

Semantically Closed Theories and the Unpredictable Evolution of the Laws of Physics

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Introduction

In a simplified realist view, the world consists of objects with properties that follow some fixed laws. Observation plays a secondary role and what is observable is derived from the laws. Quantum mechanics(QM) seems to pose some limits on the possibility to attribute properties to objects or states that are independent of measurement or observation. The difficulty lies in reconciling the apparent subjectivity of the observer with our belief in an objective reality independent of human cognition.

This difficulty is exemplified in Wigner's friend experiment, where Wigner's friend makes a measurement on an object and Wigner makes a non compatible measurement on his friend and the object. It seems both have a different account of what happened.

In this essay I take symmetries as the conceptual basis that governs the structure of the laws the objects. It also defines under which condition a system can be viewed as separated from its environment. Only if a system can be separated from its environment the laws and concepts of a system are well defined. In my opinion this might lead to a new solution to the measurement problem in quantum mechanics. The separability condition of protects Wigner's friend measurement because Wigner's intervention destroys the symmetry and unitarity of Wigner's friend measurement and hence his measurement is not well defined any more.

Objects, laws and environment build a unity which I call semantically closed theory. Taking into account the environment and the conditions under which quantities can be defined makes it thinkable that under different environmental conditions different symmetries and laws might emerge and be realized.

I apply these ideas first to social sciences (homo economicus) and philosophy of science. Then I apply this view to the arrow of time, where I show that the epistemic arrow of time (factual past, unknown future) might be explained by the succession of semantically closed theories, where the later contains the earlier.

Finally the possibility of having physically systems with changing laws and concepts might correspond to changes of the axioms defining a physical system. This gives us a new perspective on how to think about consciousness in the context of Gödel's incompleteness theorem.

The observer as object

In this essay I take a realist view insofar as the observer is treated as a physical object. Our sense impression of the external world is mental reconstruction of invariant features of the sensory input. Hence, human observation cannot serve as conceptual basis for the laws of physics, since it depends on the laws themselves. Specifically, our actual mental reconstruction of the sensory input relies on Newtonian classical mechanics as being a

good approximate realization of the laws of physics. Therefore the observer is treated as a normal physical object in the following.

Symmetries, Objects and Laws

I will use the formalism of quantum mechanics to describe the role of symmetries in physics. I will try to show that symmetries, objects and laws build a unity and are only definable together.

Symmetries certainly play a fundamental role in the conceptual foundation of physics. In QM observable quantities are given by the generators of a representation of the symmetry group. However because the laws are invariant under the symmetry transformations and these observables vary under the transformation, they are not observable¹. Only relative quantities are observable under the symmetry. For instance the position is not observable. Only distances, which are invariant under translation are observable. Similarly for velocities: Only the relative velocities are observable under Galilean invariant laws. And for rotationally invariant laws only angles between direction have an observable meaning.

The constitution of particles

From these observables other observable can be defined, which are invariant under the symmetry transformation. These so called Casimir operators serve to define fundamental objects or particles. For instance, in the case of the Poincaré symmetry this properties are the mass m and spin s . They are given by the following formulas: $m^2 = H^2 - \vec{P}^2$ and $s(s+1) = \vec{S}^2$, where H is the energy operator – the generator of time translations, \vec{P} the momentum operator – the generator of the translation transformation and \vec{S} is the spin operator, which is connected to the rotation group. These properties are the properties we generally use to characterize fundamental particles. They also can be viewed as emergent from the invariant structures from relative observable quantities.

Separability

Symmetries also give us a preferred factorization of the state space (Hilbert space) into separable non interacting free particles. The symmetry also defines the separability of a system from the environment i.e. what a closed system is. Also the laws of the free particles are determined by the symmetries. We might say that the symmetry group *defines* the behaviour of the free particle.

Interaction and measurability

The interaction can be derived by an other symmetry called gauge symmetry. One asks the total time evolution to be invariant against local phase transformation. This forces the particle to be coupled to a field looking like the electro magnetic field which – with additional assumptions² – leads to the electro magnetic interaction.³ The meaning of the

¹In quantum mechanics there is the WAY theorem[8] putting constraints on measurability under symmetries. But they might hold also in classical physics. For instance, because of the Galilean invariance absolute velocities are not observable in Newtonian physics.

²See next footnote.

³Jauch and also Feynman – in a beautiful unpublished proof recollected by Dyson[3] – showed that the coupling to a gauge field can be derived from the Galilean symmetry alone – or in Feynman's proof

gauge symmetry is largely disputed [1]. For this essay it is enough to see that a local phase transformation changes the momentum and velocity of the particle hence correlates the particle velocity to the field which makes the relative velocity measurable.

Measurability

Only relative quantities between two objects are measurable. One of these objects can serve as a reference frame. A good reference frame can be constructed by the composition of highly correlated smaller objects. For instance, a regular lattice might serve as a spacial reference frame or ruler. A gyroscope consisting of highly correlated spin up objects serve as directional reference frame.⁴ That only relative quantities are measurable is perfectly compatible with classical physics, since in classical physics the relational information – when changing reference frame – remains the same.

The measurement problem in quantum mechanics

In quantum mechanics not all information relative to a reference frame is available that would be needed to describe the full object. In a system with an object and a reference frame, one can average out the absolute values which are not measurable within the system. This averaging leads to a loss of the phase information that is present in the complex amplitudes describing the state. The loss of the phase information – relative to such a reference frame – is also called loss of coherence. In the density matrix formalism the averaging nullifies the off diagonal terms which contain the phase information.⁵ This is also called reduction of the density matrix and is part of the measurement problem.⁶

Interpretations

Various interpretations have tried to resolve the measurement problem. Some of them can be classified in two groups: the *subjective* and the *objective* interpretations. In the subjective interpretations the loss of the phase information in the measurement is merely subjective and does really happen. Many worlds, QBism, Rovelli's relational QM and Wigner's collapse by the consciousness belongs to this group. There, the difficulty is to reconcile the different subjective observations – whether they happens in different worlds or different minds.⁷

In the objective interpretations the loss of the phase information really happens in the measurement process. These interpretations need a mechanism that violates the unitarity of quantum mechanics. The Ghirardi–Rimini–Weber theory and the Penrose

from the commutation relations and the force law. The gauge field must not necessarily be the EM field. It also could be the centrifugal and Coriolis force, which also couple in a gauge invariant manner. If one requires this field to be an object of his own (an irreducible representation of the Poincaré group) with suitable commutation relations one can easily get the inhomogeneous Maxwell equations for the EM field.

⁴These highly correlated states are also called coherent states. They can be seen as high dimensional irreducible representation of a group. Typically, these states become simultaneously measurable – hence classical – the higher the dimension. They are important for the quantum to classical transition.

⁵A simple example for $SU(2)$ can be found in Poulin.[11]

⁶The other part of the measurement problem is the *collapse* of the mixed state into an eigenstate of the observed property. This is a problem, which is not specific to quantum mechanics and shall not be discussed in this essay. It arises in every probabilistic theory where probabilities are updated upon measurement.

⁷An interesting recent discussion can be found in Renner[5].

interpretation belongs to this group. But also Wigner's interpretation might belong to this group. Here the collapse happens in the consciousness of the observer.

Environmental decoherence provides an objective reduction only for all practical purposes (FAPP). The phase information is lost in the environment but not principally lost.

Separability from the environment

Before I propose my own interpretation, I want to note that the reduction of the density matrix is independent of the dynamics, that describes the measurement, because the dynamic is invariant under the symmetry. The loss of the phase information is the result of the relation between the two objects and not of some non-unitary process. The dynamics is still unitary (information conserving). Let me now make a mathematical postulate⁸ which I will use as the basis for my interpretation:

If an outside observer wants to make a measurement on a closed system, which is not compatible with the relative measurable quantities within that system, then the dynamics within that system is not unitary and not invariant under the symmetry any more.

The interpretation follows right away:

The concepts underlying a physical theory, its laws and objects are only well defined for a given symmetry, if the environment is such, that the system under consideration can be treated as a closed system.

This interpretation protects the subjective view from contradictions by not allowing unwarranted outside interventions. It makes the subjective loss of the phase information objective and thus avoiding contradictions. Contrary to decoherence I ask the system to be separated from its environment in order for a measurement being well defined. Not that decoherence never happens. It happens almost all the times. Only it is not necessary for the interpretation of QM.

I am not saying that the physics of open systems is not possible. But the terms used to describe the open system must first be defined in a closed system. Poincaré in [10] wrote that Newtons first law of motion⁹ is a convention, a definition in disguise. It is the definition of an inertial frame of reference. It is a condition that must hold in order to formulate the second law. Similarly, approximate separability from the environment is a condition for having definable and observable objects as a basis for an empirical physical theory.

I will call such a theory, in which all terms it uses are definable within this theory and in which also the conditions under which these terms are operationally definable, a *semantically closed theory*.

Semantically Closed Theories

In simplified realistic theories objects have properties, which need not to be observable. These properties also do not depend on the conditions that these properties are direct or indirect observable. This is a bit overly one-sided, since in science we demand object to have direct or indirect observability. And since objects are only observable through other

⁸With no prove. A prove might be derived from Busch's "No information without disturbance" paper[2].

⁹Objects in inertial frame of reference move at constant velocity, if no force is applied.

objects, the objects themselves can never be known. Only the relations these objects have with each other shows as properties of the objects. There is also the problem of how we ought to know the meaning of these properties without the reference to some observable relations. It looks is if concepts could be defined in a detached Platonic universe, which exists independently of its realization in the real world.

On the other hand empiricist theories pretend that concepts could be defined before or independent of the laws they want to describe. But neither our sensory impressions nor measuring devices are capable of conveying meaning independently of the laws they are supposed to describe.

In the view presented in this essay there are neither objects with predefined properties nor law independent observational languages. The meaning of concepts underlying the theory depend on the laws but also on the conditions under which these laws can be realized, i.e. the environment. The parts have meaning only in the context of the whole. The whole builds a web of connections, of meaning.¹⁰ No meaning can be assigned to the part without the others.

Wigner wrote that one of Newtons big accomplishments that made modern science possible is "the distinction between initial conditions and laws of nature." [14] Whereas the initial conditions might be complicated the laws are not. They are "simple and beautiful". In this essay, I argue that the applicability of the basic concepts, that define a physical theory and describe the laws, might depend on the environment and hence the laws themselves might depend on contingencies.

The standard model of particle physics might for instance only be valid as long as the environment is approximately invariant under the Poincaré transformation, i.e. is almost empty, the vacuum. Be aware, that the definition of the vacuum in particle physics depends on the definitions of the particles.

But near a black hole or in the early universe the environment is not invariant under the Poincaré group. So particles of the standard model might not exists as particle any more in these environment. The search for a final unified theory is often the search for a unified symmetry underlying all phenomena. Such a symmetry might not exist.

Underdetermination

In semantically closed theories, where properties of objects are only defined in relation to other objects and to the environment, there are different levels of underdetermination.

In the presence of symmetries quantities can only be assigned to objects relative to other objects. A proposition "The objects is in the location X!" is neither true nor wrong until an origin or frame of reference or other objects are put into the picture. The setting of the reference frame has to be physical and not only imaginary. This is especially important for quantum mechanics.

In quantum mechanics, the empirical existence of non compatible representations of a symmetry group leads to the situation, that not all relative (hence observable) quantities can simultaneously be defined. If we want to make propositions before the reference frame is set, then propositions like "The spin is in direction up" makes no sense. People sometimes make contradicting propositions like: "The spin has direction up *and* has direction down." If a physical reference frame is present, than which relational quantities are defined is unambiguous.

¹⁰Referencing Quine's "web of belief". See next section.

EPR

Complementary observables are not simultaneously measurable. That this is not merely an epistemic issue, is shown by the experimental violation of the Bell equalities. But the very same experimental setup (EPR), shows that the setting of the reference frame far away from the object determines the possible, defined propositions. This is not a *causal* influence – in the sense, that no information can be transmitted this way.

Delayed Choice

A similar underdetermination is true for Wheeler’s delayed choice experiment. The setting of the reference frame in the distant future defines, which proposition relating to the past are defined and which are not. There is no retrocausality. The causal description of what has happened is only given after the frame of reference has been established in the future.

The Conventionality of Reality and Locality

As we have access to properties of objects trough other objects only, only relations are knowable. The reality of things escapes us. This leads to an underdetermination in defining of what is real. For me, a consequence of the Bell inequalities was always, that one had to choose between reality or locality. Today I belief this is a matter of convention, of choice – because of the underdetermination of what is a causal (local) influence and what is real (context independent properties). It seems the two are complementary elements of our scientific language.

Analytic and Synthetic Distinction

The last level of underdetermination, I want to discuss is connected to Quine’s thesis of the impossibility of a analytical and synthetic distinction. This is finally a consequence of semantic closed theories or epistemological holism (Quine). Observational terms do not exist independent of the laws. All therms build a web of belief (Quine), where the meaning of the individual concepts depend on their connection to the other concepts. This seems to me to be a characteristic of all realistic theories. Properties of objects cannot be defined by observational terms as lied out in the first section. Since object reveal there properties only trough their lawful connection with other properties, lawful consequences (synthetic postulates) cannot be separated from analytic postulates defining the indirect properties of the hidden objects.

Conventionality of Geometry

As concrete example might serve Poincaré’s conventional interpretation of geometry. In his 1904 published book[10] he asks whether the observable geometry is Euclidean or curved. He wrote that this cannot be determined by observation (falsified) nor decided a priori. He concluded that this is a conventional choice. Either meters and objects deform, when transported along the Euclidean space, or they remain constant and space itself is deformed.¹¹ Such a conventional view is possible because the metric of spacetime is not observable. Einstein himself took a holistic view on the question whether the curved

¹¹He only imagined the curved space to have constant curvature, so that the transport of the objects along the geodesic lines would be a group transformation. What view he would have taken, if he would have known, that spacetime is dynamically curved stays unanswered.

space is observable or not. The theory as whole defines what is observable. He refused to fix parts of the theory by convention.[4]

General relativity requires in its derivation fixed (infinitesimal) spacetime line lengths (rulers). These lengths are given by the atomic line spectra hence quantum mechanics – a theory outside GR. Hence GR might be not a semantically closed theory, because not all properties are derived or defined within the theory.

Changing Laws

Since in physics we are not used to imagine the laws and basic concept as something that could change, I shall briefly give two examples from totally different areas, where the changing of the laws is much easier to imagine. The first one is from the social sciences and the second one from the philosophy of physics.

Positivism Dispute

The positivism dispute was a dispute in the 60s between the critical rationalists and the Frankfurt school about the methods of social sciences. The debate was difficult and the two parties did not really come to a mutual understanding. I shall give my own interpretation of what the debate was about.

In economics there is a theory of the homo economicus, which assumes that agents behave perfectly rationally that maximizes its own utility.¹² The theory as theory of micro behaviour also wanted to explain how macro structures as institutions, trading rules etc. come into being. The theory was also used to explain behaviour in developing countries and in traditional societies. It was shown, that the theories assumption of rationality was too narrow. In order to be universally applicable the values system had to be extended in order to fit the utility of various societies. A priest, for instance, believing in afterlife acts rational in behaving altruistic. But becoming *universal* and being able to explain any behaviour, the theory becomes tautological and cannot make any prediction any more, since any behaviour became rational. Only when a value system is given the utility that is maximized by rational behaviour can be defined. But exactly these value systems represented by different institutions ought to be explained by the homo economicus theory, by the rational behaving agent.¹³ We are moving in a circle. The value system of a society and the individual rational behaviour build a unity: a *semantically closed theory*.

For the critical rationalist social theories need to be falsifiable. But falsifiability is only defined within a semantic closed system. Different societies are described by different semantically closed theories. The change between different two different theories/societies might not be describable within one of these theory. The emphasis on falsifiability of the theory prevents system change. This finally was, in my opinion, the critic of the Frankfurt school in the positivism dispute. How different closed theories can be compared will be discussed in the next paragraph.

Theory of Science

Kuhn famously criticized the view that the history of science is a linear accumulation of facts. He rather thought, that the currant normal of scientific practice is disrupted by

¹²I do not dispute this assumption. This is not the point that I want to make.

¹³Of course in the view of the critical school the value system and the institution are given made by who is owning the means of production.

scientific revolutions, paradigm changes. The theories in the different paradigms were seen as incompatible. There are difficulties in comparing two different theories as there might not exist a correspondence between the different concepts.

Heisenberg viewed similarly the history of physics as a succession of closed theories, where the older theory is contained by the newer theory as a limit.¹⁴ The containment of the theory by the other creates an order between theories. A similar order between semantically closed theories will be discussed in the next section. This could explain the epistemic arrow of time.

The Arrow of Time

The Thermodynamic Arrow of Time

Irreversible time asymmetric processes are an observable feature of our universe. The problem of the arrow of time arises, because the fundamental laws are time symmetric.¹⁵ The explanation is found in statistical mechanics. Given a macrostate, it is much more probable that the state moves to a higher entropy state. The higher entropy state has much more possible microstates compatible with the macrostate than a low entropy state.

The past Hypothesis

Because of the symmetry of the microscopic laws also the past must have been most likely in a higher entropy state. Because however, we have never seen the entropy decreasing, it is a useful hypothesis that the cosmos started off in a low entropy state. This is the past hypothesis. Having non time symmetric initial conditions does not contradict the times symmetry of the laws. On the contrary: It is the separation of asymmetric initial condition from symmetric laws what makes physics so powerful.¹⁶

The Epistemic Arrow of Time

However the thermodynamic arrow of time does not explain the so called epistemic arrow of time: the factual past and the open future. Or why do we only have memories of the past and not of the future? On contrary: From a macro standpoint of view there are much more low entropy states compatible with the present macrostate than the high entropy state of the future. We should know the future pretty well and have no clue about the past.

Von Weizsäcker describes the expansion of the universe as a crystallization process from a simple homogeneous low entropy state into complex structures.[13] The complex structure could correspond to the realization or manifestation of a rich semantically closed theory. By rich, I mean, the theory contains more concepts than a poor theory. Keep in mind, that by theory I always mean a physically realized theory, a realized structure, that is able to describe itself. The richer theory might emerge from the poorer one by symmetry breaking. Since the earlier theory lacks the concepts realized in the later theory, it lacks the concepts to describe or predict, what will happen in the future. Conversely the later, the richer theory can describe, explain the past. It has a memory and the concepts to describe past events.

¹⁴Typically Galilean relativity is derivable from Lorentz transformation by letting the velocity of light go to infinity. But not the other way around.

¹⁵Ignoring that the weak interaction in particle physics is not invariant under time reversal.

¹⁶See earlier citation of Wigner.

Mesoscopic Theories

We don't know if such a theory change happened at a fundamental level. At least, in the last billion of years, the approximation of the environment as almost empty is a pretty good one. And the standard theory of particles has not changed in that time. It is therefore essential to show that such a theory change happens on a mesoscopic scale within a fixed fundamental theory.

Fundamental particles under specific circumstances bound together to build atoms. From atoms we get molecules, proteins, living organisms, ecosystems and so forth. On each level a new semantically closed theory might emerge. Which structures on the mesoscopic scale have meaning and what meaning is not determined from the fundamental theory but by the totality of the emerged mesoscopic structures that build the semantically closed theory.

The emergence of complex structures might be favoured by the second law of thermodynamics, since the increase of the amount of possible microstates might also increase the number of structures that can emerge on the mesoscopic level.¹⁷

Undecidability, Self-reference and Consciousness

A semantically closed theory as I tried to describe in this essay is certainly conceptually rich enough to be able to reference itself. This is because all propositions about quantities and relations must be measurable or decidable within the same theory. As such a semantically closed theory might be subject to Gödel's incompleteness theorem.

This means, that there are propositions that are not decidable within the theory. Formulated as physical realization of the theory this could mean, that within a physical system, the system has not all informations about its own state. This is not so bad. Seth Lloyd was able to derive our impression of free will by such a theorem.[7] My personal hope is, that one could derive the necessity of a probabilistic/statistical description of thermodynamics in semantically closed theories, despite having deterministic underlying laws.

The fact that we can see the truth of Gödel's incompleteness theorem, despite it is not provable, has inspired the philosopher Rebecca Goldstein[6] and maybe Penrose[9] to attribute to our consciousness abilities that are not explainable by physical systems. In my opinion, this comes from the naive realist view on the laws of physics, where the laws and objects are fixed.

On the other hand Gödel's theorem is provable by adding additional axioms i.e. by changing the axiomatic basis. This corresponds to the theory change from the previous section. That makes it thinkable, that processes of consciousness are describable by changing semantically closed theories.

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¹⁷See also the last part of the my essay in the last essay contest.[12]

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