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Honors Contract

A Brief History of Gravity

According to WordNet, a database developed by Princeton University, gravity is "the force of attraction between all masses in the universe, especially the attraction of the earth's mass for bodies near its surface." As this definition suggests, modern scientists conceptualizing gravity have not restricted the force to one circumscribed by earth's atmosphere. Early scientists, however, interpreted gravity merely as an object's heaviness or tendency to fall toward earth. Eventually, discoveries in astronomy and elementary motion prompted scientists to reconsider this force as something universal, occurring both within and beyond a terrestrial scope. The progression in understanding gravity conveniently reflects the progression of science throughout history. It was thoughtfully considered by Greek philosophers, largely ignored or suppressed by Catholic fundamentalists, and eventually recognized in a distinct mathematical form by preeminent pioneers of the Scientific Revolution. And currently, developments in scientific theory like Einstein's general relativity are still changing our understanding of gravity, making scientists reconsider what is arguably the most fundamental force in the universe.

Aristotle was the first major scientific figure to articulate the phenomenon of gravity. Unlike Plato, his predecessor and mentor who had delineated between the current imperfect world and a perfect world only comprehended through logic, Aristotle based his understanding on practical, observable data. While Aristotle accepted Empedocles' traditional classification of all earthly elements (earth, water, air, and fire) and ascribed them certain characteristics (wet or dry, hot or cold), he attributed a unique ability to each element. Aristotle called this ability "motive power," defined as that which "tended to make [that element] move to a particular direction, toward what Aristotle called its natural place" (Darling 16).

Earth and water possessed the motive power of gravity, tending to fall earthward, while air and fire possessed the motive power of levity or lightness, tending to rise heavenward. To Aristotle, the only difference between heavier and lighter objects is the amount of gravity-bearing elements they contain. Heavier objects fall faster than lighter objects because they contain more gravity-rich elements than levity-rich elements. To Aristotle, gravity and levity were not found in gradations or degrees: they were an absolute, inalterable condition possessed by the elements that had those powers.

Additionally, Aristotle established a clear demarcation between characteristics of heaven and earth. While the motion of the earth was inconsistent and unpredictable, the motion of the heavens "was uniform, never ending, and perfectly circular about the center" (Darling 18). More significantly, however, Aristotle ascribed *purpose* to the motion of objects: all objects strived to intentionally restore themselves in nature's elemental balance. Objects would only move if they experienced a continuous external pushing "force" acting upon them; without that force, they would stop moving and remain stationary until another force would act upon them. When an object was thrown upward without continuous pushing, he reasoned, air circulating in spirals around the object held it temporarily aloft until it returned inevitably to earth.

It is important to understand Aristotle's contribution to science, particularly his conviction in the motive powers of earthly elements, because his viewpoints went virtually unopposed for almost two millennia. Although Aristotle's conclusions are obviously false by modern standards, his ability to solidify many observations into one understandable theory intimidated many scientists against opposing him. While important scientists preceding the Scientific Revolution made important discoveries in their fields, they were largely subjugated by a wealthy ruling class who heavily influenced the development and focus of science. Originally, scientists were minimally funded by kings chiefly concerned with projectiles, improving their weaponry to better defeat their enemies. Eventually, as the Catholic Church gained greater power and prestige throughout Europe, science's objectivity and freedom was severely curtailed. The Church insisted on the legitimacy of Aristotle's science because it conveniently conformed to their theological beliefs. Notions that other life-sustainable planets may exist, or that the sun is the center of the universe, were undoubtedly considered heretical and were punishable by excommunication or even death. In the early 16th century, however, the merchant class became exceedingly wealthy and thus highly influential in European politics, encouraging scientists like Galileo to independently assess the legitimacy of Aristotle's long-standing hypotheses.

Galileo Galilei developed his own understanding of gravity and planetary motion from that of his predecessors, namely Copernicus and Giordano Bruno, who stated that "innumerable suns exist" with "innumerable Earths [revolving] about these suns" (Darling 58). He initially conducted his experiments with great circumspection, knowing that presenting any conflicting views against Aristotelian philosophy would be immediately considered heresy, but eventually could not suppress the truth any longer. He published the <u>Dialogue Concerning the Two Chief World Systems</u> in 1632, which subtly presented his experiments on motion and directly countered indoctrinated Church science. Instead of merely explaining his position, however, Galileo characterized the Aristotelian position in an unflattering, sarcastic way. Its spokesperson in the Dialogue was a dimwitted Simplicio, arguing unsuccessfully against an intelligent Salviati, who coincidentally supported heliocentrism. After the book's publication, Galileo was pressured under Inquisitional torture to recant his philosophy. And although he falsely attributed circular motion to planetary systems, he is generally identified as the Father of Modern Science for his reliance upon empirical evidence and observation when supporting hypotheses.

Instead of accepting Galileo's model of a heliocentric universe, the Church instead embraced ancient Ptolemaic ideas of planetary motion to explain astronomical puzzles that couldn't be explained in a geocentric universe. The biggest puzzle, called *retrograde motion*, was the apparent back-and-forth motion of the planets over prolonged periods of time. Attempting to explain this and other phenomena, Ptolemy published *The Almagest* in 150 AD, a massive scientific achievement which "[marked] the zenith of Greek astronomical achievements" (Gondhaleker 15). Ptolemy's solution to the retrograde motion dilemma was the postulation of *epicycles*, which seemed cosmetically to eliminate this problem. Instead of moving in one circular orbit around the earth, Ptolemy reasoned, the planets moved in smaller circles that traced the larger circular orbit; these smaller circles were termed *epicycles*. Although this complicated system "gave a better description of planetary motion," there were fundamental flaws, namely the "considerable difference between the observed and the predicted motion of the Moon" (Gondhaleker 17). It wasn't until almost a millennia and a half after Ptolemy's publication that his astronomical theory of epicycles was legitimately challenged and subsequently dismissed.

German scientist Johannes Kepler had originally intended to verify the ancient Aristotelian assertion that planets obeyed circular motion using contemporary technology and research methods. However, after hundreds of pages of calculations and failed hypotheses, he unwittingly stumbled upon the concept of planetary elliptical motion, a concept which "exploded upon the western world like a thunderclap" (Darling 75). Furthermore, by analyzing astronomical data collected by previous scientists, Kepler developed his now-famous three laws of planetary motion, the first two of which were published in *Astronomia Nova* (New Astronomy) in 1609. Not only did the three laws eliminate the superfluous Ptolemaic notion of epicycles to explain planetary motion, but they further challenged the Church's scientific legitimacy. But Kepler himself was extremely distraught by his conclusions. He reasoned that ellipses were "so hopelessly imperfect" compared to flawless circles, considering his findings "[a] cart-load of dung" (75).

Eventually, however, it was Isaac Newton that established gravity as a universal force, something that affects everything from Earth-bound objects to planets and stars. Although Isaac Newton easily made the greatest scientific contribution to the understanding of gravity, his contribution depended heavily on the scientists that preceded him. He was heavily influenced by Galileo's methodology and experiments, especially those experiments concerning motion, and Kepler's laws and astronomical data. Newton conducted his own experiments in 1665 and 1666 and developed three preliminary laws of motion that would be the foundations for later research. He also developed an equation for the force required to maintain uniform circular motion. That force, called the centripetal force, was demonstrated to be proportional to its velocity squared divided by its radius.

Personal tragedies and hardships in Newton's life compelled him to temporarily abandon his research and pursue the superstitious sciences of alchemy and astrology. However, when Robert Hooke, a preeminent English scientist, asked Newton about his opinion on planetary orbits – and suggested that perhaps a continuous straight-lined force affected planetary motion – Newton became intrigued and resumed his experiments with renewed vigor. Eventually, using new results gathered from new experiments, Newton confirmed Galileo's value for the acceleration due to gravity using sophisticated research that accurately measured the earth's circumference. His conclusions had effectively solved "one of the greatest conundrums of the age," considering motion along an orbit in infinitesimally small intervals of time (Darling 82). Using principles of calculus, a form of mathematics which he had invented himself, he calculated the planet's deflection from the linear motion mapped out during those time intervals and proved conclusively that planets follow elliptical orbits.

After persistent requests from Edmund Halley, an English astronomer and colleague, to distribute his findings, Newton reluctantly published *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy), which consisted of three books, in 1687. The first book introduces Newton's three laws – the law of inertia, the law relating force and mass, and the law of action/reaction pairs – which set the foundation for understanding how objects move. The second book discusses fluid mechanics and the general motion of objects through resistive mediums; Newton eventually proved that a vacuum must exist outside Earth's atmosphere. The third book is arguably Newton's greatest contribution to classical physics, and certainly provides the greatest contribution to gravity. In it, Newton establishes what became known as his law of universal gravitation, relating the gravitational force between two objects with their masses, the distance between them, and a value called the *universal gravitational constant*. Newton used this equation to explain cosmological mysteries such as the movement of comets and the motion of the tides that had befuddled his contemporaries. According to David Darling, the *Principia* demonstrated "a universe united by a single set of laws," and the implication of these laws suggested that "the cosmos would never be the same again" (86).

And despite gravity's progressive history leading up to Newton's seemingly definitive equations, our understanding of the universe – and gravity in particular – is far from comprehensive. The German physicist Albert Einstein postulated the existence of gravitational waves after publishing papers about his theory of special relativity in 1918. He demonstrated that accelerating objects create rippling waves of gravity with changes that are proportional to their masses and accelerations. This discovery prompted extensive scientific speculation about the implications of Einsteinian relativity for gravitational forces, and even for mechanical physics itself. One such theory, called Modified Newtonian Dynamics (MOND) and developed by Israeli scientist Mordehai Milgrom in 1983, attempts to link quantum mechanics with general relativity. MOND hypothesizes that Newtonian gravity only exists when gravitational force is strong; when this force gets weaker, another form of gravity appears whose strength diminishes more slowly than conventional gravity.

Throughout history and despite periodic censorship, scientists have been consistently investigating the natural world and developing theories attempting to explain its mysteries. The quest for understanding gravity illustrates scientists' relentless inclination to gather observations about the universe – everything from an object's heaviness to the motion of the planets – and develop unifying explanations of the cosmos. "Given the far-reaching power of this conceptual and philosophical unity," writes Robyn Arianrhod, "no wonder physicists are still hoping to find the unified 'theory of everything'" (280). This "theory of everything" – synthesizing Einsteinian relativity with quantum mechanics and developing a "theory of quantum gravity" – provides "the greatest challenge of our understanding of the world today" (Kallos). And discovering this theory, and its scientific implications, will mark the next greatest intellectual leap by scientists in understanding the mysteries of gravitational motion.

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