# Part 2

# *Origin of Scientific Method*

# Origin of Scientific Method

# The world around us

e.g. Alchemy was a precursor to the modern scientific discipline of chemistry.

In medieval Europe, the fundamental stuff of the universe viewed as air, earth, fire, water – alchemy.

Now, in modern Europe, the fundamental stuff of the universe is energy and mass, atoms and molecules, fields and particles – chemistry and physics.

# Evolution of mathematics

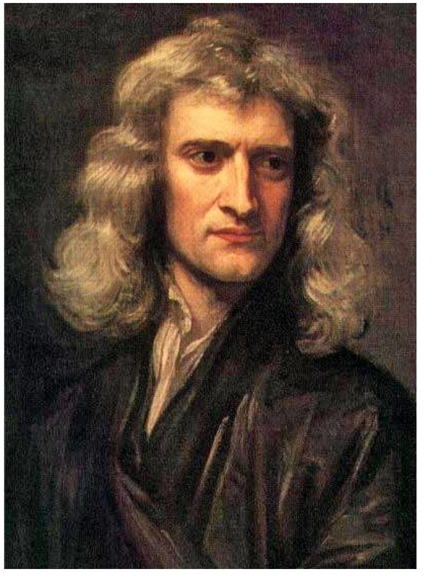
Modern science of mathematics has important historical roots in Egyptian, Greek and Arab geometry and algebra. But algebra and geometry were not integrated until 1619, when Renes Descartes created the modern mathematical topic of analytic geometry. Nor was the modern topic of calculus created until 1693, when Newton added to analytic geometry the ideas of differential calculus of infinitesimals *(infinitely small)*. 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.

# Perception of nature

Before 1600s, nature was merely a manifestation of super-nature – the supernatural and unobservable – the world of religions.

After 1600s, 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 we live in a world of superstition and magic. We live in a modern world of science and technology – without magic.

# Roots of scientific method



Isaac Newton
(1643 – 1727)
English
mathematics,
alchemy,
physics,
philosophy,
theology,
astronomy,
economics

Before Isaac Newton's grand synthesis of mechanics, there was not science – at least not as we now know it.

# Scientific method

Science began in that intellectual conjunction of the research of six particular individuals: Copernicus, Brahe, Kepler, Galileo, Descartes and Newton. 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)**

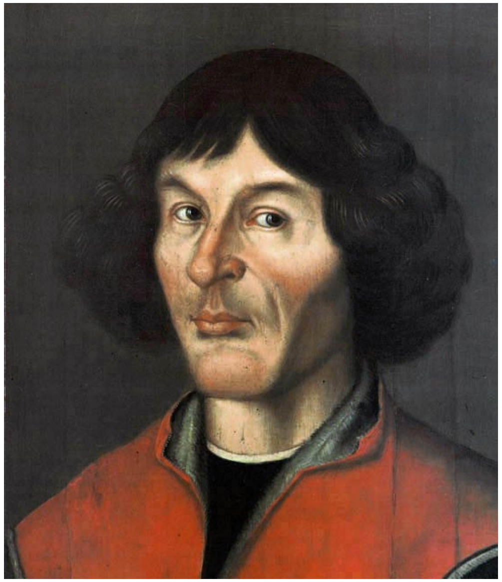
**5. Mathematics to quantitatively express theoretical ideas (Descartes and Newton)**

**6. Theoretical derivation of an experimentally verifiable model (Newton)**

# 1. Nicolaus Copernicus

He proposed an idea (actually a revival of an ancient idea) that the universe should be modeled with the sun at center and not the earth – Sun centric vs. Earth-centric system.

Copernicus' model challenged an older and then widely accepted model of Earth-centered system which had been refined by the Greek, Ptolemy (90-168 AD) of Alexandria.



Nicolaus Copernicus

(1473 – 1543)

Polish

law,

medical,

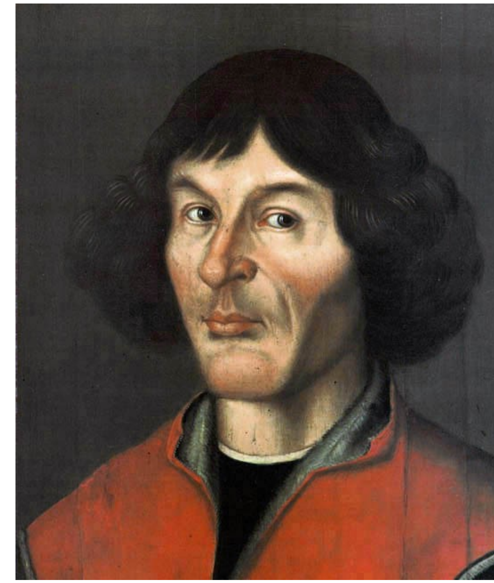
mathematics,

astronomy,

economics

# 1. Nicolaus Copernicus

The Ptolemaic model had the Earth as center and the sun and planets circling Earth. The motions of planets and sun orbiting around Earth 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. *(i.e. theoretic scientist)*



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# 2. Tycho Brahe

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. 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? (*i.e. experimental scientist and enterpreneur – importance of funding in research?*)


Tycho Brahe

(1546 – 1601)

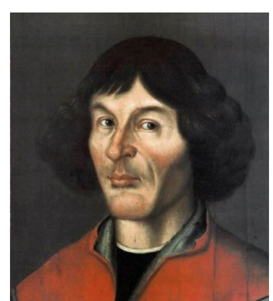
Danish

nobleman,

astronomy,

writer

?



# 2. Tycho Brahe

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 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)

Danish

nobleman,

astronomy,

writer

# 3. Johannes Kepler

Brahe made many, many astronomical measurements and, in 1600, hired a mathematician, Johannes Kepler, to analyze all the data *(i.e. First big data analysis?)*. 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 *(e.g. like regression analysis)*. **Analysis of data is the connection of observation to theory.**

But Brahe died unexpectedly on 1601. Kepler continued working on analyzing Brahe's measurements *(even though not getting paid anymore)*.

Johannes Kepler

(1571 – 1630)

German

mathematics,

astronomy,

astrology,

philosophy

# 3. Johannes Kepler

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 the law of nature. 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' 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 elliptical orbits. But this was not published until 1609 due to legal disputes with Brahe's heir over ownership of Brahe's data. *(i.e. first dispute for intellectual property rights in science?)*

Johannes Kepler

(1571 – 1630)

German

mathematics,

astronomy,

astrology,

philosophy

# 3. Johannes Kepler

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.**

Johannes Kepler
(1571 – 1630)
German
mathematics,
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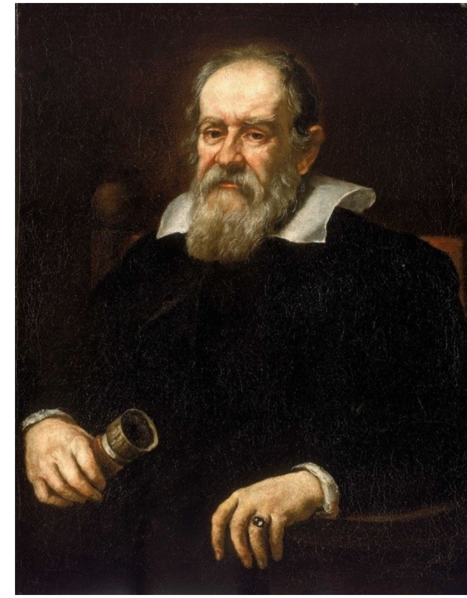
astrology,
philosophy

# 4. Galileo Galilei

Just before Kepler's publication of *Astronomia Nova*, the telescope was invented in 1608 in 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' solar model, with the sun in the center of planetary orbits as Jupiter the center of it's moons' orbits. Galileo published his first astronomical observations in 1610 as *Sidereus Nuncius*. **The double impact of Kepler's elliptical orbits and Galileo's moons-of-jupiter sent Ptolemaic model into dustbin of intellectual history**.

From 1612 to his death he was accused and denounced as heretic (*sinner*) by the church and stayed at house arrest for the remaining 16 years of his life.



Galileo Galilei

(1564 – 1642)

Italian

mathematics,

astronomy,

physics,

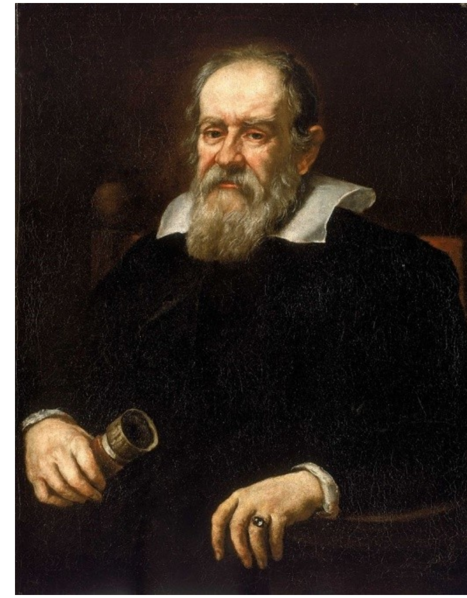
philosophy,

engineering

# 4. Galileo Galilei

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.

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



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(1564 – 1642)
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# 5. 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 calculus and their application to the expression of physical theory. Rene Descartes was a contemporary of Galileo and made a very major contribution to advancing mathematics. He conceived the analytical geometry – adding algebraic expressions to the classical geometry of Euclid. Descartes proposed to describe a space with basis vectors X,Y,Z so that every vector was at right angles with each other. Then any point in space could be described by three numbers (x,y,z) as projections on those vectors.

Rene Descartes

(1596 – 1650)

French

mathematics,

cosmology,

physics,

metaphysics,

epistomology

# 5. Rene Descartes

What Newton would add later is another time dimension ***t***. Motion of a particle in space could then be described as the succession of points occupied by that particle as time ***t*** elapsed.

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.**

Rene Descartes

(1596 – 1650)

French

mathematics,

cosmology,

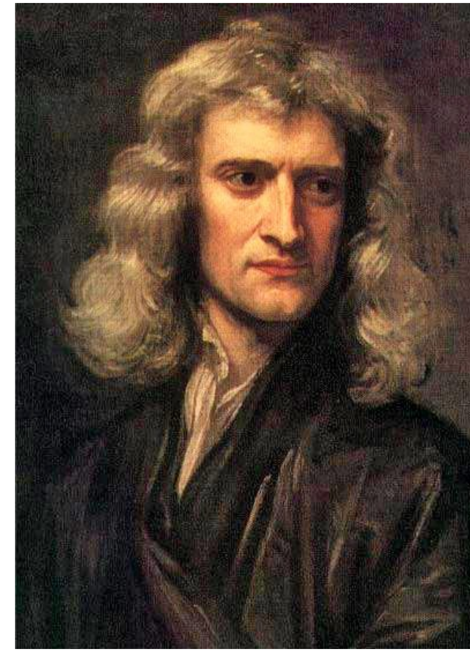
physics,

metaphysics,

epistomology

# 6. Isaac Newton

Descartes' combination of geometry and algebra enabled a quantitative description of 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, Aristotle, Augustine, Bacon, Copernicus, Brahe, Kepler, Galielo and Descartes... Then **finally the stage of history was set for Newton and his grand scientific synthesis of mechanism**.



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# ***Philosophiae Naturalis Principa Mathematica* (1687)**

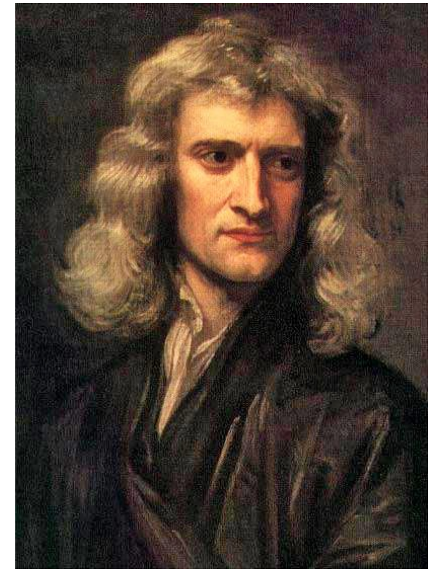


Three universal laws of motion:

1. **<u>Law of inertia:</u>** The motion of a body is constant unless acted upon by an external force

2. **<u>Law of force:</u>** The effect of an external force upon a body is to change its acceleration, proportional to the body's mass: $F = m.a = m \, . \, dv/dt$

3. **<u>Law of action-reaction:</u>** For every action (force) upon a body, there is an equal and opposite reaction (reactive force)



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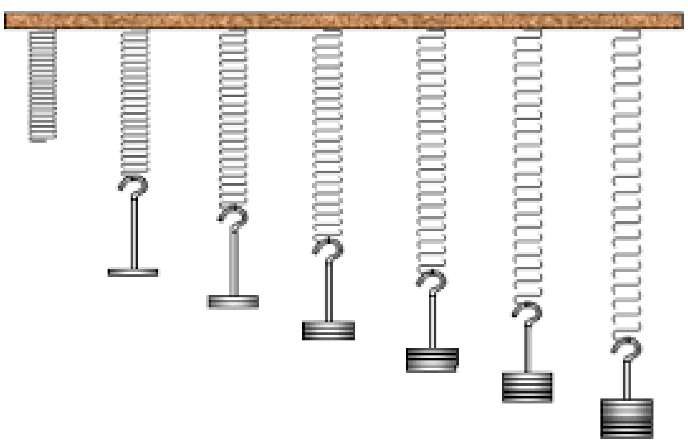
# Do you remember this scientist?



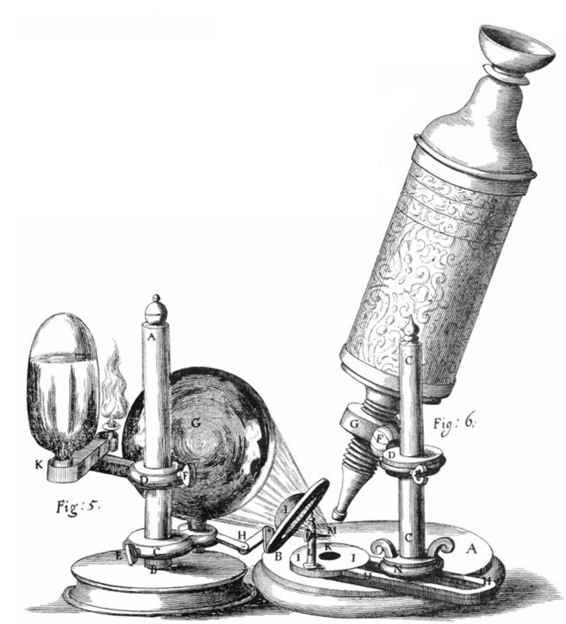
Robert Hooke

(1635 – 1703)

English

physics,

chemistry



# Publish or perish ... Again?

There was a disputed claim about who first discovered the quantitative law of gravity.

Robert Hooke 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 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.

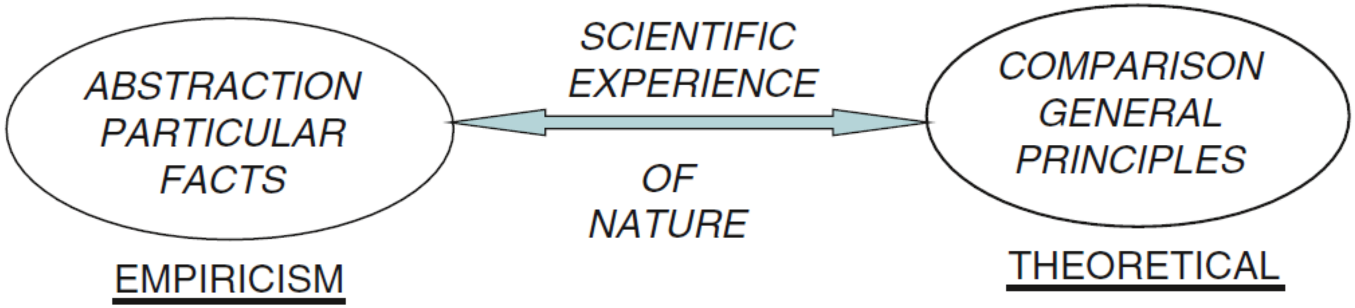
**In the organization of science, scientific credit and prestige goes to the person first to discover of explain *(or publish?)* a natural phenomenon.**

# Scientific method as empirically grounded theory

The critical component parts of scientific method are:

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

# Scientific method as empirically grounded theory




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.

# End of part 2

## *Origin of Scientific Method*

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