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Absolute and Everlasting in Einstein's Relativity

Abstract

Pointing to the importance of invariance principles (symmetry laws) has been ranked as one of Einstein's greatest merits. The symmetries represent an additional category used in a description of the physical world, additional to initial conditions and the very laws of Nature, as distinguished by Newton. Some invariances related to space and time are easy to describe: that the laws of nature are the same everywhere, that they are time independent, and that they do not change if some physical system is subjected to a rotation around an axis in space. The relativistic invariance, which Einstein re-established in his special relativity, was based on giving a full physical meaning to the transformations which Lorentz used to relate observers moving uniformly with respect to each other. He realized that there is no absolute "at rest", and no sensible "simultaneous" events. What is absolute in his relativity is the constant speed of light, and a well defined proper-time interval.

The relativity entered physics as the first great creative principle on Einstein's list. Subsequently, its marriage to the quantum principle *established in atomic physics, brought out the quantum field theory as a mighty tool for the future investigation of the subatomic world. The newly discovered fundamental interactions (weak and strong) urged to look for a principle explaining them. It has been found in the form of the gauge principle underlying the present day standard model of elementary particle interactions. It is remarkable that Einstein gave his magical touch also to quantum and gauge principles. Still, the most important Einstein's idea is that the whole of physics has to be expressed in Minkowski's space, subject to Lorentz transformations.*

Today we are aware that, like other symmetries with their restrictions, Lorentz symmetry would be restricted to the non-cosmological scale. New ideas in conjunction with the forthcoming cosmological measurements may lead to astonishing results.

Key Words

the absolute, everlasting, relativity, invariance principles, *quantum principle*, Albert Einstein

1. A historical prelude

Einstein was obsessed with discovering the universal atributes of Nature that holds for everyone who inhabits our Universe. He saught for truly universal laws, whose validity extends beyond special observers. If such truly universal laws are accompanied by universal constants of Nature, then we are prepared to begin a dialogue with extraterrestrial inteligences. In this way he generalized the Copernican view, by extending Copernican extraterrestriality to the *constants* of Nature and the *laws* of Nature.

Einstein's desire to rely on absolute is something he had in common with Planck, who several years earlier introduced the first such universal constant, the quantum of action. When Einstein proposed in his special relativity the speed of light as another universal constant, it was immediately accepted by Planck. Moreover, Planck supported Einstein's further attempts to generalise the special relativity. The final outcome of this struggle was on one side the formulation of the general relativity, and on the other hand a rise of invariance principle (symmetry laws).

In addition to the existing categories, the initial conditions and the very laws of Nature as already distinguished by Newton, there comes the third, the symmetry principle, as an essential category used in description of the physical world. Its introduction has been ranked as one of Einstein's greatest merits.

It is unfortunate that somebody's intellectual curiosity often stops because relativity has accumulated an aura of impenetrability. I am aware that the people in the audience (and eventual readers) are a diverse group, their professional goal spanning philosophy, science and arts, so that I should avoid writing the equations. Although high school algebra is enough for special relativity, the general relativity would be mathematically more demanding. Therefore, I am trying merely to convey the story of the birth of the theory of relativity. It is a story on how the observations on the speed of light in our familiar world of space and time lead to the notion of space-time. It may give some satisfaction to those having in common a sense of wonder about the world around us.

It is often believed that the early period of a man determines his later performance. Einstein in his latest ascribed his success in science to "continuing to ask questions that children eventually are taught not to ask, combined with stubborn persistence". Let us therefore recall the years during which Einstein's character was shaped to face in a certain moment in history the preconditions developed for creating the special relativity.

A period preceding Einstein's year 1905

Albert Einstein was born on March 14, 1879, as the son of Hermann Einstein and Pauline (born Koch). Already the next year his family moved from his birth place (Ulm in Germany) to Munich, where Albert later passed through a Catholic ground school. The extra classes on the Judaism he took there at the age of eleven were followed by a period of his intense religious feelings, when he wrote the songs in prise of God. On the basis of a devotion experienced in this period, he remained a deeply religious man for the rest of his life. His other most well known passion was the violin, but some other experiences from his childhood actually determined his future as a scientist. The first was a fascination at his age of five by the magnetic needle, i.e. by a hidden force governing its behaviour. The second was his discovery of simple provable geometrical statements, he found in a booklet at the age of twelve.

He kept a habit of an independent reading also after entering the study of theoretical physics at ETH in Zurich, in 1896. The notes taken by his friend Marcel Grossmann helped him to pass the exams, and the father of the same friend helped him after his diploma in 1900 to find a job in the patent office in Bern, and to acquire the Swiss citizenship in 1901. His marriage with Mileva Marić came after they got a child Lieserl in 1902. Their marriage lasted until year 1914, the period in which they got also two sons, Hans-Albert and Eduard.

The job in Bern allowed Einstein to devote himself to theoretical physics, so that in the next four years he published four articles in *Annalen der Physik*, at that time the leading German journal. In these works he considered the reality of the atoms and molecules, something that was then far from being accepted. Without doubt, the work from this period has been noticed by Max Planck, who was admired by an explosion of Einstein's creativity in year 1905, his *annus mirabilis*. Most of data and quotations we put in *italic* are taken (if not stated differently) from Pais' biography of Einstein.[1]

Einstein's **annus mirabilis** *1905*

Einstein's creativity produced five remarkable papers in *Annalen der Physik* in year 1905. The following dates are remembered by the papers that shook the world:

March 17, 1905 is known as a date on which Einstein submitted a paper in which he introduced the *light quanta* in order to explain the *photoelectric effect*. The paper was titled "A heuristic point of view concerning the production and transformation of light".[2]

April 30, 1905 is the date on which he completed a paper in which he showed how to calculate Avogadro's number. This paper was accepted (in July) as Einstein's thesis on molecular dimensions, that was published later in a modified form.[3] It was followed by *another paper* on the subject of *Brownian motion*, "On the movement of small particles, suspended in stationary liquids required by the molecular-kinetic theory of heat".[4]

June 30, 1905 is known for his submission of a paper titled "On the electrodynamics of moving bodies".[5] In this paper he introduced the *Special Theory of Relativity* (STR).

September 27, 1905 is the date of a submission of his final paper of 1905, titled "Does the inertia of a body depend on its energy content".[6]

In these papers Einstein's interest centred partly on rather special and partly on very general problems. We realise that the problems he had addressed, established the alphabet ("A, B and C") of the physics related to atomic and subatomic layers. Notably, this happened as early as in the year 1905, when even the existence of atoms was not generally accepted:

A) *Brownian motion* served to prove once and for all that the atoms do exist. The motion of the particle floating in a liqiud is determined by the pushes from the molecules of the liquid, and is essentially a random walk calculated by Einstein. This work started a revolution in statistical physics that is still going on today. Brownian motion theory entered nanotechnology, molecular motors in biology, modeling the fluctuation of share prizes on the stock market, traffic flow and chemical transport in cells. Accordingly, Einstein's papers on Brownian motion are the most cited among his work from 1905.

B) *Einstein's light quanta* initiated the particle-wave duality. The attempts to resolve this "particle or wave" dilemma marked the beginning of quantum

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[1] Abraham Pais, *Subtle is the Lord. Scientific Biography of Albert Einstein*, Oxford University Press, Oxford 1982.

[2] Albert Einstein, "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt", *Ann. Phys*. 17, Leipzig 1905, pp. 132–148.

[3] Albert Einstein, "Eine neue Bestimmung der Moleküldimensionen", *Ann. Phys*. 19, Leipzig 1906, pp. 289–306.

[4] Albert Einstein, "Über die von molekularkinetischen Theorie der Wärm geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen", *Ann. Phys*. 17, Leipzig 1905, pp. 549–560.

[5] Albert Einstein, "Zur Electrodynamik bewegter Körper", *Ann. Phys*. 17, Leipzig 1905, pp. 891–921.

[6] Albert Einstein, "Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?", *Ann. Phys*. 18, Leipzig 1905, pp. 639–641.

mechanics. Still, both founders of quantum mechanics, Planck and Einstein, were reluctant to pursue on it. That Planck was not enthusiastic about the light quantum hypothesis becomes evident from the recommendation that Planck, Nernst, Rubens and Warburg wrote in 1913, proposing Einstein for a membership in the Prussian academy:

> "In sum, one can say that there is hardly one among the great problems in which modern physics is so rich to which Einstein has not made a remarkable contribution. That he may sometimes have missed the target in his speculations, as, for example, in his hypothesis of light-quanta, cannot really be held too much against him, for it is not possible to introduce really new ideas even in the most exact sciences without sometimes taking a risk."

Einstein considered himself the hypothesis of light quanta as his only revolutionary one. In his famous Salzburg lecture in 1909, that regarded Pauli as a turning point in the development of theoretical physics, Einstein prophetically announced what was achieved by Dirac almost twenty years later:

> "… the next stage in the development of theoretical physics will bring us a theory of light that can be understood as a kind of fusion of the wave and emission theory of light".

Much later it was recognized that at the subatomic scale quantum mechanics had to be supplemented by special relativity, the fusion that resulted in the quantum field theory.

C) *Special Relativity Theory represents the most general among these issues*. It generalizes Newton's laws of motion to encompass particles moving at close to the speed of light. At low velocities it reduces to Newton's theory, providing a good description for motions at everyday speeds.

Sometimes we can come up to the realization that some of the known physical principles couldn't all be true. Exactly this happened to Maxwell equations confronted with Galilean Relativity, i.e. the classical velocity addition theorem. The latter is related to two unproven assumptions stated already by Newton, at the outset of his *Principia*: *The absolute space, and the absolute time*. Einstein must have being fascinated by impressive predictions produced by Maxwell equations, notably the existence of electromagnetic waves. What he in particularly relied on was the fact that these equations predict the speed with which electromagnetic waves propagate through space. By deciding to retain all consequences of Maxwell equations, and to abandon classical velocity addition, Einstein entered into rethinking the nature of space and time.

2. Einstein's Special Relativity

A period preceding the formulation of Special Relativity

Maxwell's electomagnetism offers some best examples for the "relativity" of the appearance: While a stationary observer will see only an electric field of a charge, an observer in motion with respect to it will see a magnetic field in addition. In fact, it was Faraday's induction that originally inspired Einstein to go in the direction of formulating Special Relativity. At the beginning, Einstein's approach did not differ much from what Newton have had with his first law (the law that was found to be true only by so called "inertial" observers). Einstein temporarily accepted things that are absolute for a certain class of observers, that are in uniform relative motion. Therefore the (unfortunate) name of "Special Relativity" for the theory that followed from this approach. This very name was for the same reason invented by Henri Poincaré one year before 1905. In addition, Poincaré acknowledges Lorentz's pioneering role, and all this has raised questions about priorities in the discovery of relativity. Later Lorentz was complaining that Einstein was just postulating what others tried to prove. Einstein dared to consider Lorentz's transformations seriously, and to conclude that by passing from one inertial observer to another, the time and space coordinates start to mix. The remaining step was joining light to time, leading to space and time being fused together into united four-dimensional space-time world.

The prevailing opinion today is that Lorentz had the *mathematics*, Poincaré had the *philosophy*, but neither of the two had the physics. The time was ripe that somebody spells out clearly also the *physics* of relativity.

From today's point of view the essential discovery came from two American physicists, A. Michelson and E. Morley. Non-observation of Earth's motion through the "ether" clearly indicated that the usual addition of velocities was not valid for light.

Let us quote from A. Pais' biography of Einstein,[7] how Einstein described the events preceding his papers on the relativity in the year 1905, year before his death:

> "I was, for general reasons, firmly convinced that there does not exist absolute motion and my problem was only how this could be reconciled with our knowledge of electrodynamics. One can therefore understand why in my personal struggle Michelson's experiment played no role, or at least no decisive role",

and two months before his death:

> "Lorentz already recognized that the transformation named after him are essential for the analysis of Maxwell's equations and Poincaré deepened this insight still further…"

To Einstein it was clear that the sought theory should rely on two absolute ingredients: *The speed of light* c, *and the proper time* τ.

On the other hand, Poincaré required the third hypothesis, that

> "A body in translation motion suffers a deformation in the direction in which it is displaced…"

This indicates that Poincaré did not realize that the contraction is already contained in the two Einstein's postulates.

Special Relativity

Einstein's special relativity is based on two *invariant quantities*, that are the same for all inertial observers. The first of them, the speed of light *c*, being the same for everybody, independent of the velocity of person measuring it, enables one to measure distances in light seconds. It has a deep consequence, revealed several years later by Minkowski, that space and time are fused into a unified four-dimensional *spacetime*. Newton's separate intervals of time and space are combined into a *space-time interval s*, obeying a generalized Pythagorean rule:

$$(\text{space-time interval})^2 = (\text{time interval})^2 - (\text{space interval})^2$$

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[7] A. Pais, *Subtle is the Lord…*, p. 172.

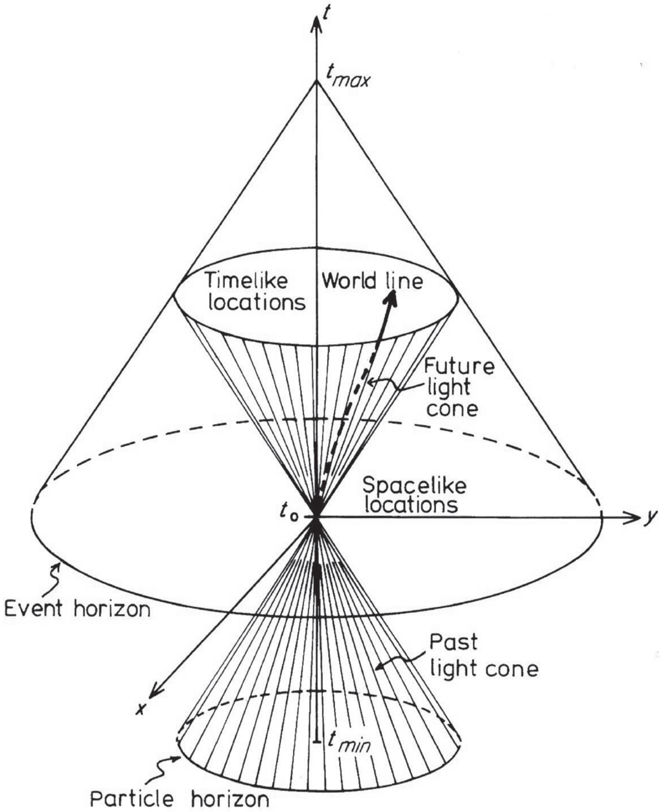


Figure 1. The light cone separates the causaly connected "timelike" region from spacelike locations unreachable to light[8]

$$s^2 = c^2t^2 - (x^2 + y^2 + z^2)$$

The precise mathematical notation defines the famous "light cone" displayed on Figure 1, the envelope of paths of light rays for which the spacetime distance is zero. Such is, for example, the distance between our eye and the stars. On the other hand, each observer possesses his proper reference frame, where he is at rest, and where he measures the proper time. In this way the proper time τ defined by

$s^2 = c^2 \tau^2$

emerges as an invariant concept. It enables us to attribute the lifetime to an elementary particle, acting as a clock. It might look as a surprise that the muons – unstable particles living at rest only a millionth of a second – travel over considerable distances in the atmosphere and in the rings od the particle accelerators. It is a feature of the four dimensional space-time that moving muons live longer, or that the path they travell appears contracted to an observer sitting on the muon. Such observation of the *time dilation* and the observation of the *length contraction* contradicts ordinary common sense. All these peculiar relativistic effects are given by the Lorentz gamma factor

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

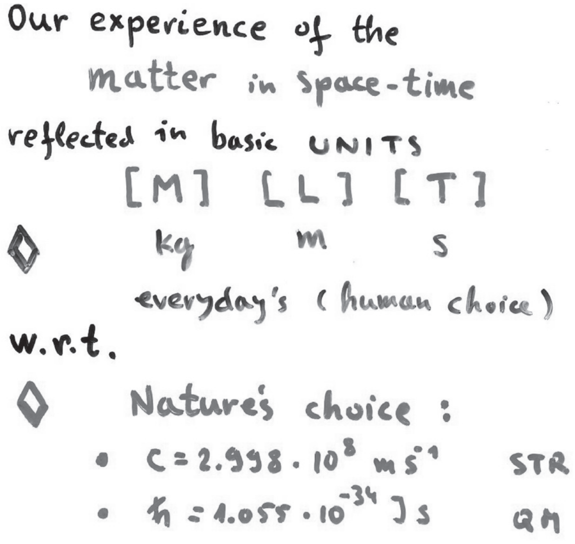
so that they became huge for velocities approaching the velocity of light.

The Special Theory of Relativity identifies the Lorentz transformations as a means to connect different inertial observers. It is obvious that two manoeuvres by the rocket are needed to approach the space station in Earth's orbit: the boost of the rocket to the speed of the station should be accompanied by the rotation, adjusting the axes of the two bodies. Each body in the four dimensional space-time is characterized by four coordinates or, technically, by the four vector (ct, x, y, z). The invariant length s^2 introduced above, is just the square of this four vector. The importance of this concept was strenghtened by observation of another four vector, that can be inferred from the first paper on relativity published by someone other than Einstein. It was published by M. Planck in *Verh. Deutsch. Phys. Ges.*, 4 (1906), p. 136, at time when he presented special relativity in the physics colloquium in Berlin in the winter semester of 1905–1906. In his later scientific autobiography in 1948 Planck explained why he was so strongly drawn to Einstein's theory:

> "For me its appeal lay in the fact that I could strive toward deducing absolute invariant features following from its theorems."

In his book on *The Theory of Heat Radiation* he wrote:

> "All the systems units which have hitherto being employed (…) owe their origin (…) not according to general points of view which would necessarily retain their importance for all places and all times, but essentially with reference to the special needs of our terrestrial civilization. Thus the units of length and time were derived from the present dimensions and motion of our planet… In contrast with this it might be of interest to note that (…) we have the means of establishing units of length, mass, time (…) which are independent of special bodies or substances, which necessarily retain their significance for all times and for all environments, terrestrial and human or otherwise, and which may, therefore, be described as 'natural units'. The means of determining the units of length, mass and time (…) are given by the constant h, together with the magnitude of the velocity of propagation of light in a vacuum and that of the constant of gravitation, G. These quantities retain their natural significance (…) when measured by the most widely differing intelligences according to the most widely differing methods."



Our experience of the
matter in space-time
reflected in basic UNITS
[M] [L] [T]
◊ kg m s
everyday's (human choice)
w.r.t.
◊ Nature's choice :
- $c = 2.998 \cdot 10^{8}\ m\, s^{-1}$ STR
- $\hbar = 1.055 \cdot 10^{-34}\ J\, s$ QM

Figure 2. The Human's with respect to Nature's choice of the basic units.

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[8] Taken over from Matts Roos, *Introduction to Cosmology*, J. Wiley and Sons, New York ^{2}1997.

Thus, Planck proposed the Newton's gravitational constant G as the third Nature's choice on Figure 2. Like Planck played a huge role in supporting Einstein's work in gravity, he was among first that understood and contributed to special relativity. Expressions that Planck wrote for total energy E and momentum p of a body with arbitrary velocity v

$$E = \gamma mc^2$$
$$p = \gamma mv$$

can be arranged to the relation expressing an equivalence of energy and mass

$$E^2 - (pc)^2 = (mc^2)^2$$

In Einstein's words (recorded is his voice on the soundtrack of the film, *Atomic Physics*, 1948):

> "It followed from the special theory of relativity that mass and energy are both but different manifestations of the same thing – a somewhat unfamiliar conception for the average mind. Furthermore, the equation E is equal to m c-squared, in which energy is put equal to mass, multiplied by the square of the velocity of light, showed that very small amounts of mass may be converted into a very large amount of energy and vice versa. The mass and energy were in fact equivalent, according to the formula mentioned above. This was demonstrated by Cockcroft and Walton in 1932, experimentally."

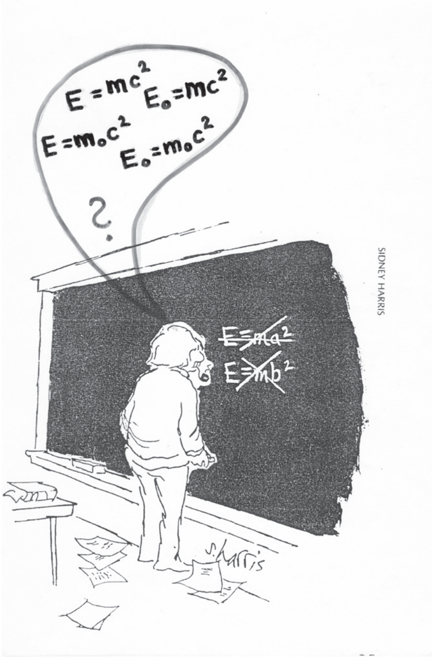

Figure 3. An artist's view on the birth and the meaning of the energy and mass equivalence.

This *equivalence* of mass and energy can be derived by assuming that the pair forming the four vector (E/c, p) transforms in the same way as the pair forming the four vector (ct, r). Then it is evident that what was *the proper time* in the square of the later four vector, the same role plays *the invariant mass m* in "Planck's" four vector. This clarifies some confusion in the literature when using also the terms of "relativistic mass m" and "rest mass m_0". This is illustrated on Figure 3, the warnings on "the pedagogical virus of relativistic mass" repeatedly given by Lev Okun.[9]

All this became obvious only after Minkowski in his famous "space and time" lecture given in Cologne in 1908 introduced the notion of four-dimensional space-time:

> "Henceforth, space by itself and time by itself are doomed to fade away into mere shadows, and only the kind of union of the two will preserve an independent reality."

In his paper from the same year, Minkowski made the transcription of Einstein's theory into tensor form, where the four-vectors are one example of the relativistic tensors. At first, Einstein regarded this formal simplification as a superfluous learnedness (*überflüssige Gelehrsamkeit*). Under the influence of his friend, a mathematician Marcel Grossman, Einstein gradually realised that the tensor calculus would enable him to express the laws of nature in a form that would look the same for all observers, irrespectively of how they were moving. The laws of nature written as tensor equations gave a precise expression to his *Principle of Covariance*. In 1912 he already accepted tensor methods on his way to formulate the general relativity.

3. From General Relativity to Unified Field Theory

Einstein's General Relativity

Einstein's 1907 paper shows that for him the special relativity is only an introduction into a more general theory that will include also the gravitational force. His correspondence from 1907 to his friend Conrad Habicht (with whom, and another friend Maurice Solovine, he had met regularly in his Bern's patent office period to discuss philosophical, scientific, and literary matters) reveals that he was "busy working on relativity theory in connection with the law of gravitation". Einstein was very fortunate that pure mathematicians already investigated, in time for him, geometries that could exist on curved surfaces. Thereby they also developed the mathematics of tensors, that enabled him to formulate the principle of covariance.

For him it was obvious that Newton's theory of gravity, with no reference to the speed of light, violated even basic principles of special relativity. Einstein later wrote

> "… that the basic demand of the special theory of relativity is too narrow, i.e. that an invariance of the laws must be postulated also relative to non-linear transformations of the coordinates in the four dimensional continuum".

From this initial step made in 1908, eight long years of hard work were necessary to execute the idea. During that period Einstein had a very important support of Max Planck, who created for him exeptional working conditions in Berlin.

In the General Theory of Relativity Einstein proposed a further big leap, to unite space-time and matter-energy. The latter curves a four dimensional space-time continuum. Warping of the space-time by the presence of the matter-energy was tested during a total eclipse on May 29, 1919. The starlight was deflected as it passed by the sun, making Einstein a famous person.

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[9] Lev B. Okun, "The concept of mass", *Physics Today*, June 1989, p. 31; "The concept of mass in the Einstein year", *arXiv:hep-ph/0602037*, 2006.

Another application of Einstein's General Relativity is cosmology. The reason is that gravitational force, weak on the laboratory scale, dominates over cosmological distances. By providing the equations that could be applied to the universe as a whole, Einstein opened a new chapter in cosmology.

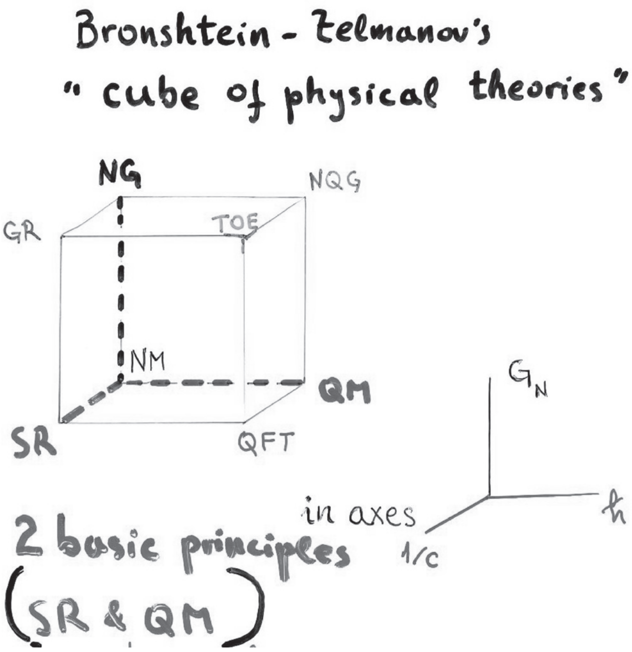

Figure 4. The cube of physical theories constructed above a basis of Newton mechanics (NM), Special Relativity (SR), Quantum Mechanics (QM) and Quantum Field Theory (QFT). Generalizations to the gravity include Newton Gravity (NG), General Relativity (GR), Nonrelativistic Quantum Gravity (NQG) and an ultimate Theory of Everything (TOE).

Idea of Unified Field Theory

The *special relativity* entered physics as the first great creative principle on Einstein's list. Besides it, the *quantum principle* has been established in atomic physics. These two principles, taken together, correspond to Nature's choice of two basic units displayed on Figure 2. There seems to be an arbitrary choice of the third unit, needed to match the three units of everyday's experience. Taking for it Planck's choice, the Newton's gravitational constant, provides a third axis that enables one to draw the Bronshtein-Zelmanov's *cube of physical theories* displayed on Figure 4.

While Einstein was focused to understand the nature of forces, the quantum mechanics lead to breakthroughs in understanding of matter. In particular, the marriage of special relativity to the *quantum principle* brought out the Quantum Field Theory (QFT corner of the cube in Figure 4) as a mighty tool for the future investigation of the subatomic world that ultimately revealed new subatomic forces. Einstein was outside of these new developments and, as he remarked himself in 1954:

> "I must seem like an ostrich who forever buries his head in the relativistic sand in order not to face the evil quanta".

Seems that Einstein believed that

> "… ultimately the weak and strong forces would be shown just to be aspects of the electromagnetic force".[10]

In fact, these newly discovered fundamental interactions (weak and strong) urged to look for a principle explaining them. It has been found in the form of the gauge principle underlying the present day standard model of elementary particle interactions. It is remarkable that Einstein gave his magical touch also to the gauge principle.[11]Although Einstein admired attempt by H. Weyl in 1918 to describe gravitation and electromagnetism within a unifying geometrical framework, he found its failure as a physical theory. This critique paved the way for the correct understanding of gauge invariance, where Weyl's exponent becomes a "phase".

After Einstein formulated general relativity (GR corner on the cube on Figure 4) he turned to investigate the "unified field theory" that would authomatically account for the features of quantum mechanics.[12] In this attempt he, on one side, followed the proposal by Theodora Kaluza from 1919 to go to another dimension, where it was possible to combine Einstein's theory of gravity with Maxwell's theory of light. Einstein wrote to Kaluza that "The formal unity of your theory is startling", but asked where did the 5th dimension gone! After Oskar Klein in 1926 discovered a possible solution, that it could be curled up into an unobservable small circle, Einstein tried for the rest of his life to figure out why the 5th dimension curled up.

Kaluza and Klein ideas returned to physics in the context of the superstrings as the candidates for the TOE corner on the cube on Figure 4. The trick of Kaluza and Klein was used for going from 26 or 10 dimensional space, where superstrings can exist, to our ordinary 4 dimensions. Cosmologically,[13] the breakdown of 10 dimensional fabric of space-time could generate the inflationary expansion of 4 dimensional universes at the expense of the 6 dimensional universes collapsing down to the Planck length scale.

Today a variety of string theories has been identified, obscuring the idea of an "ultimate TOE". A way out may be the recent discovery by E. Witten,[14] offering that superficially different string theories were just different limiting situations of a single, deeper theory. It is dubbed M (for mystery) theory, the mathematics of which is as yet unknown to us. This attitude resembles the one that Einstein had in his later period, that "the creative principle resides in mathematics", and that the pure thought can grasp reality.

This is in contrast to the way in which young Einstein arrived at his most important idea, that the whole of physics has to be expressed in Minkowski's space, subject to Lorentz transformations. Young physicists should follow young Einstein. Whatever the TOE and its mathematics is, it should be a theory of physics at every scale. Accordingly, one needs to develop the mathe-

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[10] John D. Barrow, *The Constants of Nature,* Vintage Books, NewYork 1995, p. 302.

[11] Norbert Straumann, "Gauge principle and QED", *arXiv:hep-ph/0509116*, 2005.

[12] Michio Kaku and Jeniffer Thompson, *Beyond Einstein*, Anchor Books, New York 1995, p. 32.

[13] M. Kaku & J. Thompson, *Beyond Einstein*, p. 142.

[14] J. D. Barrow, *The Constants of Nature,* p. 66.

matical tools to get out the low energy consequences that can be checked in experiments. One possible class of experiments is the search for relativity (i.e. Lorentz) violations.[15]

Although Lorentz invariance is a concept that admits a generalization to space-times with additional dimensions, Lorentz transformations in 4 dimensional space-time bear some special features, that may "select" 4 dimensions as a favourable choice. For example, the equality of the number of boosts and the number of rotations is a special feature of four-dimensional spacetime.[16] With five spatial coordinates, we have ten rotations, which is twice the number of boosts. More generally, the alternatives to

> "… three-dimensional worlds with a single arrow of time (…) are to simple, too unstable or too unpredictable for complex observers to evolve and persist within them".[17]

Today we are aware that, like other symmetries with their restrictions, Lorentz symmetry would be restricted to the noncosmological scale. New ideas in conjunction with the forthcoming cosmological measurements may lead to astonishing results.

Ivica Picek

Das Absolute und das Dauerhafte in Einsteins Relativität

Zusammenfassung

Die Hervorhebung der Bedeutung der Invarianzprinzipien (Symmetriegesetze) wird zu den größten Verdiensten Einsteins gezählt. Die Symmetrien *stellen eine neue Kategorie zur Beschreibung der physikalischen Welt dar, zusätzlich zu den* Randbedingungen *und den* Naturgesetzen*, wie sie von Newton aufgestellt wurden. Einige Invarianzen in Bezug auf die Zeit und den Raum sind leicht zu verstehen: dass die Naturgesetze überall die gleichen sind, ferner dass sie zeitunabhängig und unveränderlich sind, wenn ein Bezugssystem der Drehung im Raum um eine Achse ausgesetzt ist. Die* relativistische Invarianz *hingegen, die Einstein in seine Relativitätstheorie eingebaut hat, bleibt weniger plausibel. Den Lorentz-Transformationen, mit denen Beobachter bei konstanter Geschwindigkeit in einem gemeinsamen Bezugssystem mathematisch beschrieben werden, maß Einstein ihre volle physikalische Bedeutung zu, infolge seiner Erkenntnis, dass es nicht möglich ist, den absoluten Stillstand zu bestimmen oder die Gleichzeitigkeit verschiedener Ereignisse festzustellen. Gleichwohl bestehen in der Relativität auch absolute Bestandteile, die für alle Beobachter gelten: die konstante Lichtgeschwindigkeit und ein genau definiertes Intervall der Eigenzeit des Beobachters.*

Die Relativität *hielt als eines der ersten „kreativen Prinzipien", die Einstein erkannt hatte, ihren Einzug in die Physik. In Verbindung mit dem Quantenprinzip, das aus der Erforschung der Atomphysik hervorgeht, kam die Quantentheorie der Felder zustande, eine mächtige Waffe für künftige Erforschungen der subatomaren Welt. Die neuentdeckten fundamentalen Interaktionen (schwache und starke) eröffneten die Frage nach einem neuen Prinzip, das sie erklären konnte. Ein solches kreatives Prinzip wurde im mathematischen Messprinzip erkannt, auf dem auch das heutige Standardmodell des Zusammenwirkens von Elementarteilchen gründet. Es ist erstaunlich, dass beide Prinzipien, das Quantenprinzip und das Messprinzip, aus Einsteins Arbeit hervorgehen. Doch vor allem bleibt Einsteins bedeutendste Idee, dass nämlich die gesamte Physik im Minkowski-Raum zu verorten ist, den Lorentz-Transformationen unterstellt.*

Heute ist man sich der Tatsache bewusst, dass, wie bei allen anderen Symmetrien mitsamt ihrer Einschränkungen, auch bei der Lorentz'schen mit Abweichungen auf der kosmischen Skala zu rechnen ist. Neue Ideen in Zusammenhang mit kosmischen Messungen, deren Zeugen wir schon jetzt sind, könnten zu erstaunlichen Ergebnissen führen.

Schlüsselwörter

Das Absolute, das Dauerhafte, Relativität, Invarianzprinzipien, Quantenprinzip, Albert Einstein

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L'absolu et l'éternel dans la relativité d'Einstein

Sommaire

Le fait d'avoir signalé l'importance du principe de l'invariance (les lois de la symétrie) est considéré comme un des plus grands mérites d'Einstein. Les symétries sont présentées comme une nouvelle catégorie dans la description du monde physique, laquelle s'ajoute aux catégories des conditions initiales et des lois mêmes de la nature, définies par Newton. Certaines symétries de l'espace et du temps sont faciles à décrire: les lois de la physique doivent être les mêmes partout et indépendantes du temps, de même que ces lois ne changent pas si un système physique subit une rotation autour d'un axe dans l'espace. D'autre part l'invariance relativiste qu'Einstein a incorporé dans sa théorie de la relativité est moins évidente. Einstein a donné une signification physique pleine aux transformations dont se servait Lorentz pour relier mathématiquement les observateurs en mouvement relatif uniforme, reconnaissant qu'il n'était pas possible d'établir le repos absolu ou de déterminer la simultanéité des faits différents. Pourtant la relativité a des éléments absolus, identiques pour tous les observateurs: la vitesse constante de la lumière et l'intervalle bien défini du temps de l'observateur.

La relativité a fait son entrée en physique comme un des principes créatifs d'Einstein. Associée au principe quantique provenant des recherches atomiques, elle a donné naissance à la théorie des champs quantiques qui sera une arme puissante dans les recherches futures sur le monde subatomique. Les nouvelles interactions fondamentales, faibles et fortes qui y ont été découvertes ont posé la question d'un nouveau principe responsable des interactions fondamentales. Un tel « principe créatif » se trouve dans le principe mathématique de jauge sur lequel repose le modèle standard actuel des interactions des particules élémentaires actuelles. Il est remarquable que les deux autres principes, le principe quantique et le principe de jauge sont également attribués à Einstein. Pourtant l'idée la plus importante d'Einstein est de faire entrer l'intégralité de la physique dans l'espace de Minkowski soumis aux transformations de Lorentz.

Aujourd'hui nous sommes conscients du fait que, comme les autres symétries ont leurs restrictions, on peut, à l'échelle cosmique, s'attendre à des écarts par rapport à la symétrie de Lorentz. Les nouvelles idées conjugées avec des mesurages cosmiques dont nous sommes déjà témoins, peuvent nous conduire vers des découvertes surprenantes.

Mots clés

L'absolu, l'éternel, la relativité, principe de l'invariance, principe quantique, Albert Einstein

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