap tide.

_____ a. Occurs when the moon is halfway between a new moon and a full moon.

_____ b. High tides are higher than usual, and low tides are lower than usual.

_____ c. Occurs at times of a new or full moon.

_____ d. The pulls of the moon and sun are perpendicular to each other.

_____ e. Occurs when the sun, Earth, and moon are all lined up.

_____ f. The solar and lunar tides coincide.

_____ g. The solar and lunar tides do not overlap.

50. A tidal effect causes the solid surface of Earth to rise and fall as much as _____ meter twice each day.

51. Explain why lakes have almost no tides.

_____

_____

13.10 Black Holes (pages 249–251)

52. Explain the effects that the following processes have on stars like our sun.

a. Gravitation: _____

b. Nuclear fusion: _____

53. If the fusion rate of the sun increases, the sun will get _____ and _____.

54. If the fusion rate of the sun decreases, the sun will get _____ and _____.

55. Circle the letter that identifies the fuel for the type of fusion that currently takes place in the sun.

a. carbon b. hydrogen

c. nitrogen d. oxygen

56. Explain what will cause our sun to collapse some 5 billion years from now.

_____

_____

57. As the sun collapses, a different type of fusion will begin in which _____ fuses into _____.

58. Fusion will eventually cause the sun to expand into a(n) _____ which will extend beyond Earth's orbit and swallow Earth.

59. When our sun no longer gives off heat and light, it will be a(n) _____.

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60. Explain why a star that is at least two to three times more massive than our sun will eventually collapse into a black hole.

_____

_____

61. Circle the letters of the statements that correctly describe a black hole.
    a. It has significantly more mass than the star from which it collapsed.
    b. Its gravitational field beyond the original radius of the star is unchanged.
    c. The configuration of the gravitational field around it represents a collapse of space itself.
    d. Its volume is unchanged from the star from which it collapsed.

62. Explain how a black hole that is part of a binary pair can be detected, even though it cannot be seen.

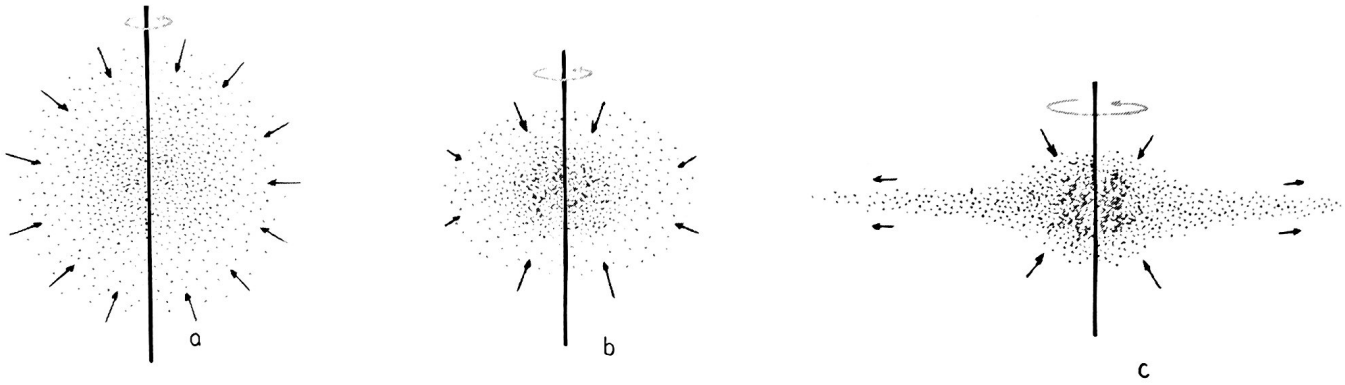
_____

_____

63. Black holes are near the centers of most galaxies. How do these black holes affect stars near them?

_____

13.11 Universal Gravitation (pages 251–254)



64. Refer to the figures above to describe the role that gravity played in the formation of the solar system.

_____

_____

_____

_____

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Chapter 13 Universal Gravitation

65. Explain why Earth is round.

_____

_____

66. Define *perturbation*.

_____

_____

67. Circle the letter of the orbiting body that was discovered in just half an hour because of a perturbation in the orbit of Uranus.

a. Jupiter
b. Neptune
c. Pluto
d. Saturn

Match each type of energy or matter with its percent of the universe.

Energy or Matter	Percentage of the Universe
_____ **68.** dark energy	a. 4%
_____ **69.** dark matter	b. 23%
_____ **70.** ordinary matter	c. 73%

71. Is the following sentence true or false? The law of universal gravitation is a complicated law that only describes a few unique instances.

_____

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Gravitational Force

Calculate the force of gravity between Earth (mass = 6.0×10^{24} kg) and Mars (mass = 6.4×10^{23} kg) when they are at their closest distance from each other, 5.6×10^{7} km.

1. Read and Understand

What information are you given?

Mass of Earth = $m_1 = 6.0 \times 10^{24}$ kg

Mass of Mars = $m_2 = 6.4 \times 10^{23}$ kg

Distance between the planets = $d = 5.6 \times 10^{7}$ km = 5.6×10^{10} m

2. Plan and Solve

What unknown are you trying to calculate?

Force of gravity between the planets = F

What formula can you use to find the unknown?

The equation for universal gravitation: $F = G(m_1 m_2 / d^2)$

What other information do you need to use?

The universal gravitational constant = $G = 6.67 \times 10^{-11}$ N·m^2/kg^2

Replace each variable and constant with its known value.

$F = (6.67 \times 10^{-11}\ \text{N·m}^2/\text{kg}^2)[(6.0 \times 10^{24}\ \text{kg})(6.4 \times 10^{23}\ \text{kg})/(5.6 \times 10^{10}\ \text{m})^2]$

$= 8.2 \times 10^{16}$ N

3. Look Back and Check

Is your answer reasonable?

A force this strong is reasonable between two neighboring planets.

Math Practice

On a separate sheet of paper, solve the following problems.

1. Calculate the force of gravity between Earth (mass = 6.0×10^{24} kg) and Venus (mass = 4.9×10^{24} kg) when they are at their closest distance from each other, 3.8×10^{7} km.

2. Calculate the force of gravity between a car (mass = 2.3×10^{3} kg) and a man (mass = 68 kg) when the man is standing a distance of 5.0 m from the car.

3. Calculate the force of gravity that Saturn (mass = 5.7×10^{26} kg) exerts on a woman on Earth (mass = 61 kg) when Saturn is closest to Earth, 1.2×10^{9} km.