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A Third Pillar for the Natural Sciences: the World of Chemistry

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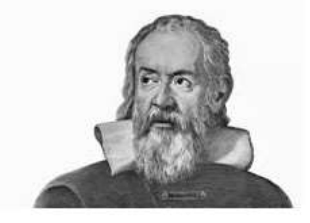


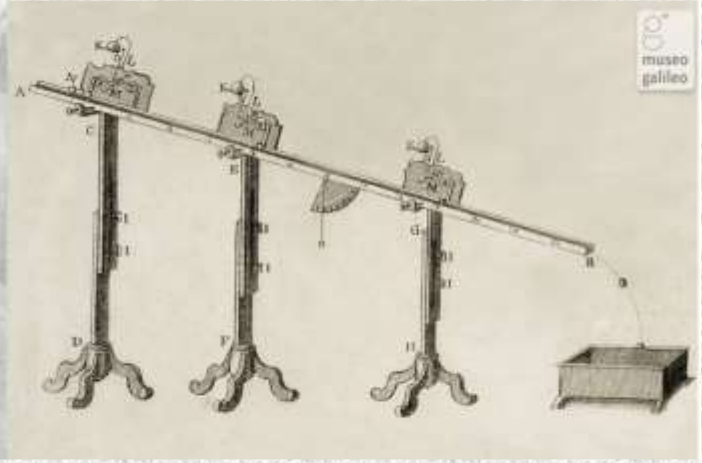
At the foundation of modern science in the 17th century, Galilean revolution led to the identification of the **scientific method** that is still considered the **boundary** between **what is scientific and what is not**.
There could be many quotations suitable to illustrate the **new worldview** of emerging modern science.

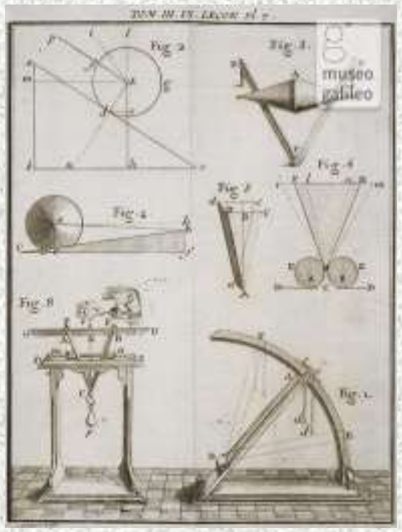
The two most common used Galilean phrases to describe this cultural change, which I will also use here, are:

(1) *Given this, therefore, it seems to me that in the disputes of natural problems one should not begin with the authorities of places of the Scriptures, but from* ***correct experiences (sensate esperienze)*** *and the* ***necessary demonstrations (necessarie dimostrazioni).***

(2) *Natural philosophy is written in this huge book that is continually open before our eyes, I mean the universe, but it cannot be understood if we do not first learn to understand the language and know the characters in which it is written.* ***It is written in the language of mathematics****, and the characters are triangles, circles and other geometric figures, without which it is humanly impossible to understand a single word of it; without these it is a wandering in vain through a dark labyrinth.*

Modern science has been structured around these two Galilean pillars: **sensate esperienze** (correct experiences because they are conducted through the senses) and necessarie dimostrazioni (mathematical demonstrations), or in modern terms, **experiments** and **mathematics**.





These **two pillars** have played a fundamental epistemological/scientific role and from that moment have delimited natural science from philosophical interpretations.

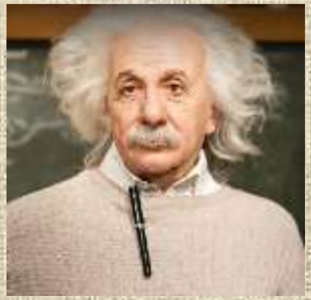
The very **close relationship** between **natural science** and **mathematics**, however, made it difficult **to include chemistry**, the reflections on living systems that we now call **biology** and **medicine** in the **scientific field**. In fact, this Galilean cultural revolution has **placed beyond the scientific boundaries not only all the human and social sciences, but also the entire chemical-biological-medical scientific area.**

The Galilean relationship between the natural sciences and mathematics was made stronger by time. For example, a century and a half after Galileo, Immanuel Kant reiterated that in every particular doctrine of nature, one can find as much science as there is mathematics within it.

I assert, however, that in any special doctrine of nature there can be only as much *proper* science as there is *mathematics* therein. […]. **Now rational cognition through construction of concepts is mathematical**. […] in any doctrine of nature there is only as much proper science as there is a priori knowledge therein, **a doctrine of nature will contain only as much proper science as there is mathematics capable of application there**.

Immanule Kant, (1786)

To get to the present, Einstein could be a good example of the relationship between science/physics and mathematics.



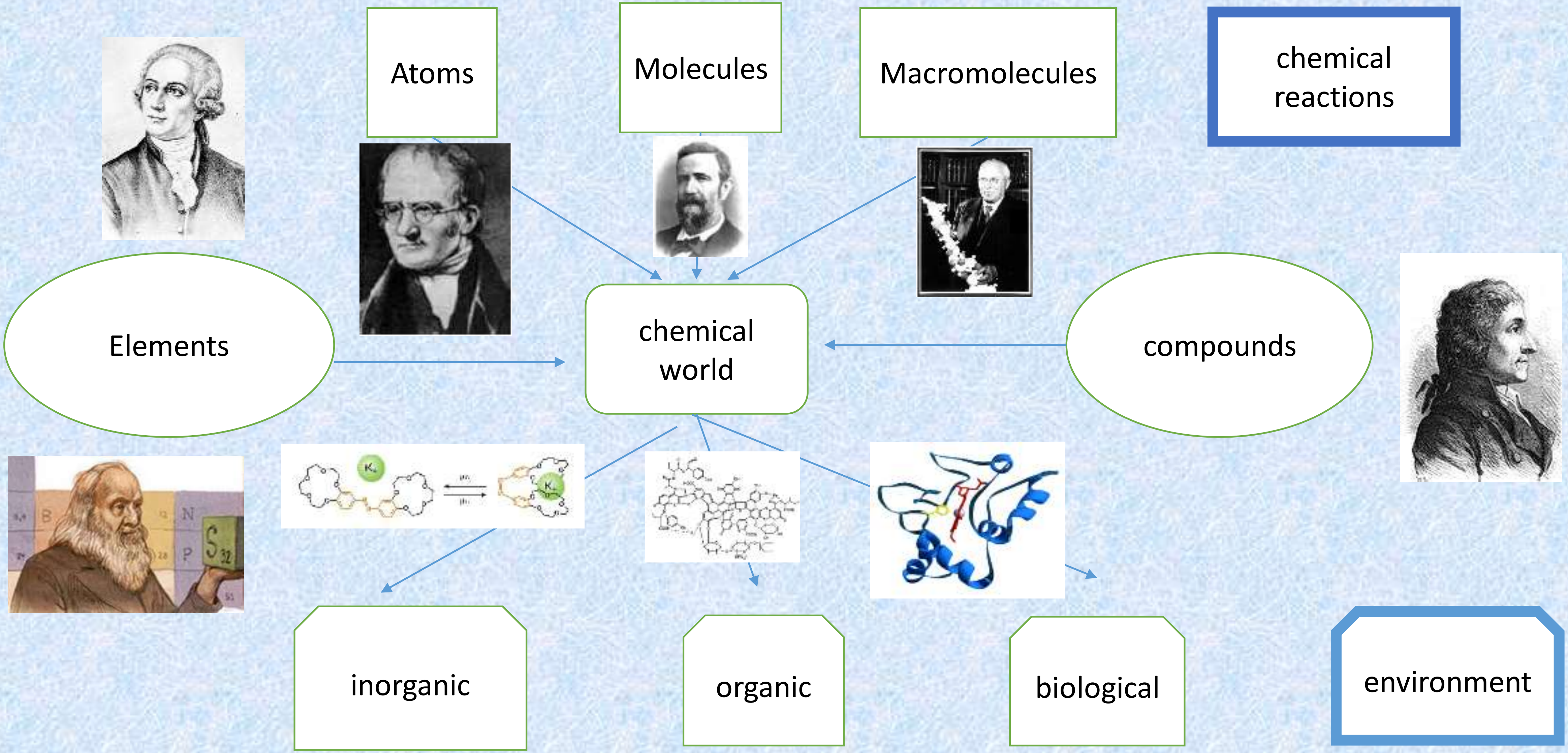
The theory of relativity is a wonderful example of how **mathematics has provided the theoretical tool for a theory of physics**, without the problem of physics having had a decisive role for the corresponding mathematical creations. The names of Gauss, Riemann, Ricci, Levi-Civita and their works would belong to the important contributions of Western thought even if these had not led to the overcoming of inertial systems.

Einstein, 1952

What about the other natural science disciplines?

In the following centuries to the Galilean revolution, the chemical-biological-pharmaceutical-medical area tries to re-enter the scientific field with, on the one hand, a partial "mathematization" and, on the other, claims its own "different" scientificity.

Chemistry, in particular, started from the revolution of the concepts of substances (elements and compounds) in the macroscopic world and of atoms and molecules/macromolecules in the microscopic world, imposes a new type of scientific explanation for the properties and processes of transformation of the material world, that we name: the **chemical world**. This type of explanation is then transferred to scientific disciplines where chemical optics can be applied.



Atoms
Molecules
Macromolecules
chemical reactions
Elements
chemical world
compounds
inorganic
organic
biological
environment

All of us have direct experience of chemical explanation of the material world; it is so obvious to us that we rarely pay attention to it.

In this context, however, I believe it is important to summarize the characteristics of the chemical explanation and I will do so according to my personal synthesis.

For me it is possible to divide the chemical explanation into three parts:

(1) A static part;

(2) A dynamic part;

(3) Modeling problems.

In the next three slides I will move along these three directions.

Chemical explanation

Static aspects

There are **millions of substances** in the **macroscopic** world and **millions of** elementary particles in the **microscopic** one, each one with **its own set of properties** that deserve a **specific name.** In the microscopic world, in particular, it is the concept of “structure” (internal organization) that identifies the entity.

These chemical individuals are placed in a **context/environment** and in this they must be integrated (physically or otherwise). The properties of these entities in the environment **can be in general different from those typical of the isolated entities**.

Interactions between entities in the environment (and with the environment globally) generate a situation that we describe with chemical concepts.

These interactions, in fact, have **a physical basis** (mechanical, electrical, magnetic), but globally they create new chemical concepts, such as **chemical bond and molecular structure**, for example.

Chemical explanation

Dynamic aspects

There is an **internal dynamics** at the level of microscopic entities. An example can be the molecular vibrations.

This **internal dynamics** is related to the **external dynamics** in which these microscopic entities are involved in the environment.

These two types of processes are **easily separated in some cases, more difficult in others.**

All these processes occur over time with their own specific mechanism and globally there is a general mechanism that **causally** explains what happens in that situation.

The concepts of **chemical reaction** and **mechanism of chemical reaction** are the main concepts **to describe the transformation** of the material world **in the dynamical chemical approach**.

Chemical explanation

Modeling

The separation between the internal and external statics/dynamics of these microscopic chemical individuals is an essential part of their modeling. Even the concepts of **isolated entity** and **entity in a context**, in fact, exist only as simplifying models of a complex reality.

As a conclusion, the concepts of structure of the entity and mechanism of transformation are the essential components of chemical explanation in the microscopic world.

Is this type of chemical explanation well recognized in the philosophy of science? My feeling is that it is valued "less than its potential", "less than it deserves". The causes of this situation are closely related to both philosophers of science and scientists, and to some extent also to chemists.

In particular, I would like to underline that today in the philosophy of science we are witnessing an important change, that of the scientific discipline of reference: from physics to biology. In my opinion, the risk is that chemistry is neglected in this paradigm shift.

What is, in fact, the current situation in the philosophy of science?

Logical empiricism (neopositivism)

The philosophy of science of the first half of the 20th century was largely dominated by logical empiricism (or neopositivism) which tended, in general, to focus on the abstract and epistemic aspects of science, with little attention to actual scientific practice. Physics was the dominant discipline, and the relationship between science and mathematics, even between philosophy and mathematics, was essential.

«Developing a philosophy of nature must therefore remain the prerogative of a particular group of scholars such as the one that has recently emerged, a group of scholars who on the one hand master the techniques of **mathematical science …**» Hans Reichenbach

In the second half of the last century, logical empiricism was questioned, but physics remained the reference science. Even Quine, who questioned neopositivist approach, said:

"Physics investigates the essential nature of the world, and biology describes a local bump. Psychology, human psychology, describes a bump on a bump" - Willard van Orman Quine, *1981*

In the 21st century, a new current of thought in the philosophy of science is emerging, called the **new mechanical philosophy**.
At the turn of century, the very influential article "**Thinking About Mechanisms**" by Machamer, Craver, and Darden becomes the birth of this new approach. This paper generate an extensive debate about mechanism and mechanistic explanation, where these authors by mechanism mean: **a set of entities that carry out their activities in a specific space-time organization**.
But should we believe that the use of the concept of mechanism in scientific explanation is specific to the study of living systems? As I tried to show, definitely not.
For example, these authors also in the cited work report the mechanism that can be found in the process that occurs at the synapse between two neurons and, significantly, in this example they use the term "**chemical synapses**".

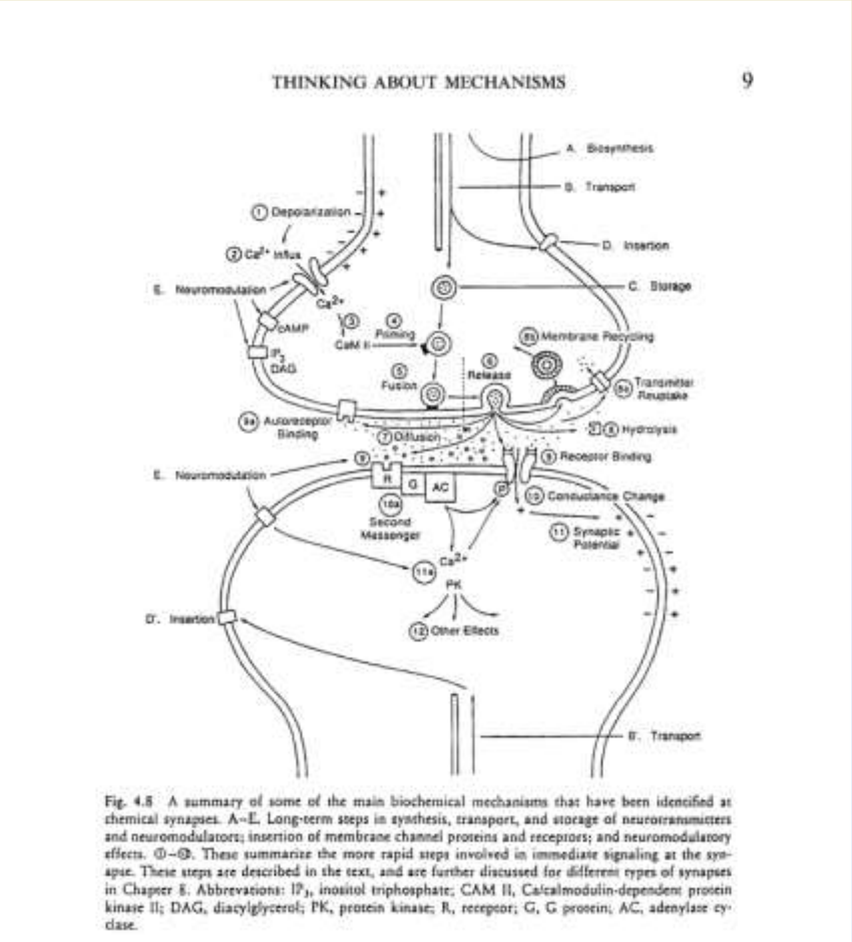


Fig. 4.8 A summary of some of the main biochemical mechanisms that have been identified at chemical synapses. A–E. Long-term steps in synthesis, transport, and storage of neurotransmitters and neuromodulators; insertion of membrane channel proteins and receptors; and neuromodulatory effects. ①–⑫. These summarize the more rapid steps involved in immediate signaling at the synapse. These steps are described in the text, and are further discussed for different types of synapses in Chapter 8. Abbreviations: IP_3, inositol triphosphate; CAM II, Calcalmodulin-dependent protein kinase II; DAG, diacylglycerol; PK, protein kinase; R, receptor; G, G protein; AC, adenylate cyclase.

Today, I believe that understanding of living systems takes place in a chemical perspective because chemical explanation works in the **same perspective**. I have decided to show this with the book *The origin and nature of life on Earth* of Smith and Morowitz. They say:

Our understanding of the biosphere must be chemical. Organic chemistry **is not an accidental stage** on which abstract principles of life perform a play that could be performed elsewhere.
Chemistry matters in detail because it matters in principle.
Some of the most important sources of stability and complexity in life would not be expressible in any other system.

At this point the question should be: "Can only living systems be understood from the chemical perspective?" An indication of the answer to this question can be found in the same book. The authors, in fact, also affirm the link between geochemistry and biochemistry.
<u>The ecosystem is the bridge from geochemistry to life, and carries much of what is deterministic and necessary in metabolic order</u>.

From this type of connection, we can arrive to the conclusion that, in Galileo’s words,

Today's scientific material world is written in **chemical language** and its characters are atoms, molecules and macromolecules in the microscopic world and chemical substances in the macroscopic one. Without these, it is a wandering in vain through a dark labyrinth.

G. Villani, L’INTERPRETAZIONE CHIMICA DEL VIVENTE

Fondamenti sistemici delle scienze della vita (Clueb, Bologna, 2023), p. 18.

To conclude, I think we can say that the chemical world, together with the two Galilean pillars (experiments and mathematics), today constitutes the third pillar of scientific explanation in all natural disciplines.