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# Warm-Up | Orbital Motion

**Lesson Question**

How does one object orbit another?

## Lesson Goals

**Explore orbital** motion.

- **Explain** how Newton's universal law of gravitation affects orbital motion.
- **Identify** the forces acting on an object in orbit.
- **Solve** problems involving the orbital speed and period of an object in orbit.

## Words to Know

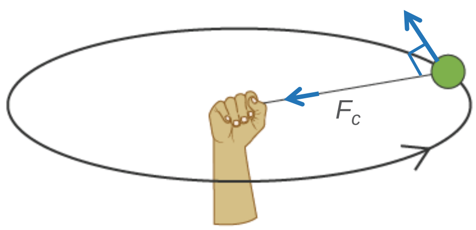
*Fill in this table as you work through the lesson. You may also use the glossary to help you.*

| | |
|---|---|
| inertia | the natural tendency of objects to resist a change in motion |
| satellite | a natural or human-made object that orbits a much larger object |
| free fall | the motion that occurs when gravity is the only force acting on an object |
| orbital period | the time it takes an object to complete one orbit around a central object |

# Warm-Up | Orbital Motion

## Circular Motion

- Centripetal force is any force directed toward the center of a circle.
- The interaction between centripetal force and inertia causes circular motion.



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## Isaac Newton's Idea

Newton recognized that the same force that causes objects to fall to the ground is responsible for keeping the moon in orbit around the Earth. But how did he come to this conclusion?

His thought process went a little bit like this:

- If I take this ball and I drop it straight down, [gravity] causes it to fall straight down to the Earth.
- On the other hand, if I give this ball a little toss in the horizontal direction, it [curves] out a wider arc as it falls towards the Earth.

What happens if I throw it really hard? What happens then? Let's see.

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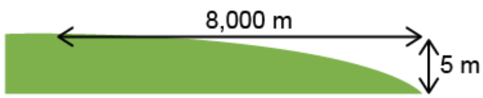
## Curvature of Earth

- Earth's surface falls about 5 m for nearly every [8,000 m] of tangential distance.
  - To match the curvature of Earth, objects must travel almost 8,000 m in [one] second.
- At roughly 8,000 m/s, an object goes into orbit around Earth.
  - An object in orbit [falls] around Earth as Earth curves away from it.

$$d = \frac{1}{2}at^2$$

$$= \frac{1}{2} \cdot 10\,\frac{\text{m}}{\text{s}^2} \cdot 1^2\,\text{s}^2$$

$$= [5 \text{ m}]$$



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## Distance above Earth

- **Inertia** keeps an object moving sideways while gravity keeps [pulling] it toward the center of Earth.
  - Gravity is the **only** force acting on objects in orbit.
- To avoid [air resistance] that would slow an object down, human-made objects are placed in orbit above most of the atmosphere.

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## Satellite Characteristics

- **Satellites** are [natural] or human-made objects that orbit a much larger object.
- Satellites are projectiles acted on by just one force: [gravity].
- Satellites that move in a uniform circular orbit are neither sped up nor slowed down by gravity, so they travel at a [constant] speed.
- An [orbital period] is the time it takes an object to complete one orbit.

 

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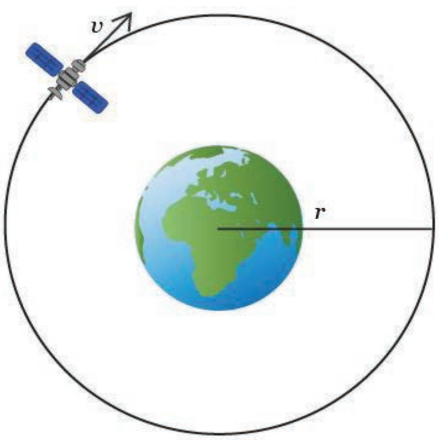
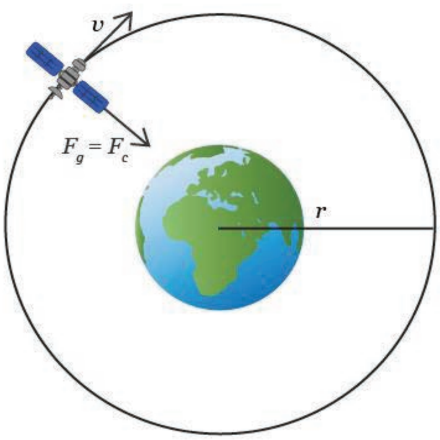
## Characteristics of Satellite Motion: Tangential Speed

- A satellite in orbit experiences a tangential speed.
    - $v = \frac{2\pi r}{T}$
- Tangential speed remains constant throughout a satellite's orbit.
- As a satellite moves farther from Earth, its period increases and its tangential speed decreases.




## Characteristics of Satellite Motion: Centripetal Force

- A satellite in orbit experiences centripetal force.
    - $F_c = \frac{mv^2}{r}$
- Gravity is the agent providing the centripetal force.
- Centripetal force is perpendicular to the velocity of the satellite.



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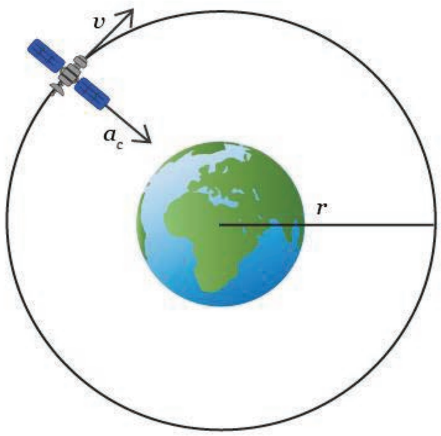
## Characteristics of Satellite Motion: Centripetal Acceleration

- A satellite in orbit experiences centripetal acceleration.
  - $a_c = \frac{v^2}{r}$
- The pull of gravity constantly pulls a satellite toward the center of Earth, so the acceleration of the satellite is pointed toward the center of Earth.

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## Tangential Velocity

- Gravity provides the centripetal force exerted on any object in orbit.

$$F_c = F_g$$

$$\frac{m_{sat} v^2}{r} = G\frac{m_{sat} m_{Earth}}{r^2}$$

$$v^2 = G\frac{m_{central}}{r}$$

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## Earth's Tangential Speed

EXAMPLE

- What is the tangential speed of Earth around the Sun?
- Given:
  - $r = 1.5 \times 10^{11}$ m
  - $T =$ 365 days
- Unknown: $v$
  - Formula to use: $v = \frac{2\pi r}{T}$

$$v = \frac{2\pi r}{T}$$

$$v = \frac{2\pi(1.5 \times 10^{11}\text{ m})}{3.2 \times 10^{7}\text{ s}}$$

$$= \frac{9.4 \times 10^{11}\text{ m}}{3.2 \times 10^{7}\text{ s}}$$

$$= \boxed{29{,}000}\text{ m/s}$$

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## Earth's Tangential Speed

EXAMPLE

- What is the tangential speed of Earth around the Sun?
- Given:
  - $m_{sun} = 2.0 \times 10^{30}$ kg
  - $r = 1.5 \times 10^{11}$ m
- Unknown: $v$
  - Formula to use: $v^2 = G\frac{m_{sun}}{r}$

$$v^2 = G\frac{m_{sun}}{r} \text{ with } G = 6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2$$

$$v = \sqrt{\frac{\left(6.67 \times 10^{-11}\,\frac{\text{m}^3}{\text{kg} \cdot \text{s}^2}\right)\boxed{(2.0 \times 10^{30}\ \text{kg})}}{1.5 \times 10^{11}\ \text{m}}}$$

$$= \sqrt{\frac{1.3 \times 10^{20}\ \text{m}^3/\text{s}^2}{1.5 \times 10^{11}\ \text{m}}}$$

$$= \boxed{29{,}000}\ \text{m/s}$$

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## Radius Example

How high above Earth is a satellite orbiting if its tangential velocity is 7,000 m/s? Earth's mass is $6 \times 10^{24}$ kg and its radius is $6.4 \times 10^6$ m.

- Given:
  - $v = 7{,}000 \text{ m/s}$
  - $r_{Earth} = 6.4 \times 10^6 \text{ m}$
  - $m_{Earth} = 6 \times 10^{24} \text{ kg}$
- Unknown: $r$
  - Formula to use: $v^2 = G\frac{m_{central}}{r}$

$$r = G\frac{m_{Earth}}{v^2}$$

$$r = \frac{\left(6.67 \times 10^{-11} \frac{\text{m}^3}{\text{kg} \cdot \text{s}^2}\right)(6 \times 10^{24} \text{ kg})}{\left(7000 \frac{\text{m}}{\text{s}}\right)^2}$$

$$= \boxed{8.2 \times 10^6 \text{ m}}$$

- The question asks us how high above the earth is a satellite at a given speed.

$$8.2 \times 10^6 \text{ m} - 6.4 \times 10^6 \text{ m}$$

$$= \boxed{1.8 \times 10^6 \text{ m}}$$

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## Gravitational Force in Orbit around Earth

- The force due to gravity on a space shuttle in orbit around Earth:

$$F_g = G\frac{m_{ss}\, m_{Earth}}{r^2}$$

$$F_g = G\frac{(2 \times 10^6\ \text{kg})(6 \times 10^{24}\ \text{kg})}{[(6.4 \times 10^6\ \text{m}) + (2 \times 10^5\ \text{m})]^2}$$

$$= 1.8 \times 10^7\ \text{N}$$

- G multiplied by any mass divided by any radius, no matter how large, will **never** equal zero.

## Weightlessness

- When gravity is the only force acting on an object, the object is in free fall.
- The space shuttle, along with everything in it, is in free fall around Earth.
  - Because the astronauts are falling at the same rate as the space shuttle, they appear weightless.

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# Summary | Orbital Motion

**Lesson Question**

How does one object orbit another?

**Answer**

(Sample answer) One object orbits another as a result of inertia and gravity. Because most human-made satellites that orbit Earth follow circular orbits, many of the rules and formulas that apply to circular motion also apply to satellite motion around Earth.

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## Review: Key Concepts

- Satellites are projectiles; the only force that acts upon them is gravity.
- Satellites are in free fall around a central object.
- Gravity provides the centripetal force to keep satellites moving in circular orbits.
  - The formulas for circular motion can be applied to satellites with circular orbits.

| Formulas |
|---|
| $v = \frac{2\pi r}{T}$ |
| $F_c = \frac{mv^2}{r}$ |
| $a_c = \frac{v^2}{r}$ |
| $v^2 = G\frac{m_{central}}{r}$ |

# Summary | Orbital Motion

*Use this space to write any questions or thoughts about this lesson.*