Chapter 2
Origin of Scientific Method

Introduction

We have emphasized that scientific method is a methodological approach to the process of inquiry – in which empirically grounded theory of nature is constructed and verified. To understand this statement, it is useful to go back in time to see how the method evolved. The origin of modern scientific method occurred in Europe in the 1600s: involving (1) a chain of research events from Copernicus to Newton, which resulted (2) in the gravitational model of the solar system, and (3) the theory of Newtonian physics to express the model.

There were many important intellectual precursors to science. For example, alchemy was a precursor to the modern scientific discipline of chemistry, but it was not science. Alchemy was a confusion of practices and un-grounded theory. In medieval Europe, the fundamental stuff of the universe was viewed as air, earth, fire, water – alchemy. But now in modern Europe, the fundamental stuff of the universe is energy and mass, atoms and molecules, fields and particles – chemistry and physics.

As another example, the modern science of mathematics has important historical roots in Egyptian and Greek and Arab geometry and algebra. But algebra and geometry were not integrated until 1619, when Renes Descartes created the modern mathematical topic of analytic geometry. Nor was the modern topic of calculus created until in 1693, when Newton added to analytic geometry the ideas of a differential calculus of infinitesimals. (And about the same time and independently, Leibnitz contributed the ideas of integral calculus.) Then the modern discipline of mathematics intellectually grew in the 1700s, as mathematicians built upon a modern analytical foundation of geometry, algebra, calculus, vectors, and (later) set theory.

What is essentially different between the civilizations before and after the origin of science in the 1600s is a very different conception of nature. Before, nature was merely a manifestation of a super-nature – the supernatural and unobservable – the world of religion. Afterward, nature now is only what is observable in the world. Nature is thought about, described, and explained through experiments and theory and scientific paradigms. No longer do we live in a world of superstition and magic. We live in a modern world of science and technology – without magic.

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So before Isaac Newton's grand synthesis of mechanics, there was not science – at least not as we now know it. Modern science is both method and paradigms. Newton synthesized scientific method as theory-construction-and-modeling-upon-experimental-data. And Newton created the first scientific paradigm – *Mechanism*.

Scientific Method

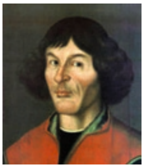
Science began in that intellectual conjunction of the research of six particular individuals: Copernicus, Brahe, Kepler, Galileo, Descartes, Newton. Why this particular set of people and their work? For the first time in history, all the component ideas of scientific method came together and operated fully as *empirically grounded theory*:

1. A scientific model that could be verified by observation (Copernicus)
2. Precise instrumental observations to verify the model (Brahe)
3. Theoretical analysis of experimental data (Kepler)
4. Scientific laws generalized from experiment (Galileo)
5. Mathematics to quantitatively express theoretical ideas (Descartes and Newton)
6. Theoretical derivation of an experimentally verifiable model (Newton)

Nicolaus Copernicus

Nicolaus Copernicus (1473–1543) was what we would now call a *theoretician*, but he thought of himself as a "natural philosopher." He proposed an idea (actually a revival of an ancient idea) that the universe should be modeled with the sun as a center and not the earth – sun-centric versus earth-centric system.

> Nicolaus Copernicus (1473–1543) was born in the city of Toruń, then in the Kingdom of Poland. Copernicus entered the Kraków Academy in 1491. Four years later he went to Italy to continue his studies, in law and in medicine at the University of Bologna and at the University of Padua. His uncle was a bishop in the Catholic Church, supported him and expected him to become a priest. While in Italy, he met an astronomer, Domenico Maria Novara da Ferrara and became his assistant for a time, making his first astronomical observations. Copernicus finished his studies at University of Padua and received a doctorate in canon law in 1503. He then returned to take a position at the Collegiate Church of the Holy Cross in Breslaw, Silesia. Just before his death 1543, he published his work, *De revolutionibus orbium coelestium*,[1]



Nicolaus Copernicus (http://en.wikipedia.org; Ncolaus Copernicus 2007)

Copernicus's model challenged an older and then widely accepted model of an earth-centered system – which had been refined by the Egyptian, Ptolemy (90–168 AD) of Alexandria. Ptolemy wrote scientific treatises, three of which were influential upon later Islamic and European thought: an astronomical treatise (Almagest), Geography, and "Four Books" astrology.

Claudius Ptolemy, by a Medieval Artist (http://en.wikipedia.org; Ptolemy 2007)

The Ptolemaic model had the Earth as center and the sun and planets circling the Earth. But it had awkward aspects – such as the planet of Venus showed an apparent retrograde motion, going forward most of the time but sometimes going backward. To account for this appearance, Ptolemy had put the planet upon a small circle upon a bigger circle around the Earth. This was to model the apparent "retrograde" motion of the planet Venus as seen from the earth. This was theoretically not elegant. It was neither simple nor direct in explanation. Copernicus argued that if all the planets were upon circles around the sun, the model became elegant – elegant in the manner of – simpler and without added complexity.

Tycho Brahe

Copernicus's work stimulated new observations by the astronomer Tycho Brahe. Brahe wanted to determine which model was correct by direct astronomical observations. Now we could call Brahe an experimental scientist (in contrast to the theoretician Copernicus).

> The importance of Brahe to Copernicus is that Brahe would use observations to ground theory – to place a theoretical model upon an empirical foundation – empirically grounded theory.

The greatly improved *precision* of Brahe's measurements over previous measurements of planetary positions enabled the breakthrough in astronomy. This precision of measurement provided data accurate enough to determine between two theoretical models of the planets which in fact was real: the Earth-centric (Ptolemy) or the Sun-centric (Copernicus) model?

In historical perspective, we can view Brahe as a great experimental scientist – because he understood that it was the precision of measurements that was the key to determining which model was correct in reality. This understanding by an experimenter as to what experimental data is critical to theory construction or validation is the mark of a great experimental scientist.

This is a key process in scientific method – precise experimental verification of a theoretical model of nature – by improved scientific instruments.

Tycho Brahe (1546–1601) was born in Denmark. His father was a nobleman. His uncle raised him, and in 1559, he went to the University of Copenhagen to study law. He turned his attention to astronomy after a predicted eclipse in 1560. Over the course of his life, he built several observatories, and constructed measuring instruments larger and much more precise than previous instruments. These were astrolabes, ten times larger than previous astrolabes. His measurements the planetary motion of Venus, Mars, and Jupiter were an order of magnitude more exact than older measurements of planetary motion.[2]

Tycho Brahe (http://en.wikipedia.org; Tycho Brahe 2007) Astrolabe

Johannes Kepler

Brahe made many, many astronomical measurements and, in 1600, hired a mathematician, Johannes Kepler, to analyze all the data. To analyze means to abstract the underlying form of the data and to generalize the form, so that data from additional new observations would fit that form. Analysis of data is the connection of observation to theory.

Kepler moved his family from Austria to Poland and began working for Brahe. But Brahe died unexpectedly on October 24, 1601. Brahe had been the imperial mathematician to the court of Emperor Rudolph II; and Kepler was appointed as Brahe's successor. Kepler continued working on analyzing Brahe's measurements. By late 1602, Kepler found a law that nicely fit the planetary data – planets sweep out equal areas of their orbits in equal times. Here was a law of nature (the mind of God in Kepler's view). It was a phenomenological law – a law of nature which nature follows – and also a quantitative law!

Kepler understood that this law was a property of elliptical orbits. Copernicus's model had used circular orbits. But Kepler saw that, in reality, planets followed elliptical orbits. By the end of the year, Kepler completed a new manuscript, *Astronomia nova*, describing the elliptical orbits. But this was not published until 1609 due to legal disputes with Brahe's heirs over ownership of Brahe's data. (This was an early dispute over what today we would call "intellectual property").

This quantitative formulation of a law-of-nature was a major step toward scientific method.

Scientific method consisted not merely of qualitative observations of nature, but also of quantitative measurements and quantitative laws depicting the underlying form of the measurements – physical laws of a natural phenomenon.

Phenomenological laws are regular patterns of relationship observed as occurring in phenomenon of nature.

Johannes Kepler (1571–1630) was born in Germany. In 1589 he entered the University of Tubingen as a theology student but was soon to excel in mathematics. His love of astronomy was long standing, and he cast horoscopes as an astrologer. Learning of the Ptolemaic model and the Copernican model, he liked the Copernican model. Kepler than took a position as a teacher of mathematics and astronomy at a Protestant school in Graz, Austria (which later was to become the University of Graz). Kepler published his first astronomical work in 1595, Mysterium Cosographicum, in which he defended the Copernican system. He was at the time interested in geometric forms (polygons) which might be used to fit the astronomical data. But his intellectual breakthrough was not to occur until he gained access to Brahe's data. Kepler could not have created his theory of planetary orbits as ellipses without the extreme precision of Brahe's measurements.[3]

Johannes Kepler (http://en.wikipedia.org; Johannes Kepler 2007)

Galileo Galilei

Just before Kepler's publication of Astronomia nova, the telescope was invented in 1608 in the Netherlands. Learning of this invention, Galileo Galilei in Italy made a telescope that same year with three power magnification. He used it to observe the moon and planets. He was the first to observe the moons of Jupiter, a large planet with four moons circling it. This was a clear analogy to Copernicus's solar model, with the sun the center of planetary orbits – as was Jupiter the center of its moons' orbits. Galileo published his first astronomical observations in March 1610 as Sidereus Nuncius. The double impact of Kepler's elliptical orbits and Galileo's moons-of-Jupiter established for the astronomical community then the realistic superiority of the Copernican model. The Ptolemaic model went into the dustbin of intellectual history.

Galileo went on to establish the first scientific laws of physics. He performed experiments about motion and gravity and inferred new physical theory based upon experimental results. He pioneered the scientific method of doing quantitative experiments whose results could be generalized in mathematical expression. After Kepler's mathematical analysis of Brahe's measurements, Galileo's physical laws provide a second historical example of modern scientific method.

Galileo Galilei (1564–1642) was born in Pisa Italy. He entered the University of Pisa to study medicine, but instead studied mathematics. In 1589 he was appointed to the chair of mathematics in Pisa. In 1592, he moved to the University of Padua, where he taught geometry, mechanics and astronomy. Here he made significant progress in the physics of motion. After Galileo published his account of the moons-of-Jupiter in 1610, he went to Rome to demonstrate his telescope and advocate the Copernican solar model. He was then admitted to a prestigious academy in Rome, Accademia dei Lincei.

But in 1612, some Catholic priests opposed the idea of a sun-centered universe. In 1614 he was denounced by Father Tommaso Caccini (1574–1648) as a heretic. Galileo was called back to Rome from Padua to defend himself. In 1616, Cardinal Roberto Bellarmino ordered him not to teach Copernican astronomy. But he was free to return to Florence.

Later in 1632, Galileo published a book which compared the two views of the universe, *Dialogue Concerning the Two Chief World Systems*, making the holders of the earth-centric model to appear as fools. This offended the Pope in Rome, who thought Galileo was making fun of him. In October of that year, Galileo was ordered to appear before the Holy Office in Rome. There he stood trial for heresy. As a judgment, he was required to recant his belief in the Copernican solar model, and he was ordered to be imprisoned. This was commuted to house arrest, and he was allowed to return to his house near Florence.

For the remaining 16 years of his life, Galileo remained under house arrest. Fortunately, he used his time to write what would become his most famous book, *Two New Sciences*. This book would establish the laws of physical motion. It was the work upon which later Isaac Newton would build his revolutionizing physical theory. Galileo died in 1642.[4]

Galileo Galilei (http://en.wikipedia.org; Galileo Galilei 2007)

Cristiano Banti's 1857 painting Galileo facing the Roman Inquisition

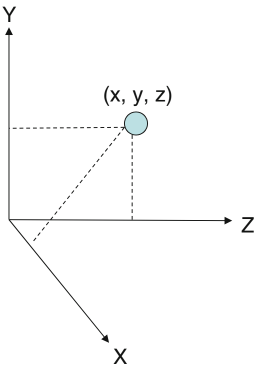
Scientific method was exemplified in Galileo's approach – physical experiments on observable objects, measurements of relationships, analysis of measurements, formulation of theory as phenomenological laws of relationship between objects.

Rene Descartes

The next step in the emergence of the scientific method was to improve the language of quantitative analysis – the invention of analytical geometry and of calculus and their application to the expression of physical theory. And this was due principally to Descartes and Newton. Rene Descartes was a contemporary of Galileo and made a very major contribution to advancing mathematics. He conceived of analytical geometry – adding algebraic expressions to the classical geometry of Euclid. As shown in Fig. 2.1, Descartes proposed to describe a space with basis vectors, X, Y, Z, so that every vector was at right angles to each other. Then any point in the space could be described by three numbers (x, y, z) as projections onto these vectors.

What Newton would add is another time dimension t. Motion of a particle in that space could then be described as the succession of points occupied by that particle as time t elapsed. At time t_1, the particle would be at position (x,y,z_1,t_1) and then proceed to position (x,y,z_2,t_2) at time t_2 and so on. This analytical geometry would provide the critical mathematical representational basis for physics and for Newton's calculus. Without analytical geometry and calculus, modern physics would not have been possible.

Fig. 2.1 Three-dimensional geometric space



Renes Descartes (1596–1765) was born in France in 1596, and as a young man attended the University of Poitiers, graduating in 1616 with a Baccalureat and License in law. He did not practice law and entered court service in the Netherlands. There he met Isaac Beeckman who interested him in mathematics. In 1619, he was traveling in Germany and thinking about using mathematics to solve problems in physics. He had the idea to combine Euclidian geometry with algebra and created a new mathematical topic, "analytical geometry." This allowed the representation of space as a three-dimensional coordinate system, with any point in the space describable as projected distances along each Cartesian coordinate.[5]

Rene Descartes (http://en.wikipedia.org; Rene Descartes 2007)

As a historical footnote, Euclidean geometry derives from Euclid's "Elements." Euclid was a Greek philosopher of Alexandria living around 300 BCE. Algebra derives from Muhammad ibn Musa al-Khwarizmi (780–850). He was a Persian mathematician, who wrote on the systematic solution of linear and quadratic equations and is considered to be the "father" of algebra. His book, *On the Calculation with Hindu Numerals*, was translated into Latin in the twelfth century as *Algoritmi de numero Indorum*. The English word "algebra" is derived from the Arabic "al-jabr," one of the operations to solve quadratic equations. The English word "algorithm" derives from "algoritmi," the Latinization of al-Khwarizmi's name.

Euclid of Alexandria (http://en.wikipedia.org, of Alexandra, 2007)

Muhammad ibn Musa al-Khwarizmi (http://en.wikipedia.org, Muhammad ibn Musa al-Khwarizmi 2007)

Isaac Newton

Descartes' combination of geometry and algebra enabled a quantitative description of space. This spatial description was essential to describe position and motion of particles in space. This would allow Newton to combine Galilean physics with that Cartesian geometry (as Descartes work is now called) and also with Kepler's astronomical ellipses to create a dynamic model of the solar universe. After all that time – from Plato and Aristotle – down through Augustine and Bacon – and down through Copernicus, Brahe, Kepler, Galileo, and Descartes – then finally the stage of history was set for Newton and his grand scientific synthesis of mechanism.

Isaac Newton (1643–1727) was born in England. He entered Cambridge University at the age of 19. He was engaged to Anne Storey. But she married someone else, and Newton never married. At Trinity College in Cambridge, most of the teachings were still those of Aristotle. But Newton read Descartes and Galileo and Copernicus and Kepler[6]

In 1665, he began to think about infinitesimal quantities and changes in velocities, and how to calculate with them in Cartesian space. This was the beginning of his development of calculus. In 1665, he obtained his degree. But then Cambridge University closed because of a Great Plague in England (which killed about one fifth of London's population, perhaps a bubonic plague). Newton went home and for the next year and a half worked on calculus and gravitation. Newton did not publish his calculus until 1693. But by then an independent invention of calculus had been made by Leibnitz which he published in 1684. Newton had approached calculus as differentials (which he called fluxions). Leibnitz had approached calculus as integration. (Of course, both differentiation and integration are essential to calculus.)

From 1670 to 1672, Newton lectured on optics. He thought light was be composed of particles (but had to also associate light as waves to explain diffraction of light). In 1675, Newton suggested that ether might exist to transmit forces between particles. Then in 1679, Newton returned to his work on mechanics. In 1687, Newton published *Philosophiae Naturalis Pricipia Mathematica.* This is the principle work which established physics on a quantitative basis (and now called the Newtonian Mechanics). It contained the three universal laws of motion:

1. Law of Inertia – The motion of a body is constant unless acted upon by an external force.
2. Law of Force – The effect of an external force upon a body is to change its acceleration, proportional to the body's mass: $F = ma = m\, \mathrm{d}v/\mathrm{d}t$.
3. Law of Action–Reaction – For every action (force) upon a body, there is an equal and opposite reaction (reactive force).

In Newton's calculus, the equation of force and motion ($F = m\, \mathrm{d}v/\mathrm{d}t$) is now called ‘a "differential equation" – an equation containing differentials of calculus in the mathematical expression. Now there are standard ways in calculus to solve many differential equations – that is to find the kinds of algebraic solutions that fit a differential equation. Newton would not only pose the first differential equation but also solved it. The modern mathematical topic of calculus consists of Newton's formulation of differentials and of differential equations and the solution of a differential equation.

The next issue to Newton for his new physics was the quantitative expression for gravitational force, as diminishing according to the inverse square of distance. Newton then formulated the gravitation force (1) as proportional to the product of the masses attracted by the force of gravity between them and (2) decreasing in force as the square of the distance: $F_g = gMm/r^2$ (where g is the gravitational constant as 32 ft/s/s and M and m are the quantities of the two masses which are attracted by gravity).

Newton set his differential force equation ($F = ma$) equal to the gravitational force to obtain a differential equation of motion for planets around the sun: $m\,\mathrm{d}v/\mathrm{d}t = gMm/r^2$. Newton solved this differential equation (using his new mathematical methods of calculus) to find that the solutions to this equation are (in analytical geometry form) the quantitative formulae which describe either an ellipse or a parabola (Fig. 2.2).

And thus was represented the solar system explained by a mechanics of universal gravitation. Using Galileo's physics, Newton's quantitative model derived Copernicus's solar model which fit with Brahe's astronomical measurements and Kepler's elliptical planetary orbital laws. These ideas all come together in the differential equation of motion of planets orbiting the sun bound by gravity!

> This is scientific theory! It was created by the methods of science – observation and measurement, analysis, theory construction and prediction. It was then that discipline of modern physics began!

Isaac Newton (http://en.wikipedia.org; Isaac Newton 2007)

In historical perspective, the origin of science can be seen as a kind of systems problem – (a) getting all the pieces of the system together in one era and (b) getting all those pieces to be coordinated and integrated. This is what Newton did. He put it all together and created the theoretical paradigm of Newtonian mechanics. After

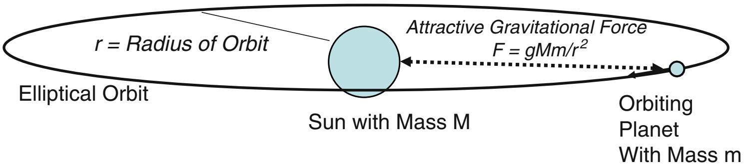


Fig. 2.2 Copernican solar system planetary model

Newton's synthesis of mechanics, there arose, in the 1700s, the modern scientific disciplines of physics and chemistry and mathematics.

As footnote in science history, there was a disputed claim about who first discovered the quantitative law of gravity, Hooke or Newton? This created bitterness between the two contemporaries. Thomas Hooke (1635–1703) experimentally demonstrated it had the quantitative form of diminishing with the square of the distance. Apparently independently, Newton also had formulated the law of gravity as diminishing by the square of the distance. However, Hooke insisted upon acknowledgement by Newton that Hooke had first discovered the law. Newton refused since he believed he had not learned it from Hooke. This was particularly bitter to Hooke since he never received fame equal to Newton. Newton wrote that he independently discovered the square of the distance form of gravity from (1) reconsidering Kepler's previous work (Kepler's third law having the wrong proportion for diminution of gravity with distance), and (2) obtaining information from Flamsteed and Halley about the length of orbits of Jupiter and Saturn, Newton then concluded that the gravitational force between two massive objects diminished as the square of the distance between them increased.

> In the organization of science, scientific credit and prestige goes to the person first to discover or explain a natural phenomenon.

Scientific Method as Empirically Grounded Theory

The development of the disciplines of science, physics, chemistry, and biology did begin after Newton's synthesis of mechanical theory. After Newton published his seminal work in 1686, the next two centuries (the eighteenth and nineteenth centuries) saw the development of the disciplines of classical physics and chemistry and mathematics and biology. Further major theoretical developments continued to occur in physics and chemistry and biology in the twentieth century. Science is still progressing. Notably in the twentieth century and in addition to great continuing progress in the physical and life sciences occurred the founding of social sciences and computer science. And in all this progress in science, the process by means of which scientific knowledge has been obtained is now called the "scientific method." The heart of scientific method is the grounding theory construction based upon experimental data (Fig. 2.3). This means to base theory on experimental facts – construction and validation of theory upon empirical results. This distinctive approach of science can be called "empirically grounded theory."

The critical component parts of scientific method are:

1. Observation and experimentation
2. Instrumentation and instrumental techniques
3. Theoretical analysis and model building
4. Theory construction and validation
5. Paradigm development and integration.

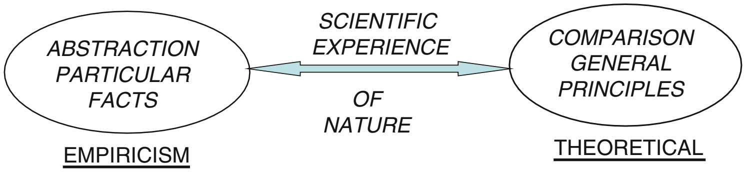


Fig. 2.3 Empirically grounded theory

Together these five techniques define the scientific method. All these components must be present and integrated. This is what happened first in the seventeenth century in Europe – when all the pieces of scientific method came together:

1. Copernicus (a theoretician) proposed a theoretical model which could be experimentally tested against another model of Ptolemy (an ancient theoretician).
2. But existing astronomical measurements of annual planetary motions were not accurate enough to determine which model more exactly fit the data, and Brahe (an experimentalist) constructed larger astronomical measuring instruments to obtain more accurate data.
3. Brahe hired Kepler (a mathematician) to analyze his measurements to determine if they fit a Copernican model; and Kepler found that an analytical pattern of elliptical planetary orbits did exactly fit the data.
4. Galileo (an experimentalist and theoretician) experimented with motion of physical bodies and induced three laws of motion (theories) giving mechanical behavior.
5. Descartes (a mathematician) invented new mathematics, analytical geometry, to extend Euclidian geometry.
6. Newton (a mathematician and theoretician and experimenter) invented differential calculus to extend analytical geometry to apply this to the description of spatial motion and also discovered the quantitative form of the gravitation force and applied all this to derive the Copernican solar model in the physical framework of Galileo's laws of motion.
7. After Newton's grand synthesis of mechanical theory, the new scientific disciplines of physics and chemistry were begun, describing material behavior in the new Newtonian mechanics.

> Central to the scientific method is the construction of theory of nature based upon and validated upon experimental observations of nature.
>
> Knowledge which is not "empirically grounded theory" is not scientific.
>
> One calls the research approach of experiments-on-nature as an "empirical approach" in scientific research – empiricism.
>
> One calls the research approach of theory-construction about nature a "theoretical approach" in scientific research – theoretical.

Vienna Circle's Logical Positivism

However, not all philosophers of science have recognized this full complexity – about how scientific theory is constructed in the practice of science. An example in the early twentieth century was the school of philosophy of science called "logical positivism." They had two positions: (1) that all objects in science must be observable and (2) scientific theory is merely logically induced from experiment. Their first position corresponds with actual historical events in science, but the second does not. Let us briefly review this school because it is still mentioned in books about research methodology.

In Vienna in 1907, Philipp Frank and Hans Hahn and Otto Neurath began holding meetings in Vienna coffee shops about the philosophy of science – hence the name for the group became "Wiener Kreis" – Vienna Circle. Frank was a theoretical physicist in classical physics (Newton's mechanics and Maxwell's electromagnetism). Hahn was a mathematician. Neurath had studied sociology, economics, and philosophy. These meetings evolved into a philosophical school called "logical positivism." Morris Schlick joined the meetings and organized the group into the Ernst Mach Society. Many others joined the group, including: Gustav Bergmann, Rudolf Carnap, Herbert Feigl, Kurt Fodel, Tscha Hung, Victor Draft, Karl Menger, Richard von Mises, Marcel, Natkin, Theodor Rdakovi, Rose Rand, Moritz Schlick, and Friedrich Waismann. Also Wittgenstein and Karl Popper would attend later meetings.[7]

Central to the philosophy of the group were two philosophical positions: (1) experience is the only source of knowledge and (2) logical analysis is the way to solve philosophical problems. The first position was an opposition to any traditional philosophy that held there was an additional reality, metaphysical reality, behind the reality of the physical world. The Vienna Circle attacked metaphysics as any source of knowledge. The Vienna circle philosophically attracted logicians – particularly influenced then by the work of Russell and Whitehead on the logical foundations of mathematics.

Ernest Mach (1838–1916) was born in Chirlitz (now part of the Czech Republic). In 1860, he obtained a doctorate in physics from the University of Vienna. In 1867, he became a professor of Experimental Physics at the Charles-Ferdinand University in Prague. Mach photographed and described shock-waves in air. Mach also advocated a philosophy of phenomenalism, recognizing sensations as the ground of reality.

(http://en.wikipedia.org; Ernest Mach 2009)

In 1929, Hans Hahn and Otto Neurath, and Rudolf Carnap wrote a "manifesto" for the Ernst Mach Society, *The Scientific Conception of the World: The Vienna Circle*. Their central theme was to abolish any metaphysics as a contender to physics for the source of reality. They wrote: "No room remains for a priori synthetic judgments. That knowledge-of-the-world is possible rests, but upon the principle of a material being ordered in a certain, natural way – and not on human reason impressing any form on the material. The kind and degree of this order cannot be known beforehand. . . Only step by step can the advancing research of empirical science teach us in what degree the world is regular. The method of induction, the inference from yesterday to tomorrow, from here to there, is of course only valid if regularity exists. . . However, epistemological reflection demands that an inductive inference should be given significance only insofar as it can be tested empirically." Hahn, Neurath, Carnap, 1929. "The Scientific Conception of the World: The Vienna Circle" (http://gnadav.googlepages.com/TheScientificConceptonoftheWorldeng.doc).

One sees in this manifesto, the three central assumptions of the logical positivism:

1. Experiment is the foundation (base, ground) of knowledge.
2. Regularity in the world (logical order) must be discovered and not presupposed philosophically (metaphysically).
3. Theory is constructed directly by induction from experiment.

Rudolf Carnap later wrote: "I will call metaphysical all those propositions which claim to represent knowledge about something which is over or beyond all experience, e.g., about the real Essence of things, about Things in themselves, the Absolute, and such like… (Traditional metaphysics) pretended to teach knowledge which is of a higher level than empirical science. Thus they were compelled to cut all connection between their (metaphysical) propositions and experience; and precisely by this procedure they derived them of any sense" (Carnap, Rudolf. 1935. Philosophy and Logical Syntax). (http://www.philosophy.ru/edu/ref/sci/carnap.html, 2009)

And because of that emphasis on induction-as-scientific-method, the Vienna Circle emphasized the role of logical analysis in philosophy. If the traditional role of metaphysics was excluded from modern philosophy (replaced by scientific method), then what was left for the modern role of philosophy? The logicians in the school, such as Rudolf Carnap, agreed that modern philosophy should become "logical analysis." Carnap wrote: "The function of logical analysis is to analyze all knowledge, all assertions of science and of everyday life, in order to make clear the sense of each such assertion and the connections between them. One of the principal tasks of the logical analysis of a given proposition is to find out the method of verification for that proposition" (Carnap 1934) and (http://www.philosophy.ru/edu/ref/sci/carnap.html, 2009).

The Vienna Circle (1) emphasized experience as the source of knowledge but (2) supposed that inductive inference is the way theory is constructed. Moreover, this latter methodological assumption – of simply inducing theory – led to an overly simple view of scientific method: (1) formulating a hypothesis (theory) and (2) then validating or invalidating that hypothesis by an experiment. However, these are two separate assumptions. Given the first assumption (that experience is the source of knowledge), the second assumption (about scientific method as simply inductive inference) need not necessarily follow.

> The philosophical position we have taken in this book is to agree with the proposition that all science is based upon experience.
>
> But philosophically we disagree that theory construction is simply and necessarily made only by simple induction from experiment.
>
> Instead, one finds in historical cases of scientific progress a circularity in logic (induction and deduction) between theory construction and experiment.

Rudolf Carnap (1891–1970) was born in Wuppertal, Germany and attended the University of Jena but had to serve in the German Army for 3 years. In 1917–1918, he enrolled in the University of Berlin (where Albert Einstein had just been appointed as a professor of physics). But then Carnap returned to finish at the University of Jena. He wrote a thesis on an axiomatic approach to space and time, which the physics department said was too philosophical and the philosophy department said was pure physics. Carnap then wrote another thesis on space and time, but taking a traditional Kantian approach on this as transcendental aesthetics, which was published in 1922 in the German philosophy journal of Kant Sudien. In 1926, Carnap was introduced to Moritz Schlick, who offered Carnap an appointment as a professor in the University of Vienna. In 1931, Carnap moved to the University of Prague as a full professor of the German language. He wrote his book there of *Logical Syntax of Language* (Carnap 1934). After the Nazi government began in Germany in 1933, Carnap foresaw the future and emigrated to the United States in 1935. (That next year in 1936, Moritz Schlick was murdered in Vienna.) From 1936 to 1953, Carnap taught at the University of Chicago and then moved to the philosophy department of University of California at Los Angles in 1954 (http://en.wikipedia.org; Rudolf Carnap 2009).

Moritz Schlick (1882–1936) was born in Berlin and studied physics at Universities of Heidelberg, Lausanne, and Berlin. In 1904, he wrote his physics dissertation under Max Planck. But he changed from physics to logic and wrote his habilitation essay in 1910 on “The Nature of Truth According to Modern Logic.” In 1915, he published a philosophy/physics paper about Einstein’s special theory of relatively. In 1922, Schlick obtained an appointment as a professor of inductive sciences at the University of Vienna. Schlick joined the Vienna group meetings and organized regular meetings as the Ernest Mach Society. With the rise of Nazism in Germany, many members of the Vienna Circle began emigrating. On June 22, 1936, Schlick was shot and killed by a former student, who thought him a Jew. The student was tried and sentenced and then paroled – as a cause celebre for the anti-Semites in Vienna (but Schlick was not Jewish). The student became a member of the Austrian Nazi Party after the “Anschuss,” in which the Germany Army marched into Austria.

(http://en.wikipedia.org; Mortiz Schlick 2009)

Hans Hahn (1879–1934) was born in Austria. He attended the Technische Hochschule in Vienna and then studied mathematics in Universities in Strasbourg, Munich and Göttingen. He wrote mathematical papers in functional analysis, topology, set theory, the calculus of variations, real analysis, and order theory. In 1905, he obtained a teaching appointment to the University of Vienna and became a professor of mathematics in 1921 (http://en.wikipedia.org; Hans Hahn 2009).

Otto Neurath (1882–1945) was born in Vienna. He entered the University of Vienna and obtained a doctorate from the Department of Political Science and Statistics. He taught political economy at the New College of Commerce in Vienna. After World War I, Neurath directed museums (institutes) for housing and city planning. In the 1920s, he joined the Vienna Circle and was an author of its manifesto. In 1937, Hitler's Germany annexed Austria, and he fled to Holland and then to England, dying there of illness in 1945.

Otto Neurath (http://en.wikipedia.org; Otto Neurath 2009)

As a footnote for those familiar with the Vienna Circle, I have not made use of Wittgenstein's association with the group. While he was valued by members of the group for his attacks on metaphysics, he made no significant contribution to the understanding of scientific method. For example, Rudolf Carnap commented on Wittgenstein: "I, as well as my friends in the Vienna Circle, owe much to Wittgenstein, especially as to the analysis of metaphysics. But on the point just mentioned ("Whereof one cannot speak, thereof one must be silent.") I cannot agree with him. In the first place he seems to me to be inconsistent in what he does. He tells us that one cannot state philosophical propositions, and wereof one cannot speak, therefore one must be silent; and then instead of keeping silent, he writes a whole philosophical book. Secondly, I do not agree with his statement that all his propositions are quite as much without sense as metaphysical propositions are. My opinion is that a great number of his propositions (unfortunately not all of them) have in fact sense; and that is the same is true for all propositions of logical analysis" (Carnap 1934).

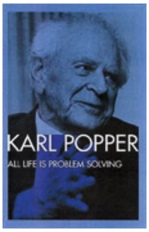
Also in the present epoch of methodology, what significantly was been passed along from the Vienna School as scientific method was a technique of hypothesis testing urged by a late-comer to the school, Karl Popper. Popper focused upon the emphasis in logical positivism was of the role of "induction" in theory construction. In 1928, Popper joined the logical positivists' movement in Vienna and formulated his idea that scientific theory could not be verified but only falsified.

> Popper argued that if theory is only induced from experiment, then theory can never be completely validated – never be certainly true.

Logically, it is correct to say that a theory constructed only inductively and directly from observation can never be absolutely true – only probably true. The reason for this is that the validity of directly induced theory depends logically always only upon the last instance of observation. There is no methodological guarantee that a future observation may not occur which contradicts the theory. No finite number of experiments can ever provide methodological certainty in a purely inductive method – only a probability of its truth. For this logical reason, Popper assumed that scientific theory could never be verified but only falsified – *because Popper believed all scientific theory is only constructed inductively.* Accordingly, Karl Popper proposed a simple methodology for science which consists only of formulating a hypothesis and testing the hypothesis for falsification. However the methodological issue is – from whence is a good hypothesis formulated?

> While hypothesis-testing is a useful research technique, it is also important to establish why and how and where-from a good research hypothesis is formulated.

Karl Popper (1902–1994) was born in Vienna; and in 1928, he earned a doctorate in philosophy at the University of Vienna. In 1934, he published, *The Logic of Scientific Discovery*. He was forced to leave Austria after Hitler's takeover of the country in 1937, when he migrated to New Zealand. After the Second World War, Popper obtained a professorship at the London School of Economics, where he remained until he retired.[8]



(http://en.wikipedia.org, Karl Popper 2009)

Illustration: Inference in Newton's Gravitational Solar Model

How does Popper's prescription for scientific method as a simple kind of "hypothesis-testing" stand up in historical comparison of how science has really progressed? Not so validly.

For example in Popper's view – if the theory of the solar system had merely been inferred inductively from watching the sun rise repeatedly, what is the proof that it will always so arise? The sun's always rising is only a probable inference – a likelihood – but not a certainty. However, suppose that instead of merely an inductively inferred hypothesis of the sun always rising in the morning, one also has Newton's quantitative gravitational model of the solar system. Newton's theory predicts this as an orbiting Earth – and with great precision and certainty. The reason in the "certainty" of the scientific theory lies in the verified solar model – *in the elliptical orbits which are solutions to the gravitational-force model.* In elliptical orbits, the earth always circles the sun (while spinning). Unless new force disturbs the earth's orbit and spin, such as an asteroid hit, then the earth will continue to circle and spin mostly as it has.

Let us briefly review the idea of "inference" in logic – inductive inference and deductive inference. Historically, the idea of "logic" originated as a formal structure of a language, the "grammar" of the language. Grammar consists of the forms of sentences constructed from terms (nouns) and relations (verbs) and their order in a sentence. The order of a sentence is to assert something about a subject – a propositional phrase ascribed to the subject. Sentence order specifies the order of terms and relations into a meaningful predication of a subject. Sentences also have different modalities: declarative, inquisitive, and imperative. The logic of sentence-structure-and-order provides a given language its grammar (sentential form).

Also we need to remind ourselves that reasoning is an operation of the mind that both constructs and relates mental objects, concepts. Linguistic reasoning operates with language. Language not only provides modes of expressing experience in sentences but also as *connections between experiences* as *inferences*.

> Inference is the form of reasoning about things as linguistic objects – relating ideas.

Inference is a proper form for making valid arguments from premises. Philosophically, there are two directions for inference:

1. Inductive reasoning – in which statements of particular facts are generalized into general ideas about the facts,
2. Deductive reasoning – in which particular statements of facts are deduced from general statements of theory.

Thus inference may proceed either from particular statements to general statements (induction) or vice versa (deduction). For example, in the classical dialogs of Plato about his teacher, Socrates, Plato emphasized logic's importance of probing at the assumptions of an intellectual position. This is the so-called Socratic method of questioning a person about assumptions. The direction of the inference lies in going from the conclusions to the assumptions of the argument – inductive inference.

In contrast, Aristotle's syllogism inference was deductive, going from general premises to particular instances. The famous example of a syllogism often repeated in philosophy courses is: all humans are mortal, and Socrates is a human, and therefore Socrates is mortal. (And which certainly was a correct inference – since historically Socrates was forced by his Athenian community to drink the lethal hemlock).

Let us now look at the construction of Newtonian theory of mechanics from this perspective of logical analysis – induction and deduction. Testing out the logical positivists' ideas about philosophy in empirical cases of the history of science – is in a form of "keeping with the scientific spirit." Certainly, philosophical theories about scientific method should be empirically grounded in the progress of science – as are all other scientific theories so grounded. This is only logically self-consistent. And in

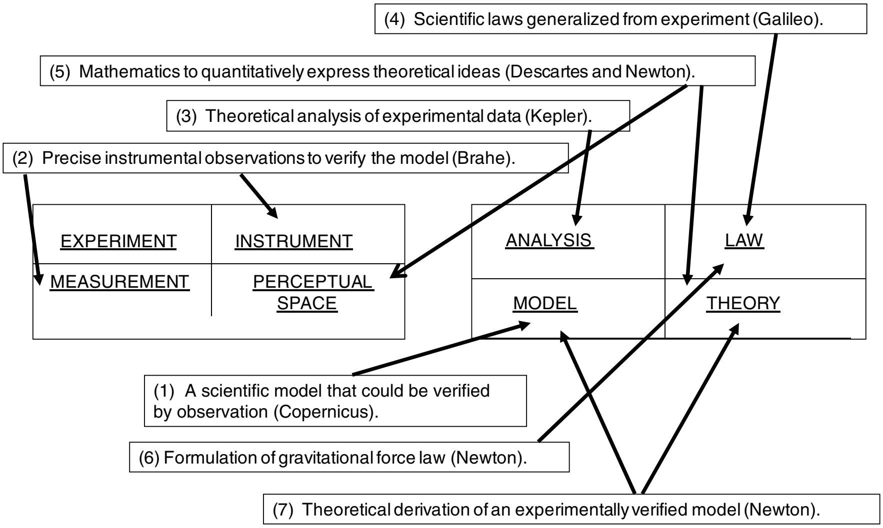


Fig. 2.4 Empirically grounded theory for Copernican model

this spirit, we saw that Newton did not directly induce his mechanical theory directly from Brahe's measurements of planetary motions (Fig. 2.4).

1. Copernicus provided a scientific model that could be verified by observation – *deductive logical approach.*
2. Brahe developed instruments and made more precise measurements to verify the model – *inductive logical approach.*
3. Kepler made a theoretical analysis of experimental data, developing a phenomenological law about planetary motion – *inductive logical approach.*
4. Galileo performed physical experiments and formulated scientific laws generalized from the experiments – *inductive logical approach.*
5. Descartes integrated geometry and algebra and Newton created differential calculus to provide new mathematics for describing and modeling physical events – *deductive logical approaches.*
6. Newton formulated a phenomenological law of gravitation as a force varying inversely with the square of the distance – *inductive logical approach.*
7. Newton theoretically derived Copernicus's solar model as a consequence of his newly formulated mechanics – *deductive logical approaches*.

In Fig. 2.5, we sketch the views of the different participants in construction of the scientific theory of the solar system.

Copernicus imagined that if earth circled the sun, then the calculations for an astronomical almanac could be simplified from a theory that the sun circled the earth. Copernicus proposed a *theory* of a sun-centric planetary system – deductive inference. Brahe decided to put Copernicus's theory to an empirical test by improving

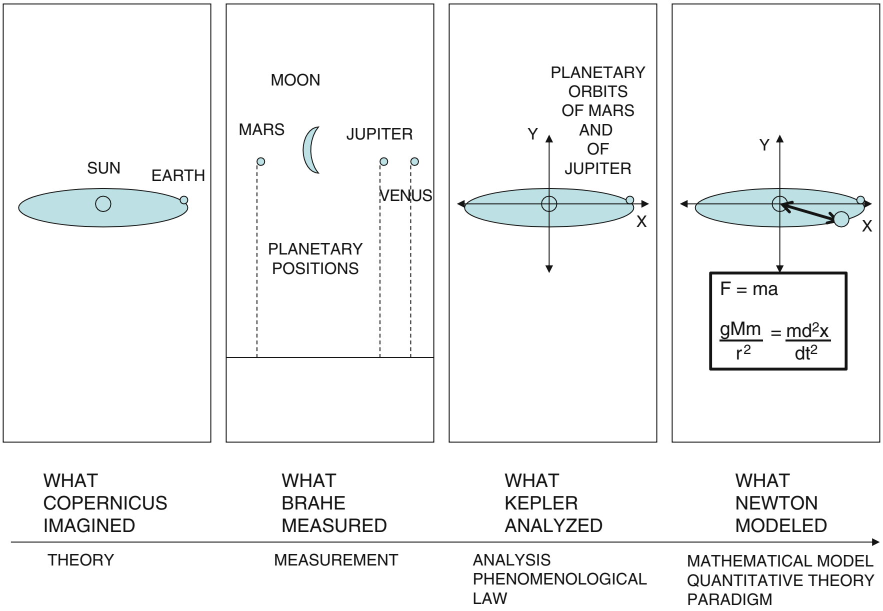


Fig. 2.5 Measurement and theory of solar system

upon the astronomical measurements of the appearance of the planets, Mars, Jupiter, Venus, throughout the year, *measuring* their planetary positions – inductive inference. Brahe hired Kepler to try to fit these planetary data to circular orbits around the Sun. The data didn't fit a circular orbit but did fit an elliptical orbit. Kepler *analyzed* the data, proposing a *phenomenological law* (Kepler's law) about planetary motion – inductive inference. Newton developed new mathematics (differential calculus) – deductive inference. Newton also proposed a *theoretical law* for gravitation (varying as the inverse square of the distance) – inductive inference. Newton *modeled* the solar system and created a *theory* of mechanics (Newtonian mechanics) – deductive inferences.

Circularity Between Empircism and Theory in Scientific Method

In the historical example of Newton's model of the solar system, we saw the empirical research technique of measurement; and this was combined with the theoretical techniques of analysis, modeling, and theory to create this dramatic progress in physical science – combinations of both inductive and deductive inferences. Most historical instances of progress in scientific theory have shown the use of both induction and deduction in the construction of theory based upon experiments. In temporal sequence, Copernicus proposed a theoretical structure for the geometry, and Brahe improved the measurement of planetary motions, and Kepler analyzed the measurements to find a pattern of elliptical orbits, and Newton quantitatively modeled Copernicus's theory in a new theoretical kinematical and dynamical physical theory (Fig. 2.4).

This is why research methodology is complicated. It is because the process of scientific inquiry is not linear in logic, going directly either from empiricism-to-theory nor theory-to-empiricism. Instead in the history of science, scientific progress has proceeded circularly in the logic of empiricism and theory – going around and around. Empiricism and induction in the logic of scientific inquiry really operate by circularly interacting with deductive theory construction. Yet even in a circular interaction between experiment and theory, a basic premise of the logic of scientific inquiry is that nature be observable. Or conversely, science only studies what is observable in nature. Empiricism in science is grounded in observing nature. Theory is grounded in the empirical observations of nature.

> Deductions from empirically grounded theory are logically certain (even if expressed as a probabilistic equation and not as a deterministic equation).
>
> Empirically grounded theory can be verified by predictions for future experiments –verifiable and not merely falsifiable.
>
> Empirically grounded theory is constructed not simply by induction but by a circularity of induction and deduction – in experiment and theory and prediction.

Yet due to the influence of the logical positivist's, much of subsequent philosophy of science taught in the twentieth century for the social sciences (but not for the physical or life sciences) became that of a simple methodological idea – theory construction consists of only a "hypothesis testing" as a research technique. This view of science was widely shared and many empirical studies in the social sciences followed the format of (1) formulating a hypothesis, (2) conducting an experimental sample, and (3) statistically analyzing the probability of the truth or falsity of the hypothesis.

A methodological weakness of the simple Popperian-research-approach occurs when researchers do not address the issue of from where or how should hypotheses come – which hypotheses are worth the effort of testing for falsification? In contrast to Popper's assumption about only being able to falsify scientific theory, the historical evidence in science is different. Most often in scientific history, it has been a scientific model rather than a hypothesis which has provided the basis for scientific verification. Newton's quantitative model of the Copernican solar system was one important

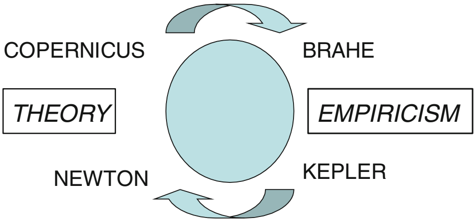


Fig. 2.6 Circularity in historical interactions between research techniques

example. Watson and Crick's model of DNA is another example (which we later review). Generally speaking, a hypothesis which is not derived from a scientific model of a phenomenon has often been insignificant.

> A significant scientific hypothesis worth testing experimentally should be derived from a scientific model.
>
> For empirical scientific research, modeling is more likely a fruitful research activity for researchers than merely hypothesis-making-and-testing. What we will do in this book is learn how to manage this circularity in scientific method (between induction and deduction) through the interactions between experiment and analysis and modeling and theory.

Summary

1. Science began when the scientific method of inquiry was established as the systematic way of understanding nature – basing theory construction and validation upon experimental data.
2. Empirical and Theoretical techniques in scientific method enable the construction of empirically grounded theories of nature.

Notes

[1] There are many books and biographies about Copernicus, such as Bienkowska (1973).
[2] An interesting account on the relationship of Brahe to Keler is Ferguson (2002).
[3] There are many books and biographies about Kepler, such as Dreyer (2004) and Stevenson (1987).
[4] There are many biographies of Galileo, such as Langford (1998).
[5] There are many biographies of Des Cartes, such as Keeling (1968).
[6] There are many books and biographies on Newton, such as Tiner (1975).
[7] There are many books about the Vienna Circle, such as Kraft (1953) and Sakar (1996).
[8] Popper's principle methodological book is Popper (1934).

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