On the evolution of Modern Sciences

(Four Books that established Natural Sciences)

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Abstract

The origin and the development of natural sciences – physics, chemistry, and biology – are traced back to the appearance of four books.

Introduction

When asked to name the persons most important in forming Science[1] and the works opening a door in scientific reasoning, one can sketch quite appropriately the history of science with just a few names. In my opinion the most seminal books for modern sciences (Physics, Chemistry, and Biology) are:

- Euclid's *The Elements of Geometry* (the Elements),
- Newton's *Philosophiae naturalis Principia mathematica* (the Principia),
- Dalton's *A new system of Chemical Philosophy*, and
- Darwin's *The Origin of Species*.

This compilation may seem to be neither convincing nor unique, but I think that these works are really outstanding compared to those preceding them in the respective subjects; the style of each one is impressive. Amongst them Euclid's Elements and Newton's Principia are towering because of their axiomatization of the large fields of what is today Geometry and Me-

[1] In my opinion Science is not merely collecting, arranging, and ordering facts and observations; this I call knowledge. Only if a more fundamental, unifying view relates and unifies knowledge (proper) science emerges (compare: to know vs. to understand). Of course this distinction is not unique and often hard to draw. By knowledge I term for example the catalogue of stars compiled by the absolutely estimable work of astronomers. On the other hand there is Newton's World System, where the motion of the planets in the solar system is explained by very few basic laws.

chanics respectively[2]. Without these four works there would be no science as we know it to-day[3]. They all do not stay on a rather descriptive level concatenating facts[4] and possibly constructing a nomenclature[5] in addition. But they introduce axioms or laws that provide successfully an explanatory and unifying view joining different subjects or phenomena satisfactorily. Of course these books are based on preceding works of 'giants' providing their shoulders and thus clearing the way.

In this article I will attempt to sketch the development of science based on the above four books together with some pioneering contributions. It is not a scientific presentation; it is conceived rather like a touristic guide introducing the highest mountains and the respective trails leading to the tops of these mountains.

1) Some issues of antique philosophy

Modern Science depends on the development of Thinking (Philosophy) in our ('western') culture. The understanding of the perceptible world was a task of antique philosophy (Plato, Aristotle). The approach to nature from it smallest parts to the universe, was speculative[6]; the method was to acquire knowledge by evidence and thinking; there was no idea of a proof by an experiment. But there existed also a knowledge based on the systematic technical use of phenomena of nature (Archimedes, Heron; see ref. [36])).

1.1) Antique mathematics

The first towering, trend-setting step in the history of science – that, by the way, is not paralleled in other cultures – was the development of Mathematics. Mathematics (μαθηματικη, viz. τεχνη (i.e. skill)) in ancient Greece consisted of:

- Arithmetic (αριθμητικη; Pythagoras): the art of computing, theory of numbers
- Geometry (γεωμετρια; Euclid, Archimedes): the art of surveying

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[2] This cannot be claimed completely concerning Euclid. Presumably there are antecessors of Euclid on the same eye level (see later). That Euclid as well as Newton stood "on the shoulders of giants" is not denied anyway.

[3] Whether such a hypothetical void could have been filled at a later time, is another question. But I believe that the ideas of the books selected were considerably ahead at their times; maybe that is not quite true for Darwin.

[4] R. Kerr in the advertisement of ref. [24]

[5] Lavoisier, preface to *Elements of Chemistry* [24]. Of course, as Lavoisier observed, already the setup of a nomenclature is closely connected with ideas about facts. Nevertheless there are more crucial steps in forming sciences, as will be shown in the following.

[6] Confer Democritus' atomism and Aristotle's cosmology. An example for the antique way of arguing: In Book II, Part 9 of his Physics [2] Aristotle states rather arbitrarily that what is heavy is naturally carried downwards and what is light is carried to the top, thus explaining the succession of stones, earth, and wood. The attitude that properties of nature are recognized and understood just by view (not observation!) and cogitation did not change very much until the renaissance period.

- Astronomy[7] (αστρονομια; Pythagoras, Ptolemy)
- Music (μουσικη; Pythagoras, Plato, Aristotle)

Later on Astronomy and music became fields of their own.

The works of Archimedes [1] on equilibrium and the center of mass of plane figures, as well as on floating bodies are examples of applied mathematics. Also engineering was pretty developed in antique Greece (ref. [36]). Archimedes is said to have written about simple machines (the lever appears already in Aristotle's Physics [2]). The so-called five simple machines – the wheel and axle, the lever, the wedge, the pulley, and the screw – are described by Heron in his (partly lost) books on Mechanics[8] (Heron calls them the five mechanical powers; power: δυναμις). Heron devised already very advanced machines like vending machines or pneumatic doors (ref. [36]).

1.2) Euclid's Elements

A new light was shed on geometry by the axiomatization through Euclid's Elements: "Euclid's Elements is certainly one of the greatest book ever written, and one of the most perfect monuments of Greek intellect." (B. Russell, ref. [35])

Euclid's Elements[9], written about 300 BC, is one of the oldest extant Greek mathematical treatises; it is presumably based on previous works[10]. Its history seems to be not unambiguous. Of course, there is no original version. The work has been saved by Arabic tradition[11]. Also during that time comments have been added and changes were made. The Elements were translated 1482 from Arabic into Latin and only 1533 into Greek. Subsequently translations into middle European languages were performed[12].

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[7] Astronomy, the first systematic observation of nature was common to many cultures. After centuries dominated by the geocentric system, Copernicus stressing the heliocentric system again gave also an important impulse to the rise of Science.

[8] Heron's *Mechanica*, in three books, survived only in an Arabic translation. It dates probably from the early 3rd century BC.

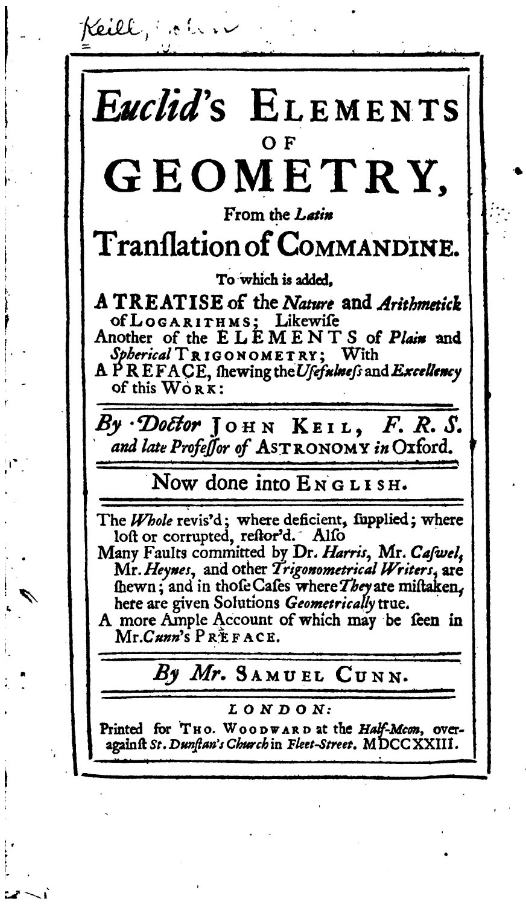
[9] This book comes from Euclid of Alexandria; sometimes this mathematician is confused with the earlier living philosopher Euclid of Megara.

[10] The Greek mathematician Proclus mentioned in his commentary to the *Elements* the names of Eudoxus and Theaetetus. Further names of antecessors are Pythagoras, Hippocrates of Chios, and Plato.

[11] The Arabs received the *Elements* from the Byzantines approximately about 760; it was translated into Arabic circa 800 AD (B. Russell [35]). The *Elements* was lost to Christian Europe until ca. 1120, when the English monk Adelard of Bath disguised himself as a Muslim student in order to obtain a copy in Muslim Córdoba. (W.W. Rouse Ball, ref. [33]).

[12] Consulting C. Thaer (ref. [10]), W.W. Rouse Ball (ref. [33]), and T. Heath (ref. [30]), I did not succeed in finding out how many different roots for the translations of the Elements in modern languages exist. Anyhow, the translations agree mainly but they differ also in some details.

Even if Euclid only collected and reshaped older theorems, already the axiomatization achieved in the Elements stayed influential for centuries. It turns the knowledge of surveying into the science of geometry.



Keill, John

Euclid's ELEMENTS OF GEOMETRY,

From the *Latin* Tranſlation of COMMANDINE.

To which is added,

A TREATISE of the *Nature* and *Arithmetick* of LOGARITHMS; Likewiſe Another of the ELEMENTS of *Plain* and *Spherical* TRIGONOMETRY; With A PREFACE, ſhewing the *Uſefulneſs* and *Excellency* of this WORK:

By Doctor JOHN KEIL, *F. R. S.* *and late Profeſſor of* ASTRONOMY *in* Oxford.

Now done into ENGLISH.

The *Whole* revis'd; where deficient, ſupplied; where loſt or corrupted, reſtor'd. Alſo Many Faults committed by Dr. *Harris*, Mr. *Caſwel*, Mr. *Heynes*, and other *Trigonometrical Writers*, are ſhewn; and in thoſe Caſes where *They* are miſtaken, here are given Solutions *Geometrically* true. A more Ample Account of which may be ſeen in Mr. *Cunn*'s PREFACE.

By Mr. SAMUEL CUNN.

LONDON:

Printed for THO. WOODWARD at the *Half-Moon*, over-againſt *St. Dunſtan's Church* in *Fleet-Street*. MDCCXXIII.

Fig. 1: Euclid's Elements: Title page of Keill's translation (London, 1723; ref. [9])

The Elements consist of 13 books. The first book starts with several definitions, followed by postulates and axioms[13]. Among the postulates there is the famous postulate or axiom[14] of parallels, the distinguishing feature of Euclidean geometry[15]:

Postulate V:
That, if a straight line falling on two straight lines makes the interior angles on the same side less than two right angles, the two straight lines, if produced indefinitely, meet on that side on which are the angles less than the two right angles.

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[13] Some of the remaining books also start with definitions. In book V of J. Keill's English translation [9] there appear also 2 axioms.

[14] The number of these varies according to the edition. So Keill's English translation [9] puts the fifth postulate within the axioms.

[15] Without that postulate one finds geometries in 'curved' space, e.g. the geometry of the surface of a sphere. Such geometries are important for the general theory of relativity and consequently for the modern picture of the universe.

Afterwards Euclid starts the main goal of his Elements: Geometric exercises are formulated as propositions; in their proofs the definitions, postulates, and axioms are applied. As an example of such a proposition I cite the first problem (ref. [9]):

Proposition I

To describe an Equilateral Triangle upon a given finite Right Line.

Instead of following Euclid's solution which refers to some of the definitions, postulates, and axioms, the answer is clear to us today from Fig. 2 accompanying this problem in the printed editions[16] (i.e. long after Euclid; the finite right line is AB): The third point of the equilateral triangle, the point C, is one of the two points of intersection of the two circles about A and B with radii AB.

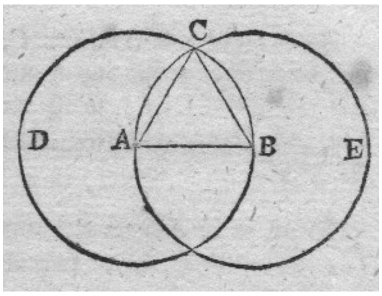

Fig. 2: The points A, B, and C form an equilateral triangle since, by construction, CA = CB = AB (figure from ref. [9]).

The style of the Elements remained exemplary for about two thousand years! For example in his Discorsi (see below) Galileo uses mainly Euclid´s style to present the topic of the 3rd and the 4th day and not the dialogue-style of the other parts of the book. Newton's Principia is completely written in this way. Even some of Spinoza's philosophical work, e.g. *Renati Des Cartes Principiorum Philosophiae …, More Geometrico demonstratae…*, Amsterdam 1663, is written in Euclid´s style[17].

2) Medieval science

Middle Ages seemed not to be a period favorable for science; there was but little progress[18]: I am not aware of any important step concerning natural sciences in the Middle Ages. The emphasis was on philosophy and theology, where the former was dominated by scholastic thinking: 'philosophia ancilla theologiae' (philosophy is the maidservant of theology); it was the purpose of philosophy to serve theology. Though, an important activity was the tradition of antique texts (e.g. Aristotle, Archimedes, Euclid, Ptolemy), many of them via Islamic scribes.

[16] The first printed edition of the *Elements* appeared in 1482.

[17] Also for the presentation of a topic more remote from science, viz. ethics, Spinoza uses the Euclid's method of presentation: *Ethica, ordine geometrico demonstrate* (1677, posthumous).

[18] For different positions see Lindberg (ref. [31], Chapter 14).

During Renaissance there was a revival of antique ideas; arts and science start to flourish. A slight liberation from the strong rules for the general view and thinking provided by the Catholic Church took place. Leonardo da Vinci, not a scientist, but an outstanding observer, who was by the same time an outstanding graphic artist and painter, made very accurate observations, even for very, very short processes. His drawings of such processes, e.g. of water streaming in a container, are inconceivably accurate. His observations induced many ideas for machines, which were ahead of his times.

3) The Beginning of the Modern Era

The modern view of the 'world system', viz. the planetary system, started 1543 with the publication of **Nicolaus Copernicus's** *De revolutionibus orbium coelestium* [4] (On the Revolutions of Heavenly Spheres), removing the Earth from the center of the world system and putting there the Sun. The heliocentric system was already proposed in Antiquity, but now it was based on a new analysis of existing astronomical observations, hardly Copernicus' ones, since his equipment was rather simple even for that time. He recognized the reason of the retrograde motion[19] of planets: For an observer on the Sun there is no such motion.

1616 it was forbidden by the Catholic Church to accept the Copernican system: Catholics were only allowed to consider this system as a hypothesis.

3.1) Kepler's laws of planetary motion

The Copernican system was a prerequisite for **Johannes Kepler's** contributions, in particular his famous **three laws** for the motion of a planet around the Sun:

1. The orbit of every planet is an ellipse with the sun at a focus.
2. A straight line joining a planet and the sun sweeps out equal areas during equal intervals of time.
3. The square of the orbital period of a planet is directly proportional[20] to the third power of the semi-major axis of its orbit.

Kepler was an exceptional author presenting also his motives, doubts, and reflections. In his writings he was guided by longing for harmony, beauty and symmetry. This can be very clearly seen in his *Mysterium Cosmographicum* [16] (published 1596), famous for Kepler's 'explanation' of the distance relationships between the six planets (known at that time) in terms of nesting the five Platonic solids[21] between successive spheres in the order (see Fig. 3): Sun – sphere of Mercury – Octahedron – sphere of Venus – Icosahedron – sphere of Earth – Dodecahedron – sphere of Mars – Tetrahedron – sphere of Jupiter – Cube – sphere of Saturn.

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[19] Planets sometimes show a motion in the opposite direction, so that the orbit observed by astronomers forms a loop.

[20] The constant of proportionality has the *same value* for all planets.

[21] The five Platonic solids are regular polyhedra showing 4 (tetrahedron), 6 (cube), 8 (octahedron), 12 (dodecahedron), and 20 (icosahedron) faces (compare Fig. 3 presenting Kepler's model).

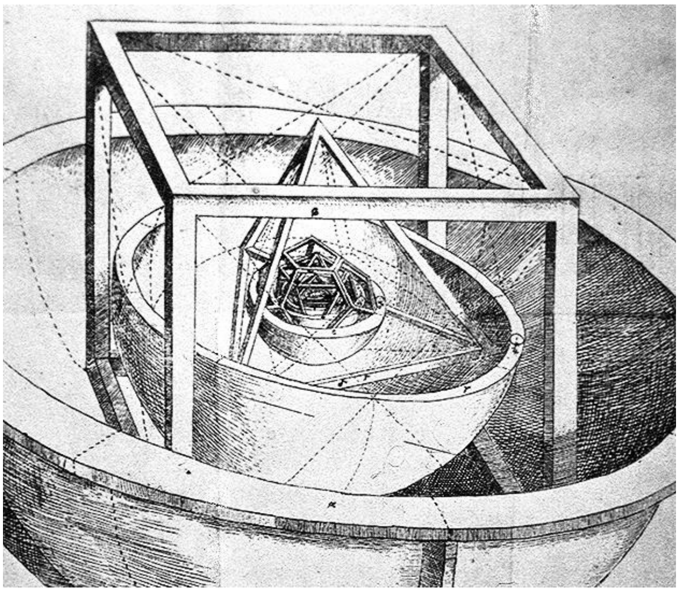

Fig. 3: Kepler's 'explanation' of the sizes of spheres housing the planetary orbits

(see ref. [16])

Kepler deduced his first and second law from Tycho Brahe's accurate observations of the orbit of Mars; 1609 he published them in his *Astronomia Nova* [17]. 1619 he disclosed the third law in *Harmonice Mundi* [18]. This book deals with harmony of geometrical figures, harmony in music, harmony between celestial bodies and (human) nature, and harmony of planetary motion.

Together with the Copernican heliocentric system, the three laws constitute the first step in establishing astronomy as a proper science in the meaning given in the beginning[22]. The accomplishment was achieved by Newton.

3.2) Galileo's investigations of motion

Galileo Galilei investigated not only the fall of bodies and the pendulum motion, but he defended also the Copernican system. In view of his ingeniousness concerning what can be observed and measured[23] as well as the measuring setup he is generally considered as founder of scientific investigation through experiments, namely carefully designed setup of conditions and measurement devices, so that experiments can be repeated and thus the previously obtained results can be checked.

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[22] A noncircular orbit can be described by introduction of a so called epicycle, i.e. the planet moves on a small cycle (the epicycle), whose center in turn moves on a circle (the deferent) around the Earth. If one epicycle gives not an accurate description one has to introduce further epicycles whose centers move on epicycles.

The variety of epicycles used in the Ptolemaic system to represent the orbits of celestial bodies around the Earth have clearly not the character of a deeper insight, they are just convenient tools to describe them mathematically. The use of circles dates back to Aristotle's assumption, that the motion of the planets is uniform and circular.

[23] Galileo's attitude is very well characterized by the tale of dropping a cannon ball and wooden ball from the top of the Leaning Tower of Pisa to scrutinize Aristotle's assertion that heavier bodies fall down faster.

Galileo's defense of the Copernican system, the *Dialogo di Galileo Galilei sopra i due massimi systemi del mondo tolemaico, e copernicano* [12] (Dialogue concerning the two chief world systems, published 1632) provoked his trial by the Catholic Church. Two issues of the 'Dialogue' shall be mentioned in particular: A relativity principle deduced from viewing the motion on a ship from the shore[24] that was replaced not until 1905 by A. Einstein and Galileo's (wrong) theory of tides[25] he used as an argument to defend the Copernican system in his trial. The results of his experiments he presented in the *Discorsi e dimostrazioni matematiche intorno a due nouve scienze attenenti alla mechanica i movimenti locali* [13] (Discourses and Mathematical Demonstrations Relating to Two New Sciences, published 1638). Of particular importance were his investigations of the pendulum motion and the free fall. Galileo's observations about breaking beams and the resulting considerations about the constitution of matter mark the beginning of a continuing scientific investigation of coherence.

3.3) Descartes' philosophy

Galileo's condemnation by the Catholic Church deterred **Rene Descartes** for years from publishing the *Principia Philosophiae* [8]. Finally the book appeared 1644 in Amsterdam. Among the contents of the book relevant to science one finds Descartes' **first law of nature**[26]: A body continues to stay in its state, in particular in its state of motion. Descartes also already formulated the law of rectilinear motion (his second law of nature[27]) and performed partly wrong considerations about linear elastic collisions. But most influential was his vortex model of the 'subtle matter' (materia subtilior) forming the 'first element' (elementum primum). Denying the existence of empty space, the subtle matter served the purpose to fill – or even: to establish -- the space between the chunks of matter, that can be distinguished. With the motion of the subtle matter he explained the motion of the planets: The planets are moved around the sun by the vortices of the subtle matter. Also the tides he tried to explain by his vortex model[28].

Descartes' picture of the universe developed in Parts II and III of the *Principia Philosophiae* may be sketched by the following statements:

• There is no empty space, matter constitutes space.
• The matter of all bodies is the same.
• Matter fills in many, many pieces of different size all of space.

[24] This situation is referred to also later in Descartes' Principia and Leibniz's *Specimen Dynamicum* (Dosch ed., Meiner, Hamburg 1982).

[25] Galileo considered the rotation of the Earth as cause of the Tides. Correctly the tides are due to the rotation of the Earth and the attraction of the Moon (see later).

[26] Ref. [8], Part II, XXXVII: Prima lex naturae: quod unaquaeque res, quantum in se est, semper in eodem statu perseveret; sicque quod semel movetur, semper moveri pergat (First law of nature: Every object on its own stays in its state, therefore it keeps moving if it has been moved once).

[27] Ref. [8], Part II, XXXIX: Altera lex naturae: quod omnia motus ex se ipso sit rectus; … (Second law of nature: Every movement on its own is carried out in a straight line; …)

[28] Ref. [8], Part IV, XLIX.

• Matter can be divided ad infinitum therefore there are no atoms.

• Since god is perfect, it is legitimate to assume that in the beginning he divided matter in nearly equal pieces, performing a circular motion of some kind; this circular motion forms vortices.
• In the beginning these pieces must have had edges (spheres would leave voids in space).
• Due to motion (caused and maintained by god) these pieces became more or less sphere-shaped by abrasion, the smallest pieces forming a kind of subtle matter that fills all the remaining space.
• The vortex motion accounts for the positions and motion of the planets.

The final paragraph CCVII of the *Principia Philosophiae* [8] may give an idea of Descartes' misgivings concerning the reaction of the church:

That, however, I submit all my opinions to the authority of the church.

Nevertheless, lest I should presume too far, I affirm nothing, but submit all these my opinions to the authority of the church and the judgment of the more sage; and I desire no one to believe anything I may have said, unless he is constrained to admit it by the force and evidence of reason.

4) Newton's Principia

Newton´s comprehensive concept of a Mathematical Philosophy of Nature[29] at the turn from the 17th to 18th century together with his fundamental conjecture of universal gravitation resulting in a concept of the world system is exemplary for the evolution of Science.

Newton's Principia [28] is a singular, outstanding creation, though it is based on the "shoulders of giants"[30]; some of them we have already mentioned. The work provides an alternative point of view to that expressed by Descartes in his *Principia Philosophae* [8], in particular it was directed against the vortex theory of planetary motion[31]. A whole realm of phenomena, the motion of the stars in the solar system, is related to a single force: Gravitation. It is said that Newton's masterpiece would have been never become public without the astronomer Edmund Halley (1656-1742). He urged Newton to publish it and took care of the publishing costs.

The composition of the Principia
is obviously inspired by Euclid's Elements. The work starts with eight Definitions followed by the famous three Axioms, or

[29] In his *Il Saggiatore* (The Assayer; contained in ref. [29]) Galileo wrote already 1623 that the book of nature is written in the language of mathematics (i.e. geometry).

[30] "If I have seen further it is by standing on the shoulders of giants" (I. Newton in a letter to R. Hooke written 1676).

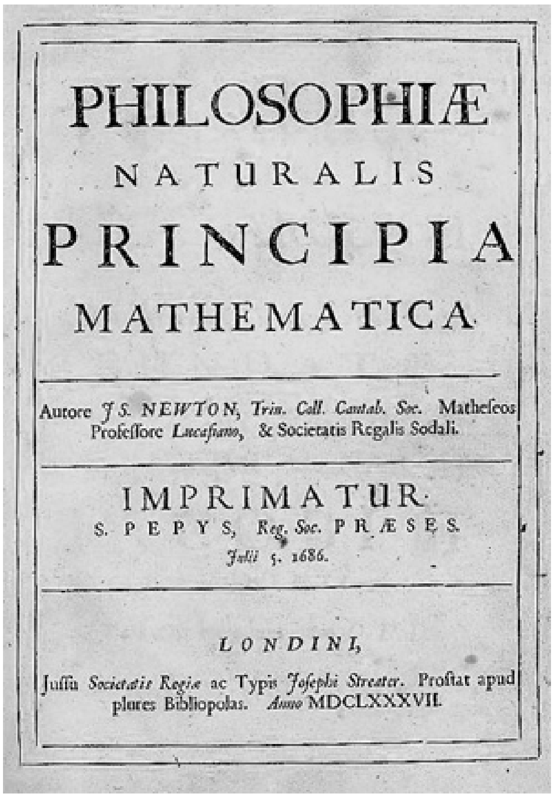
[31] See the end of Book II of Newton's Principia [28].

Laws of Motion[32]**:**

1. 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.

2. The change of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.

3. To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA

Autore *JS. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

Fig. 4: Title page of the first edition of Newton's Principia (London 1687)

Then follow three books.
In the first book for given forces the resulting orbits and vice versa are determined using the laws. The book starts with eleven Lemmas; they give a short account of the results of Newton's new theory of ratios of vanishing small quantities[33] needed for the following. Consequently Newton presents the first problem in

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[32] Newton's first law: "Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum suum mutare" maybe compared with Descartes first and second law of nature. (see footnotes 26 and 27)

[33] Newton's "ultimate ratio" (i.e. the limiting value of a ratio) can be traced back to several of Archimedes (and even Euclid's) works, where curves are approached by a sequence of polygons with an increasing number of

Proposition I:
The areas, which revolving bodies describe by radii drawn to an immovable centre of force do lie in the same immovable planes, and are proportional to the times in which they are described.

Thus Newton claims in general that for forces driving a body to a fixed center Kepler's second law applies. The proof is based on the Laws and the Lemmas. As everywhere in the Principia, geometric proportions between quantities are used to express a quantity in terms of others; these relations are drawn from figures (the so-called geometric method).
In the second book the motion in a resisting medium (gas or liquid) is discussed. It ends with the refutation of Descartes' vortices as cause of the motion of bodies.

Universal Gravitation

In the third book Newton presents first a compilation of phenomena in the world system and concludes then from them his universal Law of Gravitation:

The gravitational Force between two bodies is proportional to Mass#1 times Mass#2 divided by their Distance squared.

Or in terms of mathematical symbols:

$$F \propto m_1 \times m_2 / r^2$$

This force is generated by masses and it acts on masses; it determines the motion of masses and therefore is responsible for the state and future of the planetary system[34]. From the laws of motion and the gravitational force Newton develops the system of the world, which is the motion of the planets and their moons. Moreover, the shape of the Earth, not spherical due to its rotation, and the tides resulting from the influence of the Moon are explained.

Newton's goal is to explain nature (more specifically: mechanics, hydrodynamics, astronomy) from few basic laws. The topics of the second book of the Principia and his explanation of the shape of the Earth and the tides gave the initial impetus to the study of hydrodynamics. Strangely enough, this field of physics came in some degree to a satisfactory state rather late.

5) Fruits of the Principia

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straight parts. Newton's ultimate ratios are the basis of his calculus of Fluxions; together with Leibniz's differential calculus Newton's calculus is the root of mathematical Analysis.

[34] In practice only the motion of at most two masses can be calculated. Already for the determination of three interacting bodies one has to use approximation methods. Finally it turned out in the sixties of the last century that the motion of more than two bodies may be chaotic, i.e. basically unpredictable, thus shaking the belief in a clockwork universe (Peterson, ref. [32]).

Many ideas in Newton's Principia have been worked out in the following, but not in the form Newton used. The more powerful tool of mathematical analysis was employed to tackle problems. Moreover Newton's system of the world was augmented by explanations for its genesis in theories of Kant and Laplace.

5.1) Analytical mechanics

Using the new language of mathematics in Leibniz's version, the calculus, Newton's mechanics was converted and extended into analytical mechanics by Leonhard Euler, Joseph Louis Lagrange, and Pierre Simon Laplace, essentially by:

- **Euler's** *Mechanica sive motus scientia analytice exposita* [11] (2 volumes published 1736); the first volume is dedicated to the elaboration of Newton's theory of motion (books I and II of the Principia); it contains many worked problems and examples,

- **Lagrange's** *Mecanique analytique* [19] (published 1796), a purely analytic presentation of statics (equilibrium of forces) and dynamics (theory of the motion of bodies) without a single figure.

- **Laplace's** *Traité de mécanique céleste* [22] (5 volumes published 1799 -1825), an extremely comprehensive and detailed exposition of the world system, the third book of Newton's Principia; there is scarcely anything missing that could be also accounted for at that time.

These books rendered Newton's natural philosophy more accessible; in this form it became the foundation of modern physics.

5.2) The Kant-Laplace theory

The thesis about the evolution of the solar system from a nebula proposed independently by I. Kant and by Laplace is called Kant-Laplace theory.

Kant's *Allgemeine Naturgeschichte und Theorie des Himmels* [15] (Universal Natural History and Theory of Heaven, published 1755) is an exposition of his ideas about the mechanical origin of the world. Kant's cosmogony is the first serious non-mythological conception of evolution in European culture (a century before Darwin's *Origin of Species*!): To Newton's theory of the world *as it works*, Kant added a suggestion of the world *how it became*. His evolution of the Universe consists of conjectures based on Newton's Principia and some remarkable properties of the planetary system. The last part is devoted to speculations about the inhabitants of the stars.

Laplace's *Exposition du système du monde* [21] (published 1796) is mainly a description of the world system. His statements result from his expertise in predicting precisely the state of the world system as documented in his *Traité de mécanique céleste* [22]. The Exposition is a clear and concise resume thereof without a single formula or figure. Then, in the very last chapter, like a tentative conclusion, Laplace presents his considerations about the origin of the world[35].

The accurate description of the planetary system as presented in his *Traité de mécanique céleste* convinced Laplace of the old picture of a clockwork universe. This belief he stated in the *Essai philosophique sur les probabilités* [23] (published 1814):

To an intelligence that at a given moment knows all the momentary positions of all things of which the universe consists, nothing would be uncertain, future and past would be present before its eyes.

The 'World' seemed to be solved. On the occasion of being asked an according question Laplace answered: God – I do not need this hypothesis. For Newton god had still to take care of the universe from time to time in order that it stays regular[36].

Kant as well Laplace start from remarkable properties and relations of the planetary system and conclude that these are not mere coincidence, but must have a common reason[37], namely a rotating "basic matter" (Kant) or "nebular matter" (Laplace).

6) 18th and 19th century: The rise of Modern Sciences

The new sciences of Biology and Chemistry arise: Knowledge collected hitherto is augmented by a system of causal relations between the objects of these sciences.

6.1) Chemistry

Alchemy – the word is of Arabic origin – dates back even to times before antiquity. Amongst the practitioners in more recent times one finds also Isaac Newton. According to the general opinion one may fix[38] the separation of chemistry from alchemy with **Robert Boyle's** *The*

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[35] Laplace mentions also the influence of the Sun allowing the animals and the plants to cover the Earth. To him it is probable that different forms of organization exist on the other planets with different temperatures.

[36] Last Scholium generale of the Principia [28]. The realization of the possibility of chaotic (i.e. de facto unpredictable) behavior in the equations ruling the planetary motion in the 20th century destroyed the belief in a clockwork universe.

[37] Peculiarities of the planetary system summarized by Laplace:

- The orbits of the planets lie nearly in the same plane and are nearly circular.
- All planets move in the same direction. The Sun rotates in the same sense.
- Their satellites (moons) all move in the same sense and also in the plane of the planetary orbits.
- Together with the Sun they all rotate in the same sense about their axis of rotation that is nearly perpendicular to the orbit plane.

For Laplace "these phenomena cannot occur by chance; there must be a general reason." The regularities are due to a giant atmosphere-like fluid rotating around the Sun, which finally collapsed to form the surface of the sun. Before, there was a rotating (and therefore flat) nebula of matter with the Sun as a core.

[38] B. Russell takes the view that Boyle finished the hocus-pocus of alchemy and returned to Democritus' atoms (ref. [34]).

Sceptical Chymist [3] (London 1661), written in the form of a dialogue taking place between two persons mainly, Carneades (the sceptic; Boyle himself?) and Eleutherius. Boyle defeats the previous "chymistry" and aims for a more scientific method questioning in particular traditional doctrines[39] by experiment. The existence and the importance of elementary substances are propagated. It is said that Boyle advanced in this book also the hypothesis that matter consists of atoms ("minute particles"[40]). This is only partly true. Although he claims that experiments do neither support the four peripatetic elements (Earth, Water, Air, and Fire) nor the three alchemstic "chymical principles" (mercury, salt, and sulfur) to be basic, he still holds that the smallest "corpuscles" are differently shaped, so that the variety of substances can be explained[41]. This position is reminiscent of Democritus' atomism[42].

6.1.1) Lavoisier's chemistry

Antoine Lavoisier's *Traité Élémentaire de Chimie* [24] (1789), presents his investigations of chemical reactions[43]. The book has many beautiful illustrations of the equipment used in the experiments, drawn by Madame Lavoisier (compare Fig. 5). From his experience Lavoisier concludes his famous law of conservation of mass[44] in chemical reactions. The law is an important restriction for chemical reactions. Moreover, developing a "Nomenclature of Chemistry", he also introduces the concept of elements as substances which cannot be further decomposed "to express our idea of the last point which analysis is capable of reaching". But he refuses to speculate about the "constituent and elementary parts of matter" in view of the hitherto very "metaphysical" discussions about number and nature of elements.

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[39] For instance the Aristotelian definition of heat: "to assemble things of a resembling, and disjoyn those of a differing nature". (Preface of ref. [3])

[40] See Propositions I and II in the first part of the *Sceptical Chymist* [3]. But it is not "impossible" that elements consist of "minute masses or clusters" (Prop. II, p. 31). And: Such a minute particle, "the corpuscle of gold and mercury … be not primary concretions of the most minute particles of matter".

[41] "… For if we assigne to the Corpuscles, whereof each Element consists, a peculiar size and shape, it may easily enough be manifested, That such differingly figur'd Corpuscles may be mingled in such various Proportions, and may be connected so many several wayes, that an almost incredible number of variously qualified Concretes may be compos'd of them." (First part of ref. [3])

[42] Compare footnote 38

[43] The work is divided into three parts. The first is devoted to the formation and decomposition of gases (starting with phases and their transformations), combustion of simple bodies, and formation of acids; the second to combination of acids and bases and the formation of neutral salts; the third one to the description of instruments and operations in chemistry. Lavoisier advocates the idea of a substance – the caloric – representing internal heat, the amount of which is responsible for the appearance of the substance under consideration in one of the possible phases. But Lavoisier showed that heat played no role in adding or decreasing weight in chemical reactions, as had been claimed by the phlogiston theory.

[44] The conservation of mass was also of importance in changing alchemy to chemistry. It cleared the way for the concept of chemical elements. Lavoisier stated the conservation of mass in several instances, so e.g. an experiment on phosphorus absorbing oxygen during combustion: The mass of the result is equal to the sum of the initial masses of phosphorus and of the absorbed oxygen.

Fig. 5: Calorimeter used by Lavoisier (figure from ref. [24])

6.1.2) The Chemical Philosophy of John Dalton

A decisive step was set by **John Dalton** by relating the difference of elements to atoms differing in weight[45]. His extensive studies of the specific heats (that is the ability to store heat) of various substances led him to attribute the change in the specific heat with temperature to "a new arrangement or disposition of its ultimate particles". He was able to determine the relative weights of the atoms from "the relative weights of the simples [i.e. elements] which constitute a compound". Such he proposed the first periodic table of elements published 1808 in his *A new system of Chemical Philosophy* [5]. Part 1 contains his rather general considerations about "heat or caloric" and the constitution of bodies and liquids; part 2 is dedicated to specific elements and substances.

The new conception is summarized in the short third chapter of part one "On chemical synthesis". Dalton advances the theory that [5]

- Substances are composed of simple elementary particles (atoms) of various weights: "… the ultimate particles of all homogeneous bodies are perfectly alike in weight, figure, etc. In other words, every particle of water is like every other particle of water; every particle of hydrogen is like every other particle of hydrogen, etc."

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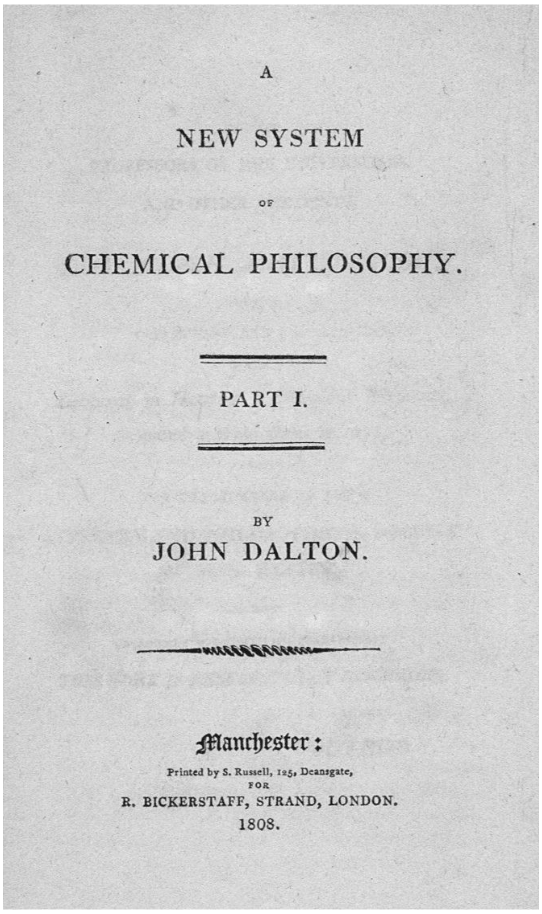
[45] Previously his studies of water vapor and gases led him to a theory about water and mixed gases. His law of partial pressures resulted:

In a mixture of gases in a given volume, each component exerts the same pressure as it would if it would fill alone the whole volume.

- Each chemical element consists of one kind of atoms. So that the atomic weight can be inferred from the relative weights of the elements. During a chemical reaction the atoms remain unchanged. So he established a first chart of twenty elements (today we have about 118 elements).

- The particles of compounds are formed by combining elementary particles, e.g.: "1 atom of A + 1 atom of B = 1 atom of C, binary. …"



A

NEW SYSTEM

OF

CHEMICAL PHILOSOPHY.

PART I.

BY

JOHN DALTON.

Manchester:

Printed by S. Russell, 125, Deansgate,

FOR

R. BICKERSTAFF, STRAND, LONDON.

1808.

Fig. 6: Title page of Dalton's *A new System of Chemical Philosophy*, London 1808

Some of Dalton's relative atomic weights are not correct; amongst other errors he attributes *one* oxygen and *one* hydrogen atom to an "atom" (molecule) of water. But one has to be aware that this was only the beginning of systematic investigations and the property of a substance to be elementary or not was often not decided yet. For example, Dalton lists also lime amongst the elements.

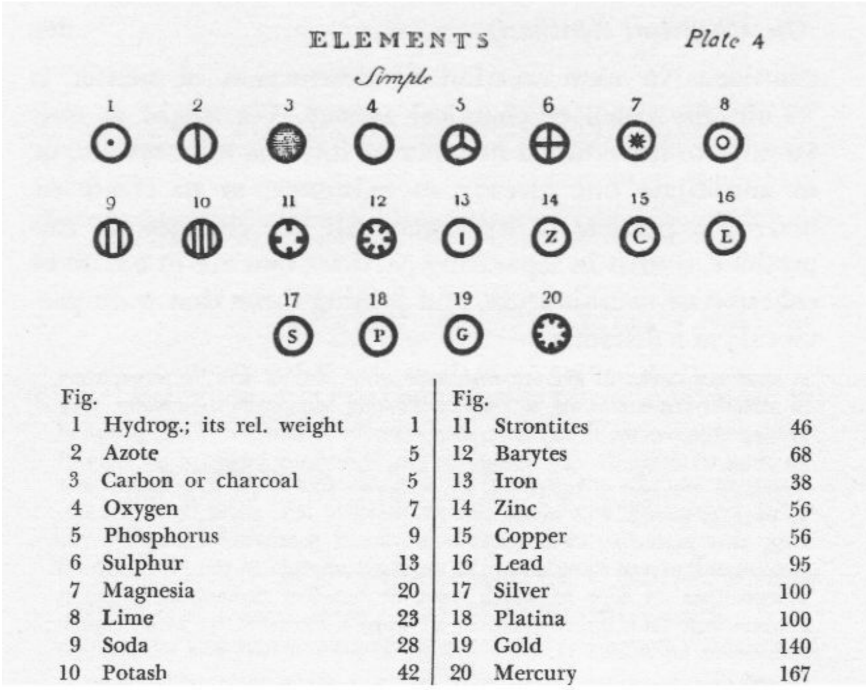


Fig. 7: Dalton's periodic table (from ref. [5])

These Fundaments of the periodic system of elements provided the unifying idea turning alchemy into chemistry; "..., the publication of … *A New System of Chemical Philosophy* in 1808 started the chemical revolution of the nineteenth century …" (cited from A. Joseph's introduction to the 1964 edition, ref. [5]).

Dalton's system was extended 1868-70 by D.I. Mendeleew (1834-1907). 1869 Mendeleev predicted new elements on the basis of vacancies in his periodic table.

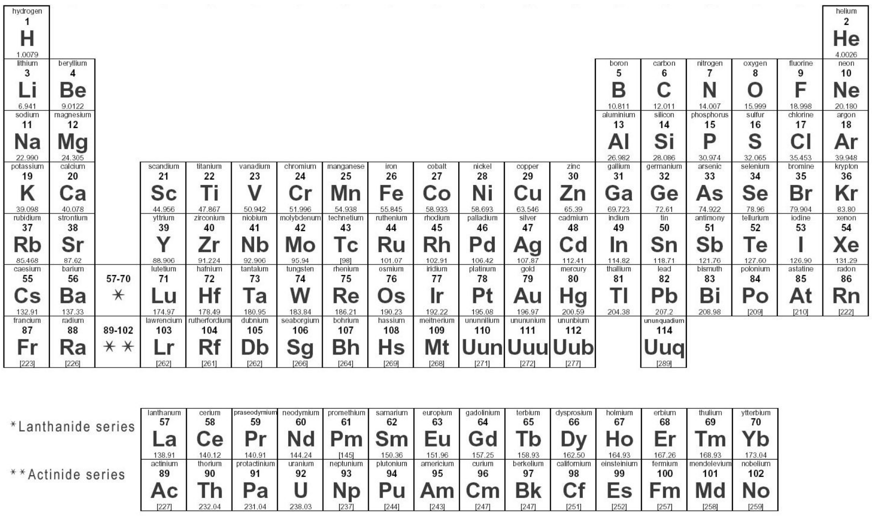


Fig. 8: A modern periodic table of elements

6.2) Biology

Systematic studies concerning growing and dying beings in nature are hardly present in antiquity. Only starting in 1665 with **Robert Hooke's** *Micrographia* [14] a continuous engagement can be traced. The Micrographia is a detailed account of his observations of various organisms[46] using a microscope devised by him; the observations are illustrated with many beautiful drawings. Famous is Hooke's description of cells in a thin slice of cork (see the following picture).

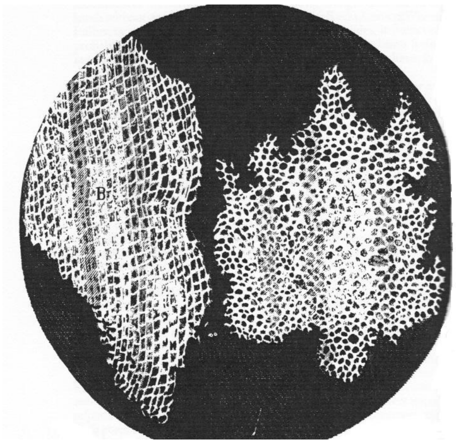


Fig. 9: Hooke's illustration showing his observation of a slice of cork using a microscope (ref. [14])

6.2.1) Linnæus' natural system and Lamarck's theory

Then, a first step towards a science of biology is performed 1735 by **Carl Linnæus** with his *Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis*[47] [25], by arranging animals, plants and minerals in a hierarchical system of classes, ordines, genera, and species. Also Linnæus wrote a book containing the word philosophy in the title: 1752 he published the *Philosophia Botanica* [26] explicating his binomial nomenclature in botany[48].

Still it was generally considered to be self-evident that nature (creation) is invariable. This opinion was challenged by **Jean-Baptiste Lamarck**. From his studies of animals and plants, taking also into account already extinct species, an idea of descent emerged. 1809 he presented in his book *Philosophie zoologique* [20] a theory of evolution relying mainly on his studies of invertebrates (insects and worms). In particular Lamarck established two laws:

1) For every animal the frequent use of an organ strengthens and develops the organ, whereas a continuous disuse weakens the organ and diminishes its capabilities.

[46] The very last part contains also observations of the fixed stars and the moon using a telescope. Worth mentioning is Hooke's discovery of the multiple refraction of the atmosphere.

[47] *System of nature through the three kingdoms of nature, according to classes, orders, genera and species, with characters, differences, synonyms, places*. The first edition of *Systema naturae* was printed 1735 in the Netherlands. It was an eleven page work. By the time it reached its 10th edition (1758), it classified 4,400 species of animals and 7,700 species of plants. (Wikipedia)

[48] Still present in Linnaeus' works are topics and observations not considered today to be part of biology like pharmacy and other, more equivocal influences of plants, minerals on humans (e.g. Systema naturae [25] p. 251 and Philosophia Botanica [26] Ch. XII, Potencies)

2) Individuals, whose organs are changed according to the first law, due to the influence of the environment, bequeath the changes to their descendants.

It is mainly the second law that arose much attention and controversy.

6.2.2) Darwin's Origin of Species

From 1831 until 1836 Darwin participated in the mission of the British ship 'Beagle' to survey the coasts of several countries and to explore them. This expedition was a big chance for the young man and Darwin took the opportunity: All his life-long work is rooted in the experiences he made during that expedition, particularly his famous theory of natural selection. In 1859 he published[49] his *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life* [6].

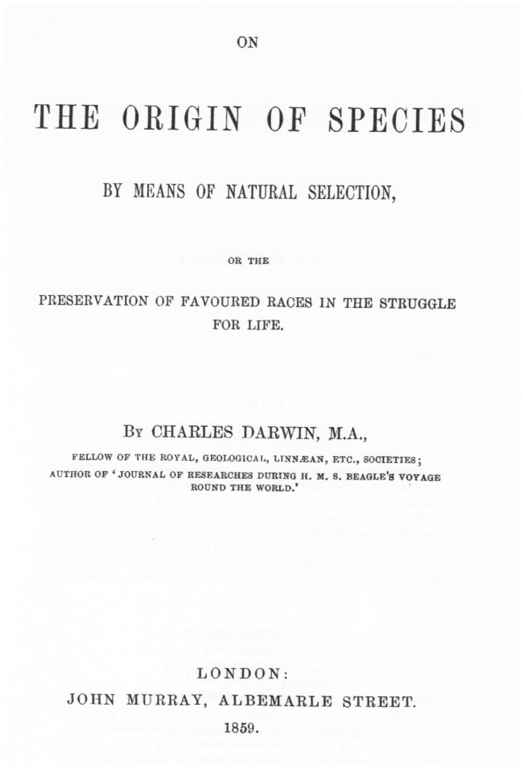
The central idea of Darwin's Origin of Species, presented in Chapter 4, is the selection of species by "survival of the fittest" [50]. His conclusions are based on many different aspects, e.g. geological records or geographic distribution. It is said that Copernicus removed the Earth together with Man from the center of the universe[51] and Darwin removed Man from the center of nature[52]. Already in 1844 he handed over a preliminary version to his wife and asked her to publish it in the case of his death.

[49] The publication of the *Origin of Species* was a rather hastily procedure. Considering the publication already for many years, 1858 there appeared suddenly a competitor: A.R. Wallace, who sent a short article containing the same ideas just to Darwin. It was then decided that Wallace's article together with an outline of Darwin's intended book should be presented at the next meeting of the Linnæus society.

[50] The phrase "Survival of the fittest" was coined by H. Spencer in his *Principles of Biology* of 1864; Spencer drew parallels between his ideas of economics with Charles Darwin's "natural selection". Starting with the 5th edition of the "Origin of Species", published 1869, the chapter about natural selection is headed by: "*Natural Selection; or The Survival of the Fittest*".

[51] See E. Kästner's preface to H. Kesten's biography of Copernicus, K. Desch, Munich 1953

[52] Author unknown


ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

BY CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

Fig. 10: Title page of the 1st edition of Darwin's *Origin of Species*, London 1859

Darwin was anxious not to conflict with the public religious opinion in that Victorian time. So he hesitated to publish his opus magnum for about 15 years. And of course, after publication, he had many objections from this side. Darwin's *Origin of Species* caused an immense public response: numerous discussions, objections, and approvals. This was partly due also to the general language used – only few technical terms appear – and the topic, which is close to general interest and apprehension.

The second famous book by Darwin is his *The Descent of Man, and Selection in Relation to Sex* [7], published 1871. It presents Darwin's theory of sexual selection in three parts: Descent or Origin of Man, Sexual Selection (within animals), Sexual Selection in Relation to Man and Conclusion.

The two books, the *Origin of Species* and *The Descent of Man*, are written in complete different styles. The second one is full of footnotes references, citations and pictures; all these are absent in the former book.

In particular the unifying view of Darwin´s *Origin of species* establishes Biology as a science; his point of view and his laws governing evolution are given as a conclusion in the very last paragraph of the book (ref. [6], my emphasis):

"It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us. These **laws**, taken in the largest sense, being **Growth** with Reproduction; **Inheritance** which is almost implied by reproduction; **Variability** from the indirect and direct action of the external conditions of life, and from use and disuse; a Ratio of Increase so high as to lead to a **Struggle for Life**[53], and as a consequence to **Natural Selection**, entailing Divergence of Character and the Extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."

6.2.3) Mendel's experiments

This short account on the rise of the science of biology is concluded by referring to another important work, **Gregor Mendel's** *Versuche über Pflanzenhybriden* [27] (Experiments on Plant Hybridization), presented 1865 at two meetings of the Natural History Society of Brünn (Brno) in Moravia. Between 1856 and 1863 Mendel cultivated and tested about 30,000 pea plants (*Pisum sativum*)[54]. From his experiments he concluded two laws known as Mendel's Laws of Inheritance. When Mendel's paper was published in 1866 in the *Verhandlungen des Naturforschenden Vereins in Brünn* (Proceedings of the Natural History Society of Brünn), it had little impact and was cited about three times over the next thirty-five years. His paper was criticized at the time, but is now considered a seminal work. Mendel's Laws of inheritance are an essential, basic contribution to the foundation of biology.

7) Epilogue: The adolescence of Sciences

In the second half of the 19th century the foundations of natural sciences may be considered finished. Physics, being in advance, came seemingly to its perfection: In the first half of the 19th century Maxwell's Theory of Electrodynamics was added to the building of physics[55]. **James Clark Maxwell's** *A Treatise on Electricity and Magnetism* published 1873 is the last big book that marks the beginning of a new branch in physics[56]. In the second half of the 19th

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[53] Elsewhere in the book Darwin used mainly the words "Struggle for existence".

[54] This study showed that one in four pea plants had purebred recessive alleles (i.e. slightly modified genes), two out of four were hybrid and one out of four was purebred dominant.

[55] Afterwards the onset of new theories can only traced back only to articles in periodicals and journals and not to books. These new fields are presented later on in textbooks.

[56] There is almost one exemption I am aware of. In 1930 M. Born and P. Jordan published their *Elementare Quantenmechanik* (Elementary Quantum Mechanics) in order to propose the matrix mechanical version of Quantum Mechanics they invented recently together with W. Heisenberg. This attempt was ineffective. The rival candidate, Schrödinger's wave mechanical version became the `official´ form of Quantum Mechanics.

century the last, missing part of physics, Statistical Physics, was created by J.C. Maxwell, L. Boltzmann, and J.W. Gibbs in order to explain the macroscopic appearances of matter from its constituents, the atoms. Now the physics-building seemed to be pretty finished. Still, seemingly only minor problems and inconsistencies had to be removed – that was the general belief. But the detailed inspection of these problems gave rise to the most recent physical theories: the Theory of Relativity and Quantum Mechanics.

Subsequently the picture of the system of the world created by Newton and Laplace changed. The theories of relativity and quantum mechanics also led to a new understanding of the evolution of our universe: the Big Bang Theory, based on the modern physical theories of fields and matter in space and time and not on Kant's and Laplace's conjectures[57].

The successful methods and the subject of physics brought about the desire to use its concepts in astronomy and biology as well: astronomy and biology are augmented by some of the physical concepts to give Astrophysics and Biophysics. It characterizes the development of science in general that both, astrophysics and biophysics, expand or even replace the rather descriptive and classifying sciences (knowledge in the sense of the introduction) of astronomy and biology. And chemistry could benefit from the incredible progress of physics, due to its close relatedness. Chemistry always used the concepts of physics and there still is a fruitful exchange of ideas between these two sciences. An example is the award of the 1998 Noble prize in chemistry to physicist W. Kohn for his quantum mechanical description of many body systems, allowing a much more effective calculation of system properties.
But also other sciences took advantage of the powerful methods of physics[58], in particular of statistical physics. So, for example, from economy the new field of Econophysics originated. In many areas dealing with risk-management, like insurances, the statistical methods of physics enter.

Final review

I have tried to sketch the birth and rise of natural sciences. These sciences emancipated from philosophy under severe observation of theology, or more exactly, the doctrine of the Roman Church. For both, philosophy and theology, reality – more precisely the current picture of reality – is an important prerequisite. But it is just the task of natural sciences to explore reality and to provide pictures of reality as accurate as possible. Now sciences became grown up and there is a kind of turnaround in the relationship between natural sciences on the one hand and philosophy and theology on the other. Natural sciences do not depend on philosophy or theology, they are no maidservants any more, neither to theology nor to philosophy; now

[57] A book on big bang theory could be entitled 'On the Origin of the Universe' thus paralleling explicitly Darwin's *On the Origin of Species*.

[58] A caricature of the (mis)use of physical ideas and terms was provided 1996 by A. Sokal's „entropy-hoax" (Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity, Social Text #46/47 (Duke University Press, 1996)).

these two have to follow the scientific progress and to reconsider their systems constantly according to the advance of scientific insight.

Appendix

Table of lifetimes (1)

(Biographical data are approximate)

Thales (624-546)
Pythagoras (530-497)
Democritus (460-370)
Plato (429-348)
Aristotle (384-322)
Euclid (365- 300)
Archimedes (287-212)
Heron (10-75)
Ptolemy (100-175)

Table of lifetimes (2)

Copernicus N. (1473-1543)
Galileo G. (1564-1642)
Kepler J. (1571-1630)
Descartes R. (1596-1650)
Boyle R. (1627-1692)
Hooke R. (1635-1703)
Newton I. (1643-1727)
Leibniz G. (1646-1716)
Euler L. (1707-1783)
Linnæus C. (1707-1787)
Kant I. (1724-1804)
Lagrange J. L. (1736-1813)
Lavoisier A. (1743-1794)
Lamarck J.-B. (1744-1829)
Laplace P.S. (1749-1827)
Dalton J. (1766-1844)
Darwin Ch. (1809-1882)
Mendel G. (1822-1884)
Mendeleev D.I. (1834-1907)

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Darwin: J. Browne, Darwin's Origin of Species. A Biography, Atlantic Books 2006

My search for a biography on Dalton was not successful, only short biographies on the internet are available.
I did not look for extensive biographies on the other persons mentioned above. Short biographies of each of them are available on the internet.