The Legacy of 17th-Century Science in Britain

Waseda University, SILS,
History of Modern Physical Sciences

Observation vs. Experiment

Observation:

- The causes of things will be revealed by a rational observation of nature.
- Things themselves have the *qualities* we perceive.
- The state of things is governed by general causes that operate *always or for the most part*.
- We observe the natural state.

Experiment:

- The nature of things is hidden and appearances are ultimately deceptive.
- Things are not determined by our perception of them.
- The state of things is governed by *immutable laws*, which we cannot perceive.
- We investigate by trial, interrogation, "torture."

Experimental Philosophy

- Exemplified in the writings of Francis Bacon (1561–1626).
- Experiments were a way of putting nature on trial.
- Conclusions reached by experiment are necessarily *tentative* and should be considered mere *hypotheses* in need of further testing, through further experiments.
- Experiments could be used to decide between two competing hypotheses, in a crucial experiment.

Theories of Matter

- Aristotle: Four elements (earth, air, fire, water), built up from qualities (hot, cold, moist, dry), plenum (no vacuum), change is qualitative.

- Early modern atomism: Matter is made up of different types of corpuscles; all change is the local motion of these tiny bodies.

Characteristics of matter:

Primary:

- Not accessible to us. Example: extension, weight, motion, etc.

Secondary:

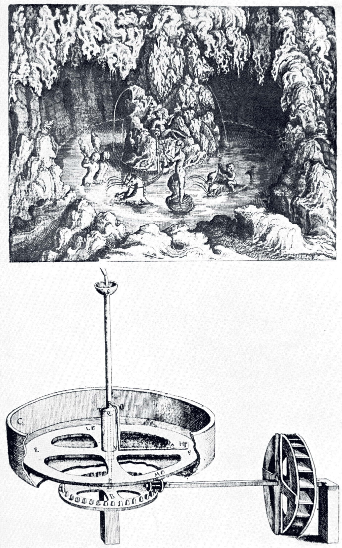
- What we perceive. Example: Color, odor, temperature, etc.

Mechanical Philosophy

The position that all physical processes should be explained by analogies with human constructs (examples: clocks, automata).

All explanations should be based on the primary characteristics of matter.

Generally, change should be explained in terms of direct contact, as opposed to tendency or force, but this was often difficult.



Salomon de Caus, 1620

Robert Boyle (1627–1691)

- 7th son of the Earl of Cork.
- Active in the creation and development of the Royal Society of London.
- Advocate of mechanical philosophy and experimental science.
- Diligent experimenter—or rather Robert Hooke, his one-time assistant—producing results in chemistry, and pneumatics.
- Remembered as an early advocate and practitioner of the experimental method.
- Worked to reconcile mechanical and experimental philosophy and religion.

Boyle's Experimental Philosophy

While observations tell us about what nature does on its own, experiments tell us about nature when it is guided and mastered—they force nature to yield *hidden secrets*.

Experiments should be constructed based on prior assumptions (hypotheses).

Conclusions reached by experiment are necessarily tentative and should be considered mere hypotheses in need of further testing.

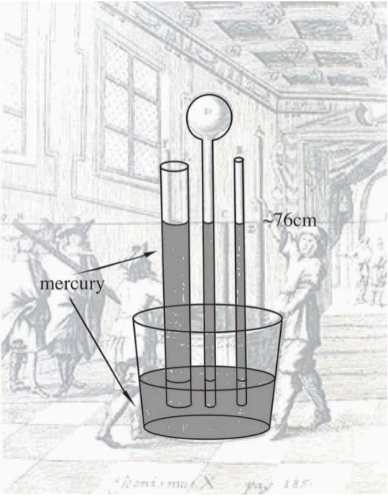
Boyle argued that experiments could be used to decide between two competing hypotheses, in a crucial experiment.

- In this lecture, we will look at two examples of this process, which we can call (1) "vacuum within a vacuum," and (2) "adhering marbles."

- Long tubes sealed on one end are filled with mercury. The open end is then submerged in a tub of mercury.
- The mercury always drops down, or is raised, to the same height.
- Unfortunately, it is difficult to get access to the chamber.

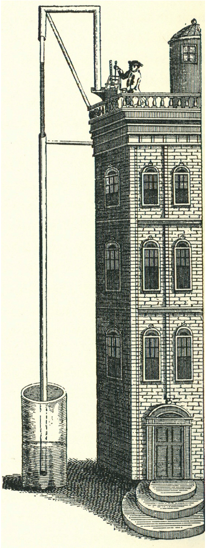
Torricelli's Experiment

- Long tubes sealed on one end are filled with mercury. The open end is then submerged in a tub of mercury.
- The mercury always drops down, or is raised, to the same height.
- Unfortunately, it is difficult to get access to the chamber.



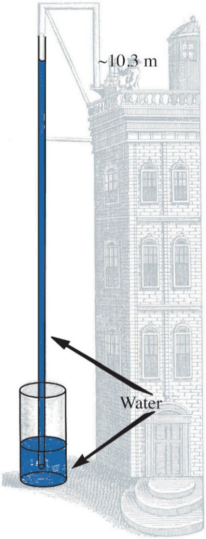
Boyle's Air Pressure Experiments

- Boyle carried out a series of experiments on air pressure and the *spring* (elasticity) of air.
- These involved using an air pump to vary the pressure and volume.
- This led to the discovery of the relationship between pressure, volume and temperature.

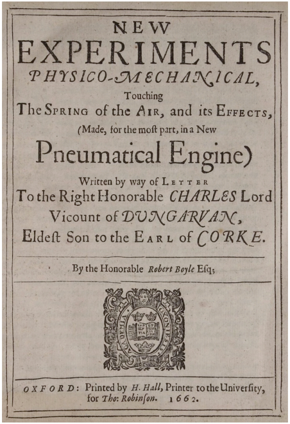


Boyle's Air Pressure Experiments

- Boyle carried out a series of experiments on air pressure and the *spring* (elasticity) of air.
- These involved using an air pump to vary the pressure and volume.
- This led to the discovery of the relationship between pressure, volume and temperature.



Boyle's Air Pump



NEW
EXPERIMENTS
PHYSICO-MECHANICAL,
Touching
The Spring of the Air, and its Effects,
(Made, for the moſt part, in a New
Pneumatical Engine)
Written by way of Letter
To the Right Honorable CHARLES Lord
Vicount of DUNGARVAN,
Eldeſt Son to the Earl of CORKE.

By the Honorable *Robert Boyle* Eſq;

OXFORD: Printed by *H. Hall*, Printer to the Univerſity,
for *Tho: Robinſon*. 1662.

The first air pump had been made by Guerick; the first pneumatic experiments carried out by Torricelli. Boyle and Hooke perfected the air pump so as to carry out experiments on the evacuated chamber.

Boyle's Law:

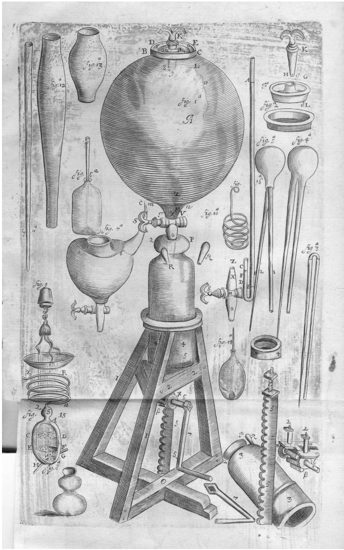
Given a quantity of air at constant temperature, pressure, P, varies inversely with volume, V,

$$P \propto 1/V, \text{ or } P = k/V,$$

where k is some constant.

The First Pump

- Primarily designed and operated by Robert Hooke.
- Designed to give the experimenter some access to the evacuated chamber.
- At the time, it was a very expensive and difficult piece of equipment. Boyle funded the research from his private wealth.

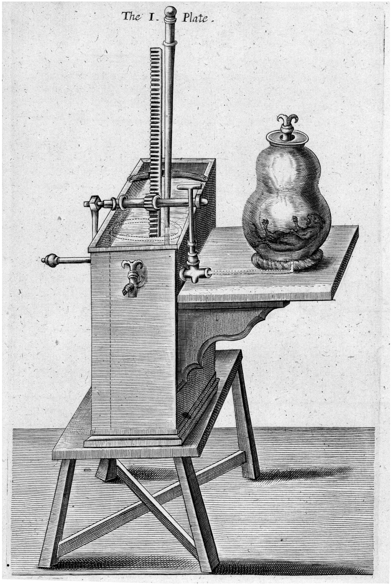


The First Pump

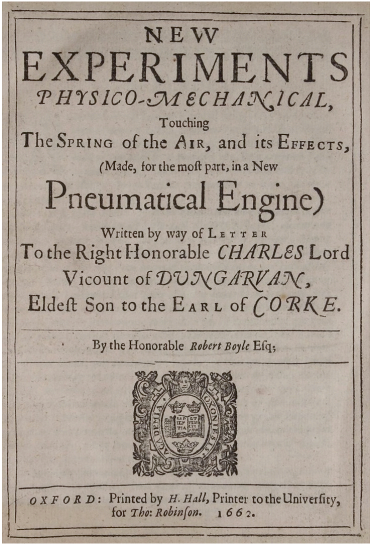
- Primarily designed and operated by Robert Hooke.
- Designed to give the experimenter some access to the evacuated chamber.
- At the time, it was a very expensive and difficult piece of equipment. Boyle funded the research from his private wealth.

The Second Pump

- A superior, but more expensive apparatus.
- The rarity and difficulty of the pump meant that in practice the experiments were difficult to reproduce.
- The main issue concerned the contents of the chamber.



Air Pump Experiments


NEW
EXPERIMENTS
PHYSICO-MECHANICAL,
Touching
The SPRING of the AIR, and its EFFECTS,
(Made, for the moſt part, in a New
Pneumatical Engine)
Written by way of LETTER
To the Right Honorable CHARLES Lord
Vicount of DUNGARVAN,
Eldeſt Son to the EARL of CORKE.

By the Honorable *Robert Boyle* Eſq;

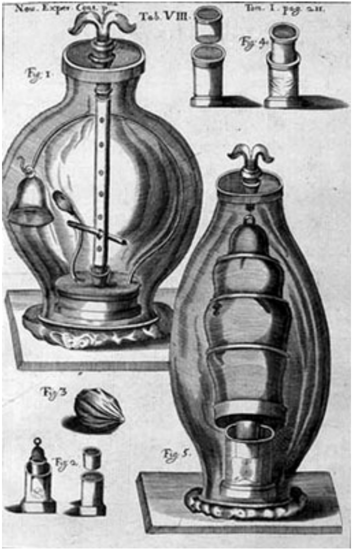
OXFORD: Printed by *H. Hall*, Printer to the Univerſity, for *Tho: Robinſon*. 1662.

- *New Experiments* (1660) recorded 43 “trials” made with the new engine.
- This was the first time people had worked inside evacuated chambers. They performed various experiments such as:
  - Dropping feathers and coins at the same time.
  - Extinction of naked flames.
  - Others …
- Boyle concluded that these were caused by the absence of common air, *a vacuum*, which he interpreted as the *real absence of anything*.

Suffocating animals

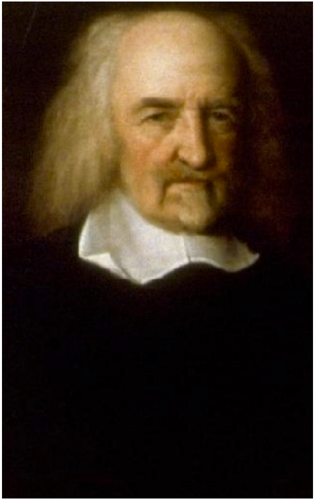
Joseph Wright of Derby, "An experiment on a bird in an air pump," 1768

Transmission of Sound



Thomas Hobbes (1588–1679)

- Remembered primarily as a political philosopher (*The Laviathan*; the famous phrase *bellum omnium contra omnes*), he was also famous in his own time for work in optics, geometry and natural philosophy.
- He was anti-Aristotelian and one of the most famous *mechanical philosophers* of his time, but retained a number of Aristotle's ideas about nature and the role of observation.
- He was an outspoken opponent of the *experimental philosophy*.
- He was never admitted to the Royal Society.



Hobbes' Doubts about the Experimental Philosophy

Hobbes doubted the public nature of experiment.

He believed that one should find natural causes by observation and then reason from these.

He treated Boyle's "hypotheses" as statements about natural causes.

He objected to designing experiments based on theoretical conjectures.

He claimed that experiments constructed situations that were "unnatural" and hence could not yield *natural causes*. Hence, they did not produce "philosophy."

Hobbes' Theory

Hobbes believed in a *plenum* (no vacuum) and that the evacuated chamber was full of a very fine airy substance (tiny particles) that got in around the side of the piston.

He believed that air is composed of a number of different kinds of particles of different sizes and densities, and that the pump only evacuated the large, massy ones.

He neither experimented nor saw the pump in action.

Winds and Springs

Boyle explained the force on the plunger by the "spring of the air" (some kind of *elastic force*). Hobbes claimed this was an anti-mechanistic attribution of *agency* to air—because such a force was regarded as a kind of agency. He used his different kinds of particles to explain the situation.

- There were more massy particles on the outside, which beat against the plunger.

Boyle attributed the phenomena in the chamber to a (near) vacuum. Hobbes denied that there could be a vacuum at all and attributed these to violent winds.

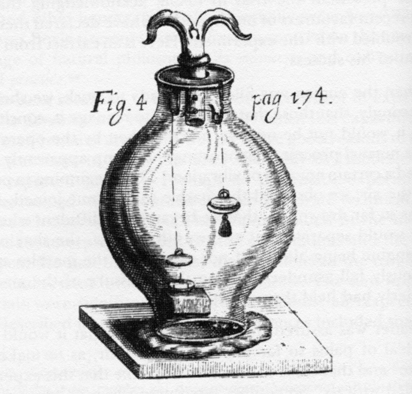
- Candles were blown out.
- Animals were literally blown to death.

Adhering Marbles

It was well known that two flat pieces of polished marble would stick together and required great force to separate.

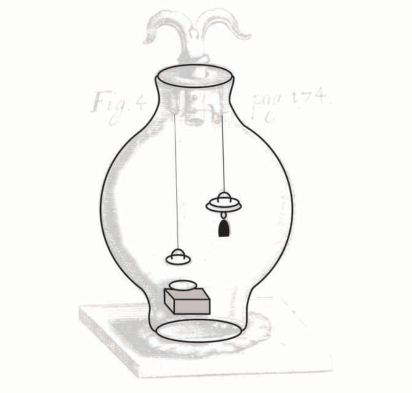
It was believed, correctly, that they were held together by the pressure of the surrounding air.

Hobbes claimed that if a vacuum really could be produced, they should fall apart easily, *of their own accord*.

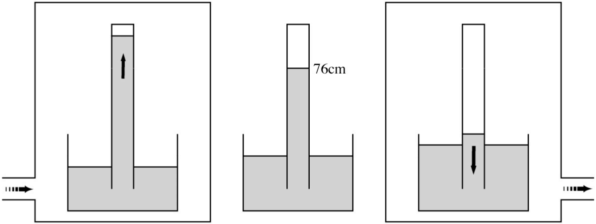


Boyle had great difficulty separating the marbles in experiments. He used alcohol between them and a weight suspended from the bottom one.

Even when he eventually effected it, few people took notice. For example, Newton and Huygens continued to believe that marbles would not separate.



Vacuum within a Vacuum

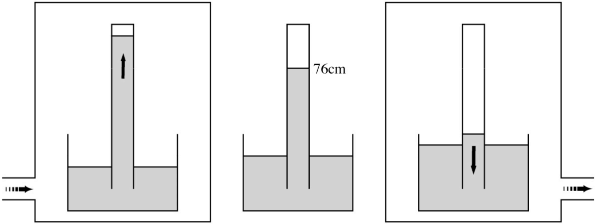


The air pump could be used to change the volume of an *internal* evacuated chamber, such as a barometer.

When air is pushed into the outer chamber, the column of mercury moves up. (Left image.)

When air is drawn out of the outer chamber (right), the column of mercury moves down. (Right image.)

Vacuum within a Vacuum



Hobbes claimed that if a vacuum existed, the column on the left should go all the way up and that on the right should become level. With Boyle's pump, however, the process was never complete.

Boyle attempted this experiment numerous times without "success." He claimed that it *remained a crucial experiment*, to be tested by other pumps.

Final Thoughts and Questions

We are now firmly committed to Boyle's position on experiment. (Hobbes' objections may even seem absurd to many modern people.)

What can crucial experiments prove or disprove? How do we know when they are sucessful?

Is there a real distinction between cause and law?

What are the implications of the claim that experimental results must be public and reproducible?

He developed the calculus (around 1665) and did much original work in mathematics. Wrote many papers, but left the majority unpublished.

He worked continuously on *alchemy* and *theology* – left many volumes of notes, never published. (The majority of Newton's writing are of these kinds.)

He founded a new form of mathematical dynamics; published in the *Principia* (1686).

He developed a new science of optics based on the refractive properties of light; published early in some papers in the *Transactions* of the Royal Society, and later in *Optics* (1704).

Newton's Legacy

Newton brought to a close the astronomical revolution begun by Copernicus. He combined the dynamic research of Galileo with the astronomical work of Kepler and reorganized all of this in a new synthesis.

He produced a new cosmology and a new way of thinking about the world, based on the *interaction between matter and mathematically determinate forces*.

He joined the mathematical and experimental method, producing the hypothetico-deductive method.

His work became the model for *rational mechanics* as it was later practiced by mathematicians, particularly during the Enlightenment.

Anni Mirabiles (1664–1666)

When he was still an undergraduate, away from Cambridge to avoid the plague, he had two years of incredible productivity, which have been called "the miraculous years."

During this period, he laid the foundation for most of his life's work in the mathematical sciences.

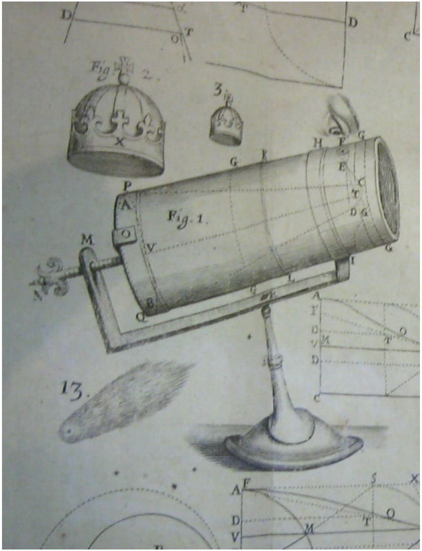
- He developed the differential and integral calculus.
- He discovered the refractive property of colored light.
- He began to speculate on a mathematical law of gravity.

The Refraction of Colored Light

- Used a prism to separate white light into a spectrum.
- Concluded that white light was composed of all of the colored lights.
- Calculated the individual "refractabilty" of each of the colors.

The Reflection Telescope

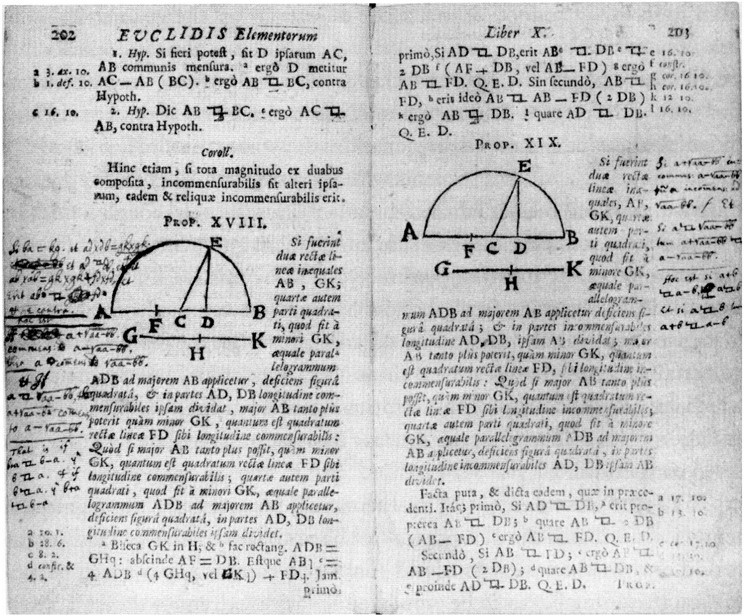
- These results led to the development of the reflection telescope, to correct chromatic aberration.
- He sent the telescope and a paper to the Royal Society.
- This lead to a fierce debate with Robert Hooke.



Years of Silence

The debate with Hooke was too much for Newton. He withdrew from the public sphere and stopped publishing.

- He taught at Cambridge and focused on alchemy and biblical studies.
- He spent all of his time in his chambers, working.
- He read classical Greek mathematics.
- He carried out correspondences with other scientists.



202 *EUCLIDIS Elementorum*

a 3. ax. 10. b 1. def. 10. 1. *Hyp*. Si fieri potest, sit D ipsarum AC, AB communis mensura. [a] ergò D metitur AC — AB (BC). [b] ergò AB ⊓ BC, contra Hypoth.

c 16. 10. 2. *Hyp*. Dic AB ⊓ BC, [c] ergò AC ⊓ AB, contra Hypoth.

Coroll.

Hinc etiam, si tota magnitudo ex duabus composita, incommensurabilis sit alteri ipsarum, eadem & reliquæ incommensurabilis erit.

PROP. XVIII.

Si fuerint duæ rectæ lineæ inæquales AB, GK; quartæ autem parti quadrati, quod fit à minori GK, æquale parallelogrammum ADB *ad majorem* AB *applicetur, deficiens figurâ quadratâ, & in partes* AD, DB *longitudine commensurabiles ipsam dividat, major* AB *tanto plus poterit quàm minor* GK, *quantum est quadratum rectæ lineæ* FD *sibi longitudine commensurabilis: Quòd si major* AB *tanto plus possit, quàm minor* GK, *quantum est quadratum rectæ lineæ* FD *sibi longitudine commensurabilis; quartæ autem parti quadrati, quod fit à minori* GK, *æquale parallelogrammum* ADB *ad majorem* AB *applicetur, deficiens figurâ quadratâ, in partes* AD, DB *longitudine commensurabiles ipsam dividet.*

a 10. 1. b 28. 6. c 8. 2. d constr. & 4. 2. [a] Biseca GK in H; & [b] fac rectang. ADB = GHq: abscinde AF = DB. Estque ABq [c] = 4 ADB [d] (4 GHq, vel GKq) + FDq. Jam primò,

Liber X. 203

e 16. 10. f constr. g cor. 16. 10. h cor. 16. 10. k 12. 10. l 16. 10. primò, Si AD ⊓ DB, erit AB [e] ⊓ DB [e] ⊓ 2 DB [f] (AF + DB, vel AB — FD) [g] ergò AB ⊓ FD. Q. E. D. Sin secundò, AB ⊓ FD, [h] erit ideò AB ⊓ AB — FD (2 DB) [k] ergò AB ⊓ DB. [l] quare AD ⊓ DB. Q. E. D.

PROP. XIX.

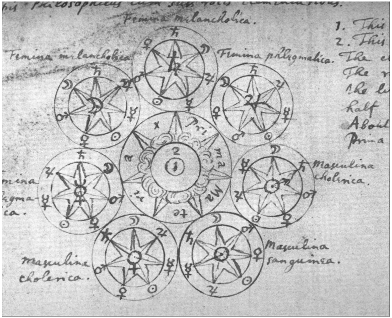
Si fuerint duæ rectæ lineæ inæquales, AB, GK, quartæ autem parti quadrati, quod fit à minore GK, æquale parallelogrammum ADB *ad majorem* AB *applicetur deficiens figurâ quadratâ; & in partes incommensurabiles longitudine* AD, DB, *ipsam* AB *dividat; major* AB *tanto plus poterit, quàm minor* GK, *quantum est quadratum rectæ lineæ* FD, *sibi longitudine incommensurabilis: Quòd si major* AB *tanto plus possit, quàm minor* GK, *quantum est quadratum rectæ lineæ* FD *sibi longitudine incommensurabilis; quartæ autem parti quadrati, quod fit à minore* GK, *æquale parallelogrammum* ADB *ad majorem* AB *applicetur, deficiens figurâ quadratâ, in partes longitudine incommensurabiles* AD, DB *ipsam* AB *dividet.*

a 17. 10. b 13. 10. c cor. 17. 10. Facta puta, & dicta eadem, quæ in præcedenti. Itaq; primò, Si AD ⊓ DB, [a] erit propterea AB ⊓ DB; [b] quare AB ⊓ 2 DB (AB — FD) [c] ergò AB ⊓ FD. Q. E. D.

Secundò, Si AB ⊓ FD; ergò AB ⊓ AB — FD (2 DB); [d] quare AB ⊓ DB, & [e] proinde AD ⊓ DB. Q. E. D.

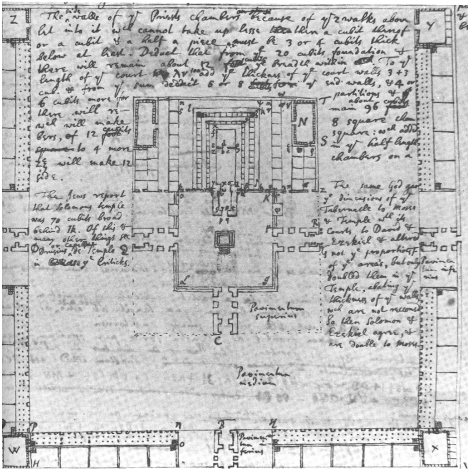
PROP.

Newton’s copy of Eulcid’s *Elements*

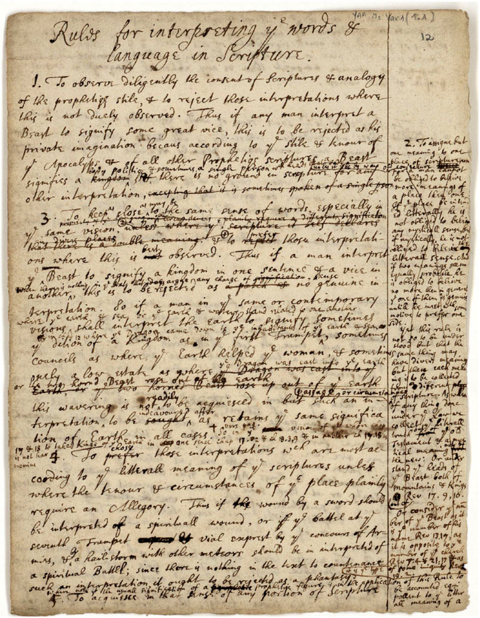


- Newton’s manuscripts contain more writings on alchemy than on mathematics or experimental physics.
- He was interested both in the chemico-physical aspects and in the spiritual implications.
- For example, we find a warning to Boyle about the transmutation of gold into silver.

- Taught himself Hebrew in order to read the Old Testament.
- Tried to prove that the Christian concept of the trinity (God, Christ, and Holy Ghost) was a late development.
- Became interested in sacred geometry.



Newton's "Rules for interpreting the words and language in Scripture"



Rules for interpreting ye words & language in Scripture.

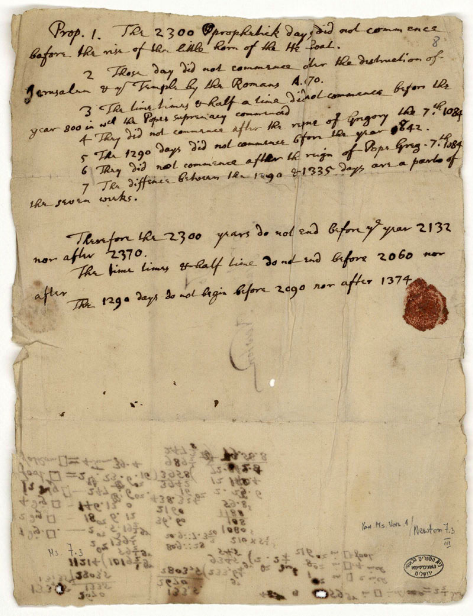
1. To observe diligently the consent of Scriptures & analogy of the prophetiq stile, & to reject those interpretations where this is not duely observed. Thus if any man interpret a Beast to signify some great vice, this is to be rejected as his private imagination becaus according to ye stile & tenour of ye Apocalyps & of all other Prophetiq scriptures a Beast signifies a ~~kingdom~~ body politiq & sometimes a single person wch heads it & there is no ground in scripture for any other interpretation, ~~excepting that it is sometimes spoken of a single person~~

3. To keep as close as may be to the same sense of words, especially in ye same vision, ~~unless where ye scripture it self declares that there is a double meaning~~. & to prefer those interpretations where this is best observed. Thus if a man interpret ye Beast to signify a kingdom in one sentence & a vice in another, this is to be rejected as ~~a patch of~~ no genuine interpretation. So if a man in ye same or contemporary visions shall interpret the earth to signify sometimes ye dition of a Kingdom as in ye first Trumpet, sometimes councils as where ye Earth helped ye woman, & sometimes onely a low estate as where ye Dragon was cast into ye earth or the two horned Beast rose out of the earth ~~Earth, or ye two horned Beast rose up out of ye Earth~~ this wavering is not readily to be acquiesced in but such an interpretation to be ~~sought~~ indeavoured after as retains ye same signification of Earth in all cases.

4. To ~~prefer~~ chose those interpretations wch are most according to ye litterall meaning of ye scriptures unless where the tenour & circumstances of ye place plainly require an Allegory. Thus if ~~the~~ wound by a sword should be interpreted of a spirituall wound, or if ye Battel at ye seventh Trumpet ~~exprest~~ & vial exprest by ye concours of Armies, & of a hail-storm with other meteors should be interpreted of a spiritual Battel; since there is nothing in the text to countenance such an interpretation it ought to be rejected as a phantasy.

5. To acquiesce in that sense of any portion of Scripture

One of Newton’s many calculations of the year of the apocalypse, when the “antichrist” would return and the world would end – 2060


Prop. 1. The 2300 prophetick days did not commence before the rise of the little horn of the He Goat.
2 Those day did not commence after the destruction of Jerusalem & ye Temple by the Romans A.70.
3 The time times & half a time did not commence before the year 800 in wch the Popes supremacy commenced
4 They did not commence after the reigne of Gregory the 7th. 1084
5 The 1290 days did not commence before the year 842.
6 They did not commence after the reign of Pope Greg. 7th. 1084
7 The difference between the 1290 & 1335 days are a parts of the seven weeks.
Therefore the 2300 years do not end before ye year 2132 nor after 2370.
The time times & half time do not end before 2060 nor after
The 1290 days do not begin before 2090 nor after 1374

Newton's *De Motu coporum in gyrum*

Edmond Halley (of the comet) visited Cambridge in 1684 and talked with Newton about inverse-square forces ($F \propto 1/d^2$).

Newton stated that he had already shown that inverse-square force implied an ellipse, but could not find the documents.

Later he rewrote this into a short document called *De Motu coporum in gyrum*, and sent it to Halley.

Halley was excited and asked for a full treatment of the subject.

Two years later Newton sent Book I of *The Mathematical Principals of Natural Philosophy* (*Principia*).

Key Point

The goal of this project was to derive the orbits of bodies from a simpler set of assumptions about motion. That is, it sought to *explain* Kepler's Laws with a simpler set of laws.

Kepler's Laws

I. The planets move in ellipses with the sun at a focus.

II. Equal areas are swept out in equal times.

III. Periods are as the three-halves power of the distances ($P^2 \propto D^3$, or $P \propto D^{3/2}$).

Newton’s *Principia*, 1687, 1713, 1726

Newton was able to show how all of Kepler’s laws depended on certain simple *mathematical assumptions* about the nature of motion and force.

The structure of the *Principia* was is as follows:

- Book I: The mathematics of dynamic systems in void spaces.
- Book II: The mathematics of dynamic systems in gases and fluids.
- Book III: The application of these general methods to the solar system, comets and mechanics – that is, to our world.

Newton's Hypothetico-Deductive Method

Newton, *Principia*

"I consider *philosophy* rather than [mechanical] arts and write not concerning manual but natural powers, and consider chiefly those things which relate to gravity, levity, elastic force, the resistance of fluids, and the like forces, whether attractive or impulsive; and therefore I offer this work as the *mathematical principles of philosophy*, for the whole burden of philosophy seems to consist in this – from the phenomena of motions to investigate the forces of nature, and then from these forces to demonstrate the other phenomena; and to this end the propositions in the first and second Books are dedicated.

Newton's Hypothetico-Deductive Method

Newton, *Principia*

"In the third Book, I give an example of this in the exposition of the *System of the World*; for … I derive from the celestial phenomena the forces of gravity with which bodies tend to the Sun and the several planets. Then from these forces, by other propositions, which are also mathematical, I deduce the motions of the planets, the comets, the Moon, and the sea."

Newton's *Principia*, 1687 (1713, 1726): Laws of motion

[12]

AXIOMATA SIVE LEGES MOTUS

Lex. I.

Corpus omne perſeverare in ſtatu ſuo quieſcendi vel movendi uniformiter in directum, niſi quatenus a viribus impreſſis cogitur ſtatum illum mutare.

PRojectilia perſeverant in motibus ſuis niſi quatenus a reſiſtentia aeris retardantur & vi gravitatis impelluntur deorſum. Trochus, cujus partes cohærendo perpetuo retrahunt ſeſe a motibus rectilineis, non ceſſat rotari niſi quatenus ab aere retardatur. Majora autem Planetarum & Cometarum corpora motus ſuos & progreſſivos & circulares in ſpatiis minus reſiſtentibus factos conſervant diutius.

Lex. II.

Mutationem motus proportionalem eſſe vi motrici impreſſæ, & fieri ſecundum lineam rectam qua vis illa imprimitur.

Si vis aliqua motum quemvis generet, dupla duplum, tripla triplum generabit, ſive ſimul & ſemel, ſive gradatim & ſucceſſive impreſſa fuerit. Et hic motus quoniam in eandem ſemper plagam cum vi generatrice determinatur, ſi corpus antea movebatur, motui ejus vel conſpiranti additur, vel contrario ſubducitur, vel oblique oblique adjicitur, & cum eo ſecundum utriuſq; determinationem componitur.

Lex. III.

[13]

Lex. III.

Actioni contrariam ſemper & æqualem eſſe reactionem: ſive corporum duorum actiones in ſe mutuo ſemper eſſe æquales & in partes contrarias dirigi.

Quicquid premit vel trahit alterum, tantundem ab eo premitur vel trahitur. Siquis lapidem digito premit, premitur & hujus digitus a lapide. Si equus lapidem funi allegatum trahit, retrahetur etiam & equus æqualiter in lapidem: nam funis utrinq; diſtentus eodem relaxandi ſe conatu urgebit Equum verſus lapidem, ac lapidem verſus equum, tantumq; impediet progreſſum unius quantum promovet progreſſum alterius. Si corpus aliquod in corpus aliud impingens, motum ejus vi ſua quomodocunq; mutaverit, idem quoque viciſſim in motu proprio eandem mutationem in partem contrariam vi alterius (ob æqualitatem preſſionis mutuæ) ſubibit. His actionibus æquales fiunt mutationes non velocitatum ſed motuum, (ſcilicet in corporibus non aliunde impeditis:) Mutationes enim velocitatum, in contrarias itidem partes factæ, quia motus æqualiter mutantur, ſunt corporibus reciproce proportionales.

Corol. I.

Corpus viribus conjunctis diagonalem parallelogrammi eodem tempore deſcribere, quo latera ſeparatis.

Si corpus dato tempore, vi ſola M, ferretur ab A ad B, & vi ſola N, ab A ad C, compleatur parallelogrammum $ABDC$, & vi utraq; feretur id eodem tempore ab A ad D. Nam quoniam vis N agit ſecundum lineam AC ipſi BD parallelam, hæc vis nihil mutabit velocitatem accedendi ad lineam illam $B\ D$ a vi altera genitam. Accedet igitur corpus eodem tempore ad lineam $B\ D$ ſive vis N imprimatur, ſive non, atq; adeo in fine illius temporis reperietur alicubi in linea illa

Newton's Laws

Law I

"Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it." [Inertia]

Law II

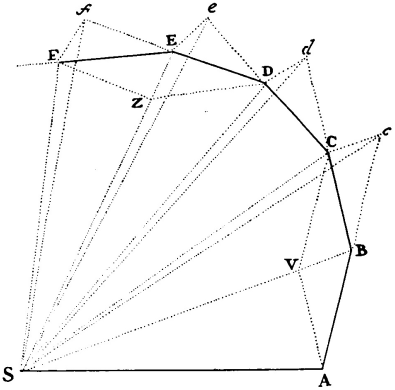
"The change of motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed." [$F \propto a$, $F = ma$]

Law III

"To every action there is always opposed an equal reaction, or the mutual action of two bodies upon each other are always equal, and directed to contrary parts." [Equal and opposite reactions]

Newton used the ideas of limits developed in the calculus to develop a geometry of forces.

Principia, Prop. 1 shows that a body which is continuously acted upon toward a center of force will move in a *closed curve*.

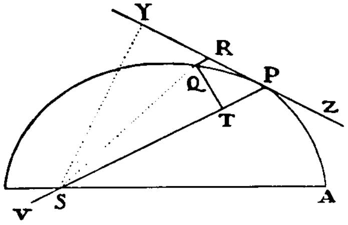


The Geometry of Force

By studying the *geometrical objects* that model the force, Newton was able to show what kinds of forces would produce what kinds of curves.

In this way, he was able to prove that a force that acts inversely as the square of the distance ($F \propto 1/d^2$, such as gravity) will produce an ellipse.

That is, he was able to derive Kepler's 1st law from his own laws of motion and the mathematics of limits.



The General Scholium

At the end of the *Principia*, in a section called the "General Scholium," Newton introduces the concept of God and explains how God functions in his philosophy. This section explains that God is always and everywhere acting on the world to maintain the laws of nature.

God is the *active cause* of gravity.

God's presence produces the two absolute substrates in which all action occurs: Absolute Space and Absolute Time.

God's constant action preserves the world in its present state; He maintains the forces that control matter.

Absolute and Relative *Time*

Newton, *Principia*, Scholium on Time and Space:

"Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external…

Relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year."

Absolute and Relative *Space*

Newton, *Principia*, Scholium on Time and Space:

"Absolute space, in its own nature, without relation to anything external, remains always similar and unmovable.

Relative space is some movable dimension or measure of the absolute spaces; which our senses determine by its position to bodies; and which is commonly taken for immobile space; such is the dimension of a subterraneous, or aerial, or celestial space, determined by its position relative to the Earth."

Newton on God

Newton, *Principia*, General Scholium:

"The true God is a living, intelligent, and powerful Being; and it follows from his other perfections, that he is supreme, or most perfect. He is eternal and infinite, omnipotent and omniscient; that is, his duration reaches from eternity to eternity; his presence from infinity to infinity; he governs all things, and knows all things that are or can be done. He is not eternity and infinity, but eternal and infinite; he is not duration or space, but he endures and is present."

Newtonianism

Much of Newton's actual interests and activities were stripped away from the public memory of his *style of science*.

In France, Newton was held up as a key figure of the Enlightenment (by for example Voltaire, Laplace).

When we talk about *Newtonianism*, and the Newtonian worldview, we are talking about this public image created by Enlightenment thinkers, not the historical man himself with all his spiritual interests.