Pliny and Newton: Filling in the Gaps with Physics

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Ancient knowledge has provided a foundation for both present and future discoveries in physics. Scientists draw upon past concepts in order to create explanations of everyday events. The concepts and observations of Pliny the Elder, in *Historia Naturalis*, contributed to Sir Isaac Newton's explanation of the three inertial laws that are said to govern most physical space. Without the observations of Pliny the Elder, physicists such as Sir Isaac Newton and Johannes Kepler may have never made such discoveries at the time that they did, such as the Inertial Laws and their many modifications. These modifications include Johannes Kepler's Law of Gravitational Attraction.

Pliny the Elder was born in 23 CE, in the city of Novum Comum, Transpadine Gaul, now known as Italy (Britannica.com). He was known as a scientist, and had a few famous works, including the *Life of Pomponius Secundus* and a literary piece about the *History of the Germanic Wars* (Livius.com). This piece is based on experiences he had while he was serving in the Roman army. Pliny the Elder also spent some of his lifetime as a procurator in Spain. Later in life, Pliny lived in semi-retirement, spending most of his days writing and studying. This constant writing and studying resulted in one of his greatest literary pieces, the encyclopedia that goes by the name *The Natural History* and spans 37 books, his most famous work on the natural sciences (Biography.com).

The Natural History covers a wide variety of subjects. For instance, there is a book in the series about Cosmology, Zoology, Botany, and even pieces of information on Ornithology. The series of studies were made for Titus Vespasian, the emperor of Rome who was crowned right before Pliny the Elder died on August 24, 79AD (Biography.com). *The Natural History* contains many of Pliny the Elder's observations including Eclipses, Planetary Motion, and opposing forces. Pliny's observation paved the way for future physicists to make the discoveries that they made in these areas.

Another scientist who has shaped our present understanding of the universe is Sir Isaac Newton. He was born on December 25th, 1642, according to the Julian Calendar, in the town of Woolsthorpe, Lincolnshire, England. During his life he was a well-known mathematician, scientist and physicist. His father, a prosperous farmer, died before Newton was born. When his mother re-married, she left Newton with his grandmother and went to live with her new husband. By the time his mother re-entered his life, Newton was attending the King's school in Grantham, Lincolnshire. His mother pulled him out of school so that he would become a farmer. Newton detested this and he failed at farming in the later years, since he found it monotonous (Biography.com).

After some time, Newton was allowed to return to The King's school to complete his basic education. Newton's uncle was then able to convince his mother to allow him to attend Cambridge University. During his first few years at Cambridge, he studied the general curriculum, but he was very curious about the more advanced courses. He would spend most of his time reading about the modern philosophers. This lack of concentration on his studies led to average academic performance, and Newton graduated from Cambridge University without any honors or distinctions. However, he graduated with a scholar title and financial aid to help with his future education (Biography.com). In 1668, Newton constructed a telescope to further study in optics. However, this was only the beginning of Newton's scientific achievements. He became a professor at Cambridge University. After his mother died in 1679, he took a hiatus from Cambridge University, which was when his truly groundbreaking discoveries began. During this time, Newton worked on one of the most influential books in the world of science, *Mathematical Principles of Natural Philosophy* or *Philosphiae.*

Newton's book discusses the three inertial laws. These laws changed the world of physics since they explain the phenomena that scientists had observed for ages. Newton's laws are based on foundations laid by Pliny the Elder.

Most of Pliny's discoveries are recorded in *The Natural History.* These concepts have laid a good foundation for the future laws of physics. A primary example is Pliny's discussion of an eclipse. In Chapter 12 of Book 2 of *The Natural History,* Pliny states

> *quippe manifestum est solem interventu lunae occultari lunamque terrae obiectu ac vices reddi, eosdem solis radios luna interpositu suo auferente terrae terraque lunae. hac subeunte repentinas obduci tenebras rursumque illius umbra sidus hebetari. neque aliud esse noctem quam terrae umbram*,

> it is evident that the sun is hid by the intervention of the moon, and the moon by the opposition of the earth, and that these changes are mutual, the moon, by her interposition, taking the rays of the sun from the earth, and the earth from the moon (Trans. Bostock, 1855, and Mayhoff, 1906).

Here Pliny states that an eclipse is the result of the sun being blocked by the moon. This interference in the paths of the sun's light is what causes the darkness.

This is how Pliny defines an eclipse, and it is very similar to the present definition of the phenomenon. This phenomenon that occurs close to 4-5 times a year, is defined as an event where the moon gets between Earth and the sun, and the moon casts a shadow over Earth (Space.com). Both sources are describing what is known today as a lunar eclipse. Prior to this observation, this phenomenon was tied to most civilizations religious beliefs. For instance, those associated with the Hindu religion tied the phenomenon to their god Vishnu beheading the demon Rahu (Osbourne, 2015).

Newton goes on to explain the phenomenon of eclipses with the first inertial law of physics. An eclipse is the result of the moon interrupting the sun's light. This movement is constant and it is therefore predictable. The first inertial law is described in Newton's *Principia Mathematica*:

> *Lex I: Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare.*
>
> An object at rest will remain at rest unless acted upon by an external and unbalanced force. An object in motion will remain in motion unless acted upon by an external and unbalanced force (Trans: Andrew Motte).

According to this law, if an object is in motion, it will remain in its path unless an unbalanced force acts upon it. If nothing interrupts it, the object will go on in its current path with the constant velocity that it always had. This concept can be applied to was observed by Pliny the Elder's observation that an eclipse is the result of the moon's path interfering with the path of the sun's light. This observation gave insight into the orbital path of the moon. Upon Newton's discovery of the Gravitational force, it would later be agreed that the moon has this path because it is affected by the Earth's gravity. As long as this interaction continues, the moon will continue orbiting the Earth. An object with a large enough force would have to collide with the moon in order to affect this interaction. Unless this unlikely event occurs, the moon will continue on its current path, and therefore the eclipse will also continue. This constant movement makes it very simple to predict and map eclipses. This is a prime example of how modern physics has been greatly affected by ancient physics. These observations were made by many ancient scientists. However, until Newton made this discovery the phenomenon could not be explained.

This connection between an ancient and a modern scientist shows how the principles of physics remain constant. Pliny's observations have laid an immense and strong foundation for later physicists, such as Sir Isaac Newton and Johannes Kepler, who added to the information known about the universe.

Pliny the Elder also makes observations about the orbital paths of the planets in Book 2, Chapter 15 of *Historia Naturalis.* Here he mentions the difficulty in both the observations and recording of the paths of the planets as they orbit the sun. This observation must have been quite difficult since Newton did not invent the first fully reflecting functional telescope until the year 1668. This observation was the beginning of the quest to find out as much as possible about the planets. If enough is known about these planets many questions like "Can such objects sustain life?" and "Were they ever able to sustain life?" and even "Are there any planets out there that are currently sustaining life?" may be answered. These observations have ignited the interests of many scientists to come.

To illustrate this idea, examine Pliny the Elder's discussion of the orbital paths of Mars:

tertium martis, quod quidam herculis vocant, igne ardens solis vicinitate, binis fere annis converti, ideoque huius ardore nimio et rigore saturni, interiectum ambobus, ex utroque temperari iovem salutaremque fieri. deinde solis meatum esse partium quidem trecentarum sexaginta. Historia Naturalis 2.15

There are many other secrets of nature in these points, as well as the laws to which they are subject, which might be mentioned. For example, the planet Mars, whose course is the most difficult to observe, never becomes stationary when Jupiter is in the trine aspect, very rarely when he is 60 degrees from the sun (Trans. Bostock, 1855, and Mayhoff, 1906).

Pliny is stating that the orbital path of Mars is quite hard to track since it is constantly moving at a different rate than the Earth is. However, he also locates Mars barely within 60 degrees of the sun, something that we know today is incorrect. Nevertheless, this example shows that there were instruments in Pliny’s time that allowed them to measure the bearings between the sun and the respective planets. Prior to the time of Pliny, the planets’ paths had been said to contain some retrograde, defined as “moving backward, or having backward motion” (Dictionary.com). According to the Ptolemaic Model, Ptolemy made this point around 100 AD, and it was also widely believed in ancient Greece. During this era the Geocentric model, in which that the earth was thought to be orbited by the sun and other planets. The retrograde theory was an attempt to explain the seemingly arbitrary orbits of each of these planetary bodies. This retrograde was also proven by another physicist around the time of Sir Isaac Newton, Johannes Kepler, and in conjunction with Newton’s second inertial law**,** it can explain the observation of retrograde of the planets.

Newton’s second inertial law deals with the momentum of an object. It considers the changing of an object’s momentum and states that this change in momentum is equal to the force of this object. It can be found in the *Principia Mathematica:*

> *Lex II: Mutationem motus proportionalem esse vi motrici impressae, et fieri secundum lineam rectam qua vis illa imprimitur.*
>
> The rate of change of momentum of a body is equal to the resultant force acting on the body and is in the same direction (Trans: Andrew Motte).

This law refers to the momentum of an object. Momentum is defined as the mass of an object multiplied by its velocity (Dictionary.com). The law states that the momentum is changing over time; since the mass of an object does not change, its velocity changes. A change in velocity over time is called acceleration. Therefore, the equation of force changes from

$$F = m\frac{dv}{dt}$$

With “m” representing the mass of an object and ($\frac{dv}{dt}$) being the change in velocity over time. When applying acceleration, the equation changes to:

$F = ma$ (With “a” being the acceleration of an object.)

This second equation can be used along with Kepler’s third law of Planetary motion in order to explain why this retrograde happens. Astronomer Christopher Palma explains Kepler’s first law: “The orbital paths of the planets are elliptical with the Sun at one focus” (Kepler's Laws of Planetary Motion). In other words, all planets travel in elliptical shaped paths around the sun.

The second law can also be used to derive Newton’s Law of Universal Gravitation. This law states that gravity is everywhere and everything is affected by gravity. It is the force of attraction between two objects such as a force of attraction between the planets. Since the shape of a planet's orbital path is an ellipse, it would at times be closer to the sun since some parts of its path are closer to the sun. There the planet will move faster, compared to other parts of its path. This also applies to the Earth. In fact, the phenomenon of elliptical orbits is the reason why the retrograde was observed. As the Earth was "catching up" to the other planet's orbital path, the other planets would seem to move backwards. However, we now know that other planets do not truly move backwards, but rather this illusion is created by the Earth moving at a faster rate than the other planets. This retrograde had been disturbing the minds of scientists for ages. Newton's second law actually shows that since the distance between it and the sun (*r)* is shorter in some areas, in order to keep the same force, the velocity of the planet has to increase.

Now moving on to Pliny's other observations, Book 2, Chapter 8 of *Historia Naturalis,* "The Magnitude of Stars,*"* describes the movement and configuration of the stars. In this chapter of *The Natural History,* Pliny hints at the sun being the center of our solar system. Pliny describes the configuration of the shadows of the trees during the day:

> *inmensum esse, quia arborum in limitibus porrectarum in quotlibet passuum milia umbras paribus iaciat intervallis, tamquam toto spatio medius, et quia per aequi noctium omnibus in meridiana plaga habitantibus simul fiat a vertice, item quia circa solstitialem circulum habitantium meridie ad septentrionem umbrae cadant,*
>
> by arguing from its visible appearance, or from any conjectures of the mind; it must be immense, because the shadows of rows of trees, extending for any number of miles, are disposed in right lines, as if the sun were in the middle of space. (Trans. Bostock, 1855, and Mayhoff, 1906)

Here Pliny states that the sun is orbited by the earth, and explains how he reached this conclusion. He observes the long shadows of rows of trees that extend for a number of miles and are in straight lines and compares the shadows of the trees to the tangential lines of circles, since the lines are always perpendicular to the radius of the circle. This may have been the reasoning behind the statement that the solar system is heliocentric, an epiphany that has greatly influenced the world of physics. If the solar system was still thought to be geocentric, many calculations for space exploration attempts may have failed. Thus obliterating the prospect to ever travel outer space, which would have inhibited humankind from ever understanding the ever expanding universe. The fact that our solar system is heliocentric has also led to subsequent questions like “Why does the Earth orbit the sun?” and “Why does the Earth never break off from its orbit?” Many physicists prior to Newton have asked the latter, and it has led to many civilizations researching for answers. In the 1500’s Polish astronomer Nicolai Copernicus, where he restated an old theory by Aristarchus of Samos. As stated in “The Copernican Model: A Sun-Centered Solar System”, this theory stated the earth was orbiting the sun, and this theory has probably existed since 200 BC.

Newton’s third law not only confirmed the possibility of this observation, but also explained it. This law is commonly known as “The action reaction law” and can be applied to planetary motion especially. The third law states:

> *Lex III: Actioni contrariam semper et æqualem esse reactionem: sive corporum duorum actiones in se mutuo semper esse æquales et in partes contrarias dirigi.*
>
> All forces occur in pairs, and these two forces are equal in magnitude and opposite in direction. (Trans: Andrew Motte)

Based on this law, as the sun is exerting a force on each of the planets, each of the planets are also exerting a force on the sun. However, only the planets appear to be in motion. This can be explained when considering the size of the sun compared to the size of the planets. The average radius of the sun is 6.96×10^{8}m, while the mean radius of the Earth is 6.37×10^{6}m (Wolfson, 2007). This shows that the sun is at least 100x bigger than the Earth, which explains why the Earth feels more of the sun's force being exerted upon it compared to the amount of force from the Earth that the sun feels. This discovery shows the influence that the ancient scientists had on modern science. The forces of attraction between the sun and earth are actually third law pairs, meaning that they are equal and opposite to each other, even though the effects from the force exerted on the sun by the Earth are negligible. They are what keeps the earth in its elliptical path, and this path is what causes the shadows of the trees to appear the way that they did to Pliny. Thus, this shows how Newton built upon the observations of Pliny the Elder.

As we have seen, the principles of physics have never fully changed, only our understanding of these principles. The laws and principles of physics that we know, such as planetary motion, are based on observations initiated by ancient scientists such as Pliny the Elder. Just as planetary motion was first observed by ancient scientists like Ptolemy and Pliny the Elder, it was proven by Sir Isaac Newton using his inertial laws. However, this is not the end; more questions still have to be answered, and one day they will. Looking at the humble beginnings of Newton, we see that a revolutionary mind can come from anywhere. A new generation of physicists may arise from anywhere, and add more to the ever-expanding world of physics.

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