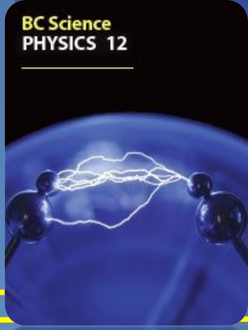
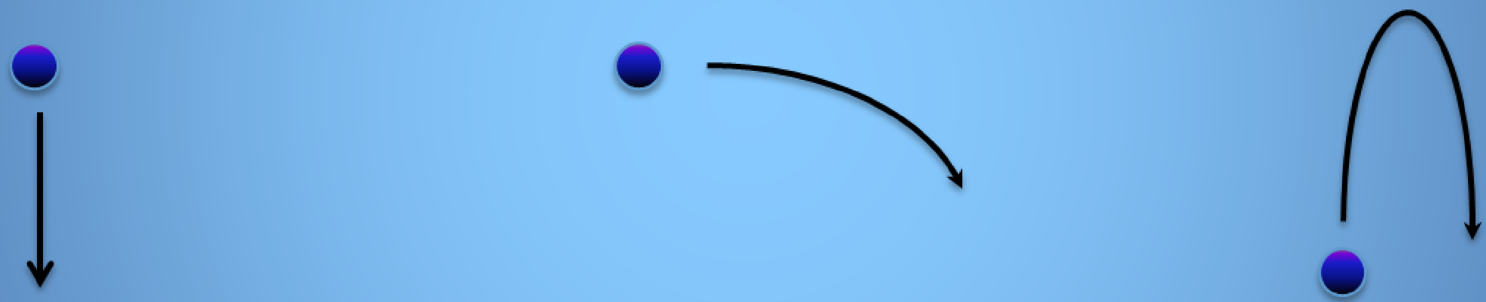



# 4.2 Gravity and Kepler's Solar System

## Falling Objects

Objects that are acted upon only by the force of gravity are said to be in **<u>free-fall</u>**.



All three of these situations show **<u>free-falling</u>** objects.

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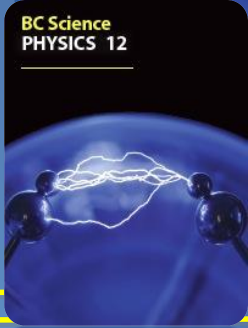


# 4.2 Gravity and Kepler’s Solar System

## The Moon in Free Fall

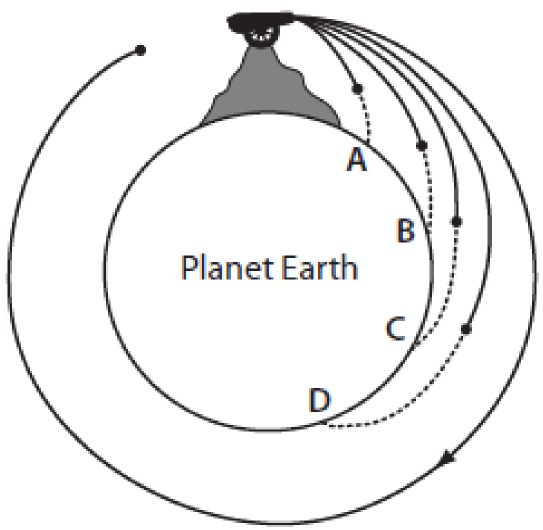


**Figure 4.2.2** *Newton's diagram explaining why the Moon doesn't fall to Earth.*

Newton understood that the **Moon** was in free-fall around the Earth. He created diagrams to explain why the Moon never falls to surface of the Earth.

He described firing a cannon horizontally off the top of a mountain at ever **increasing** speeds. Eventually the cannon ball is travelling so fast that it travels horizontally as much as the Earth’s is curving away. The cannon ball has become a **satellite**. Our Moon was our first satellite.

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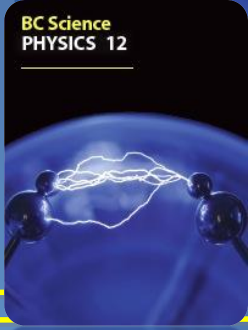
# 4.2 Gravity and Kepler's Solar System




## Gravitational Force, Earth, and the Moon

There must be **centripetal** force to keep the Moon is **orbiting** the Earth. Newton explained that a **gravitation** force was required to provide this centripetal force.

Using known values for the **period** of the Moon and it's **distance** from the Earth Newton was able to determine the centripetal acceleration of the Moon as it orbits the Earth:

$$a_c = \frac{4\pi^2 R}{T^2} = \frac{4\pi^2(3.84 \times 10^8 \text{ m})}{(27.3\cancel{\text{d}} \times 24\ \cancel{\text{h}}/\cancel{\text{d}} \times 3600\ \text{s}/\cancel{\text{h}})^2} = 2.7 \times 10^{-3} \text{ m/s}^2$$

The centripetal acceleration is actually the acceleration of **gravity**, g, due to the **Earth** at the **Moon's** location. Newton was absolutely **convinced** that it was the **gravitation** force that provided the necessary **centripetal** force keep the Moon in its orbit about the Earth and that the gravitational force must rapidly decrease as the distance from the Earth increases.

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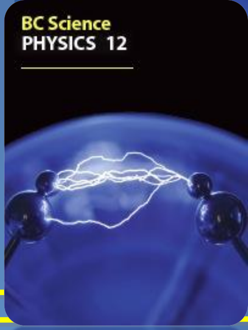
# 4.2 Gravity and Kepler's Solar System




**Johannes Kepler (1571 – 1630)**

Johannes Kepler worked in Tycho Brahe's (1546 – 1601)laboratory. Brahe is famous for making precise **observations** of over 800 stars and accurate records of planets over a period of 2 decades.

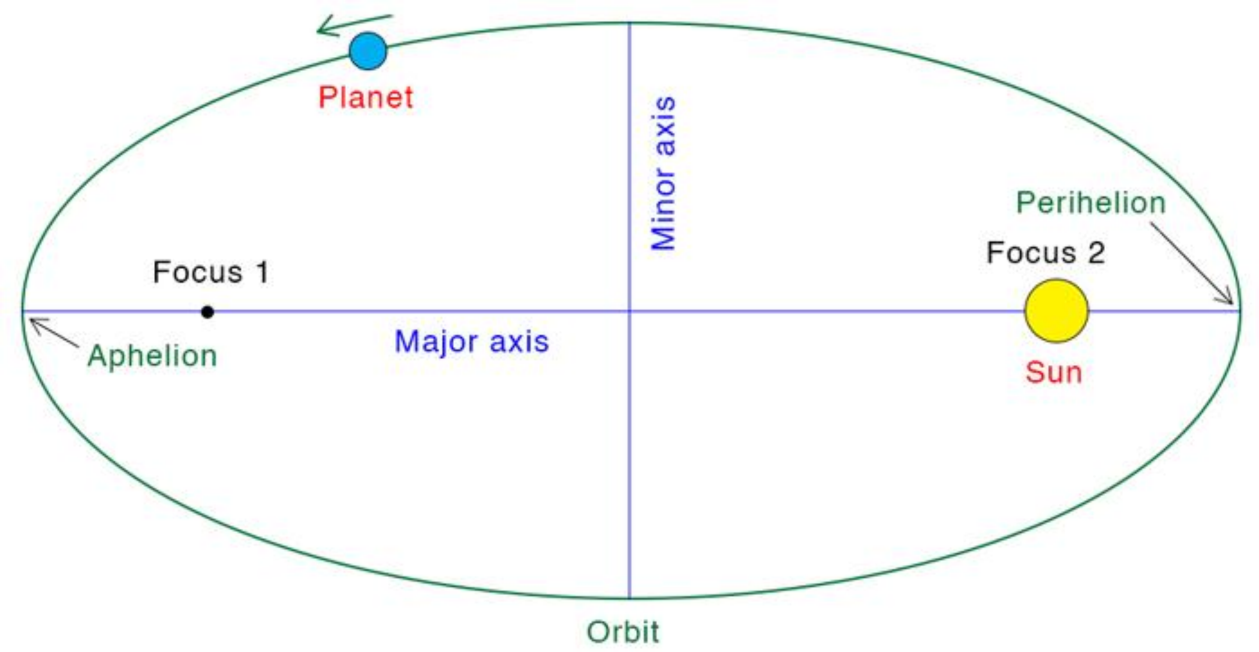
Kepler used these precise observations  to search for **mathematical** patterns in the motions of the planets. Kepler formulated **three** laws describing the orbits of the planets around the Sun.

p.

# 4.2 Gravity and Kepler's Solar System

## Kepler's First of Three Laws of Planetary Motion

1. Each planet orbits the Sun in a **elliptical** path, with the **Sun** at one of the two **foci** of the ellipse.

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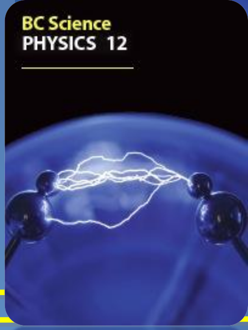


# 4.2 Gravity and Kepler’s Solar System

**Kepler’s Second Law of Planetary Motion**

2. A line joining the center of the Sun and the center of any planet will trace out equal **areas** in equal interval of **time**. If time intervals $T_2 - T_1$ and $T_4 - T_3$ are **equal** the **areas** traced out by the orbital radius of a planet during this interval will be equal. (This really is a version of the Law of Conservation of Energy!)

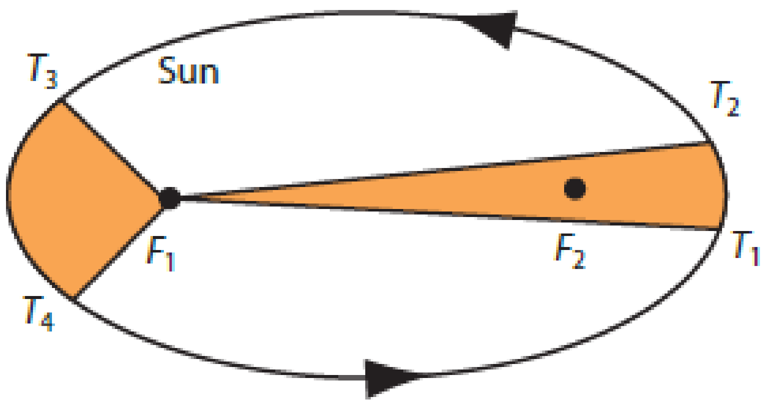


**Figure 4.2.3** *Kepler’s second law*

In order for this to be true a Planet during $T_4 - T_3$ has to be travelling **faster** than during interval $T_2 - T_1$.

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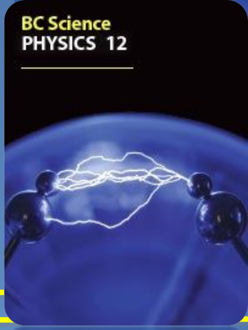
# 4.2 Gravity and Kepler’s Solar System




**Kepler’s Third Law of Planetary Motion**

3. For any planet in the solar system, the **<u>cube</u>** of its mean orbital radius divided by the **<u>square</u>** of its **<u>period</u>** of revolution is a constant.

$$K = \frac{R^3}{T^2}$$

**Note:**

This is **<u>not</u>** Universal constant. Change the solar system or orbiting system in question and you would have a **<u>new</u>** value for Kepler’s constant.

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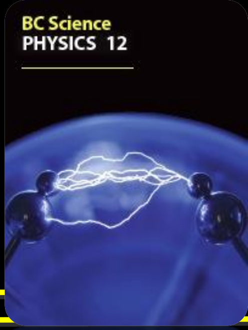
# Example 1




Planet Xerox ( a close copy of planet Earth) was discovered by Superman on one of his excursions to the far extremes of the solar system. Its distance from the Sun is 1.50 x $10^{13}$ m. How long will this planet take to orbit the sun?

$$Earth's\ orbital\ radius, \boldsymbol{R_E = 1.5 \times 10^{11}\ m}$$

$$Earth's\ period\ of\ revolution, \boldsymbol{T_E = 1.0a}$$

$$Xerox's\ orbital\ radius, \boldsymbol{R_X = 1.50 \times 10^{13}\ m}$$

$$\boxed{\frac{R_X^3}{T_X^2} = \frac{R_E^3}{T_E^2} = K_{sun}}$$

$$*** \ solve\ for\ T_X$$

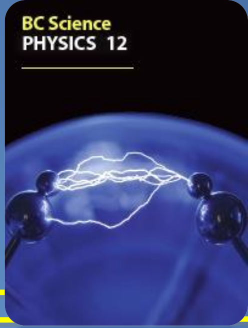
$$T_X^2 = \frac{R_X^3}{R_E^3} \cdot T_E^2$$

$$T_X^2 = \frac{[1.5 \times 10^{13}\ m]^3}{[1.5 \times 10^{11}\ m]^3} \cdot [1.0a]^2$$

$$T_X^2 = 1.0 \times 10^6\ a^2$$

$$\boxed{T_X = 1.0 \times 10^3\ a}$$

# 4.2 Gravity and Kepler’s Solar System




***In this section, you should understand how to solve the following key questions.***

Page #131 Practice Problems 4.2.1 Kepler’s Laws#1– 2

Page #134 – 135 4.2 Review Questions #1 – 8