

Writing Assignment – Essay on Kepler’s Laws.

You have been provided two short articles on Kepler’s Three Laws of Planetary Motion. You are to first read the articles to better understand what these laws are, what they mean, and why they are important to scientists. Then, you are to fill in the graphic organizer to help you to compose and organize your thoughts for the essay. Finally, you will compose your essay using the graphic organizer as your guide.

Your best writing skills are required and you are to use the information from both articles for your essay. Your essay will be five paragraphs in length and must be word-processed. You will also turn in your graphic organizer with this assignment.

This assignment is due Friday, November 9th.

http://projects.astro.illinois.edu/data/KeplersLaws/

Kepler’s Laws of Planetary Motion

In the sixteenth century, most people believed in the ideas of the ancient astronomer Ptolemy, that the planets, Moon, and Sun all orbited around the Earth. Then in 1543, Nicolaus Copernicus proposed the idea that the planets and the Earth orbited around the Sun. However, Copernicus’ new theory was no better at predicting the positions of the planets in the sky than the older, Earth-centered theory. There was still something missing.....

Half a century later, Johannes Kepler sought to refine the Copernican system and truly understand how the planets move around the Sun. He studied observations of Mars recorded by his mentor, Tycho Brahe. Rather than trying to force the data to support a pre-determined view of the Universe, Kepler used Tycho's observations to guide the creation of his theories. This was a radical departure from the thought processes of his era, and it is a signal of the beginning of our modern scientific age.

In 1609, Kepler published his first and second laws of planetary motion, The Law of Ellipses and The Equal-Areas Law. Ten years later he published a third law, The Harmonic Law. He had succeeded in using a scientific method to create a simple, elegant, and accurate model to describe the motion of planets around the Sun

Kepler's First Law: The Law of Ellipses
Previous theories of the Solar System, including those of Ptolemy and Copernicus, believed that the orbits of the planets were **perfect circles**. Kepler was unable, however, to fit Tycho's observations with circular orbits. He rejected the ancient idea of circular orbits had discovered that:

The orbits of the planets are **ellipses** with the Sun at one of the foci.

This is now called Kepler's First Law or The Law of Ellipses.

What is an ellipse? Glad you asked. An ellipse is a closed, curved shape that is defined by two foci. An ellipse is like a flattened circle. In fact, if both of the foci of an ellipse are at the same point, an ellipse becomes a circle! If you think about it, the relationship between an ellipse and a circle is similar to the relationship between a rectangle and a square.

An ellipse has two axes. The long one is called the major axis, and the short one is called the minor axis. Astronomers will often use the term "semimajor axis". That's just half the length of the major axis!

The shape of an ellipse is measured by its **eccentricity**. The "flatter" the ellipse, the greater the eccentricity. A circle, for example, has an eccentricity of zero since both foci are at the center. As the ellipse becomes flatter and flatter, the foci get farther from the center, and the eccentricity will approach, but never equal, one.

**Kepler's Second Law: The Equal-Areas Law**

In addition to determining that the orbits of the planets around the Sun were ellipses, Kepler also noticed that their speeds varied throughout their journeys. Kepler noted that the planets seemed to move fastest when they were at their closest point to the Sun (called **perihelion**) and slowest when they were at their farthest point from the Sun (called **aphelion**). Using some rather brilliant insights of geometry, Kepler discovered that:

The line that connects the planet to the Sun sweeps out equal areas in equal times.

This is now known as Kepler's Second Law or The Equal Areas Law.

The motion this law describes also tells us that the average distance from a planet to the Sun is equal to the length of the semimajor axis. That's why astronomers love the term so much!

**Kepler's Third Law: The Harmonic Law**

After determining his first two Laws of Planetary Motion, Kepler continued to study the orbits of the planets. Ten years later, he discovered a relation between the time of a planet's orbit and its distance from the Sun:

The squares of the orbital periods of the planets around the Sun are proportional to the cubes of the orbital semimajor axes.

What does this mean? This means that if you know either how much time a planet's orbit around the Sun takes you can easily know it's average distance from the Sun, or vice-versa! Now you will often see Kepler's Third Law written like this:

\[ P^2 = a^3 \]

Where \( P \) is the orbital period in Earth years and \( a \) is the length of the semimajor axis (average distance from the Sun) in Astronomical Units.

[http://www.physicsclassroom.com/class/circles/u6l4a.cfm](http://www.physicsclassroom.com/class/circles/u6l4a.cfm)
Kepler’s Three Laws

In the early 1600s, Johannes Kepler proposed three laws of planetary motion. Kepler was able to summarize the carefully collected data of his mentor - Tycho Brahe - with three statements that described the motion of planets in a sun-centered solar system. Kepler’s efforts to explain the underlying reasons for such motions are no longer accepted; nonetheless, the actual laws themselves are still considered an accurate description of the motion of any planet and any satellite.

Kepler’s three laws of planetary motion can be described as follows:

- The path of the planets about the sun is elliptical in shape, with the center of the sun being located at one focus. (The Law of Ellipses)
- An imaginary line drawn from the center of the sun to the center of the planet will sweep out equal areas in equal intervals of time. (The Law of Equal Areas)
- The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the sun. (The Law of Harmonies)

Kepler’s first law - sometimes referred to as the law of ellipses - explains that planets are orbiting the sun in a path described as an ellipse.

An ellipse can easily be constructed using a pencil, two tacks, a string, a sheet of paper and a piece of cardboard. Tack the sheet of paper to the cardboard using the two tacks. Then tie the string into a loop and wrap the loop around the two tacks. Take your pencil and pull the string until the pencil and two tacks make a triangle (see diagram at the right). Then begin to trace out a path with the pencil, keeping the string wrapped tightly around the tacks. The resulting shape will be an ellipse. An ellipse is a special curve in which the sum of the distances from every point on the curve to two other points is a constant.

The two other points (represented here by the tack locations) are known as the foci of the ellipse. The closer together that these points are, the more closely that the ellipse resembles the shape of a circle. In fact, a circle is the special case of an ellipse in which the two foci are at the same location. Kepler’s first law is rather simple - all planets orbit the sun in a path that resembles an ellipse, with the sun being located at one of the foci of that ellipse.

Kepler’s second law - sometimes referred to as the law of equal areas - describes the speed at which any given planet will move while orbiting the sun. The speed at which any planet moves through space is constantly changing. A planet moves fastest when it is closest to the sun and slowest when it is furthest from the sun. Yet, if an imaginary line were drawn from the center of the planet to the center of the sun, that line would sweep out the same area in equal periods of time.

For instance, if an imaginary line were drawn from the earth to the sun, then the area swept out by the line in every 31-day month would be the same. This is depicted in the diagram below. As can be observed in the diagram, the areas formed when the earth is closest to the sun can be approximated as a wide but short triangle; whereas the areas formed when the earth is farthest from the sun can be approximated as a narrow but long triangle. These areas are the same size. Since the base of these triangles are shortest when the earth is farthest from the sun, the earth would have to be moving more slowly in order for this imaginary area to be the same size as when the earth is closest to the sun.
Kepler's third law - sometimes referred to as the law of harmonies - compares the orbital period and radius of orbit of a planet to those of other planets. Unlike Kepler's first and second laws that describe the motion characteristics of a single planet, the third law makes a comparison between the motion characteristics of different planets. The comparison being made is that the ratio of the squares of the periods to the cubes of their average distances from the sun is the same for every one of the planets. As an illustration, consider the orbital period and average distance from sun (orbital radius) for Earth and Mars as given in the table below.

<table>
<thead>
<tr>
<th>Planet</th>
<th>Period (s)</th>
<th>Average Dist. (m)</th>
<th>( T^2/R^3 ) (s²/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td>3.156 x 10⁷</td>
<td>1.4957 x 10¹¹</td>
<td>2.977 x 10⁻¹⁹</td>
</tr>
<tr>
<td>Mars</td>
<td>5.93 x 10⁷</td>
<td>2.278 x 10¹¹</td>
<td>2.975 x 10⁻¹⁹</td>
</tr>
</tbody>
</table>

Observe that the \( T^2/R^3 \) ratio is the same for Earth as it is for Mars. In fact, if the same \( T^2/R^3 \) ratio is computed for the other planets, it can be found that this ratio is nearly the same value for all the planets (see table below). Amazingly, every planet has the same \( T^2/R^3 \) ratio.

<table>
<thead>
<tr>
<th>Planet</th>
<th>Period (yr)</th>
<th>Ave. Dist. (au)</th>
<th>( T^2/R^3 ) (yr²/au³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>0.241</td>
<td>0.39</td>
<td>0.98</td>
</tr>
<tr>
<td>Venus</td>
<td>0.615</td>
<td>0.72</td>
<td>1.01</td>
</tr>
<tr>
<td>Earth</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Mars</td>
<td>1.88</td>
<td>1.52</td>
<td>1.01</td>
</tr>
<tr>
<td>Jupiter</td>
<td>11.8</td>
<td>5.20</td>
<td>0.99</td>
</tr>
<tr>
<td>Saturn</td>
<td>29.5</td>
<td>9.54</td>
<td>1.00</td>
</tr>
<tr>
<td>Uranus</td>
<td>84.0</td>
<td>19.18</td>
<td>1.00</td>
</tr>
<tr>
<td>Neptune</td>
<td>165</td>
<td>30.06</td>
<td>1.00</td>
</tr>
<tr>
<td>Pluto</td>
<td>248</td>
<td>39.44</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*(NOTE: The average distance value is given in astronomical units where 1 a.u. is equal to the distance from the earth to the sun - 1.4957 x 10¹¹ m. The orbital period is given in units of earth-years where 1 earth year is the time required for the earth to orbit the sun - 3.156 x 10⁷ seconds.)*

Kepler's third law provides an accurate description of the period and distance for a planet's orbits about the sun. Additionally, the same law that describes the \( T^2/R^3 \) ratio for the planets' orbits about the sun also accurately describes the \( T^2/R^3 \) ratio for any satellite (whether a moon or a man-made satellite) about any planet.
Name:

Graphic Organizer – How to Write a Short Essay

Introduction
- Include what each body paragraph will be about. Who is Kepler? What did he do and why? And a topic sentence stating what the body of the essay will be about (should be about? What? Where? When? Main ideas?)

Body
- Give an example.
  - Name the law, what does it mean (explain), why is it important, how is it used –
  - Supporting details

Law
- Statement on Kepler's 3rd
  - Topic sentence

Law
- Statement on Kepler's 2nd
  - Topic sentence

Law
- Statement on Kepler's 1st
  - Topic sentence

Conclusion
- Summarize the ideas of information and why it may be important
Graphic Organizer – How to Write a Short Essay
Grading Rubric – Kepler Essay

Written communication (50 points)

- **Organization**
  - Inadequate (10 points): There appears to be no organization of the essay’s contents. No graphic organizer used.
  - Needs Improvement (15 points): Organization of the essay is difficult to follow, due to inadequate transitions and/or rambling format. Graphic organizer used sparingly.
  - Adequate (20 points): The essay can be easily followed. A combination of the following is apparent: Basic transitions are used; a structured format is used. Graphic organizer is used fully.
  - Professional quality (25 points): The essay can be easily followed. A combination of the following is apparent: Effective transitions are used; a professional format is used. Graphic organizer is used fully.

- **Mechanics and grammar**
  - Inadequate (10 points): Sentences and paragraphs are difficult to read and understand due to poor grammar or mechanics
  - Needs improvement (15 points): The essay contains numerous grammatical and mechanical errors.
  - Adequate (20 points): The essay contains minimal grammatical or mechanical errors.
  - Professional quality (25 points): The essay is clear and concise and contains no grammatical or mechanical errors.

Content (50 points)

- **Correctness of facts**
  - Inadequate (10 points): Most facts are wrong.
  - Needs improvement (15 points): Some facts are wrong.
  - Adequate (20 points): Technical details are generally correct.
  - Professional quality (25 points): All facts are correct, and the technical explanation is both concise and complete.

- **Completeness**
  - Inadequate (10 points): Did not address some of the questions.
  - Needs improvement (15 points): Addressed the questions, but provided few details.
  - Adequate (20 points): Address the questions, but left out some details.
  - Professional quality (25 points): Addressed all questions completely.