The path of science towards increasing formalization and abstraction, and the roots of the “revolution” in physics of the early Twentieth century

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Wien, 3 March 2017
Through the 19\textsuperscript{th} and 20\textsuperscript{th} centuries science has drastically evolved towards increasing formalization and abstraction.

Was this an intrinsic evolution, imposed by the increasing complexity of the levels of nature disclosed, or was it a reflection of new needs expressed by changes of the social economic situation?

Science is not a simple aspect of knowledge, of investigation of nature, but a socially interested and oriented activity.

Nature is not immediately given in itself to humankind, but always as a pole of a relationship, in which the other pole is “man” as a social, materially interested being (interest, Latin etymology inter-esse “being-between”).
Think for instance how culture, traditions, language deeply influence our concepts of nature.

The *pacha mama* (mother earth) of the indigenous peoples of Latin America is very different from our conceptions.

Lovelock's theory of “Gaia” conceives Earth as a living organism.

Etc.
I submit you a pure speculation:

If aliens with superior intelligence would arrive on Earth, they would clearly have higher scientific knowledge then ours, but I would deeply wonder that they would have developed scientific concepts, theories and formalisms identical to our ones.

I always wonder of the naivety of certain science-fiction. In “Independence Day” even computers and information systems would be the same!
Of course, science is not directly determined by society.

Production of science is a social activity, intertwined with the social environment, its contradictions, cultural currents, the role of scientists and their organization, economic and technological demands.

In every historical period many ways are open to scientific development: society determines the real choice.

Main social interests drove science towards an increase of formalization and abstraction.

A formal approach is more flexible, formally applicable to a variety of phenomena, suited to a variety of techniques. But alternatives were always viable.
Modern science was a product of Western industrial society

During the First Industrial Revolution in England and France, an empirical approach prevailed, based on empirical facts, experimental data.

For instance: atomic models were not accepted (Avogadro-Ampère hypothesis), phenomenological classification of organic compounds (Gerhardt, later acknowledged as inconsistent).

Even technology was empirically based. Scientific knowledge depended on phenomena empirically disclosed by technical inventions.
Turning period: 1848

Middle (business) class prevailed in Central Europe. It had to compete with the one-century-old industrial England.

To this end, it searched for radical innovations, not merely empirical technologies.

1850-1870, spectacular increase of the pace of inventions and patents (E. Hobsbawm, “The Age of Capital, 1848-1875”): innovative processes for steel, Solvay process for soda ash, ...

But something more effective than ingeniousness was needed, in order to design radically new techniques.
Science had to shake off its dependence from empirical facts, and become predictive!

Needless to say, there was no automaticity in such a process, it was a change of mindset, a social class transition.

Since mid-1850s models, unobservable entities were (mathematically) introduced in physics and chemistry:

- 1855, Maxwell: e.m. fluid (ether),
- 1857, Clausius, kinetic theory,
- 1859, Cannizzaro, Karlsruhe, distinction atom-molecule

Beyond experimental evidence, but effective probes for highlighting new, unknown phenomena
Maxwell, eather

Fig: "Model of aether composed of wheels and gears"
Division of scientific labour, birth of \textit{theoretical physics} as an autonomous activity, with a \textbf{predictive power}:

- 1865-1873, Maxwell, theory of electromagnetism, prediction of e.m. waves, historic discovery!

- 1866, Clausius, Maxwell, \textit{kinetic theory}

- 1876, Boltzmann, \textit{probability}.
Chemistry

- The chemists formulated 3-dimensional models of molecular structures.
- Classification of organic compounds
  Instance: Kekulé, 1865-66, benzene, C6H6

- Operations of true “molecular engineering”
- Design of new compounds, and new processes.
- Performed works of true molecular engineering, designing new molecules.
How Germany overcame Great Britain in the leading industrial sectors: through radically innovative technological changes!

At the turn of the century the average dimensions of German steelworks were four times those of the British' (D.S. Landes).

Chemical scientists and engineers (Polytechnics) were deeply involved in German chemical industry (BASF, Bayer, Hoechst, Agfa).

Delay of British science, Parliamentary Committees of Inquiry appointed:
“It is impossible for a chemist to get a modern preparation in Britain, he must go to Germany” (Roscoe)
Steel Production

Millions of tons

Year

1870  1880  1890  1900  1910

Germany

England

France
End of 19th century:

Second Industrial Revolution

E. Hobsbawm, “The Age of Empire, 1875-1914”; D.S. Landes, “Technological Change and Industrial Development in Western Europe”)

Processes centered in Germany.

The paths of the physicists and the chemists diverged
Decline of British industrial power.
The ranking of industrial powers turned upside down!

1850
Great Britain
France
[United States]
Germany

1900
[United States]
Germany
Great Britain
France

Remark: Great Britain remained a stronger economic-financial-commercial power than Germany (the two World Wars!)
PHYSICS

Paradoxes:
– Ether wind
– Reversibility
– Recurrence

Harsh controversies:
Mach, empirio-criticism; Ostwald, energetics.
Refusal of models.

“It was impossible to be listened against the authority of Ostwald and Mach” (Planck, Autobiography)

“I am conscious of being an individual who weakly fights against the trend of the time” (Boltzmann, 1896)
ULTIMATELY, THE ORIGIN OF THE PARADOXES WAS MECHANICISM

During all the 19th century the physicists considered only mechanical models.

“A phenomenon is explained when we find a mechanical model for it” (Lord Kelvin)

*Contradiction*: since models were conceived as tools to foresee new phenomena, why restrict oneself to mechanical models?

Only in the year 1900 this limitation began to be overcome (by a new generation).
The chemists and chemical engineers (Technische Hochschulen) were widely (thousands) employed in the German chemical industries.

Each industry established collaborations with local university professors (chemist and/or chemical engineer).

German chemists were strongly pushed to rapidly and effectively solve extremely complex problems.
The physicists dealt with relatively simple problems.

The problems that the chemists faced were EXTREMELY complex and difficult!

Chemical equilibrium of complex, multi-staged reactions

1856, Guldberg and Waage:

\[
\begin{align*}
A + B & \rightleftharpoons C + D \\
\end{align*}
\]

\[
k = \begin{vmatrix} C & D \\ A & B \end{vmatrix}
\]

A kinetic treatment materially impossible!

Without conflicts the chemists shifted towards a thermodynamic treatment
Free energy (chemical “potentials”)

- Free energy = Internal energy – T
- Entropy \( A = U - T \cdot S \)

Equilibrium: Minimum of Free energy

Quite intuitive: Energy tends to decrease, Entropy tends to increase.

Important remark: state functions depend only on initial and final states, independently from intermediate steps.

The case of multi-stage chemical reactions, impossible to calculate on a kinetic basis.
PHYSICS ~ 1890 - 1900

“Creakings”:
- Atomic spectra (internal structure?!) 
- Radio-activity (Becquerel, 1896)
- Cathode rays
- The electron (J.J. Thomson, 1897)

Big technical progress
Physikalisch-Technische Reichsanstalt, Berlin

Spectrum of cavity radiation, 1900
Physics in the early 1900s

a small world

(J. Heilbron, Physics 1900)

ACCADEMIC PHYSICIST (Faculty, Total):

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<th>Country</th>
<th>Faculty</th>
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<td>Japan</td>
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A small world, Wien around 1900 (Janik, Toulmin, Wittgenstein's Vienna):

«It is not easy today ... to recognize just how small and tightly knit were the cultural circles of the Habsburg monarchy. [...] Mass education makes it difficult to conceive of a country in which there was only one real university, contained pretty much in one single building; [...] Thus it comes as a slight shock to discover that Anton Bruckner gave piano lessons to Ludwig Boltzmann; that Gustav Mahler would bring his psychological problems to Dr. Freud; that Breuer was Brentano's physician, that the young Freud fought a duel with the young Viktor Adler, who had attended the same high school as both the last of the Habsburgs; and that Adler himself, like Schnitzler and Freud, had been an assistant in Meynert's clinic. In short, in late Habsburg Vienna, any of the city's cultural leaders could make the acquaintance of any other without difficulty, and many of them were in fact close friends despite working in quite distinct fields».

A world at the brink of its disintegration:

«A layer of waltz and whipped cream covered at the surface a desperate society ... any proportion between semblance and reality had disappeared.»
Radiation spectrum, Planck 1900

Generally accepted Wien heuristic formula (1893):
\[ u(\lambda, T) d\lambda = \gamma \lambda^{-5} \cdot \exp(-\delta / \lambda T) \cdot d\lambda \]

REMARK: Planck opposed Boltzmann's concepts, he even did not accept the atomistic view!

February 1900: he got a purely thermodynamic “justification” (parametrization) of Wien formula.

October 1900: congress, experimental results.

The same night Planck modified his thermodynamic parametrization: his result satisfied the experimental data (“historical” Planck formula).

Then he searched for an “explanation' He formally turned to Boltzmann statistical approach

This is the paper in which he is said to have introduced the quantum, but . . .
Planck had to calculate the different numbers of partition of energy \( E \) on the oscillators: but if \( E \) is continuous, infinite number of partitions, probability concepts lose sense.

Planck “discretized” energy adopting an “energy element”, however calculating the ratio between the energy of the oscillators of a given frequency and the ”energy element” \( h\nu \), he stated that

«When the ratio is not an integer, we take for it the nearest integer»
Nobel lecture, 1920, Planck called this approach “An act of desperation”!

1931: «It was a purely formal hypothesis, and I certainly did not devote much attention to it: the only thing that interested me, at any cost, was to arrive at a positive result»

Only around 1912 Planck accepted the truly statistical nature of the second law.

**Einstein 1905** really introduced the physical quantum of light. Einstein definitely abandoned a mechanical description (special relativity re-formulates Newtonian mechanics), and adopted thermodynamics in its statistical formulation.

However he strongly relied on a realistic description of phenomena in space and time.
After the carnage of World War I, the 1917 Soviet revolution, the demolition of the old order, a wind of irrationality spread in Europe

«The belief in a rational world order was shaken by the way the war ended and the peace dictated; consequently one seeks salvation in an irrational world order.»  (Sommerfeld, 1927)

Weimar Republic

A melting pot, a laboratory of innovative experiences, explosive contradictions.

The crisis upset every social activity and expression. Direct reference to the object of (artistic or scientific) interest, got into deep crisis, with the very substance of human existence, in the tormented and desperate conception of human existence in Expressionism, as well as in the developments of philosophical thought. The rationality of human behavior was subverted by Freud’s unconscious. All that reflected in the artistic expressions, in the deconstruction of the object; Schönberg upset the rules and concepts of classical harmony.
The new, very young generation of physicists who around 1926 formulated Quantum Mechanics, rejected any reference to the description in space and time of the state of the system and its evolution, conceiving the description of atomic systems as a mere correlation between their possible states, which could not be further specified.

[analogy with Wiener information theory]

Heisenberg wrote to Pauli: “The more I weigh up the physical part of Schrödinger’s theory, the more horrible it appears to me”; while to Schrödinger, Heisenberg’s theory “Made me depressed”.

Culmination of the abstraction process, a formal theory devoid of a direct physical substratum, a formalism applicable to every physical or chemical problem.
Generally speaking, the problem of controlling the increasing instability at an economic and social level (monetary chaos, inflation, overproduction crisis, social disorder, etc.), which contrasted with the previous view of an inexhaustible pace of economic growth, posed the need of more flexible and effective control tools. The shift from a rigid organization of labour and production towards an organization based on the statistical correlation of an increasing flux of products and goods (including the labour force), led to the adoption of the “Scientific Organization of Labour”, aimed precisely at the coordination, correlation and control of multiple, unpredictable factors.
The aftermaths of the 1929 crash reinforced the necessity for a full flexibility of productive and technological innovation. The birth and proliferation of specialized scientific disciplines in the United States in the 1930s supported a continuous differentiation of productive sectors and output, avoiding the accumulation of overproduction crises.

In this new situation also the role of scientists and their conceptions and activities changed: it could no longer consist in providing general representations of the world, but rather the most flexible frame of reference, such that it did not limit, but rather stimulate free developments and practical solutions.

Quantum Mechanics had in some sense anticipated and embodied these needs, and presented itself as the ideal framework for these developments.
I apologize for some confusion

Thank you