H1. PHYSICS AT THE FIN THE SCIÈCLE

I. Reflections on the physics discipline

End of 19th century:

- ☹ general dissonance, social discontent, bourgeois decadence
- ☺ at the turn of the century: revolution: 'transformation of physics'
  → going from 'classical physics' to the 'new physics'

Many contextual factors that made the 'new physics' possible:

- establishment of research institutes and laboratories
- increased accessibility of scientific instruments were concurrent with the overhauling of methods of university instruction and laboratory practice
  ➔ shift towards collaborative research that would have been beyond the reach of individuals
  ➔ frequently experiment was ahead of theory, sometimes technology was ahead of both
  ➔ professionalization of the physics discipline

! the perceived upswing turn-of-the-century mood in physics by no means was thought by contemporaries to be the sole prerogative (voorrecht) of the natural science.
(also eg in literature, music and art)

meaning of 'physics' at that time:
(1809) the science or group of sciences, basically treating of the properties of matter and energy
= called 'classical physics' (in 1920)
= conclusions based on concepts and theories established before the discovery of quantum theory or relativity
⇔ 'new physics'

New physics by Paul Dirac: (introduced the word: "classical physics")

> *"Fundamental laws do not govern the world as it appears in our mental picture in any very direct way, but instead they control a substratum of which we cannot form a mental picture without introducing irrelevancies. The formulation of these laws requires the use of mathematics of transformations. The important things in the world appear as the invariants of these transformations."*

➔ In the newly (mathematical) domains the reciprocity between experiment and theory was seen to be largely dominated by theories that are grandiose in claim and powerful in suggestion of experiments that support the theory.

Three domains of 'classical physics':

1) mechanics
2) thermodynamics
3) electromagnetic theory

➔ By the end of the century considerable effort had been devoted to achieving some kind of deep-level integration of these three domains but without overall success.
Enthusiasm for theoretical unification gave way to phenomenological expansiveness where novel discoveries did not fit into any of the known niches (eg X-rays in 1895; study of the atomic nucleus)

II. Frontiers of physics

The transformation of physics was realized simultaneously at the frontiers of experimental, theoretical and mathematical physics.

EXPERIMENTAL PHYSICS

= due to the growth of physics and the recognition of its social value
+ due to industrial patronage and professional institutionalization.
→ invention of electric lamp, …
➔ at the end of the century: university posts in experimental physics increasingly came to be established

MATHEMATICALS PHYSICS

A sizeable number of British physicists (eg Stokes, Maxwell, …) exhibited extraordinary competence in mathematics.
Coincident with the political unification of Germany (1870) cam the movement to reshape the institutional structure and training ideals in physics at the universities.
By 1880, in Germany, physics came to be looked upon as a special domain of physics.
A positive stimulus, that served to enhance the status and significance of both mathematical and theoretical physics, was provided by the rapid growth of investigations made possible by the refinement and proliferation of scientific instruments.

There was also a growing technical awareness of the relevance of physics in industry at the international levels.

?How was one to come to terms with formalisms - mathematically elegant and scientifically powerful - that it were so effective in physics but so difficult to transpose into meaningful physical models - mechanical, thermodynamic or field theoretic?

BUT: the mathematical formalism worked.
➔ When explanatory success was accompanied by theoretical, conceptual or mathematical complexity, physicists, then as now, explored strategic moves that would lead closer to a unitary physics.

Henri Poincaré: meaning of "unitary":

> *"The view that was needed was not so much an abstract and general conception of the unity of nature, as a search for the sense in which nature might be conceived from a unitary point of view within the context of the available resources in experimental and theoretical physics."*

It was not until the 1870s that 'theoretical physics' came to recognized as an autonomous domain within the physics discipline.
And there were relatively few academic chairs explicitly established for theoretical physics.
In comparison with experimental physics, theoretical posts, early on, did not always carry great prestige.

This imbalance in the discipline goes a long way towards explaining why persons who did not have access to the best (experimental) positions in physics would have specialized in the more speculative and less traditional, i.e. theoretical, domains of physics.
Example: In the new domains became the theoretical contribution of Jewish physicists prominent.

III. FIN-DE-SCIÈCLE mentality

View: science were on the move while deterioration (achteruitgang) and retrogression were rampant in most non-science domains.

The positive reinforcement that physics enjoyed within the small and privileged circle of scientists served to generate within the minds of the general public a growing awareness of the importance of physics.

Emile Du Bois-Reymond:

- = most domineering of nineteenth-century European scientists.
- played an active role in promoting discussions on the connection between natural sciences and the humanities.
- developed an experimental science that would reduce physiological processes to electrical, molecular and atomic mechanism drawn from physics.
- wanted the natural sciences to occupy a position of primacy above all other branches of learning and arts, because he believed that only science was able to provide the basis upon which the ancillary furniture of healthy civilizations could thrive (gedijen, voorspoed hebben).
- had no sympathy with Goethe's view on nature and science (= holistic view: holism = is the idea that natural systems (physical, biological, chemical, social, economic, mental, linguistic, etc.) and their properties, should be viewed as wholes, not as collections of parts)

Ludwig Büchner:

- came to fame with a popular scientific and moralistic exploitation of the principles of conservation of energy.
- saw that almost everything that falls beyond the boundaries of the natural sciences had deteriorated (verslechterd)

Religion and religious lie - spread by state, church, judge and the educated modern priest - were seen to dominate the civilized world and had served to demoralize men's public and private lives.
Spiritualism, as the retrograde movement of mind, and belief in ghosts and spooks, had infected millions.
Politics without wisdom was the order of the day.
Anarchism, wild and egoistic impulses, and antisocial instincts, were on the increase. The general esteem (waardering) and standing of women had decreased from former times while their workload had increased.

IV. Transformation of physics

During the last two decades of the nineteenth century, scientists had witnessed an expansive growth in the scope, content, practice and technological relevance of the natural sciences.

In physics the maturity and refinement of theoretical principles was conspicuous, notably in continuum mechanics, thermodynamics and the electromagnetic theory of radiation.

In the midst of these grand accomplishments, formidable phenomenological and theoretical difficulties were identified.

The prevailing (de overhand krijgen) mood in physics was one that was oriented towards correlating newly discovered information with what already had been laid down.

1895, physicists were forced to recognize that their discipline was potentially open-ended to fundamental novelty in both experiment and theory.
➔ general opinion: perhaps the more important physical features of nature already had been discovered, and that improvements in theory were to be looked for mainly in the details rather than elsewhere on new theoretical frontiers.

Gustav Kirchoff:

- whose forte was theory, but he also placed great value on the essential long-range need for experiment
- his lectures on mathematical physics are a living symbol of self-contained unitary physics form a phenomenological point of view

Throughout the nineteenth century: the atom was conceived of as a mechanical entity subject to attractive forces and possessing properties such as mass, density, …

Towards the end of the century, however, many physical scientists felt that the atomic-molecular-kinetic model of matter was not deeply embedded in mechanics, thermodynamics, electrodynamics or structure of matter theory.

The fundamental significance of the corpuscular theory of matter for physics came about only after the discovery of

- the electric atom (the electron);
- the planetary and nuclear models of the atom;
- the correlation of spectra with atomic structure;
- the quantum theory;
- the artificial transmutation of elements;
- the particle nature for all forms of radiation;
- the wave number of particles.

➔ By 1910: the atom was a complex, structured, unstable, dynamic unit.

V. Concluding remarks

Reconstruction of a number of most prominent landmarks current among members of the physics community around 1900, plus or minus 5 years:

1) A widespread belief existed that an expansive unity in ‘classical ‘ physical theory was feasible (haalbaar) if not yet within reach.
2) Between 1900-1905 considerable emphasis was given to mastering the physics discipline in a unified way in order to encompass (omvatten) fundamental reformulations in physics indicated by new discoveries.
3) The complete switch of interest and confidence in structure of matter investigations around 1900 is nowhere more conspicuously seen than in the sudden way in which physicists and chemists retreated from their anti-atomistic positions.
4) The correlations of gravitational theory with spectroscopy at the end of the century was critical for the establishment of astrophysics as a major branch of physics. It served to reinforce the essential uniqueness of the atomic-molecular perspective throughout nature.
5) Attention: almost none of the new discoveries had been foreseen or predicted on the basis of established theoretical principles. This perception encouraged the taking of risks.
   → It all began with intense and innocent curiosity about nature of the physical world.
6) The classical nineteenth-century categories of physics no longer were sacrosanct (heilig).
7) There were a number of unsolved problems and puzzles whose resolution was to be of crucial importance for future direction of physics. For example:
   a. the assumption of a pervasive (doordringende) universal ether - the medium for all physical phenomena - was invoked (ingeroepen) as an intellectual phenomena.
   b. The paradigm (model) example of a deep puzzle brought on by a phenomenon totally unconnected with classical physics and chemistry was the discovery in 1896 of radioactivity.
   c. The planetary theory of the atom, nuclear theory, the identification of particles and particle - induced transmutations of elements set the stage for the discovery of nuclear fission in 1939

H2. A QUANTUM REVOLTUION?

I. The law of blackbody radiation

a. Robert Kirchhoff

A perfect blackbody = one that absorbs all the radiation incident upon it;
The emitted energy will be independent of the nature of the body
& depend only on its temperature.

b. Josef Stefan

The energy of Kirchhoff's ideal heat radiation varied with the 4th power of the absolute T
= Stefan-Boltzmann law

The Stefan-Boltzmann law helped direct attention to the new area of theoretical and experimental physics.

The spectral distribution of the radiation, a question about which the Stefan-Boltzmann law had nothing to say, soon emerged as a major and widely discussed problem.

c. Wilhelm Wien

Wien's displacement law: the distribution function:

$$u(\lambda, T) = \lambda^{-5}\, \varphi(\lambda, T)$$

→the peak of the $u(\lambda, T)$ function will be displaced towards smaller wavelengths when T increases
= in excellent agreement with experiments

BUT neither the form of $\varphi(\lambda, T)$ not its explanation was known.

Solution in 1896: $\varphi(\lambda, T) \sim e^{-\alpha/\lambda T}$
→ seemed to be correct and was generally accepted.

Although Wien's law appeared empirically convincing, however, it rested on theoretical arguments of unsatisfactory nature and for this reason, a more rigorous derivation was wanted.

d. Max Ludwig Planck

His main occupation in the early 1890s was not theoretical physics, but rather chemical thermodynamics.

The concepts of entropy and irreversibility were central in his theories.
→ The core of Planck's research program was an attempt to explain irreversible processes on a strict thermodynamic basis, that is, without introducing any statistical or atomistic assumptions in the manner of Boltzmann.

1895: examination of the relation between thermodynamics and electrodynamics.

1897-1900: Annalen der Physik: a series of 6 papers on irreversible radiation processes.
→ 1899: expression for the entropy of an oscillator by means of which he could derive Wien's radiation law.

In the history of blackbody radiation, and hence in the birth of quantum theory, experiment was no less important than theory. Most of the decisive experiments were made at Berlin's Physikalisch-Technische Reichsanstalt.

The blackbody radiation was thought that it would lead to knowledge that could be useful to the German lighting and heating industries.

e. Otto Lummer & Ernst Pringsheim

1899: Wien's law was incorrect for long wavelengts.

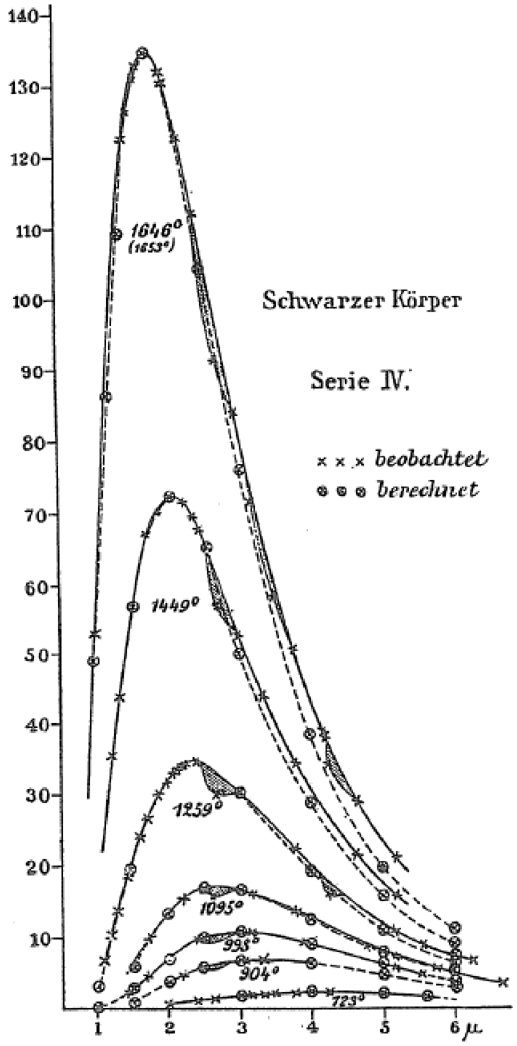

Figure 5.1. Blackbody spectra at different temperatures measured by Lummer and Pringsheim in November 1899. For large values of λT, the measured curve (continuous line) lies above the calculated curve (dashed line), indicating the inadequacy of Wien's radiation law. *Source:* Kangro 1976, 176.

f. Heinrich Rubens & Ferdinand Kurlbaum

The “Wien-Planck law” was only approximately true. (see figure above)

According to this law, the radiation energy density $u(\lambda, T)$ would approach 0 for very small values of $\frac{\nu}{T} = c/\lambda T$, while the experiments of Rubens and Kurlbaum showed that $u(\lambda, T)$ approached T.

g. Planck

Planck’s primary interest was not to find an empirically correct law, but to derive it from first principles.

After reconsiderations: new assumption for the entropy of an oscillator.
→ derivations of what Planck considered to be merely an improved version of Wien’s law.
➔ the spectral energy density varies as

$$\frac{\nu^3}{\exp\left(\frac{\beta\nu}{T}\right) - 1}$$

= in complete agreement with experimental data!

BUT the entropy expression was not theoretically satisfactory.

→ Planck realized that he had to introduce a new approach, namely, to turn to Boltzmann’s idea of entropy as an expression of molecular chaos.

→ Plank reinterpreted Boltzmann’s theory in his own non-probabilistic way
→ Boltzmann equation: $S = k\ logW$

➔ in order to find W, Planck introduced what he called “energy elements”, namely, the assumption that the total energy of the oscillator of a black body (E) was divided into finite portions of energy ε.

= in December 14, 1900 (=”birth of the quantum theory”)

BUT Planck did not really understand the introduction of energy elements as a quantization of energy, i.e., that the energy of the oscillator can attain only discrete values.

!To Planck and his contemporaries, the quantum discontinuity was at first considered a feature that did not merit serious attention.
What mattered was rather the impressive accuracy of the new radiation law.

!There was no “ultraviolet catastrophe” involved in the formation of Planck’s radiation law.

h. Rayleigh & Jeans

The Rayleigh-Jeans law: $u \sim \nu^2 T$

II. Early discussions of the quantum hypothesis

During the first 5 years of the century, there was almost complete silence about the quantum hypothesis, which somewhat obscurely was involved in Planck's derivation of the blackbody radiation law.

BUT the law itself was quickly adopted because of its convincing agreement with experiment.

➔ Only a handful of theorists found it worthwhile to go into the details of Plank's calculations and ask why the formula was correct:

Hendrik A. Lorentz:

- gave a survey of the blackbody problem or, in his terminology, the division of energy between ponderable matter and ether

  = a choice between:
  - theoretically satisfactory but empirically inadequate Rayleigh-Jeans-Lorentz formula
  - empirically confirmed but theoretically unsatisfactory Planck formula

  → Lorentz preferred the first one, BUT due to German experimentalists: Lorentz was forced to accept Planck's formula and try to understand its true meaning.

  → Lorentz recognized that Planck's theory involved some nonclassical features.

- As a result of Lorentz's Rome lecture: "Ultraviolet catastrophe" (name is given by Ehrenfest in 1911)

  → it was tempting to believe that the electron theory (as the dominant and successful microscopic theory of the period) would somehow be able to solve the puzzles of blackbody radiation.

Planck:

- pursued (nagestreefd) the idea that quanta of electricity might lead to quanta of energy.

- suggested an alternative system based on what corresponded to the constants h, c and G
  = independently of special bodies and substances, necessarily retain their significance for all times and all cultures, even extraterrestrials and extrahuman ones.

- for most of a decade, Planck believed that his radiation law could be reconciled (verzoend) with classical mechanics and electrodynamics
  & that the discontinuities were features of the atomic oscillators, not of energy exchange as such.

- In 1908: he converted to the view that the quantum action was an irreducible phenomenon beyond the understanding of classical physics

At the end of the first decade of the 20th century, quantum theory was still badly understood and studied seriously only by a few theoretical physicists:

Lorentz, Ehrenfest, Einstein, Larmor, Planck.

Until 1906: Einstein was alone in realizing the radical, nonclassical nature of Planck's theory.

During the first decade, quantum theory was largely identical with blackbody radiation theory, and the small field did not make much of an impact on the physics community:

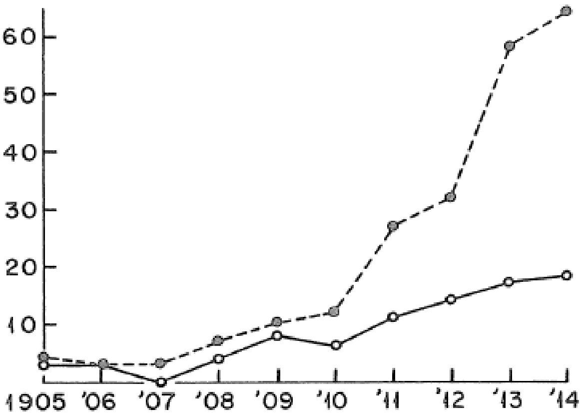

Figure 5.2. The slow rise of quantum theory. The solid circles indicate the number of authors who published on quantum topics. The open circles refer to the number of authors who dealt with blackbody theory, a subset of early quantum physics. *Source:* T. S. Kuhn, *Black-Body theory and Quantum Discontinuity*. Copyright © 1978 by Oxford University Press, Inc. Used by permission of Oxford University Press, Inc.

III. Einstein and the photon

The candidate as a hypothetical discoverer of quantum theory = Einstein

!Planck became a revolutionary against his will, Einstein recognized the revolutionary implications of the quantum hypothesis much more clearly and willingly acted as a prophet of the quantum hypothesis.

Einstein's approach differed markedly from Planck's and hardly relied at all on Planck's radiation law and its associated quantum of action.
→ Einstein focused on the old Wien law in its experimentally confirmed regime.

He calculated the probability that the entire radiation energy in a container is contained in a small part of the total volume.

→ reasoning by analogy to classical gas theory that "monochromatic radiation of low density behaves - as long as Wien's radiation formula is valid … as if it consisted of mutually independent energy quanta"

→ the energy of the oscillator responsible for the emission and absorption on light would change discretely.

(It was no accident that Einstein did not use either Planck's notation of his more mature theory of blackbody radiation. At the time Einstein believed that Planck's theory could not be mate to agree with the idea of light quanta)

!Because there was an impressive evidence for the wave theory of light, that Einstein emphasized that his concept of light quanta was provisional (voorlopig).

BUT he tried to show that his hypothesis was empirically fruitful.
= by considering the photoelectric effect as an energy exchange process in which electrons are liberated from the surface of a metal illuminated by light.

➔ it followed directly from Einstein's theory that the maximum energy (E) of the photo-generated electrons must be related linearly to the frequency of the incoming light.

BUT: Einstein's theory of light quanta was either ignored or rejected by experimenters and theorists alike. It was just a too radical hypothesis.

Undisturbed by the cool response to the light quantum, Einstein continued to work on the quantum theory, which in the years 1906-11 was his main area of professional occupation and of greater importance to him than the theory of relativity.

1909: Einstein derived the energy fluctuations of the blackbody radiation. It consists of 2 terms:

- quantum-corpuscular nature of radiation
- classical wave term

IV. Specific heats and the status of quantum theory by 1913

In 1907: Einstein applied the quantum theory to calculate the specific heats of solids.

In1876: the Dulong-Petit law: success was not complete
→ attempts to explain the variation failed and so the problem of specific heats remained an anomaly until Einstein, largely successfully, attacked it in 1907.

Using Planck's distribution law, Einstein found an expression for the average energy of an atom in a crystal vibrating in 3 directions with the same frequency.
→ this expression gave the classical value $3kT$ at high T (and thus led to the law of Dulong and Petit), but fell off exponentially for T approaching 0.

BUT new experiments showed the low T variation to disagree quantitatively with the theory.
➔ a much more sophisticated version of Einstein's theory was developed in 1912 by the Dutch theorist Peter Debeye, and this version gave a very close agreement with experiment.

In 1913, there were more publications on the quantum theory of specific heats than on the blackbody theory.

Walther Nernst: the German pioneer of physical chemistry
→ for Nernst: quantum theory was important because it might help to understand the structure of matter

Solvay congress in physics: (by Ernest Solvay, Brussels)
= due to growing interest in quantum theory

= a congress on the problematic relationship between:
- quantum theory
- kinetic theory of gases
- theory of radiation

No Americans were invited.

Although the discussions in Brussels did not result in any definite answer to the many questions that were raised, they were useful in making the problems of radiation and quantum theory more sharply focused. (but the attitude was cautious (voorzichting, bedachtzaam) and somewhat skeptical)

Encouraged by the success of the conference, Solvay decided to establish a permanent institution: the International Institute of Physics (was directed by a board consisting of 9 prominent physicists from 5 countries)

Remark:
The undecided state of affairs in quantum theory may be illustrated by Planck's attempts between 1911-1914 to revise the theory in order to retain as much as possible of the classical theory of electrodynamics.
→ new proposal: abandon the hypothesis that the energy of an oscillator is quantized in the sens that absorption and emission of energy are discrete processes.
→ Planck suggested absorption to be a continuous probabilistic law
→ the energy of an oscillator did not vanish at T=0 (zero-point energy)

H3. THE FORMAN THESIS

Germany was the world's leading scientific nation in the early part of the 20th century & served as a model for other countries.

1918: lost the war
→ ☹ lack of food, political murders, a drastic fall in the country's economy & a hyperinflation

BUT German physics did remarkably well during the difficult years and succeeded in maintaining its high position.
In some of the new exciting areas, such as atomic and quantum theory, German physicists set the international agenda.

I. Science policy and financial support

The German scientific community remained intact after the war, but It was a poor community in desperate search of money.

!Scientists were also excluded from international collaborations.

The leading German scientists realized that they needed to legitimize their sciences in a new way, both to satisfy themselves ant to appeal more convincingly to potential government sponsors.
→ ? What was left to carry the nation on the new honor (roem) and dignity (waardigheid)?
→ answer according to many scientists: science

Planck:

- "as long as German science can continue in the old way, it is unthinkable that Germany will be driven from the ranks of civilized nations"

- "science should be supported, not primarily because it would lead to technological and economic progress, but also because it was Germany's premier cultural resource."
  → science should be seen as a "*Kulturträger*" in German

The appeal to cultural and political values of science was not only the rhetoric of a few scientists in search of support. (eg Einstein)

In the Wilhelmian Germany, academic science was funded mostly by the German states and not by the federal government in Berlin.

Notgemeinschaft der deutschen Wissenschaft:

- = most important of the new central scientific-political agencies.
- represented several German science institutions: eg Kaiser-Wilhelm Gesellshaft,…
- main activity: raise and allocate (toewijzen) money for research of all kinds.
- supported individual scientists and research projects on the basis of merit (verdienste) and the grants were allocated (toegewezen) independent of the recipient's (ontvangende) university.
- by far, most of the Notgemeinschaft's resources came from the government of Berlin, but there were also substantial donations from abroad: including major contributions form General Electric and the Rockefeller Foundation in the US.
- was controlled by Berlin scientists.
- favored the kind of pure theoretical physics that Planck thought was culturally important.

Electrophysics Committee:

- = a subcommittee of the Notgemeinschaft.
- based on General Electric donations.
- was essential to German atomic physics.

Physikalisch-Tecnische Reichanstalt:

- = one of the central physics organizations that survived the war.
- BUT did not live up to its former glory and position as one of the world's leading institutes of pure physics.
- deteriorated (verslechterd) scientifically.

II. International relations

At a medical congress in Copenhagen (1884):
Louis Pasteurs confirmed the neutrality and internationality of science
BUT " Even if science does not have any native country the scientist should particularly occupy himself with that which brings honor to his country. In every scientist you will always find a great patriot."

After WOI: patriotism was the stronger of the 2 ideals:

- scientific internationalism
- patriotism

During the last phase of the war, French, British and American scientists discussed the structure of a new international science organization to replace the International Academy of Sciences.
→ RESULT: formation of the IRC: International Research Council, with membership at first restricted to Allied power and those nations that had been associated with them of otherwise opposed the German.

= clearly a political selection, rather than based on scientific excellence.

IUPAP: International Union of Pure and Applied Physics.

- was not very active until 1931, when it was reorganized in connection with the change for IRC to the ICSU: International Council of Scientific Unions.

- IUPAP was one of the 8 scientific unions within the council, the others: astronomy, chemistry, …

Because of the hatred and suspicion (achterdochtig, wantrouwen) resulting from the terrible war, Germany, Austria, Hungary and Bulgaria were kept out of the IRC, and even the neutral countries were not allowed in.

Only in 1922, some neutral countries were admitted: the Netherlands and the Scandinavian countries

In 1925, Lorentz suggested that the exclusion policy be annulled, but it did not receive the necessary majority of all the member nations.

But in the following year: the Locarno Treaty had secured a milder political atmosphere in Europe.
→ leading scientists in the IRC accepted German admission and invitations were sent to Germany and the other former enemy countries.
BUT it was rejected by the German and Austrian scientists.
➔ this 2 countries remained outside the official body of international science until after WOII

Thus: 1919-1928: German science was subject to an international boycott, in the sense that German scientists were not allowed to attend many international conferences.

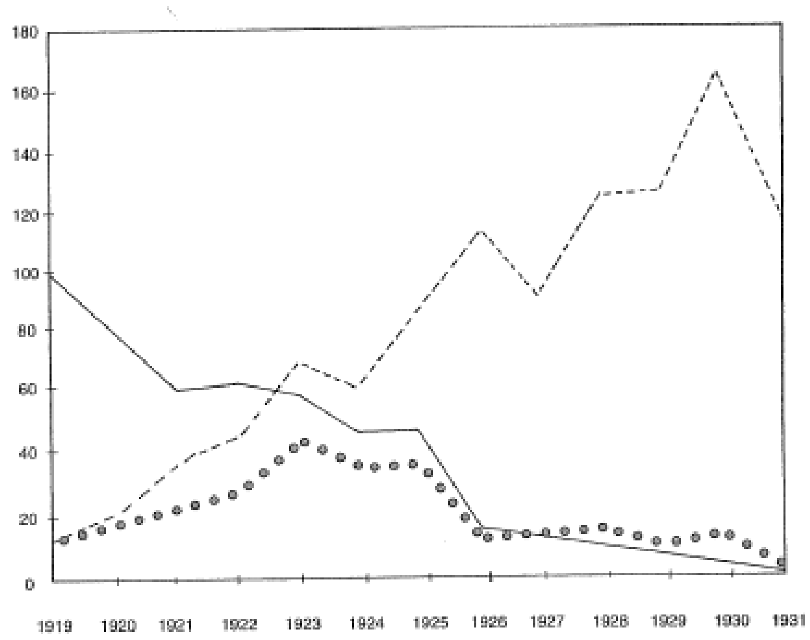

Figure 10.1. The number of international scientific congresses (dashed line) and those from which Germany was excluded (dotted line). The solid line gives the percentage of congresses that excluded German participation. *Source:* Redrawn from Schröder-Gudehus 1966.

The boycott did cause some inconvenience to German science, although the harm was more psychological than substantial.
It probably did more harm to the boycotting nations which had to do without Germans at conferences devoted to subjects in which Germans scientists were undisputed experts.

!The boycott was never total!

In 1919: The Swedish Academy of Sciences decided to award the Nobel prize to Planck & Stark, and Fritz Haber
➔ The Swedes had made a political choice in an effort to rehabilitate German science.

Einstein was 1 of the German scientists who was welcome at international conferences, because:

- it was world's most famous scientists
- pacifist
- democrat
- was not considered to be a "true" German

But even a pacifist Swiss-German Jew could be too controversial in the early 1920s. When Einstein accepted an invitation from Paul Langevin to speak in Paris (spring of 1922), he was brought to the French capital secretly in order to avoid demonstrations.

The organizers of the 1923 Solvay Congress wanted Einstein to participate, but Einstein refused when he realized that other German scientists would not be invited.

Hafnium - Celtium:

In January 1923, the Hungarian George Hevesy and the Dutchman Dirk Coster announced that they had discovered element 72 (Hafnium) while working at Niels Borh's institute in Copenhagen.

BUT French scientists argued they had already discovered the element (Celtium).

The discovery of hafnium, and especially the discredit (oneer) thereby brought upon French science, was regarded by militant Allied scientists as a conspiracy against the French gloire, a sinister (onheilspellend) attempt to provide Germany with intellectual revenge for its military defeat.

Although German scientists had contributed to the discovery of hafnium, it nevertheless was associated with "Teutonic science".

! During, as well as after, the war Bohr had kept normal and friendly relations with his German colleagues and during the zenith of the boycott, visits between Copenhagen and Germany were frequent.

➔ Bohr & Copenhagen physics look pro-German & increased the vague feeling of Teutonism connected with hafnium

! Only during 1930 was hafnium totally accepted!

Remark: Material conditions were even worse in the young Soviet Union.

III. The physics community

In the early 1920s the German physics community was split up in questions of:

1. science
2. politics
3. ideology

Whereas there was an identifiable right wing in German physics, there was no left wing with socialist sympathies.

! the young generation of physicists who had not served under the war (Heisenberg, Jordan & Pauli) was largely apolitical.

1) scientific view of the right-wing physicists were parallel with their political views: conservative:

    - worldview of classical mechanicism and electrodynamicism, including such notions as ether, determinism, causality,…
    - not in complete disharmony with the Weigmar Zeitgeist
    - a more or less direct dissociation from quantum & relativity theories and a preoccupation with experiments at the expense of theory

2) division between: progressives & reactionaries
   = a reflection of the tension between the powerful Berlin physicists and the physics institutes at the provincial universities

   → to many physicists "Berlin" came to signify abstract theory, Jewish intellectualism, arrogance and bad taste.

   In 1920: Start organized a rival organization: the Association of German Academic Physics Teachers, but the importance of the new association was limited.

3) the application of physics to technical and industrial needs

   → most mainstream physicists had little respect for technical physics
   On the other hand, many right-wing physicists were eager (verlangend) to apply their science for technical purposes.

   A large percentage of German physicists had been occupied with industrial or military physics during the war and they felt that their work was not sufficiently respected in the Physical Society.

   When the German Society for Technical Physics was founded in 1919, it was partly as a reaction against the perceived predominance of theory in the Berlin-dominated German Physical Society.

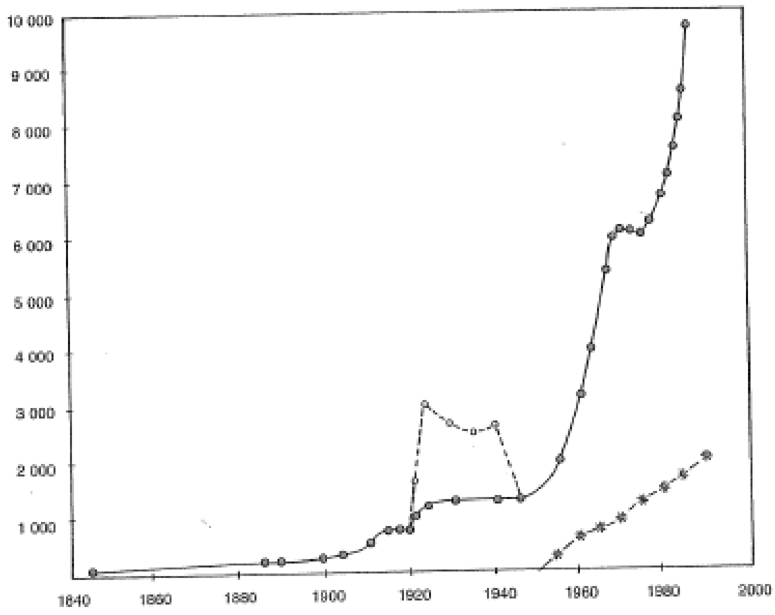

Figure 10.2. Membership of the German Physical Society from its origin in 1845 to 1986. *Source:* Redrawn from Mayer-Kuckuk 1995, with permission from Wiley-VCH Verlag GmbH.

Journals for academic publications:

- Annalen der Physic = preferred by the right-wing physicists
- Zeitschrift für Physic
  ! language of the journal was German
  → by 1925 it was evident that the French and British efforts to limit German as a scientific language had failed.

IV. Zeitgeist and the physical worldview

During the decade following 1918, physics in German faced not only economic difficulties, but also a changed intellectual environment that in many ways was hostile (vijandig) to the traditional values of physics.

→ non- or antiscientific attitudes were popular in philosophy, psychology, …

Forman: "we are thus evidently confronted once again with a wave of irrationality and romanticism like that which a hundred years ago spread over Europe as a reaction against the rationalism of the 18th century and its tendency to make the solution of the riddle (raadsel) of the universe a little too easy."

Authors and philosophers emphasized *Lebensphilosphie* and *Weltanschauung* rather than the results of science, which they identified with an outdated materialism and unwarranted belief in causality and objective knowledge.

The new-age program was most influentially presented by Oswald Spengler in his gloomy, yet enormously popular: Der Untergang des Abendlandes
→ Spengler's analysis: the ups and downs of civilizations, modern science was in a state of deep crisis, but only because it had not managed to adapt to the new culture.
→ Spengler's believed that time was ripe for a new physics that unified thought and spirit. However, the new physics could not build on the old; it would need a whole new civilization.

Given that this antirationalistic and antipositivistic climate dominated a large part of the Weigmar culture, and given that it questioned the very legitimacy of traditional science, it was only natural that physicists felt forced to respond to the new ideas.

The quantum mechanics that appeared in 1925 was a German theory, which broke with microphysical causality.
It is therefore natural to ask if there was a causal connection between the general ideas about acausality before 1925 and the formation and interpretation of quantum mechanics.

→ Paul Forman: German physicists were predisposed towards an acausal quantum mechanics and craved for a crisis in the existing semimechanical atomic theory.

However, there are good reasons to reject the suggestion of a strong connection between the socio-ideological circumstances of the young Weimar republic and the introduction of an acausal quantum mechanics.

1. Whereas the physicists often discussed the (a)causality question and other Zeitgeist-related problems in talks and articles addressed to general audiences, these topics were almost never mentioned in either scientific papers or addresses before scientific audiences.

2. To the extent that physicists adapted to the Zeitgeist, the adaption was concerned with the values of science, not with its content.

3. Many of the physicists had good scientific reasons to reject detailed causality and did not need to be "converted." At any rate, only a very small proportion of the German physicists seem to have rejected causality before 1925–26.

4. Sommerfeld, Einstein, Born, Planck, and other leading physicists did not bow to the Zeitgeist, but criticized it explicitly.

5. The recognition of some kind of crisis in atomic physics was widespread around 1924, primarily because of anomalies that the existing atomic theory could not explain. Bohr and a few other physicists suggested vaguely that energy conservation and space-time description might have to be abandoned (see chapter 11).

6. The first acausal theory in atomic physics, the 1924 Bohr-Kramers-Slater radiation theory, was not received uniformly positively among German physicists, contrary to what one would expect according to the Zeitgeist thesis. And those who did accept the theory were more impressed by its scientific promises than by its ideological correctness. The theory's element of acausality was not seen as its most interesting feature. Moreover, the theory had its origin in Copenhagen, with a cultural climate very different from that of Weimar Germany, and was proposed by a Dane, a Dutchman, and an American.

7. Among the pioneers of acausal quantum mechanics were Bohr, Pauli, and Dirac, none of whom was influenced by the Weimar Zeitgeist. The young German physicists who created quantum mechanics were more interested in their scientific careers than in cultural trends and sought deliberately to isolate themselves from what went on in society.

H4. SCIENCE AND DICTATORSHIP

I. In the shadow of the Swastika

With Adolf Hitler's rise to power as Reich chancellor on January 30, 1933, a new sad chapter started in European history.

Letter from Lise Meitner to Otto Hahn:

> *"The speech from Hitler was moderate, tactful and personal and hopefully things will continue in this vein. Everything depends on rational moderation"*

BUT: rational moderation was not what characterized the following months and years…
→ Lise Meitner had to flee Germany 5 years later.

→ other political parties were forbidden
& Jews and socialists could not hold positions as civil servants in the Reich

➔ "Law to Restore the Career Civil Service" (April 7, 1933): a non-Aryan was defined as a person who had one parent of grandparent who was not Aryan. eg Beth

The first wave of dismissals according to the law of April 1933 included more than one thousand university teachers.
Because the Nazi rulers had neither understanding of nor interest in science.

A large part of the German population may have agreed with the Führer.

German physicists, like most other groups, responded differently to the new situation.
A few of them protested in public, but a far more common reaction was to express the worry quietly and try to reach some kind of understanding with the new rulers.
→ the majority of non-Jewish German physicists felt strongly bound to their country and had no wish to leave it: Planck, Laue and Heisenberg

When Einstein publicly resigned from the Prussian Academy of Sciences in March 1933, the academy, eager to appease the government, accused him of "agitatorial behavior".

Of course, there were also physicists who welcomed the new regime, either because they believed in the Nazi cause, or at least sympathized with parts of it, of because they saw in the changed circumstances a way to further their own careers.

After 1933, Nazi party membership grew dramatically, especially among young scientists.

The Uranverein, the German nuclear power project, included 71 scientists, among them most of Germany's nuclear physicists.

The scientific-political infrastructure and support system changed after 1933, but many of the institutions of the Weimar republic continued and, in general, they were not heavily politicized.

→ the Notgemeinschaft continued to play a dominant role, though under the name of the Deuthsche Forschungsgemeinschaft from 1937 on.

→ for the Kaiser-Wilhelm-Gesellschaft, with Planck as its president, the decade after 1933 was a period of growth
= financed jointly by the government

➔ as fas as money and institutions ware concerned, German physicists had no reason to be dissatisfied with the new regime.

German physics suffered severely, both quantitatively and qualitatively, because of the regime's dismissal policy.
BUT the decline was roughly countered by an increase in physicists working at the polytechnical institutes.
On the other hand, compared with the situation in the US, where the number of physics positions continued to increase, the stagnation was a sign of illness.

In general, the more theoretically oriented the institute was, the more dismissals.
BUT the drain of scientific talent was remarkable.

As the realities of Nazi regime's measures against Jewish scientists become known in other countries, many foreign physicists responded, first quietly by avoiding visiting Germany, canceling subscriptions to German periodicals, or resigning membership in German scientific associations.

Starting in 1936, German scientists were forbidden to participate in meeting associated with the League of Nations. In 1937 the Nazi regime forbade Germans to accept the Nobel prize.

The majority of foreign physicists were uncertain how to act and were careful not to break connections with their German colleagues.
They were against Hitler and the Nazi policies, not against the Germans themselves.

German physicists and science administrators were well aware that Germany was no longer able to compete with the US in many important areas of physics.
(& the Nazi dismissal policy in large part responsible for the decline)

In general, Nazi authorities were not opposed to science, and they channeled very large amount of money to scientific research. German physics declined after 1933, but high-class research continued in both experimental and theoretical fields.

TABLE 16.1
Publications in Quantum Theory

	Publications		By later emigrants	
Year	*Total no.*	*Percent in German*	*No.*	*Percent in German publications*
1926	173	49.7	16	18.6
1927	319	50.8	42	25.9
1928	295	44.4	31	23.7
1929	286	43.4	28	22.6
1930	326	44.5	35	24.1
1931	208	50.5	33	31.4
1932	170	30.6	12	23.1
1933	153	38.6	20	33.9
total	1930	44.8	217	25.1

Note: Based on data in Fischer 1988.

TABLE 16.2
German Publications in Physics, 1925–33, Select Fields

Field of physics	*Publications in German*	*By emigrants*	*Percent*
Quantum theory	864	217	25.1
Nuclei, radioactivity, particle rays	532	100	18.8
Spectra	958	123	12.7
Mechanics of fluids and gases	1740	163	9.4
Technical mechanics	1030	58	6.6
Acoustics	482	18	3.8
Total, all fields	23216	2505	10.8

Note: Based on data in Fischer 1988.

II. Aryan physics

Philipp Lenard,
published a physics textbook in 4 volumes, entitled Deutsche Physik.

> *"German physics? I could also have said Aryan physics of physics of the Nordic type of peoples, physics of the probers of reality, of truth seekers, the physics of those who have founded scientific research. Science is international and will always remain so! But in reality, as with everything that man creates, science is determined by race of by blood."*

The German or Aryan physics that Lenard advocated (verdedigen) in his work had its origin back in the 1920s, when Lenard and a group of other right-wing German physicists attacked Einstein's theory of relativity and, more generally, modern theoretical physics.

The view that there were different forms of physics, depending on race and nationality, agreed perfectly with the anti-internationalistic ideology of the National Socialists, as expounded in Hitler's *Mein kampf* and Alfred Rosenberg's *Mythos der 20. Jahrhundert*.

In 1924, they coauthored a praise of Hitler and his allies, whom they described as "God's gifts from times of old when races were purer, people were greater, and minds were less deluded (misleid)".

Whereas the aging Lenard, who had retired in 1931, acted mainly on the ideological front, the younger Stark worked politically and sought to take power over the German physics organizations.

What characterized the Aryan physics view was rather what it was against, namely:

- modern physics with its complex mathematical apparatus,
- lack of visualizabilty
- counterintuitive results
- dismissal of the classical worldview of Newton, Faraday, Helmholtz

➔ Aryan physicists were antimoderns and romanticists, who longed for a return to a physics based on experiments and simple, understandable theory in agreement with intuition.
& advanced theory would lead to nowhere.

BUT the Aryan physicists were not fools without knowledge of science; they were supported by at least one philosopher of science of some prominence: Hugo Dingler.
& the Aryan physicists were kept out of the mainstream physics journals.
→ a favorite jounal was the *Zeitschrift für die gesamte Naturewissenschaft*.

Remarks:

- Aryan physics launched a viscious campaign against the 2 quantum theorists and accused Heisenberg of being a "white Jew".

- Wilhelm Müller, a good Nazi and antirelativist with no knowledge of modern physics at all, was appointed professor of theoretical physics in Munich.

The influence of the Aryan physicists was limited and short-lived.
Because, Aryan physics just was not able to replace the physics of Einstein, Bohr and Heisenberg, and in practice, teaching of physics at many German universities was unaffected by the attempt to ban the theory of relativity. The theory was taught in textbooks and lectures, but Einstein's name was often left out.

III. Physics in Mussolini's Italy

Mussolini came to power in 1922.

There was no one to replace the old generation of experimentalists of high reputation, and in theory the situation was even worse.

But a changing: during 1925-38 (the years of fascism), Italian physics flourished in a most remarkable way
➔ the country became one of Europe's most advanced nations in modern physics.

Central figure: Fermi: the Italian physicists

- were strongly international in their outlook and practice and often spent periods abroad.
- were absorbed in physics
- were not very interested in politics

In 1929: Fermi was appointed as the only physicist member of the newly created Accademia d'Italia, an institution that Mussolini had established as an alternative to the old and distinguished Accademia dei Lincei, the members of which Mussolini suspected were hostile (vijandig) to fascism.

Fermi was also a member of the Italian National Research Council.

➔ Fermi was part of the Italian politics and his research group in Rome, in reality, was protected by the fascist state.

Many Italian physicists decided that collaboration with a nation that dismissed Jewish colleagues must be cooled down. This was the background for Fermi's decision to publish the important papers on neutron-induced nuclear reactions in English and not, as would have been natural under other circumstances, in German.

BUT: In the summer of 1938, the fascist government introduced racial laws modeled after the notorious German Nuremberg laws
➔ Jewish scholars and scientists were dismissed from Italian universities and, in general, life became difficult for Italian Jews.

AND Fermi's wife was Jewish
➔ he decided to leave the country and soon found an opportunity, namely, his receipt of the Nobel prize on December 10, 1938. Instead of returning to Rome from Stockholm, he and his family went to the US.

IV. Physics, dialectal materialism and Stalinism

Among the political weakness of Aryan physics was that it could not appeal to an accepted philosophical foundation of National Socialism.
→ National Socialism was built on action and emotion, not on a coherent system of ideas.

= in contrast to the situation in the Soviet Union, where the regime was based ideologically on the socialist corpus of writing of Marx, Engels and Lenin.

During most of the 1920s there were no serious conflicts between the party philosophers and the physicists, but in the 1930s the debate sharpened, especially in connection with the question of the interpretation of quantum mechanics.

Alexander Maksimov (1939)

> *"Einstein, Schrödinger, Bohr, Dirac and Heisenberg were all idealists of the Machian variety and that their views of quantum physics were ideologically unacceptable."*

Party philosophers tried to engage the physicists in ideological discussions and to convince them about their errors, but they were not very successful.

The controversy was not simply between fanatic party philosophers and reasonable physicist. There were Soviet physicists whose scientific views were not more modern than those of, say, Lenard in Germany.

As in Germany, the attacks of the "new physics" included aspects of anti-Semitism.
Another aspect of the dispute was regional, with Leningrad playing a similar role to that of Berlin in the German case. Leningrad was the stronghold of the quantum an relativity theorists.
→ the Leningrad Physico-Technical Institute has a bad reputation among communist hardliners as it had a good reputation in international physics.

In the mid-1930s, the Academy of Sciences was transferred from Leningrad to Moscow, and the many physics institutions began to concentrate in the capital.

There was a broad (but not total) agreement that the theories of relativity and quantum mechanics were basically correct, ant the attempts to create a specific communist of proletarian physics were feeble and not taken very seriously.

Many leading Soviet physicists adhered (aangehouden) to the views of the Copenhagen school and argued that these views could well be brought into harmony with dialectical materialism.
BUT a minority of physicists and a majority of philosophers disagreed violently.

In some aggressive arguments of the late 1930s, to brand a physicist as an "idealist" came unpleasantly close to Aryan physicists' labeling their enemies as "white Jews".

As in Germany, the well-established theory of relativity became a target of some philosophers' politically motivated criticism.

Most of the Soviet critics were both more open and more advanced than their counterparts in Germany, who totally denied the validity of relativity theory and rarely distinguished between the special and the general theories.

The dispute in the 1930s between philosophers and physicists was of a different nature from that taking place in Germany. Physicists and enlightened philosophers had no trouble advocating their views in opposition to the attack of party philosophers, and there was no question of creating a specific Marxist physics as a counterpart to Aryan physics.

But: changing after WOII: = when Soviet intellectual life experienced a much harder ideological climate and when the question of the interpretation of quantum mechanics became part of the political-ideological game.

➔ after 1933: the climate in the Soviet Union was marked by an unhealthy cocktail of xenophobia (angst voor vreemdelingen), suspicion (wantrouw), sycophancy (vleierij) and fear of the secret police.

➔ Whereas Soviet physicists had earlier been active participants in the international physics life and main contributors to German physics journals, they were now increasingly forced into isolation.

➔ 1932: Physickalische Zeitschrift der Sowietunion: included a strange mixture of:

- technical and military physics,
- politically correct philosophy of science
- high-qualtiy technical papers on quantum field theory and other fields of mainstream physics

1935-1941: millions of Soviet citizens were killed.
+ 20% of all the Soviet physicists may have been arrested.

➔ Gamov escaped to the West

! Whereas the Nazis expelled unwanted physicists, the Communists either shot them, jailed them, or did their best to keep them within the borders of the Soviet Union.
→ they were not allowed to go abroad and attend scientific conferences.

H5. BIG SCIENCE AND SCIENCE POLICY

Learned societies, one accessible to anyone of appropriate social standing, were pretty much closed institutions by the end of the 19th century.

The great scientists-popularizers of the 19th century (eg Charles Darwin) who would write their new ideas in books accessible to a wide range of people, were replaced by the popular scientists of the early 20th century (eg Arthur Eddington) who would publish a journal paper and a popular book aimed at different, separate readership.

> ➔ The 20th century sees scientific communication divided between disciplines within science, and between science and the public.

At the beginning of the 20th century popular science was well established in the US and was in the hands of people sympathetic to science who were proselytizing (bekeren) rather than responding to public demand.
➔ AIM: public appreciation of science
➔ start of public information campaigns (about health)

Science stories had previously been written mostly by scientists, where professional "scribes" were involved.
They usually wrote down scientists' lectures verbatim. But as public interest in science grew, the task of reporting - in contrast to "scribing" - was falling more and more into the hand of journalists.
> ➔inventive writing

BUT: scientists kept a close eye on the popular press & when the need arose: they rushed in to set the record straight.

At the turn of the century: science journalism reflected the growing division between:

- those who felt that science was the answer to all our problems
  eg: tanks and airplanes demonstrated the power of science

- those who felt that it might be causing them
  eg: there was the horror of poison gas

Chemistry seems to offer a particular case of changing public attitudes.
→ it was clear that the war forced the governments to take an active interest in chemistry.

Although they were not seen to be associated with some of the war's worst excesses, afterwards chemists were forced to accept publicly that they did have some responsibility for the use made of their science.

Svante Arrhenius

> War came and everything else was pushed aside. Now it is over and we stand contemplating the dismal ruins. We have learned by bitter experience what it means to be cut off from supplies of coals and metals. We have gained a presentiment of the desolation which may threaten our descendants in a couple of centuries in case we do not succeed very shortly in inaugurating a more sensible way of keeping house.[33]

The lesson was clear: "there holds in chemistry a rule which must be applied to all our housekeeping.. Herein lies our hope for the future. Priceless is that forethought which was lifted mankind from the wild beast to the high standpoint of civilized humanity."

Shortly after the war, physics captured the public imaginations:

→ Albert Einstein's theory of relativity hit the British press in 1919: *The Times* announced: "Revolution in Science - New Theory of the Universe - Newton's Ideas Overthrown."

→ Relativity and quantum mechanics found their way into broader intellectual spheres, and thus, in a shift away from religion as a source of authority, elite or "high culture" media became forums for science.

The economic boom of the 1920s had positive consequences for popular science:

- From 1921: the Science Service, a national news agency for science, was distributing science news produced by and for science journalists
(= a step toward the professionalization of science popularization and away from the utterances (uitingen) of great men)

- In the 1920s: cinema newsreels and radio became new media for science: Einstein's visits to the US were major events for cinema news.
However, business interests were a powerful lobby, and in 1931 the advice to eat less meat in hot weather prompted the introduction of censorship by the Treasury Department of health information broadcasts.

The movement for the emancipation of women found some empathy with movements for the advancement of sciences.

General-interest magazines have long been a much more prominent feature of American than of British culture.

→ Growth in popular science book publishing in the US outstripped growth in book publishing generally.

Huxley: was a key figure in the intellectual life of 1920s Britain: he was a vocal supporter of reform in sexual matters, and his relatively explicit novels, in which scientists play a key roles, ranted against contemporary mores (zeden, gewoonten)

Science fiction as a genre in its modern form had grown out of dramatic technological and intellectual developments of the late 19th century and came of age in the US in the magazines of the 1920s.

→ Science fiction would take new impetus (impuls, aandrijfkracht) from the new mass media of the 1950s: television and particularly film increasingly brought the images and ideas of science into popular culture.

→ However, by the mid-1920s, science also had plenty of facts to share with the public: it was the decade of quantum mechanics…

The Great Depression on the 1930s brought a dip in the coverage of science, and a decline, in the US at least, of scientists' participation in popularizing science.

> → The Great Depression politicized the public, and many scientists were caught up in this process. Some scientists were mobilized for social and political reasons.
>
> → From the mid-1920s, as intellectual communism gained momentum among scientists, a new motive emerged for popularizing science: rather than keeping the worker in their place, science could liberate and empower them.

J.B.S Haldane:

- was an unconventional figure in his professional and his personal life
- was a gifted scientist and loyal to the cause of science and to the scientific community
- his scientific training had taught him that popularizing was bad
- but, whatever Haldane's talent to amuse, his politics were never out of sight: *"a knowledge of science should be spread among socialists, and a knowledge of socialism should be spread among scientists"*
- by 1946, he wrote an essay: "How to write a popular scientific article"

Socialist groups encouraged their scientist-members to stick to the rules of science: as public socialists, they had also to be good scientists, both in the laboratory and within the social structure of the scientific community.
←→ The scientific establishment saw it rather differently: any political stance (houding) could only detract (afbreuk doen aan) from the pursuit (vervolging) of scientific excellence.

Socialism may have been a force for popularization in Britain, but in the US, capitalism was hard at work.

> → science and technology = key factors in this change
> → public schools were beginning to teach diet and health

SCIENCE IN POLITICS

During WOII: science became an integral part of the public information effort in Britain

→ = in particular for health and nutrition (voedsel)

→ the radio became the first truly mass medium in Britain, uniting the nation in time of crisis

→ when the men went off to war, women scientists became a feature of US science coverage, both as subjects and as authors of magazine articles.

BUT: no popularization anymore during WOII
= due to: scientists' work was often secret

→ scientists could still communicate the value of science, and their mysterious war work gave them a new heroic image

Atomic bomb

atomic physicist: J. Robert Oppenheimer:

- had directed the Manhattan project to build the first atomic bomb.
- cited a colleague who cautioned (waarschuwen) him against discussing openly the horrors of atomic warfare (oorlogvoering), because it would turn the public against science.
- opinion of Oppenheimer:

  I think that it is for us among all men, for us as scientists perhaps in greater measure because it is our tradition to accept and recognize the strange and the new, I think it is for us to accept as fact this new terror, and to accept with it the necessity for those transformations in the world which will make it possible to integrate these developments into human life. I think we cannot in the long term protect science against this threat to its spirit and this reproach to its issue unless we recognize the threat and the reproach . . . . Whatever the individual motivation and belief of the scientist, without the recognition from his fellow men of the value of his work, in the long term science will perish.
- was a popular hero and a respected public figure in the US immediately after the war.
  → Oppenheimer became a symbol of the new status of science in American society.
- Oppenheimer's arguments against nuclear weapons development were, like those of many of his former colleagues on the Manhattan Project, largely moral arguments, BUT he mad them in public.

As in the social upheavals (omwenteling) of the 1930s, many scientists had become politicized by the war:

→ organizations such as the British Society for Social Responsibility in Science were set up by scientists concerned, for example, by the enormous power of atomic weapons and other wartime inventions.

→ because many academic scientists were taken out of the universities and put to work for government of military agencies, the scientific community had an inside look at the seats of national power. Some of them were less than impressed by what they had seen

H6. THE VIEW FROM NOWHERE: Militarization and megatrends

I. Physics - a branch of military?

Jerrold Zacharias wrote in 1984:

> *"WOII was in many way a watershed (stroomgebied) for American science and scientists. It changed the nature of what it means to do science and radically altered the relationship between science and government … the military … and industry"*
>
> →the watershed caused by the war depended very much on a changed scale and structure of funding for science, in particular a spectacular rise in federal funding.

In the 1950s and 1960s, federal money was, to a large extent, synonymous with military money from the Department of Defense and the civilian Atomic Energy Commission:

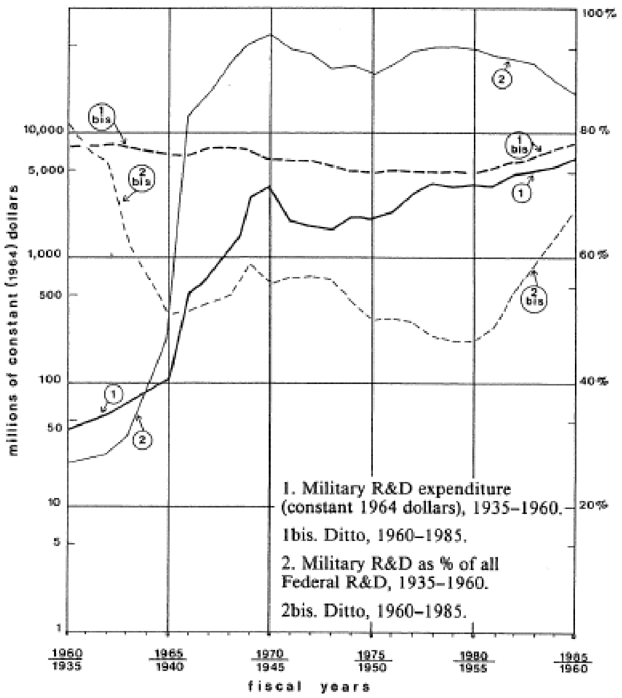

Figure 20.1. The development of U.S. military R&D expenditures, 1935–85. The figure is folded in order to facilitate a comparison between the two periods 1935–60 and 1960–85. *Source:* © 1987 by The Regents of the University of California. Reprinted from *Historical Studies in the Physical and Biological Sciences* vol. 18, figure p. 153, by permission.

Research and development (R&D) = a much broader category than science, which is again much broader than physics.

Of course, it was only a small part of the money that went to physics, but it was a very substantial part of the budget of American physics and, thereby, world physics.

It was no wonder that some physicists thought that their science was dangerously close to becoming just a branch of the military.
→ Philip Morrison: "for every dollar the University of California spends on physics at Berkeley, the Army spends seven."
→ was worried by what looked like militarization of physics.
→ advocated that the civilian NSF (National Science Foundation) should replace the military as the principal benefactor of physics.

Philosophy of the NSF: “a civilian-controlled organization with close liaison (verhouding) with the Army and the Navy, but with funds direct from Congress, and the clear power to initiate military research which will supplement and strengthen that carried on directly under the control of the Army and the Navy.

BUT: with the advent of the Korean War, criticism was largely silenced. Many physicists who had been critical of the military dominance now accepted the situation and were ready to work for the military or receive its money.

The bonds between the military, the defense industry and the physicists were further reinforced after the so-called Sputnik shock in 1957.

The establishment in 1958 of the National Aeronautics and Space Administration (NASA) produced new advantages for the physicists.

The cold war and the space and missile (raket, projectile) race created unique opportunities for the physicists who could now, in many cases, choose among:

- military: DOD
- civilian: NSF, NASA
- quasi-civilian: AEC

funding for their ever-more-expensive projects.
➔ In the 1960s American physicists were at the top of the world, economically, socially and scientifically

In 1958: there were nearly three times as many chemists as physicists, chemistry received only half as much federal research support.

The military’s support was not limited to areas of direct - or even indirect - relevance to warfare, but covered all of physics, including areas that could seem to be utterly irrelevant to military interests.

The most important of the early military science-funding agencies was probably ONR, which in 1949 could boast that “the huge university research program of the Navy Department is the greatest peacetime cooperative undertaking in history between the academic word and the government.

> → Within the span of a decade, the Navy’s expenditure on research and development had increased by the incredible factor of 20.
>
> ➔ Since 1950, more than 30 US Nobel prize winners have drawn direct support from DOD. Participation in defense-oriented work soon became accepted and was even considered an academic qualification.

The US was not the only country that mobilized physics in the service of the Cold War: so did the Soviet Union.

> ➔ In 1955, the American Institute of Physics, with support of the NSF, started a program to translate Soviet journals so that Western physicists could keep abreast with the latest developments in the Soviet Union.

? What was the effect of the massive military patronage of American physics?

1) it led to real growth, not only in applied physics, but also in fundamental physics.

2) it influenced the kind of physics under research and the physicists’ attitude to their science.

Remark: the brief description given here has focused exclusively on the American scene, where the historical development of the military-physics relationship has been the subject of many detailed studies. Much less historical work has been devoted to the corresponding relationships in Europe and in the Soviet Union.

! An important reason for the relative backwardness of European physics was simply that the European nations were much poorer than the US.
+ The difference in productivity and quality was not only due to economic reasons. It was as much - or more - rooted in different mentalities, cultural traditions, and education system.

II. Big machines

Big money is not a sufficient, but it is a necessary condition for “big science”, therefore it is not surprising that the big science era in physics coincided with the increase in government funding.

BUT big science is not purely a postwar phenomenon.

Example: cyclotron
→ the big, expensive cyclotrons needed a new organization of researchers, a new spirit of work.
The machines

- inspired group work
- increased the demand of external funding
- tended to lead to a new attitude of what constitutes successful science.

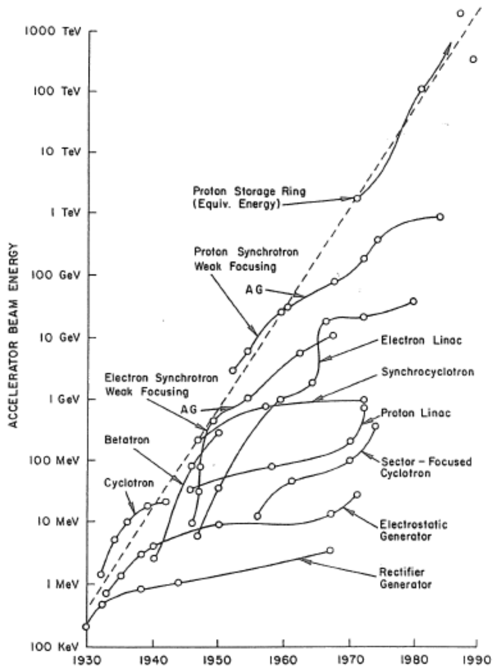

Figure 20.2. Growth of accelerator beam energy with time, 1930–84. *Source:* Reprinted with permission from *Physics Through the 1990s: Elementary-Particle Physics.* © 1986 by the National Academy of Sciences, Courtesy of the National Academy Press, Washington, D.C.

The Rise of Big Science in High-Energy Physics

Name or type	*Location*	*Energy (GeV)*	*Year in operation*
synchrocyclotron	Berkeley	0.35	1946
Cosmotron	BNL	3	1952
Bevatron	Berkeley	6.2	1954
proton synchrotron	Dubna (USSR)	10	1957
PS	CERN	28	1959
AGS	BNL	33	1960
proton synchrotron	Serpukhov	76	1971
proton synchrotron	FNAL	400	1972
SPS	CERN	400	1976
Tevatron	FNAL	1000	1985

Note: Select proton accelerators 1946–85. Because of the different principles behind the accelerators, their energies cannot be compared directly.

The 2 most important accelerators research facilities in the early postwar period both emerged as direct consequences of war efforts:

1. Brookhaven National Laboratory BNL:
   - mainly serving universities in the north-eastern United States
   - most powerful accelerator: Cosmotron

2. Lawrence Radiation Laboratory LRL: synchrotron: Bevatron

The Cosmotron and the Bevatron dominated the early phase of accelerator-based high-energy physics, leading to important discoveries, such as pair production of strange particles in 1953.

CERN: proton synchrotron PS

In 1957, Standford physicists proposed to AEC, DOD and NSF to build a new linear electron accelerator, a further development of a type of linear accelerator (LINAC) already in operation at Stanford.
= a step into a new range of big science.

BUT the project was simply too expensive to be justified by its assumed scientific merits (verdiensten) alone.
→ ? "What is the practical result of the accelerator"? asked a Congress-man
→ Answer: the SLAC: the Standford Linear Accelerator Center would not raise the standard of living

In America: in 1967: President Johnson signed the bill for the National Accelerator Laboratory or Fermilab: FNAL (= completed in 1972)

Many physicists felt that a truly international accelerator facility would be the most rational choice in a field that is international. Why not skip the ridiculous and expensive competition between nations and work together? (= world accelerator for world peace) ➔ unrealistic…

Sensing that the initiative in high energy physics was on its way being taken over by Europe, in 1983, American physics suggested building the ultimate accelerator facility based on Superconducting Supercollider SSC

→ it would be the largest and most expensive physics facility ever built. The gigantic project was endorsed (steunen) by president Reagan and the next president Bush.

→ There were good scientific reasons to build the SSC, but for an investment of this size, scientific reasons alone would not do. Among the other reasons that were suggested by SSC advocates was the misleading suggestion that work on superconducting magnets might help in the development of medical techniques that might prove useful in the fight against cancer.

Philip Anderson: *"The pie is finite and what is 'pro' high-energy physics is 'con' to somebody else, so that it is now obvious that if we are to retain a healthy science we must look at all of its divisions critically."*

➔ SSC was rejected due to political and economical reasons

Remark: the project might conceivably have been accepted, namely if it could be connected to questions of national security. But it was not thought to have any particular military value and, at any rate, the timing was bad: By 1992, the Cold War ended, and the Soviet Union no longer existed.

One of the effects of the new kind of big science that flourished in the 1950s was a marked shift of the role of the physicist, from an individual researcher to a small wheel in a collective research effort.

Not only there was little room for individuality in large-scale experiment, but the expensive instruments also seemed to live their own lives and become more important that the physicists who worked with them.

III. A European big science adventure

About 1950, when nuclear and particle physics began to increasingly dominated by accelerators, Europe lagged far behind the US.

➔ CERN (Conseil Européen pour lar Recherche de Nucléaire)

The initiative was mostly French (Pierre Auger) and Italian (Edoarde Amaldi)

The founding of CERN was widely seen as not just a scientific but also a political project, namely a model for European cooperation.
→ For Heisenberg and other German physicists, it was also a way to rehabilitate (herstellen) German physics after the war and forget the unpleasant Nazi past.

AIM OF CERN: “provide collaboration among European States in nuclear research of pure scientific and fundamental character, and in research essentially related thereto”.

One of the major differences between American and European high-energy physics, and big science projects in general, was the very different roles played by the armed forces. Of course, one of the reasons for the indifference with which European military establishments regarded CERN was that here was no European military.

To underscore the nonmilitary, apolitical picture of CERN, it was decided not to include a nuclear reactor and to locate the laboratory near Geneva in neutral Switzerland.

TABLE 20.2
Distribution of CERN Personnel

Category	*1955*	*1960*	*1965*
Scientists and engineers	83	170	349
Technicians	102	527	604
Ancillary staff	35	241	871
Administrative staff	49	127	316
Fellows	18	71	73

Note: Based on data from Hermann et al. 1990, 396–98.

Although the joint European effort was successful in many ways, at first it did not succeed in seriously challenging the American leadership in high-energy physics.

→ The American accelerator laboratories came first with the important discoveries that were typically confirmed by the Europeans shortly later.

BUT when the European physicists first learned the new methods of doing and organizing physics, CERN became competitive with the finest of the American laboratories.

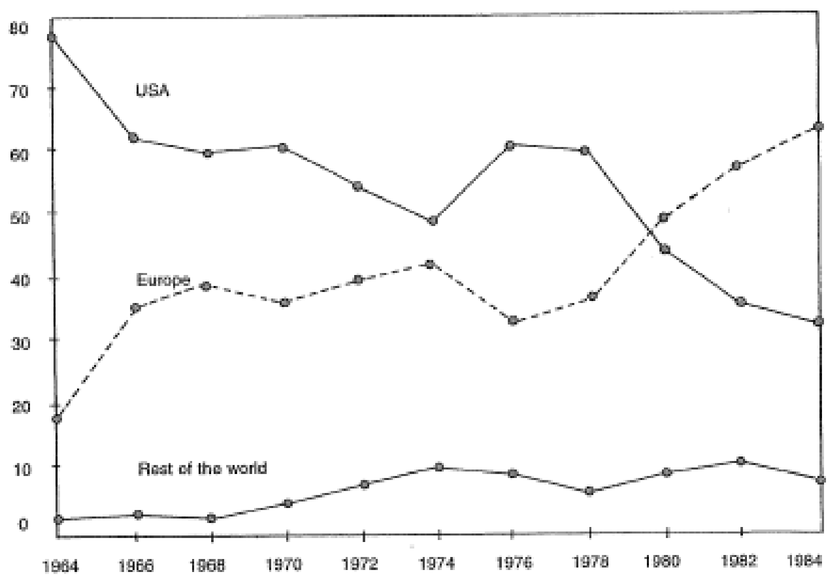

Figure 20.3. Percentage of citations to high-energy physics papers published in a given year and in the previous three years, by region and year. *Source:* Redrawn from Irvine et al. 1986.

In the late 1997, 4 years after the demise of the SSC, the US reached an agreement with CERN to participate in the construction and use of the future Large Hadron Collider LHC and its associated particle detectors.

This latest phase of accelerator physics history demonstrates that the center of high-energy physics has now definitely shifted to Europe.

It also demonstrates that very big, international particle physics was not killed with the SSC project.

Although it is a European project, the LHC is not confirmed to the CERN member states, but involves a cooperation of 45 different nations.

➔ In a sense, it is the realization of the old dream of a “world accelerator”

H7. View from nowhere

"Global webs of knowledge"

Knowledge is globally institutionalized as 3 differentiated and interpenetrating social institutions:

1. education
   = a social institution for transmitting humankind's existing knowledge
   = organized as a formal training of the youth of humankind
   Remark: the content of schooling comprises increasingly instrumental knowledge
   & is similar from place to place

2. science
   = a social institution for creating new knowledge that becomes a global public good
   = organized throughout the world in the form of professional academic research
   = conducted mainly in a university

3. technology
   = a social institution for creating new knowledge that becomes privately appropriated
   = organized around the world in the form of a professional inventive work
   = conducted mainly in research and development laboratories in industry, agriculture and military

= governed by a global regime

The social relations among cultivators of these 3 traditions of knowledge are wide ranging, even globe spanning.

Support for knowledge is treated as an investment in economic production and is often measured as a percentage of Gross National Product (GNP)

The public expenditure (uitgaven) on education does not greatly differ from one nation to another.

BUT, the isomorphism among nations in their institutionalization of knowledge, and in their similarity of support, does not entail (met zich meebrengen) an equalization in their intensity of benefit. BUT may actually entail a widening of their inequality.

! When support is similar among nations, the expenditure is larger in rich than in poor nations
  ➔ the rich get richer and the poor get relatively poorer

US has highest volume of knowledge
= correlated to the population
do not indicate the web of knowledge, but they affect the flow

Intensity of knowledge cultivation
= ratio of volume of knowledge / size of the population

Remark: Nations specialize in their cultivation on knowledge.
eg, Japan = specialized in technology

	Education	Science	Technology
What?	a social institution for transmitting humankind's existing knowledge	a social institution for creating new knowledge that becomes a global public good	a social institution for creating new knowledge that becomes privately appropriated
Organized by?	formal training of the youth of humankind	the world in the form of professional academic research	the world in the form of a professional inventive work
Conducted in?	Schools	Universities	Research and development laboratories in industry..
Volume?	By the students enrolled in higher education	By the articles authored by the scientists	By the patents
Inequality among nations in Intensity of knowledge cultivation?	Large, but is decreasing	Larger, seems rather stable	Larger, and increasing

I. The global web of education

- Knowledge flows around the world through
  - the study of nonlocal textbooks
  - the import of teachers
- The global web of education can be mapped by date on the movement of students around the world
- The center of higher education is the US
  → other nations form a periphery attached to this center
- center & periphery hierarchy (= vertical stratification) has been combined with horizontal differentiation, where a region is a cohesive group of nations with strong relations with one another and weak relations with outsiders
  eg, Communist bloc

II. The global web of science

- = mapped by a survey of scientists and their ties (banden)
- sources of influence on scientific research in a country can be indicated by the locations of the influential scholars named by the scientists surveyed in the country
- scientific research in the US is influenced mostly by knowledge created within the US and very little by knowledge from abroad.
  ➔ scientific research in each other country is influenced mainly by knowledge created within the country and knowledge from the US

  ➔ science has a center, located at the US, from which the knowledge flows and influences research in the rest of the world

- the global web of science has been undergoing a process of globalization:
  →the flow of knowledge across national boundaries have been intensifying, relative ti the flow within countries

  BUT, this globalization has not entailed an equalization

III. The global web of technology

- technology = public announcement and private appropriation (inbezitneming) of new knowledge

- comprises (bestaat uit) a flow of knowledge (like science);
  this flow of knowledge through patents is essential to technology as a social institution

- has not only a center and periphery hierarchy, but also a horizontal differentiation into regions. For more than a generation, Eastern Europe was a region in the flow of technological knowledge, and now regionalization (is het ordenen van gegevens in ruimtelijke klassen) is occurring in the European Union, North America and East Asia

- technology differs from science by its private appropriation
  BUT, an invention may be patented in some countries and perhaps not patented in other countries. The ownership of knowledge in a country is thereby reflected in patents granted in the country for inventions made around the world

- not only technological inventions and property rights have been institutionalized more and more globally but also private appropriation increasingly extends across long distances (globalization)

IV. Formations in webs of knowledge: center-periphery hierarchy, regions, and globalization

Typically, a strong relationship between 2 nations in 1 web coincides with a strong relationship between them in another web, and a weak relation in a dyad (principle of twoness) in 1 web coincides with a weak relationship between them in another web.

Each web has a hierarchy.
BUT, the center is the same in the various webs, namely the US.

BUT, the steepness of the hierarchy differs among the webs. Peripheries are least marginal (rand) in education; they are more marginal in science and most marginal in technology.

$ vertical stratifications in a web & horizontal differentiation by region

V. Sources of the webs of knowledge: embeddedness in geopolitical webs

Where do the webs come from?
→ students who travel to apprentice (leermensen) themselves to prominent scientists may become colleagues of those scientists

Coupling between web of education and web of science = promoted by agreements between governments to pursue (nastreven) international exchanges and cooperation in education, science and technology

The web of knowledge are not autonomous but are embedded in geopolitical webs.

The center-periphery formations are due mainly to differences among nations in their cultivation of knowledge.
But, the centrality of the center has seemingly accumulated over and above its cultivation of knowledge.

The globalization of the webs may be attributed in part to the growing ease of communication and transportation around the world.

The attraction of the center is exerted not only on its surroundings but also within the center itself, ant the inwardness of the center has also accumulated and turned into a local parochialism, a "Not Invented Here" syndrome devaluing (reduction of the value of the currency) foreign cultivation of knowledge and enhancing the value assigned to local knowledge.

VI. Consequences of the webs of knowledge: unequal opportunities and restrictions

Project of modernization that unfolded along with decolonization in the decades after WWII envisioned a world in which the modernity of the West would be a model for emulation and catch-up by other societies around the world; some eventual equality among nations was expected,
BUT the cultivation of knowledge remains dominated by the West

Education, science and technology are coupled to the economy within each nation with positive effects that in a wealthy nation, form an upward spiral but, relatively in a poor society, form downward spiral, thus exacerbating (verergeren) the inequality in the world in knowledge and wealth.