Does Physics Provide Us With Knowledge About the Things in Themselves?

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Kant said that we were never be able to know about the true nature of matter. The things in themselves would remain unknown to us. There is a similar problem in quantum mechanics. You cannot provide directly any property to a physical state represented by a ray in a Hilbert space. The general theory of relativity teaches time and space were not how they appear to us, but claims to know that in fact space and time would belong to a curved space-time. It turned out in the last decades that it is extraordinary difficulty to combine both theories. Based on quantum mechanics I argue in this paper that the things in themselves remain unknown. There is probably no substance which we can call spacetime.

Contents

1 Things in Themselves

The term "things in themselves" has become a technical term of Kantian philosophy although Kant himself did not use the German term "Dinge an sich" consequently.

Instead of “Ding an sich” he used more often “Ding an sich selbst”, “Gegenstand an sich selbst ”or “Objekt an sich selbst”[1]. I believe what he simply meant with those expressions is that there is a difference between how a thing or an object appears to us and how the thing or object really - in itself - is. At least this is the way I will use these terms afterwards. But it is certainly necessary to be more precise. Kant did use and define two technical terms which cover these issues: phenomena and noumena.

> At the same time, if we entitle certain objects, as appearances, sensible entities (phenomena), then since we distinguish the mode in which we intuit them from the nature that belongs to them in themselves [...], in opposition to the former, and that in doing so we entitle them intelligible entities (noumena).[2]

Kant gave a destinction between noumena in a negative sense and noumena in a positive sense which is important for the following.

> If by ’noumenon’ we mean a thing so far as it is not an *object of our sensible intuition*, and so abstract from our mode of intuiting it, this is a noumenon in the *negative* sense of the term. But if we understand by it an *object* of a *non-sensible intuition*, we thereby presuppose a special mode of intuition, namely the intellectual, which is not what we possess, and of which we cannot comprehend even the possibility. This would be ’noumenon’ in the *positive* sense of the term.[3]

I believe that Phyrrhonian skepticism conclusivly proved that we cannot be in possession of knowledge of things in themselves, neither based on emirism, nor based on rational grounds. Of course modern physics is a challenge to this philosophical point of view. To Kant physics had to be purely phenomenological, although he was aware that this phenomenological treatment does not describe matter in the way it is in itself. He used the term matter as a noumenon in the negative sense, not believing that someday anything positive could be said about them. In this article I will examine if physics can provide us with knowledge about matter in this positive sense. I will start with phenomenological non-equilibruum thermodynamics and from there I will go on to the general theory of relativity and at last I will have a brief look at quantum mechanics.

2 Phenomenological Non-Equilibruum Thermodynamics

In phenomenological non-equilibruum thermodynamics a *body* or a *system* $\mathcal{B} \subset \mathcal{M}$ is a connected and compact subset of elements $\mathcal{X}$. These elements $\mathcal{X}$ are called the particles of $\mathcal{B}$ and in general there will be an inifinite number of them. The state of a body or a system is given by the values of a complete set of independent quantities. A state is

[1] A list of all citations containing those or similar terms can be found in Prauss, G., *Kant und das Problem der Dinge an sich*, [Pra89, 13].

[2] Kant, I., *Critique of Pure Reason*, [Kan39, B 306]

[3] ibid., [Kan39, B 307]

a point of the statespace which is spanned by a set of independent quantities. There are two kinds of quantities in thermodynamics: intensive quantities and extensive quantities. Intensive quantities are temperature T, pressure p, density ρ and so on. Extensive quantities are for example volume V, mass M, energy E or entropy S. This destinction goes back to Kant who said in his axioms of intuition that "All intuitions are extensive magnitudes"[4] and in his anticipations of perception: "In all appearances, the real that is an object of sensation has intensive magnitude, that is a degree."[5]. It is true that we do feel temperature but we do not feel entropy and we do feel pressure but we do not feel a volume. What about mass and density? Kant's distinction of extensive and intensive magnitudes is not always easy. The physicists formulated a simpler criterion to distinct intensive quantities from extensive quantities. If you combine two systems, extensive quantities will add, intensive quantities won't. For example: If you pour 1 liter of water with a temperature of 20°C into a container which already included 1 liter of water with a temperature of 20°C you will get 2 liters of water but the temperature will remain 20°C and won't get to 40°C. Therefore the volume V is an extensive quantity and the temperature T is an intensive variable. In mathematical terms all quantities of phenomenological nonequilibruum thermodynamics can be given as exterior differential forms. An exterior differential form of degree p is a totally antisymmetric covariant p-tensor field over $\mathcal{M}$. A 0-form f is a simple function $f : \mathcal{M} \to \mathbb{R}$ and might correspond to an intensive quantity. Forms ω get their physical meaning from the fact that they can be integrated.

- 1-forms θ are integrated over paths $\gamma : \mathbb{R} \to \mathcal{M}$,
- 2-forms ω are integrated over surfaces $S : \mathbb{R}^2 \to \mathcal{M}$,
- and 3-forms ρ are integrated over volumes $V : \mathbb{R}^3 \to \mathcal{M}$.

Their addity which justifies the name extensive quantities can be seen as follows. Let ω be now an abritrary p-form integrable on X. Let X_1 and X_2 be two complementary subsets of X and χ_1, χ_2 be their respective characteristic functions in X; then[6]

$$\int\limits_X \omega = \int\limits_X (\chi_1 + \chi_2)\omega = \int\limits_X \chi_1\omega + \int\limits_X \chi_2\omega = \int\limits_X \chi_1\omega + \int\limits_X \chi_1\omega = \int\limits_{X_1} \omega + \int\limits_{X_2} \omega.$$

In order to understand the way those intergrals are used in phenomenological thermodynamics it is necessary to study how a body $\mathcal{B}$ is given to us in terms of coordinate systems although the value of those intergrals does not depend on the choice of coordinates. A *reference configuration* is a mapping[7]:

$$\begin{aligned} \gamma(0)_i : \mathcal{B} \subset \mathcal{M} &\longrightarrow \mathbb{R}^3 \\ \mathcal{X} &\longmapsto \mathbf{X}_i = \mathbf{X}_i(\mathcal{X}). \end{aligned}$$

[4] ibid., [Kan39, B 202]

[5] ibid., [Kan39, B 207]

[6] Choquet-Bruhat, Y. and DeWitt-Morette, C. and Dillard-Bleick, M., *Analysis, Manifolds and Physics*, [CBDMDB77, p 215]

[7] The following treatment is based on Greve, R., *Kontinuumsmechanik*, [Gre03, pp.1].

This reference configuration describes a special state of the body for example at time $t = 0$. The *momentary configuration* is a mapping:

$$\begin{aligned} \gamma(t)_i : \mathcal{B} &\longrightarrow \mathbb{R}^3 \\ \mathcal{X} &\longmapsto x_i = x_i(\mathcal{X}, t). \end{aligned}$$

The index i stands for the observer I. A motion of $\mathcal{B}$ is a mapping χ:

$$\begin{aligned} \chi_i : \mathbb{R}^3 &\longrightarrow \mathbb{R}^3 \\ \mathbf{X}_i &\longmapsto x_i = x_i(\mathbf{X}_i, t). \end{aligned}$$

All coordinate representations of extensive or intensive quantities are given either as material coordinate expression $\omega_{\alpha,\beta}(X_i, t)$ or as spatial material coordinate expressions $\omega_{\alpha,\beta}(x_i, t)$. There are two kinds of time derivations, the material time derivation

$$\dot{\omega}_{\alpha,\beta} = \frac{d\omega_{\alpha,\beta}}{dt} = \frac{\partial\omega_{\alpha,\beta}(\mathbf{X}_i, t)}{\partial t}$$

or the local or spatial time derivation

$$\frac{\partial\omega_{\alpha,\beta}}{\partial t} = \frac{\partial\omega_{\alpha,\beta}(x_i, t)}{\partial t}.$$

The velocity v_i is material time derivation of the motion χ_i

$$v_i = \frac{dx_i}{dt} = \frac{\partial x_i(\mathbf{X}_i, t)}{\partial t}.$$

A finer point of this construction is that the reference configuration somewhat gives all particles $\mathcal{X}$ a Name $\mathbf{X}_i$, but in fact there is nothing available that can be named and identified throughout the motion $x_i(\mathbf{X}_i, t)$. We do not observe particle trajectories and we cannot name particles. We identify physical bodies as appearances in our mind and not as bodies summed up out of elementary particles. Therefore our physical phenomenological knowledge is not objective knowledge of the matter itself. It is subjective knowledge of appearances and the point is that this knowledge is intersubjectively valid. Different observers I and K will give different reference and momentary configurations. But they will be linked by transition functions g_{ik}.

$$\mathbf{X}_i = g_{ik}(0)\mathbf{X}_k, \quad x_i = g_{ik}(t)x_k$$

Therefore one needs to have a fibre bundle structure $(\mathcal{M}, \mathbb{R}, f, G)$ on the manifold $\mathcal{M}$ with f beeing a global time function

$$f : \mathcal{M} \longrightarrow \mathbb{R}$$

which projects $\mathcal{M}$ on the base space $\mathbb{R}$ which models the timeline and G is the structure group with $g_{ik} \in G$[8]. Locally and maybe globally the bundle is a trivial bundle, which

[8]For a general treatment of fibre bundles see Choquet-Bruhat, Y. and DeWitt-Morette, C. and Dillard-Bleick, M., *Analysis, Manifolds and Physics*, [CBDMDB77, pp 125].

means that there are open intervals U_i on $\mathbb{R}$ for which the momentary configuration maps $f^{-1}(U_i)$ into $\mathbb{R}^3$. Therefore $\mathcal{M}$ is (locally) the $\mathbb{R} \times \mathbb{R}^3$.

$$\begin{array}{rcl} f^{-1}(U_i) & \longrightarrow & \mathbb{R} \times \mathbb{R}^3 \\ \chi & \longmapsto & (t, \gamma(t)_i(\chi)) \end{array}$$

These requirements are in fact a little stronger than needed, since it is just necessary to define the momentary configuration $\gamma(t)_i$ on the body $\mathcal{B}$ and not on $f^{-1}(U_i)$[9]. The most important equations in nonequilibruum thermodynamics are balance equations like the conservation of energy or the entropy production. The conservation of energy, written down in differential forms with energy densitiy e is simply

$$de = 0$$

In coordinates of the momentary configuration the energy density e takes the form $e = edx \wedge dy \wedge dz + j_x dt \wedge dy \wedge dz - j_y dt \wedge dx \wedge dz + j_z dt \wedge dx \wedge dy$ and the first law of thermodynamics becomes

$$\frac{\partial e}{\partial t} + \frac{\partial j_x}{\partial x} + \frac{\partial j_y}{\partial y} + \frac{\partial j_z}{\partial z} = 0$$

in a similar way, with entropy density s and entropy production σ,

$$ds = \sigma$$

gives the second law of thermodynamics by demanding that $\sigma \geq 0$. The main criticism coming from the theory of relativity is that this fibre bundle structure on $\mathcal{M}$ is some sort of prejustice towards $\mathcal{M}$. Physicists hope that by writing down all equations in a coordinate independent form they can avoid assuming that $\mathcal{M}$ is isomorphic to $\mathbb{R} \times \mathbb{R}^3$. They say: There is no absolute time and no absolute space.

3 The Geometry of Spacetime

I will skip here the discussion of special relativity and go on directly to the general theory of relativity. In general relativity the fibre bundle structure of $\mathcal{M}$ is abandoned. One refers directly to the elements $\mathcal{X}$ of $\mathcal{M}$, which are not called particles anymore but events. A chart (U, ϕ) on the manifold $\mathcal{M}$ is an open set $U \subset \mathcal{M}$ together with a homomorphism[10]

$$\begin{array}{rcl} \phi : U & \rightarrow & V \\ \mathcal{X} & \longmapsto & x^\alpha \end{array}$$

[9] The intervall U_i must cover the time of the existance of $\mathcal{B}$ or at least the time in which $\mathcal{B}$ is physically described.

[10] Choquet-Bruhat, Y. and DeWitt-Morette, C. and Dillard-Bleick, M., *Analysis, Manifolds and Physics*, [CBDMDB77, pp 111]

of U onto an open subset V in $\mathbb{R}^4$. There is no structure group of coordinate transformations in general relativity and given two charts (U_i, ϕ_i) and (U_k, ϕ_k) the transitions functions arise as mappings

$$\begin{array}{rcl} g_{ik} \equiv \phi_i \circ {\phi_k}^{-1} : \phi_k(U_i \cap U_k) & \longrightarrow & \phi_i(U_i \cap U_k) \\ {x_k}^{\alpha} \longmapsto \mathcal{X} & \longmapsto & {x_i}^{\beta} \end{array}$$

I find it even more implausible to refer to elements $\mathcal{X}$ of a spacetime $\mathcal{M}$ than to refer to particles of a body $\mathcal{B} \subset \mathcal{M}$. **The question arises wether physicists actually know the mappings ϕ_i or ${\phi_k}^{-1}$.** The first guess would be to assume that the coordinates arise from measurements. But what is there to measure? You cannot measure the coordinates of an event $\mathcal{X}$. A coordinate system, like it is given by the Global Navigation Satelite System (GNSS), is constructed, which means that the engineers know from a priori what they want to achieve and then they realize it. They start with atomic clocks, which give the proper time $s = \int_\gamma ds$ of their world line γ. But in order to spread out this local time throughout an open supset $U_i \subset \mathcal{M}$ one needs to synchronize several atomic clocks. Einstein made the following proposal to synchcronize clocks: A lightray should be emitted from clock A at time t_A, measured by clock A, and should be reflected in B at time t_B measured by clock B. Finally the light ray will be absorbed in A at time $t_{A'}$, measured by clock A. The two clocks A and B are considered to be synchronous if the following equation holds:

$$t_B - t_A = t_{A'} - t_B$$

This definition is not sufficient for the GNSS, because there one has to match the speed the clocks operate. All kinds of 'relativistic effects' have to be taken into account before one is able to endorse a perfectly prerelativistic coordinate system. The GNSS does not give the 'real' coordinates of a local subset $U_i \subset \mathcal{M}$ of the spacetime, it gives a coordinate system, which is chosen to be easy to operate without any knowledge of the theory of relativity and this coordinate system is therefore in agreement with time and space as "forms of our intuition". In order to give the user the desired coordinate system the engineers break what is considered to be a law of nature by some physicists. They do not obey what Einstein said about the synchronisation of clocks. He said all clocks must be built in the same way and therefore operate at the same rate. But if the engineers had done so, the positions the GNSS gives would have been inaccurate. The deeper reason is that in the GNSS there is an absolute time in the sense that all clocks show the same time coordinate t independently from their actual proper time $s = \int_\gamma ds$ and this is what enables the notion of a position in space defined by $t = const$. Let us now leave the coordinate systems and the GNSS aside: Writing down all laws of physics in a coordinate independent way might free us from the prejudice coming from the a priori use of prerelativistic coordinate systems. Given a curve $\gamma : t \mapsto \gamma(t)$, the velocity is the tangent vector

$$v^a = \frac{d}{dt}\gamma(t).$$

This velocity is contrary to the usual three-dimensional velocity four-dimensional and is not defined relative to some body of reference but in an absolute way against the spacetime $\mathcal{M}$. The acceleration is defined as

$$a^b = v^a \nabla_a v^b.$$

The derivative operator ∇_a is chosen to conserve the metric g_{bc}:

$$\nabla_a g_{bc} = 0$$

There are three different phenomena wich are included in the definition of an acceleration. The body might simply speed up or slow down. In this case the acceleration points into the same direction as the velocity.

$$v^a \nabla_a v^b = \alpha v^b$$

Generally the body will change its direction througout his motion. This effect, when $v^a \nabla_a v^b \neq \alpha v^b$, is called acceleration as well, even if the body does not seem to speed up or slow down. It is mathematically often convenient to choose the time parameter t of the curve γ in a way that the effect of speeding up and slowing down are removed from the equation $v^a \nabla_a v^b = \alpha v^b$ which becomes $v^a \nabla_a v^b = 0$. These definitions give an astonishing picture. The movement of free falling objects including the planets and the stars is in fact unaccelerated. But the "solid" ground on earth is accelerated! What most physicists actually say about this is something entirely different. They take the equation for an unaccelerated geodesic motion $v^a \nabla_a v^b = 0$ and split up the derivative operator ∇_a

$$v^a \nabla_a v^b = v^a \partial_a v^b + \Gamma^b_{ac} v^a v^c = 0$$

and then they write the equation above as follows

$$v^a \partial_a v^b = -\Gamma^b_{ac} v^a v^c.$$

All of a sudden $v^a \partial_a v^b$ describes the accelaration and the terms $-\Gamma^b_{ac} v^a v^c$ are interpreted as gravitational and inertial forces. But $v^a \partial_a v^b$ is only in flat spacetime the acceleration of a moving object. $v^a \partial_a v^b$ equals zero for the "solid" ground and therefore

$$v^a \nabla_a v^b = v^a \partial_a v^b + \Gamma^b_{ac} v^a v^c = \Gamma^b_{ac} v^a v^c \neq 0.$$

According to the genral theory of relativity the surface of our earth is accelerated. But when it comes to applications the physicists return to space and time as they are in phenomenological physics despite all that theory demands. The general theory of relativity describes a world which is fundamentally different from the world we percieve. Even in the limit of small masses and small velocities the general theory of relativity does not describe the world as we know it.

4 Quantum Mechanics

Apart from Pyrrhonian skepticism I have no general objections against the attempt to get rid of the a priori prejudice of Euclidean geometry with the help of differential geometry. But there are deep problems in combining this approach with quantum mechanics. In quantum mechanics physical states are represented by rays $\mathcal{R}$ in Hilbert space $\mathcal{H}$ and with 'physical state' I believe this time the things in themselves are meant. It has always been a puzzling aspect of Kantian philosophy that physics should be based on the analogies of experience like the law of causation, which are only valid for appearances - representations of our mind - while the matter, which in fact causes our experiences, is nevertheless not accessible to us. A similar problem - I believe that it is in fact the same problem - exists in quantum mechanics. Just like Kant's transcendental object x we cannot address any physical properties to rays in Hilbert space, which shall nevertheless represent the physical state. Kant explains why it is like this:

> We have stated above that appearances are themselves nothing but sensible representations, which, as such and in themselves, must not be taken as objects capable of existing outside our power of representation. When, then, is to be understood when we speak of an object corresponding to, and consequently also distinct from, our knowledge? It is easily seen that this object must be thought only as something in general = x, since outside our knowledge we have nothing which we could set over against this knowledge as corresponding to it.[11]

Physical observables are represented by Hermitian operators A on that Hilbert space $\mathcal{H}$. In quantum mechanics our physical knowledge, most importantly the form of the Hamilton operator, is taken from classical mechanics, from a phenomenological point of view. The physical state itself does not possess the properties of classical mechanics. It remains general. If a vector Ψ representing a ray $\mathcal{R}$ were an eigenvector of that operator A

$$A\Psi_n = \alpha\Psi_n$$

then we could somehow say that this physical state Ψ_n possesses the property A with the amount of α. But in general vectors are superpositions Ψ of these eigenvectors Ψ_n and all we can do is to measure the property A where we will find the quantity α with propability $\mid (\Psi, \Psi_n) \mid$. Some physicists say that during this measurement the state Ψ collapses to the state Ψ_n so that the physical state afterwards really possesses the measured property A with the amount α at least for a while. I feel that this assumption is unneccessary and causes more problems than it solves. Let us have a closer look at the measurement of a position x of a single particle state without leaving the minimal interpretation of quantum mechanics given above. X shall be the operator that represents the position x of that particle. Let Ψ_5 be the eigenvector of X to the eigenvalue 5.

$$X\Psi_5 = 5\Psi_5$$

A physical state can be a superposition of some of these eigenvectors, for example $\Psi = a(5)\Psi_5 + a(7)\Psi_7$, but in general it might be a superposition $\Psi = \int \Psi_i(x_i)\Psi_{x_i} dx_i$ of all these infinitely many eigenvectors Ψ_{x_i}. $\Psi_i(x)$ is called the wavefunction of that

[11]Kant, I., *Critique of Pure Reason*, [Kan39, A 104]

particle and it contains the same information as Ψ. One often says that $\Psi_i(x)$ is the representation of Ψ in coordinate space. And although we have mappings $\Psi_i : x_i \mapsto \Psi_i(x)$, **there are no mappings $\Phi_i : x_i \mapsto \Psi$ and no mappings $\Phi_k^{-1} : \Psi \mapsto x_k$ and consequently we do not know the transition functions $g_{ik} : \Phi_i \circ \Phi_k^{-1}$.** The coordinates do not arise from the things in themselves. Space and time remain forms of our intuition.

5 Comments

It is said that Einstein outgrew the limits of our understanding concerning space and time. The question arises with what kind of expertise I put that in question. I have to admit: With no other expertise than what you can read from what I wrote above. I did not become a physicist because I felt that I would have to follow too many main lines that I do not believe in. Tony Rothman describes in "The Man Behind the Curtain"[12] what detered me from becoming a physicist:

> "I want to get down to the basics. I want to learn the fundamentals. I want to understand the laws that govern the behavior of the universe." Thousands of admissions officers and physics department chairs have smiled over such words set down by aspiring physicists in their college-application essays, and that is hardly surprising, for every future physicist writes that essay, articulating the sentiments of all of us who choose physics as a career: to touch the fundamentals, to learn how the universe operates. It is also the view the field holds of itself and the way physics is taught: Physics is the most fundamental of the natural sciences; it explains Nature at its deepest level; the edifice it strives to construct is all-encompassing, free of internal contradictions, conceptually compelling and—above all—beautiful. The range of phenomena physics has explained is more than impressive; it underlies the whole of modern civilization. Nevertheless, as a physicist travels along his (in this case) career, the hairline cracks in the edifice become more apparent, as does the dirt swept under the rug, the fudges and the wholesale swindles, with the disconcerting result that the totality occasionally appears more like Bruegel's Tower of Babel as dreamt by a modern slumlord, a ramshackle structure of compartmentalized models soldered together into a skewed heap of explanations as the whole jury-rigged monstrosity tumbles skyward. [...] But even at the undergraduate level, far back from the front lines, deep holes exist; yet the subject is presented as one of completeness while the holes—let us say abysses—are planked over in order to camouflage the danger. It seems to me that such an approach is both intellectually dishonest and fails to stimulate the habits of inquiry and skepticism that science is meant to engender.

I understand and accept that "Reality is not what it seems." as Carlo Rovelli puts

[12]Rothman, T., *The Man Behind the Curtain*, [Rot11]

it.[13] But I prefer explanations that lie within the limits of my understanding. A sentence like 'Photons are particles and waves at the same time.' does not teach me anything. When I am told that Gallilean coordinate transformations are wrong and Lorentz transformations are correct, but afterwards in general relativity it does not matter which coordinate system is used at all, I do not understand why I had to give up the Gallilean transformations, which look totally sensible, in the first place. Poincaré said that the choice of coordinate transformations is a matter of convention and this convention defines what is to be understood by an ideal rigid rod and what kind of geometry should be valid.[14] Einstein thought he could define time and space by measurements of real clocks and real rigid rods and make geometry in this way a part of physics[15]. Poincaré saw this idea before him and rejected it for good reason. Einstein was aware of that.

> Why is the obvious equivalence of the practically-rigid body of experience and the body of geometry rejected by Poincaré and other researchers? Simply because on closer inspection the solid bodies are not rigid, because their geometric behaviour, i.e. their relative storage facilities, depend on temperature, external forces, etc.. ... Sub specie aeterni Poincaré was right with this view. There is no object in the real world that exactly corresponds to the concept of a measuring rod and to the concept of a measuring clock. It is also clear that the solid body and the clock do not play the part of irreducible elements in the concept of fundamental physics, but the role of compound structures that may play no independent role in building physics. Though, it is my belief that these terms at today's stage of development of theoretical physics must be used as independent items because we are still too far away from such a secure knowledge of the theoretical foundations of atomism to be able to give exact theoretical constructions of these structures.[16]

Einstein used the example of a two dimensional coordinate system of small measuring rods on a table. If you put in the middle of the table some heat on, the measuring rods will lengthen a bit and the coordinate system will get into disorder. Einstein said that one is able to consider this as an example of a curved space.[17]. That is an unorthodox way of looking at things. The physicists have to rely on measurements. But if these measurements do not show the expected Euclidean behaviour, there might be an explanation why they don't, apart from saying that they measure out a curved spacetime. The measurement of distances is based on the measurement of time and the propagation of light. The Maxwell equations are simply $dF = 0$ and $dH = j$ with the material conditions $H = *F$. No difference between Gallilean or Lorentz transformation can be read from these equations and one cannot see why these equations should be able to describe the influence of gravitation but no ordinary refraction of

[13] Rovelli, C., *Reality Is Not What It Seems*, [Rov16]
[14] Poincaré, H.,*Science and Hypotheseis*, [Poi05]
[15] Einstein, A., *Über die spezielle und allgemeine Relativitätstheorie*, [Ein13, pp 2]
[16] Einstein, A., *Mein Weltbild*, [Ein80, pp.122], translation M.W
[17] Einstein, A., *Über die spezielle und allgemeine Relativitätstheorie*, [Ein13, pp 56]

light. If one puts a stick into water and it looks bended, does that mean that spacetime is curved? If it looked bended due to gravitation affecting the propagation of light, physicists would say that the bending comes from curved spacetime. Why do physicists make a difference here? Einstein said he made a difference between gravitation and other influences, because gravitation affects every body in exactly the same way and there would be no way of defining a distance without 'stark arbitrariness' (krasse Willkür)[18]. But I think that geometry is in fact conventional as Poincaré said.

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