In the previous class, we explored a mostly historical introduction. This time, we will examine the rise of modern science and the philosophical challenges that accompanied it.

We have already covered some aspects of ancient Greek and medieval philosophy, both of which are crucial. Even in the Middle Ages, the foundations of modern science were laid, though this is often overlooked. Remember that the philosophy of *physis* was a rational endeavor aimed at understanding the universe through reason, rather than merely developing utilitarian applications.

When discussing **Plato (c 428-348 BCE)** and **Aristotle (384-322 BCE)**, we highlight their differing approaches to explaining the world. For Plato, true reality was immaterial, unchanging, and ideal—existing in what he called the *Hyperuranion*, a metaphysical realm separate from our physical world (recall the allegory of the cave). Aristotle, on the other hand, had a completely different perspective. He introduced the concepts of *substance* and *essence*. Substance represents the actual being of something, while essence defines and limits it. He also introduced the idea of *energeia* (actuality) and *dunamis* (potentiality), concepts that are quite familiar to physicists today as they relate to energy and dynamics. Aristotle was deeply concerned with explaining causes, particularly the *final cause*, which addresses why things move in a certain direction. Until the 17th century, the prevailing worldview was largely based on Aristotelian ideas, which influenced the organization of knowledge. Plato can be considered a rationalist, believing that ideas are more fundamental than material reality. Aristotle, on the other hand, was more of a realist—convinced that an external world exists independently of our minds and that truth must be discovered outside of human thought. This distinction between ideas and external reality also plays a role in differentiating scientific facts from laws and theories.

A common narrative suggests that during the Middle Ages, knowledge was dominated by the **authority** of Aristotle and the Bible, until Galileo came along, conducted experiments, and revolutionized everything, paving the way for modern science. While this is a simplified version of events, we will explore the details step by step.

Last week, we focused on Greek philosophy, whereas today, we will shift our attention to Europe, particularly Northern Europe, where many key scientific discoveries occurred. The 16th and 17th centuries saw a philosophical revolution against Aristotle, which had both positive and negative consequences. While it freed scientific thought from Aristotelian constraints, philosophy itself did not necessarily benefit in the same way.

We can distinguish two types of philosophy concerning the 16th and 17th centuries:

1. **Broadly defined philosophy**, which includes natural philosophy and played a key role in scientific advancement by moving beyond Aristotelian limitations.  
2. **Philosophy in the narrow sense**, referring to university teachings and scholasticism during the Middle Ages, which declined in influence.

This shift led to two dominant approaches, both emphasizing experimentation and observation:

• **René Descartes’ Dualism**: He distinguished between the material, external world and the realm of the mind, introducing the famous division between *mind* and *matter*.  
• **British Empiricism**: Thinkers in this tradition focused on external observations and practical results, prioritizing what worked over abstract explanations of reality.

The philosopher who attempted to reconcile these two perspectives was **Immanuel Kant (1724-1804)**. I won’t go into detail today, but he was remarkable. He sought to bridge the gap between the ideas that exist in our minds and the sensory information we receive from the external world. Since Kant, philosophy has continually referenced his work.

Later, **Friedrich Hegel (1770-1831)** introduced *idealism*, arguing that the external world does not exist independently and that everything we perceive is shaped by our minds. He proposed that all reality is rational and that what comes into existence does so through reason.

It is essential to focus on the major scientific revolutions that redefined our worldview.

**The Shift from Geocentrism to Heliocentrism**

Ptolemy (c 100-178 BCE) initially proposed a geocentric model, placing Earth at the center of the universe. However, the first major scientific revolution occurred with the transition to heliocentrism, which ultimately supplanted geocentrism.

1. **Scientific Uniformity:** The realization that the laws of physics operate uniformly across the universe was a crucial breakthrough. Before Galileo, people believed celestial bodies followed different principles from those governing Earth.
2. **Mathematical Science:** Today, we take for granted that physics relies on quantitative calculations. However, in earlier times, scientific predictions and models were not necessarily mathematical.
3. **Predictive Models:** The use of mathematics in physics allowed for accurate predictions of natural phenomena.

**Early Scientific Experiments**

One of the earliest physics experiments was the Greek measurement of Earth's radius. By placing posts at different locations in Egypt and measuring the shadows they cast, they successfully estimated Earth's circumference. Such methods marked the beginning of systematic scientific inquiry. Although steam engines existed in ancient times, they were primarily used for entertainment rather than practical applications.

**The Contributions of Copernicus (1473-1543)**

Nicolaus Copernicus, a key figure of the Scientific Revolution, was not the first to propose heliocentrism—Aristarchus of Samos (c. 310-230 BCE) had suggested it earlier. However, Copernicus sought to refine the existing Ptolemaic model rather than outright reject it. His theory addressed the perplexing issue of retrograde motion, previously explained through complex epicycles. By placing the Sun at the center, Copernicus eliminated the need for these additional constructs, making the system more elegant.

Despite the scientific merits of heliocentrism, common sense at the time dictated that Earth must be stationary, as Aristotelian physics dictated that heavy objects naturally settled at the universe's center. As a result, Copernicus' book, *De revolutionibus orbium coelestium*, was largely ignored initially but later banned by the Catholic Church in the 17th century.

**Tycho Brahe (1546-1601) and Kepler (1571-1630)**

Tycho Brahe built an advanced observatory in Copenhagen, maintaining the belief that Earth was at the center while producing precise astronomical measurements. His assistant, Johannes Kepler, later used Brahe’s data to develop the three laws of planetary motion. Despite their significance, Kepler’s *Rudolphine Tables* were initially overlooked due to their complexity.

**Galileo Galilei (1564-1642): The Pioneer of Modern Science**

Galileo revolutionized science by introducing mathematical descriptions of motion. He argued that explaining motion without mathematics was futile. His experimental approach was groundbreaking—he conducted experiments not just to make things work, but to understand the underlying principles.

Galileo’s personality was combative, often leading to conflicts. Though he initially challenged Aristotelian physics—asserting that objects fall at the same speed regardless of mass—he later tempered his statements, aware of the fate of Giordano Bruno. His reasoning extended beyond direct observation, incorporating abstract thought experiments, paving the way for Newtonian physics.

One of Galileo’s most significant contributions was the concept of inertia, explaining why we do not perceive Earth's motion. He encountered the inventor of the telescope (a Dutch optician) and greatly improved its magnification, using it to observe celestial bodies. His discoveries—moons of Jupiter, lunar craters, the Milky Way, phases of Venus, and sunspots—challenged long-held beliefs. His book, *Sidereus Nuncius* (*The Starry Messenger*), earned him a prestigious position with the Grand Duke of Tuscany.

**Galileo vs. The Catholic Church**

By the early 1600s, the Catholic Church had condemned Giordano Bruno, and Galileo treaded cautiously. Initially, he presented heliocentrism as a mere mathematical model rather than absolute truth. However, his 1632 book, *Dialogue Concerning the Two Chief World Systems*, portrayed heliocentrism favorably, with the Aristotelian view represented by the character Simplicio. The Pope, feeling mocked, had Galileo tried and placed under house arrest. Despite his confinement, Galileo emphasized empirical observation and experimentation as fundamental to science.

**Isaac Newton (1642-1726): The Architect of Modern Science**

Newton synthesized the discoveries of Galileo, Kepler, and Copernicus in his *Philosophiæ Naturalis Principia Mathematica*, laying the foundation for classical mechanics. His work solidified several key philosophical and scientific principles:

* The universe operates according to fixed, universal laws.
* These laws allow for accurate, mathematical predictions.
* The concept of a *clockwork universe* emerged, where deterministic laws govern all phenomena.

Newton’s work marked the true birth of modern science, establishing a framework that continues to shape our understanding of the physical world.

**The Evolution of Philosophical Thought in Science**

**The Role of Francis Bacon (1561-1626)**

Let’s take a moment to explore the evolution of philosophical thought, starting with Francis Bacon. Though he wasn’t the founder of the Royal Society in the UK, he played a crucial role in inspiring its creation. Bacon wrote *Novum Organum*, which translates to “New Tool,” a work that aimed to move beyond the ideas of Aristotle.

Aristotle had written *Organon*, a comprehensive treatise on logic, which we’ll revisit when we discuss syllogism and deductive reasoning next week. Bacon, however, sought to go beyond Aristotle’s influence, marking a shift away from Aristotelian philosophy. He redefined metaphysics, arguably reducing its importance in favor of a more empirical approach to science.

Bacon divided philosophy into two main branches:

1. **Speculative Philosophy**, which includes areas like physics and metaphysics.  
2. **Operative Philosophy**, which deals with practical fields like mechanics and even magic.

At the time, the supernatural and natural worlds weren’t seen as strictly separate, a view that would emerge later during the positivist movement. Bacon, sharing some views with Descartes, envisioned knowledge as a tree:

• **Physics** served as the roots, focusing on material and efficient causes observed in nature.  
• **Metaphysics** formed the tree’s foundation, addressing teleological (purpose-based) and formal causes.

Later, physicist Max Planck would highlight that physics still relies on certain implicit metaphysical assumptions, showing that even modern science is rooted in philosophical thought.

**The Shift from Natural Philosophy to Physics**

The early scientific era saw a profound shift. Initially, studies of the natural world were grouped under the umbrella of “natural philosophy.” Over time, this evolved into two separate fields:

1. **The Philosophy of Natural Science** – which explores fundamental concepts like space, time, motion, and change.

2. **The Science of Physics** – which focuses on observation, experimentation, and falsification to build upon established concepts.

Although physics seems more practical, the philosophy of science remains crucial. In Bacon’s time, Aristotle’s influence was often seen as an obstacle to progress, but the real issue was how his teachings were interpreted rather than the ideas themselves. Key thinkers of the era, like Galileo, Bacon, and Descartes, helped pave the way for this transformation.

**The Impact of the Scientific Revolution on Philosophy**

The rise of physics during the Scientific Revolution came at the expense of philosophy’s broader influence. Before this shift, philosophy was richer and more comprehensive. Despite the changes, Aristotelian frameworks remained dominant in universities through scholasticism, and even today, some philosophers of science still embrace Aristotelian ideas.

**Galileo and the Philosophical Debate**

Looking beyond history, we can analyze Galileo’s impact on philosophy. Many scholastic professors in places like Oxford, Rome, Padua, and Bologna strictly adhered to Aristotle’s teachings. They often relied on a priori reasoning rather than empirical observation, which set the stage for Galileo’s challenge.

It’s important to note that the common narrative suggesting Galileo championed experimentation while Aristotelians resisted it is oversimplified. In fact, Aristotle valued observation and emphasized that theories must align with observed phenomena—a principle that became central to the scientific method.

**The Conflict: Authority vs. Free Thought**

The true conflict wasn’t between science and philosophy but rather between **authority** and **independent inquiry**. During this time, Europe had rediscovered Aristotle through Arabic translations and become a culture centered around authoritative texts, including religious ones.

Aristotle’s writings were revered much like scripture, and Galileo’s challenge to his views was seen as an attack on institutional authority. Interestingly, the Bible itself doesn’t explicitly support geocentrism except in metaphorical references (e.g., in *Joshua* and *Psalms*). The Church’s opposition to Galileo was more about preserving its power than defending theological accuracy.

**The Scientific Method: A Simplified View**

While the scientific method isn’t always formally taught, it generally follows these steps:

1. Systematic observation to analyze phenomena.  
2. Formulating a theory to explain those observations.  
3. Deriving predictions based on the theory.  
4. Empirical testing to confirm or refute the predictions.  
5. If predictions hold true, the theory is maintained; otherwise, it is discarded.

Though this model is effective, it can be somewhat simplistic, and we’ll revisit it next time to refine our understanding further.

This is quite a profound and intricate exploration of the philosophy of science, the historical development of scientific thought, and the role mathematics has played in that evolution. From Aristotle and Galileo to Newton and the 20th-century philosophical challenges, you cover a wide range of topics. Let me break down a few key themes for clarity and to facilitate a more focused discussion:

**1. The Role of Mathematics in Science:**

Early scientists like Galileo and Newton saw mathematics as the essential language of the universe. Galileo famously said that the “book of the universe” is written in mathematics. He believed that to truly understand the world, we had to describe it mathematically. This was a shift from earlier philosophers, like Aristotle, who focused more on qualitative descriptions.

As you pointed out, mathematics played a key role in the scientific revolutions of the 17th century. Thinkers like Kepler and Newton made groundbreaking discoveries using precise mathematical models—something earlier philosophers hadn’t emphasized.

**2. Philosophical Questions About Science and Mathematics:**

The debate between inductive and deductive reasoning (like Aristotle’s deductive method vs. Galileo’s reliance on empirical observation) is crucial in understanding the development of the scientific method. This debate continues today. Inductive reasoning, based on observation and patterns, can lead to generalizations that turn out to be false. On the other hand, deductive reasoning starts from basic principles but might not always connect to the complexity of the real world.

A big philosophical question is whether mathematics is discovered or invented. Are mathematical truths already embedded in nature, waiting to be uncovered, or are they just human-made tools we use to describe the world? This question remains a central issue in philosophy.

**3. Scientific and Mathematical Progress in the Modern Era:**

You mentioned the crisis in the foundations of mathematics in the early 20th century. Philosophers like Gödel and Russell challenged previous assumptions about mathematical certainty, revealing that even mathematics has limits to what can be known for sure.

In the 20th century, quantum mechanics also changed how we view the universe. Classical views, like those promoted by Descartes and Newton, saw the universe as a giant clock where everything operates deterministically. However, quantum mechanics introduced a probabilistic nature to reality, challenging this older, more predictable worldview.

**4. The Debate on the Nature of Scientific Theories:**

The discussion about models and theories (like Galileo’s idea of models vs. the search for certainty in scientific predictions) is important. While a hypothesis may be confirmed by successful predictions, scientific theories are always subject to change. This connects to Karl Popper’s idea that for a theory to be scientific, it must be testable and falsifiable.

As you noted, Galileo’s belief that mathematics was the key to understanding the universe was challenged by some, like Bellarmine during the Inquisition, who saw Galileo’s mathematical models as approximations, not absolute truths.

**5. The Role of Philosophy in Science:**

Philosophers like Kant made important contributions by questioning the assumptions we make about the world (such as the nature of space, time, and knowledge). His ideas highlight the challenges of combining observation with rational deduction.

The separation of metaphysics from science, particularly during the Enlightenment, was a pivotal moment. Philosophers who focused on metaphysical questions (like “What is the nature of reality?”) were often sidelined in favor of more empirical, scientific approaches that emphasized observable phenomena. This divide still exists today—some argue philosophy and science should be kept separate, while others see them as interconnected.