Beginning with a discussion of Galileo's key experiment, describe the emergence of (strict) causality. You will need to develop the idea of predicting the motion of an object by considering the forces acting upon it.

Briefly indicate how this (strictly) causal picture differs from both Greek ideas about motion, and modern knowledge of the movement of elementary particles, such as electrons.

In the field of dynamics (the study of motion), a single experiment performed by Galileo provided the basis for modern science, as was later developed by Newton. Galileo details the original experiment in his *Discorsi e Dimostrazioni Matematiche Intorno a Due Nuove Scienze,* published in 1638. The experiments were carried out while he was under house arrest, and involved the movement of a ball along inclined planes.

The basis of the experiment was rolling a ball down an incline, along a horizontal plane, and then up an identical incline. Without the luxury of air tracks and motion sensors that can be used today to demonstrate this, Galileo argued that were it not for friction and air resistance, the ball would return to an equal height when rolling up the second incline. Developing this idea he showed that if the upward incline was gentler than the downward, the ball would still return to the equivalent height but it would take longer to do so. Taking this concept to the extreme (and still assuming a frictionless and air resistance free environment) if the ball was to roll down the initial incline and then along a horizontal plane, the ball would continue rolling along the horizontal plane forever at a constant speed. This would occur as there would be nothing (the upward incline) to alter, and subsequently halt, its progress.

In keeping with Galileo's description as the "first modern scientist" (Leri, 2001) this experiment was repeatable and conclusions could be drawn from observations. The conclusion to the experiment lies in the final example of the ball rolling continuously: as it would not slow down there could not be any force acting upon it, illustrating that something can move without a force. This was to form the basis of what is now referred to as Newton's first law:

> "*Corpus omne perseverare in statu suo quiescendi vel movendi uniformite in directum, nisi quantenus illud a viribus impressis cogitur statum suum mutare*.
> Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it" (Knowles, 1999, p327)

Philosophers had explored the concept of causality, or the relationship between cause and effect, before but this experiment gave an insight into its relevance in science: the forces that Galileo and Newton refer to cause a body's motion to change in a particular way. A simple example is Newton's cradle, today seen as an executive toy, which is a demonstration of causality and forces at work. The force of the moving ball on the stationary ball causes the moving ball to stop, and the other ball to swing away from it. Providing the mass of the two balls is the same they would (in a perfect experimental environment) continue to move back and forth forever as the momentum is transferred between the balls. It is difficult to see such examples today without being able to make correct assumptions as to the predicted motion because of experience, and an innate sense of what will happen.

If a change is made to part of the demonstration, such as one ball in the cradle being made several times heavier than the other, both instinct and Newton's laws indicate that the heavier ball would cause the lighter ball to move more quickly. A more practical example of the same science would be a car running into a stationary car: if the cars both had the same mass the stationary car would move away with the original car's speed. However, if the car were to run into a stationary lorry (with several times the mass of the car), the lorry would only move at a fraction of the car's original speed.

A far larger example that illustrates both the practicality of scientific causality and the ability to predict motion based on prior knowledge of the forces involved can be seen in astronomy. Newton's other laws describe how the motion of an object is changed by a force thereby enabling the future position of an object to be forecast. Indeed, it was possible to calculate all planetary motion based on a single set of observations. Causality meant that if the "positions and velocities of the planets [are known] at some initial time, the configuration at any other time can be calculated […] without further recourse to observations" (Waismann, 1959, p85ff).

This ability to predict a planet's orbit led to the discovery of Neptune, and in turn Pluto. Uranus's motion had been predicted but between 1792 and 1821 it was noticed that the predicted position did not match the observed location. With a general acceptance of the infallibility of Newton's laws, John Adams started work in 1841 to prove this anomaly was due to the gravitational pull of a planet even further away from the sun. While Newton's gravitational theory "had been used many time to calculate the effects of bodies on one another", it had never "been used to predict the position of a body from observations of the effects of its gravity on other bodies" (O'Connor & Robertson, 1996). By 1845 Adams knew where the new planet was, although it was not officially viewed and recognised as Neptune until 1847. Work using similar methods began in 1915 ultimately leading to the discovery of Pluto.

The concept of the predictability of nature was taken to its logical extreme by Lamettrie in his book *L'homme machine*, in which he suggested that as all matter is made of the same building blocks, and the motion of the planets can be predicted it must be possible to predict the behaviour of every atom. Predicting the motion of every atom would therefore include those that make up the human body. Although scientifically erroneous, this was an interesting philosophical viewpoint as it would deny the idea of freedom of choice (Waismann, 1959, p94).

The Greek concept of motion was based on an intuitive sense of the constituent parts of matter, and the difference between natural and violent movements. Every object was believed to be at rest at all times unless it had been acted on by a force, in which case it would move – the concept of a vacuum was unimaginable. Forces were either seen as 'natural' (or 'internal'), for example a stone falling to the ground had a natural affinity for the earth (because of its construction) or fire licking upwards towards the outermost elemental region, or they were seen as 'violent'. A 'violent' force was where an external influence acted on the body, such as weights being lifted from the ground, or a cart being pulled by a horse to defy the natural internal forces keeping the weight on the ground (Finocchiaro, 1997, p16ff). Another ancient misconception was the speed at which objects fell: it was assumed that a larger object would fall to the ground faster than a smaller one. Galileo was responsible for dismissing this idea by dropping objects from the Tower of Pisa and showing they landed together. Whilst these views of the physical world seem quaint to modern readers, their foundations in the very tangibility of the matter that was being considered suggest that logical and considered conclusions were made. It is worth remembering that this interpretation held sway for around two thousand years, compared to the three hundred it took to prove Newton flawed when examined at the subatomic level.

Strict causality cannot be witnessed when exploring the motion of elementary particles. In 1927 a theoretical experiment (it was not carried out until 1961) based on Young’s double-slit experiment demonstrated that “electrons and other discrete bits of matter […] have wave properties such as wavelength and frequency (‘Siltec’, 2002). During the experiment, which incidentally was voted the “most beautiful experiment” (Crease, 2002) earlier this year, the motion of the individual particles cannot be predicted although the ultimate outcome can be. The experiment has been described by Richard Feynman as “containing everything you need to know about quantum mechanics”.

Ironically it is impossible to examine this experiment in greater detail as the addition of sensors and detectors change the outcome of the experiment. Opposing the popular myth that ‘science has the answers’, it is not possible to explain this phenomenon, unlike earlier scientific endeavours such as Newton’s laws of motion. Whilst the experiment proves that elementary particles do not adhere to the classical laws of motion, it is important to remember that in no way does it reduce the import and relevance of the work of Galileo and Newton which still holds true for larger physical bodies.

Galileo’s work which provided the foundations for classical (as opposed to ancient) science was critical for the development of modern science. Without his heretical beliefs in, and work on, the heliocentric planetary system for which he was placed under house arrest, his simple experiments answering how motion occurred, rather than why it occurred might never have been executed. Scientific development had already been stalled for centuries because of the adherence to Aristotle, but these discoveries lead to the explosion in the understanding of the physical world and to the associated technical developments, for which we may otherwise have still been awaiting.

(1531 words)

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