Special Relativity as a Theory of Principles

On the Emergence of Einstein's Distinction between Constructive and Principle Theories

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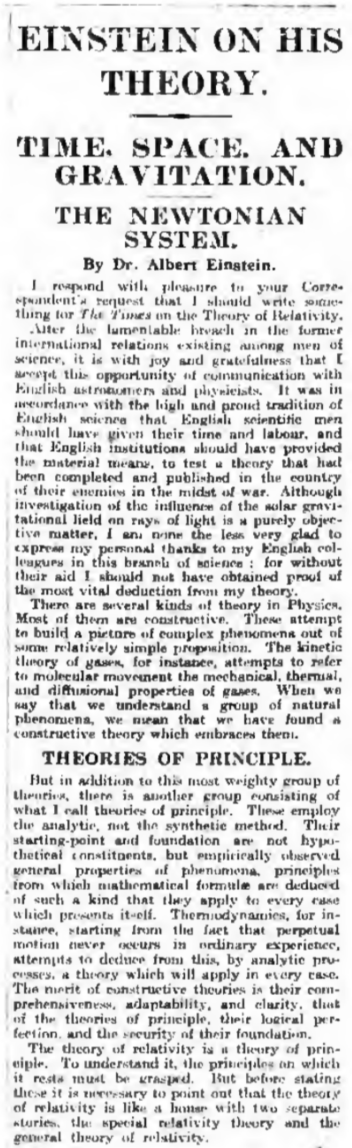
Introduction



EINSTEIN ON HIS THEORY.

TIME. SPACE. AND GRAVITATION.

THE NEWTONIAN SYSTEM.

By Dr. Albert Einstein.

I respond with pleasure to your Correspondent's request that I should write something for *The Times* on the Theory of Relativity.

After the lamentable breach in the former international relations existing among men of science, it is with joy and gratefulness that I accept this opportunity of communication with English astronomers and physicists. It was in accordance with the high and proud tradition of English science that English scientific men should have given their time and labour, and that English institutions should have provided the material means, to test a theory that had been completed and published in the country of their enemies in the midst of war. Although investigation of the influence of the solar gravitational field on rays of light is a purely objective matter, I am none the less very glad to express my personal thanks to my English colleagues in this branch of science: for without their aid I should not have obtained proof of the most vital deduction from my theory.

There are several kinds of theory in Physics. Most of them are constructive. These attempt to build a picture of complex phenomena out of some relatively simple proposition. The kinetic theory of gases, for instance, attempts to refer to molecular movement the mechanical, thermal, and diffusional properties of gases. When we say that we understand a group of natural phenomena, we mean that we have found a constructive theory which embraces them.

THEORIES OF PRINCIPLE.

But in addition to this most weighty group of theories, there is another group consisting of what I call theories of principle. These employ the analytic, not the synthetic method. Their starting-point and foundation are not hypothetical constituents, but empirically observed general properties of phenomena, principles from which mathematical formulæ are deduced of such a kind that they apply to every case which presents itself. Thermodynamics, for instance, starting from the fact that perpetual motion never occurs in ordinary experience, attempts to deduce from this, by analytic processes, a theory which will apply in every case. The merit of constructive theories is their comprehensiveness, adaptability, and clarity, that of the theories of principle their logical perfection, and the security of their foundation.

The theory of relativity is a theory of principle. To understand it, the principles on which it rests must be grasped. But before stating these it is necessary to point out that the theory of relativity is like a house with two separate stories, the special relativity theory and the general theory of relativity.

Nov. 1919, *Times* of London

relativity theory

- is a principle theory like thermodynamics
- not a constructive theory like the kinetic theory of gases

Introduction

- philosophical literature (Brown, Janssen, Acuña, etc.) $\Longrightarrow$ Einstein's original insight into the nature of spacetime

  dynamical vs. geometrical explanation

- historical literature (Darrigol, Frisch, Howard, etc.) $\Longrightarrow$ Einstein's threadbare variation on a 19th century theme

  physics of principles vs. physics of models

only part of the truth

Introduction

the constructive/principle theory distinction

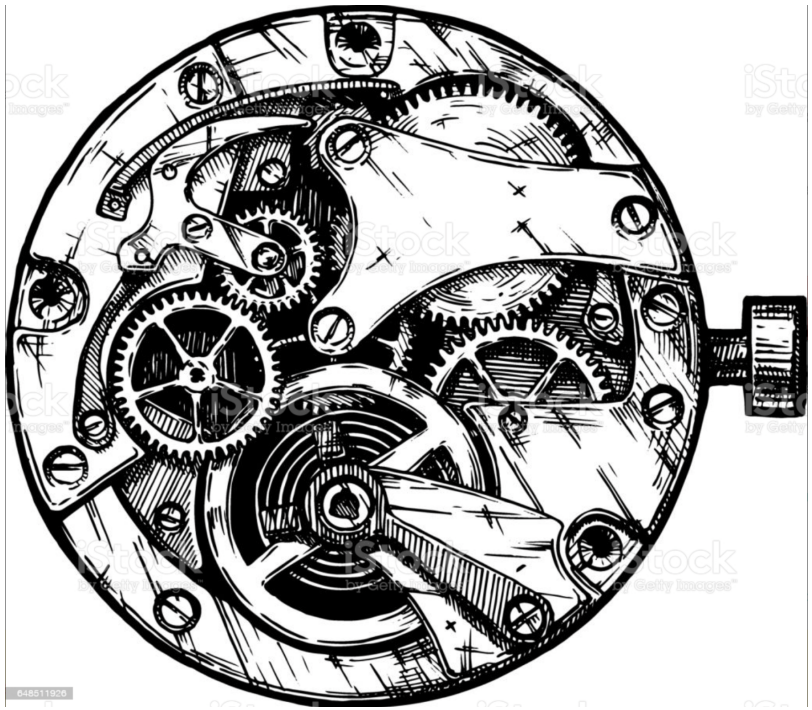
- context of justification $\Longrightarrow$ criteria for evaluation of existing theories
- context of discovery $\Longrightarrow$ heuristics for the discovery of new theories

these two aspects have to be disentangled

Introduction

- Swiss years (1905–1909) $\Longrightarrow$ apologetics
- Berlin years (1914–1933) $\Longrightarrow$ heuristics
- Princeton years (1933–1955) $\Longrightarrow$ autobiographics

Introduction



physicists are like someone who tries to understand how a watch works but cannot open its unbreakable case (Einstein, 1925; Einstein and Infeld, 1938)

- not only predict *how* the visible parts of the watch behave
- but understand *why* the visible parts of the watch behave as they do

a ‘theory’ that allows constructing a hypothetical ‘model’ of the clockwork

Introduction

how can such a theory can be discovered?

- constructive strategy: search for dynamical laws that allow to construct models of the clockwork
- principle strategy: search for principles that constraint the allowable dynamical laws and thus of possible clockworks' models

- constructive theories: entail dynamical *laws* whose solutions serve as models of the internal mechanism
- principle theories: entail constraints that the dynamical laws have to satisfy

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- today debate: dynamical vs. geometrical

  $\Longrightarrow$ special relativity as a constructive theory (Brown vs. Janssen)

- Marc Lange: coincidences vs. constraints

  $\Longrightarrow$ special relativity as principle theory

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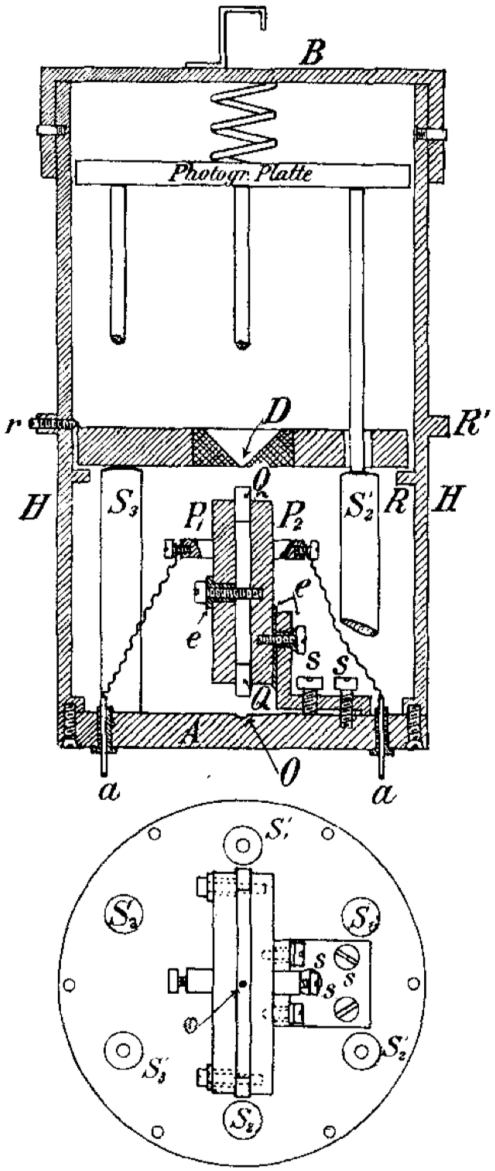
Part I

Swiss Years (1905-1914)

Kaufmann's Experiments



- Einstein (1905) cited for the first time by Kaufmann (1905, 1906)

mass of the electrons moving in the β-rays of radium grows as their velocity approaches that of light

- Abraham 's rigid electron (absolute theory)
- Lorentz deformable electron (relativity theory)

Einstein-Ehrenfest Debate (1907)

> The principle of relativity [. . .] together with the principle of the constancy of velocity of light, is not to be conceived as a 'complete system', in fact it is not as a system at all [. . .] [It is] merely as a heuristic principle which, when considered by itself, contains only statements about rigid bodies, clocks, and light signals. It is only by requiring relations between otherwise seemingly unrelated laws that the theory of relativity provides additional statements. [. . .] Thus, we are not dealing here at all with a system in which the individual laws are implicitly contained and from which they can be found by deduction alone, but only with a principle that (similar to the second law of thermodynamics) permits the reduction of certain laws to others

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- to derive the “laws of motion of electrons by electrodynamic methods, one found it necessary to make more specific assumptions on the distribution of electricity so that the problem is not an undetermined one” (Einstein, 1907).
- electron is charge attached to a “(rigid) scaffold” thus “laws that govern the motion of such a structure cannot be derived from electrodynamics alone” (Einstein, 1907, 207)

relativity principle

- one starts “from the law for the acceleration of the slowly moving electron (which is assumed or obtained from experience)” (Einstein, 1907, 207), i.e. Newton’s equations of motion which are supposed to be valid for small velocities.
- using the Lorentz transformations one obtains “the law for the acceleration of an electron moving at arbitrary speed” (Einstein, 1907, 207).

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Einstein's Constructive Theory of Electrons and Light quanta

A. Einstein (Zürich), Über die Entwicklung unserer Anschauungen über das Wesen und die Konstitution der Strahlung.

Als man erkannt hatte, daß das Licht die Erscheinungen der Interferenz und Beugung zeige, da erschien es kaum mehr bezweifelbar, daß das Licht als eine Wellenbewegung aufzufassen sei. Da das Licht sich auch durch das Vakuum fortzupflanzen vermag, so mußte man sich vorstellen, daß auch in diesem eine Art besonderer Materie vorhanden sei, welche die Fortpflanzung der Lichtwellen vermittelt. Für die Auffassung der Gesetze der Ausbreitung des Lichtes in ponderabeln Körpern war es nötig, anzunehmen, daß jene Materie, welche man Lichtäther nannte, auch in diesen vorhan-

non-Maxwellian electrodynamics with electron and light quanta as solutions (Einstein 1909–1911)

> "... construction [*Konstruktion*] of the elementary quantum of electricity and the light quantum"

(Einstein, 1909, 550)

Einstein: Constructive strategy failed

not too many possibilities: modify the existing laws of nature and check if they allow to construct models that account for available phenomena

- "I no longer ask whether these quanta really exist [n]or am I trying any longer to construct them [*zu konstruieren*] because I now know that my brain is incapable of prevailing this way" (Einstein to Besso, 13-05-1911).
- "I have also come to the opinion, as a result of many fruitless attempts based that through merely constructing [*blosses Konstruieren*], [...] that it is more advantageous [to proceed] without making use of any model [*Bild*]" (Einstein to Wien, 17-05-1912)

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too many possibilities: search for general principles that constraints the numbers of possible laws:

- it “raises the question of which general laws of physics we can still expect to be valid in the domain with which we are concerned” (Einstein et al., 1912, 436)
- draw “conclusions about the admissibility of any fundamental theory whatsoever on the basis of [empirically motivated principles]” (Einstein et al., 1912, 436)

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- new kinematics without abs. sim (transformation eq.'s for x, y, z, t)

  testable by using rods and clocks (e.g., transverse Doppler effect)

- express a dynamical law mathematically in a system K using the four coordinates x, y, z, t
- apply the Lorentz transformations
- obtain the mathematical expression of the law in a system K' with the variables x', y', z', t'.
- are the two expressions identical?

  yes: the law is well-formulated (justificatory power)
  no: law is not acceptable (heuristic power)

- modify the law so that it complies to the new kinematics (e.g. Newton laws of motion for charged point particles)

  test the new relativistic effects (e.g. electrons in β rays)

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all laws of nature must be Lorentz invariant

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- obtain the mathematical expression of the law in a system K' with the variables x', y', z', t'.
- are the two expressions identical?

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  no: law is not acceptable (heuristic power)

- modify the law so that it complies to the new kinematics (e.g. Newton laws of motion for charged point particles)

  test the new relativistic effects (e.g. electrons in β rays)

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- incompatible, but empirically supported postulates (RP and LP)
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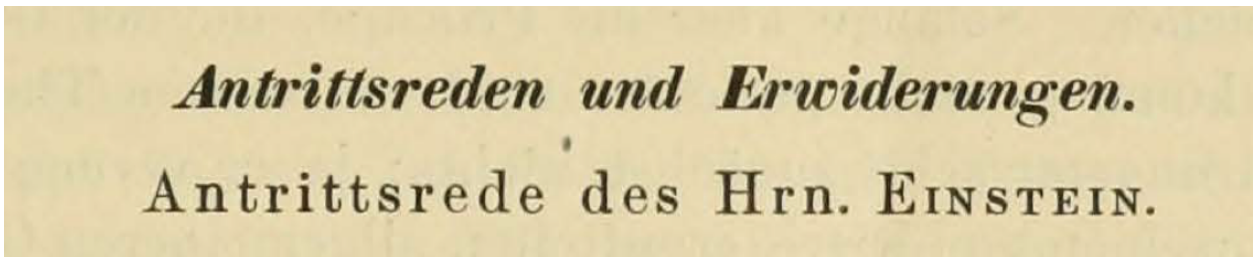
Part II

Berlin Years (1914-1933)

The Method of the Pure Theoretician


Antrittsreden und Erwiderungen.

Antrittsrede des Hrn. Einstein.

The Method of the Pure Theoretician

> the researcher should eavesdrop [*ablauschen*] general principles on nature by recognizing in larger sets of empirical facts certain general traits that can then be sharply formulated

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> 2. No state of motion is singled out with respect to others
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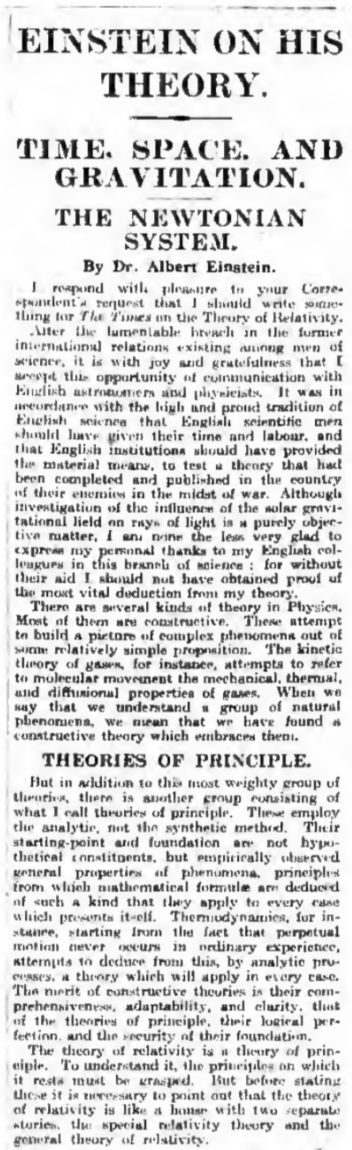


EINSTEIN ON HIS THEORY.

TIME. SPACE. AND GRAVITATION.

THE NEWTONIAN SYSTEM.

By Dr. Albert Einstein.

I respond with pleasure to your Correspondent's request that I should write something for *The Times* on the Theory of Relativity.

After the lamentable breach in the former international relations existing among men of science, it is with joy and gratefulness that I accept this opportunity of communication with English astronomers and physicists. It was in accordance with the high and proud tradition of English science that English scientific men should have given their time and labour, and that English institutions should have provided the material means, to test a theory that had been completed and published in the country of their enemies in the midst of war. Although investigation of the influence of the solar gravitational field on rays of light is a purely objective matter, I am none the less very glad to express my personal thanks to my English colleagues in this branch of science; for without their aid I should not have obtained proof of the most vital deduction from my theory.

There are several kinds of theory in Physics. Most of them are constructive. These attempt to build a picture of complex phenomena out of some relatively simple proposition. The kinetic theory of gases, for instance, attempts to refer to molecular movement the mechanical, thermal, and diffusional properties of gases. When we say that we understand a group of natural phenomena, we mean that we have found a constructive theory which embraces them.

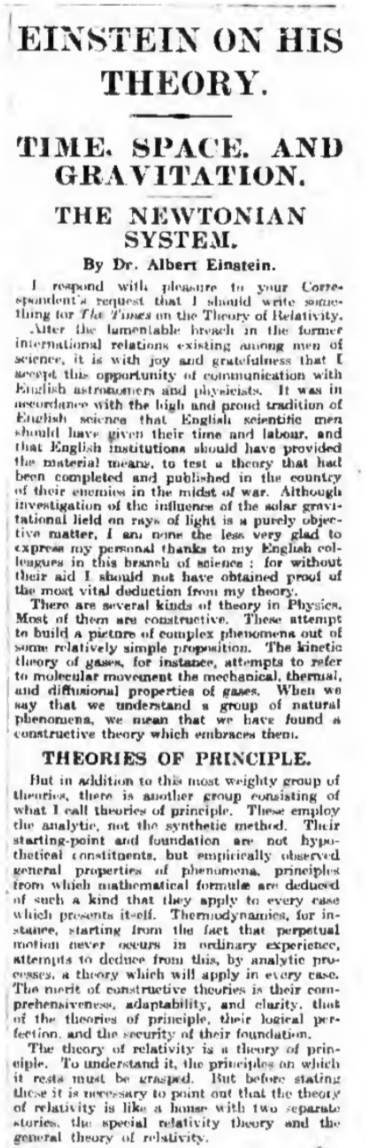
THEORIES OF PRINCIPLE.

But in addition to this most weighty group of theories, there is another group consisting of what I call theories of principle. These employ the analytic, not the synthetic method. Their starting-point and foundation are not hypothetical constituents, but empirically observed general properties of phenomena, principles from which mathematical formulæ are deduced of such a kind that they apply to every case which presents itself. Thermodynamics, for instance, starting from the fact that perpetual motion never occurs in ordinary experience, attempts to deduce from this, by analytic processes, a theory which will apply in every case. The merit of constructive theories is their comprehensiveness, adaptability, and clarity, that of the theories of principle, their logical perfection, and the security of their foundation.

The theory of relativity is a theory of principle. To understand it, the principles on which it rests must be grasped. But before stating these it is necessary to point out that the theory of relativity is like a house with two separate stories, the special relativity theory and the general theory of relativity.

- constructive theories: try to "to construct [*zu konstruieren*] synthetically a model [*ein Bild*] of more complex phenomena" according to the certain actual physical laws
- principle theories: starting from universally recognized empirical facts search "analytically" for "mathematically formulated criteria" that any possible dynamical law must satisfy if those facts have to hold.

The article for the London Times



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Einstein's heuristic trick: instead of guessing for new theories search for principles that restrict the manifold of possible theories

> [TH:] What must the laws of nature be like so that it is impossible to construct a perpetual motion machine of either the first or second kind? [SR: What must the laws of nature be like so that it is impossible to construct device that detects the ether-drift?]

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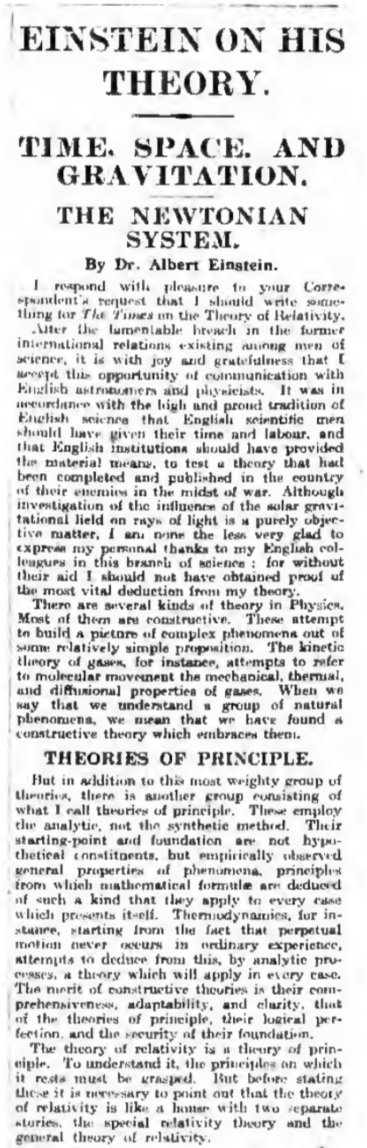

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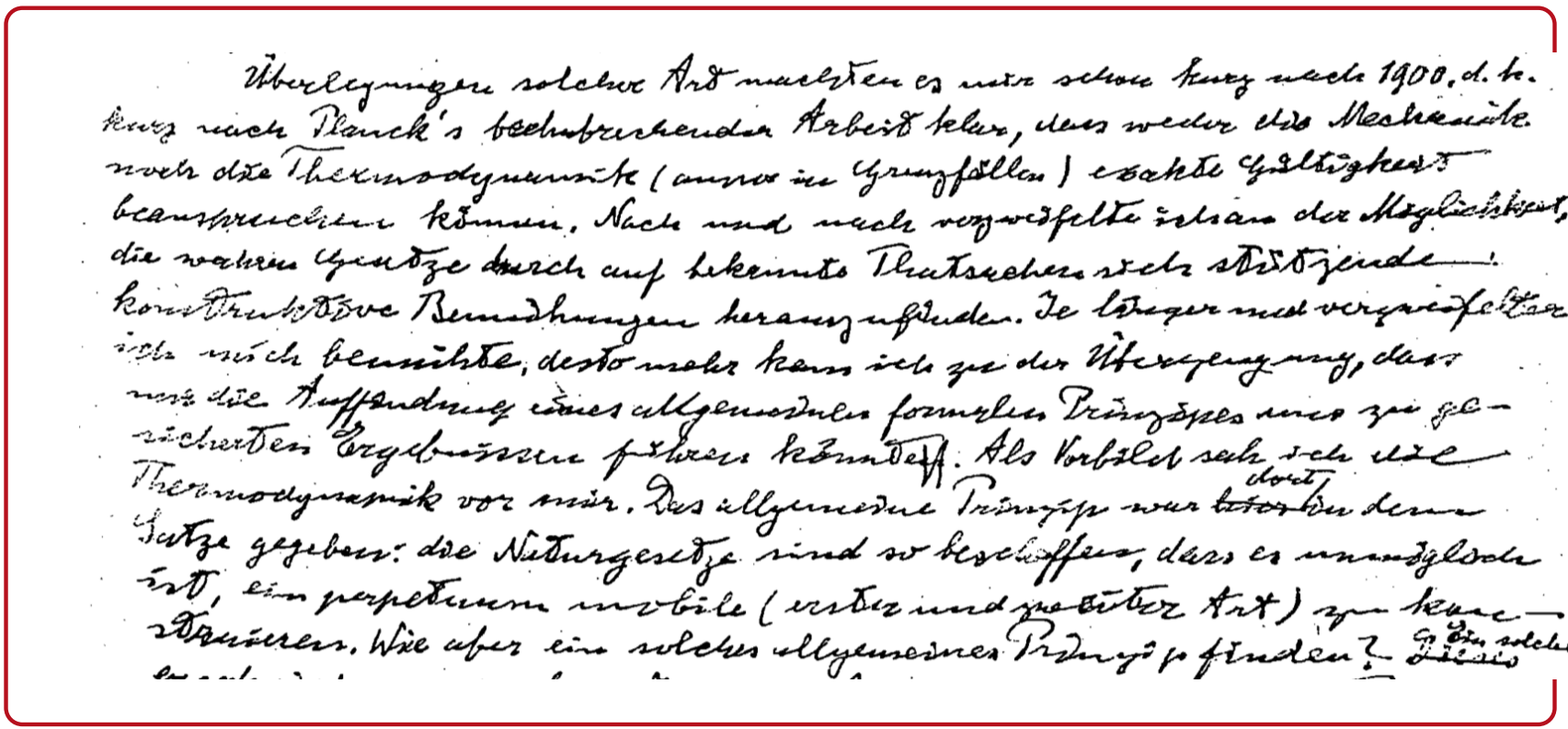
Part III

Princeton Years (1933-1955)

Autobiographical notes (1946)



Überlegungen solcher Art machten es mir schon kurz nach 1900, d. h. kurz nach Planck's bahnbrechender Arbeit klar, dass weder die Mechanik noch die Thermodynamik (genau in Grenzfällen) exakte Gültigkeit beanspruchen können. Nach und nach verzweifelte ich an der Möglichkeit, die wahren Gesetze durch auf bekannte Tatsachen sich stützende konstruktive Bemühungen herauszufinden. Je länger und verzweifelter ich mich bemühte, desto mehr kam ich zu der Überzeugung, dass nur die Auffindung eines allgemeinen formalen Prinzipes uns zu gesicherten Ergebnissen führen könnte. Als Vorbild sah ich die Thermodynamik vor mir. Das allgemeine Prinzip war dort bereits in dem Satze gegeben: die Naturgesetze sind so beschaffen, dass es unmöglich ist, ein perpetuum mobile (erster und zweiter Art) zu konstruieren. Wie aber ein solches allgemeines Prinzip finden? Ist ein solches Prinzip

Autobiographical notes (1946)

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Einstein's Distrust of Electrodynamics

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non-existence of *perpetuum mobile* of f. or s. kind without ref. to mechanics)

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> Maxwell's equations imply the 'Lorentz group,' but the Lorentz group does not imply Maxwell's equations. The Lorentz group may indeed be defined independently of Maxwell's equations as a group of linear transformations which leave [. . .] [c] invariant.
>
> *Einstein, 1950*

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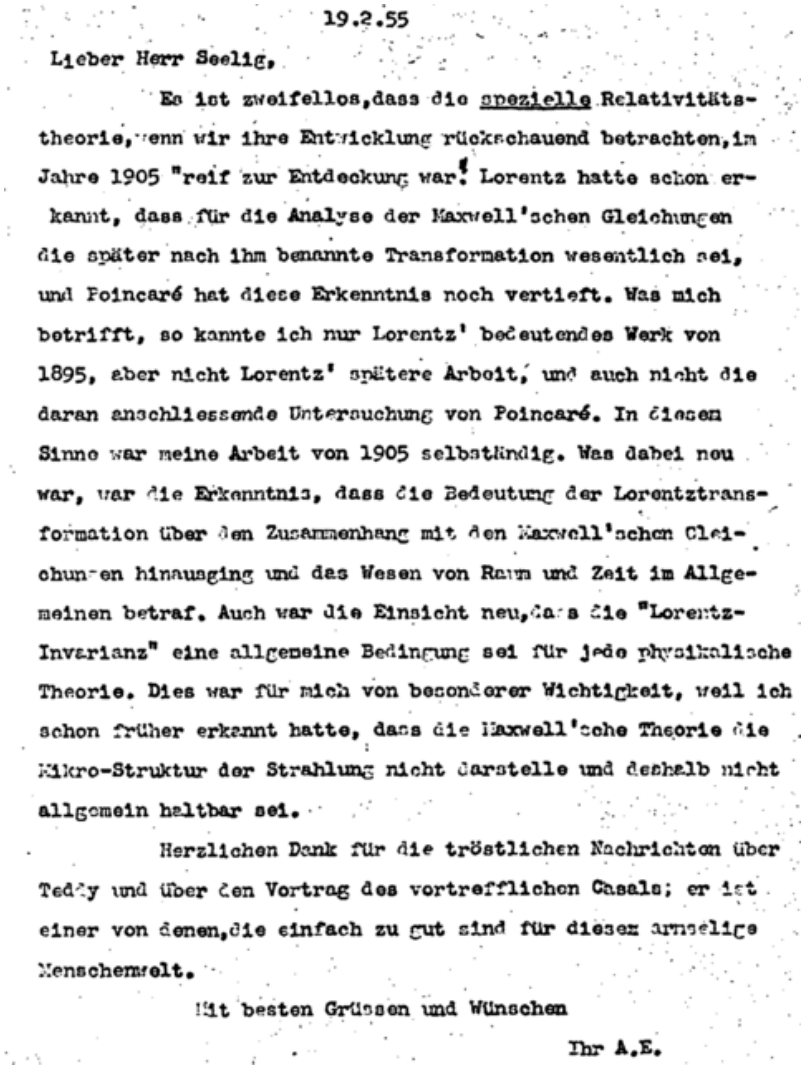
"... But in 1905 I already knew [...] [that] radiation has an atomistic structure. [...] However, [...] [it is consoling that] special relativity is based essentially only on the constant c, and not on the presupposition of the reality of the Maxwell field"

Einstein to von Laue, 17-01-1952.

Conclusion: The letter to Seelig



19.2.55

Lieber Herr Seelig,

Es ist zweifellos, dass die spezielle Relativitäts-theorie, wenn wir ihre Entwicklung rückschauend betrachten, im Jahre 1905 "reif zur Entdeckung war". Lorentz hatte schon erkannt, dass für die Analyse der Maxwell'schen Gleichungen die später nach ihm benannte Transformation wesentlich sei, und Poincaré hat diese Erkenntnis noch vertieft. Was mich betrifft, so kannte ich nur Lorentz' bedeutendes Werk von 1895, aber nicht Lorentz' spätere Arbeit, und auch nicht die daran anschliessende Untersuchung von Poincaré. In diesem Sinne war meine Arbeit von 1905 selbständig. Was dabei neu war, war die Erkenntnis, dass die Bedeutung der Lorentztransformation über den Zusammenhang mit den Maxwell'schen Gleichungen hinausging und das Wesen von Raum und Zeit im Allgemeinen betraf. Auch war die Einsicht neu, dass die "Lorentz-Invarianz" eine allgemeine Bedingung sei für jede physikalische Theorie. Dies war für mich von besonderer Wichtigkeit, weil ich schon früher erkannt hatte, dass die Maxwell'sche Theorie die Mikro-Struktur der Strahlung nicht darstelle und deshalb nicht allgemein haltbar sei.

Herzlichen Dank für die tröstlichen Nachrichten über Teddy und über den Vortrag des vortrefflichen Casals; er ist einer von denen, die einfach zu gut sind für diesen armseligen Menschenwelt.

Mit besten Grüssen und Wünschen

Ihr A.E.

Conclusion: The letter to Seelig

> There is no doubt, that the special theory of relativity, if we regard its development in retrospect, was ripe for discovery in 1905. Lorentz had already recognized that the transformations later named after him were essential for the analysis of Maxwell's equations, and Poincaré has deepened this knowledge. [. . .] The new feature of [the relativity theory] was the realization that the Lorentz transformation transcends its connection with Maxwell's equations and has to do with the nature of space and time in general [. . .] A further new result was that the 'Lorentz invariance' is a general condition for any physical theory. This was for me of particular importance because I had already previously recognized that Maxwell's theory does not represent the microstructure of radiation

(Einstein to Seelig, 19-02-1955)

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Conclusion: Coincidences and Constraints

Lange: coincidences vs. constraints

- Lorentz and Poincaré: Lorentz-transformations are the byproduct of feature that the actual laws governing field and matter as a feature happen to posses (coincidence!)

  theory of radiation and matter $\Longrightarrow$ Lorentz transformations

- Einstein: Lorentz-transformation are a requirement that all possible theories of matter and radiation *must* satisfy (constraint!)

  Lorentz transformations $\not\Longrightarrow$ theory of radiation and matter

Conclusion: Coincidences and Constraints

special relativity as a constructive theory

- Brown *et al.* constructive theory about matter and radiation (like thermodynamics before Boltzmann) $\Longrightarrow$ Lorentz invariance is feature that actual dynamical laws happen to have
- Janssen *et al.* constructive theory about space and time (Minkowski is the Boltzmann of relativity) $\Longrightarrow$ Lorentz invariance is feature of spacetime happens to have

two sides of the same coin (Acuña)

special relativity as a principle theory

- Lange: Lorentz invariance is a feature that all possible dynamical laws that must have
- Einstein: principle theories constrain, constructive theories explain

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> General principles are formal conditions that constraint the choice of possible theories. [. . .]
>
> 1. Step. Special relativity. Constraining principle: The equations of physics are [Lorentz invariant].
>
> 2. Step. General relativity. Constraining principle: The equations of physics are [generally covariant]. This theory determine univocally the law of gravitational field, but let a quite wide space for the theoretical presentation of the electromagnetic field
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Einstein to Seelig, 01-07-1952

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Thanks!

Marco Giovanelli

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