Present and Future in Quantum Mechanics

Parmenides Workshop 19: "The Forgotten Present," April 29–May 2, 2010

Michael Drieschner

Abstract After a short overview over the questions of time, permanence, and change in the philosophical tradition, the concept of time in physics is discussed. The fact is emphasized that the usual real parameter t is not sufficient, in some cases, to solve conceptual problems of physics. Sometimes it becomes necessary to consider the "full" concept of time with present, past, and future. This can be seen already with the concept of objectivity, which is intimately connected with predictions. It comes out very clearly especially in probability considerations: The concept of probability can be best understood when it is identified with predicted relative frequency. This insight is used to recall a solution of the problem of the "time arrow" in statistical thermodynamics. It is applied mainly to quantum mechanics, where it is shown that there are rather simple solutions, e.g., to the problem of the "collapse of the wave function" and the "EPR" problem; there the "spooky actions at a distance" are unmasked to be no actions at all.

What makes the present so particularly interesting that a whole volume of papers is devoted to it? Let me take the key word "present" as shorthand for time in general. The structure of time as present, past, and future tends to be "forgotten" in the natural sciences, especially in physics.

Why is that?

1 Time, Space, and Change

Science is interested in "laws of Nature," i.e., in structures we can describe, and which for that very reason have to be in a sense permanent, "eternal" in the extreme case. But still we want to describe changes; we want to be able to predict what will happen under certain circumstances, etc. As long as physics, e.g., is successful, it uses equations to describe changes, movements. Such equations contain a parameter

---

M. Drieschner (✉)
Ruhr-Universität, Bochum, Germany
e-mail: Michael.Drieschner@t-online.de

A. von Müller, T. Filk (eds.), *Re-Thinking Time at the Interface of Physics and Philosophy*, On Thinking 4, DOI 10.1007/978-3-319-10446-1_10

usually named t that is supposed to represent time. This t is a real number parameter; we could imagine it representing in reality the position of the hand on a clock, or of a planet on the sky. So we actually use a spatial representation of time in order to be able to deal with it in an equation in order to describe change.

But the equation itself does not change; it is supposed to be of "eternal" validity. A law of nature is a "general" law; what it describes is change that can occur at any time. In this sense an equation, a physical theory as a whole, is "objective," i.e., it depends neither on the individual who applies it nor on the time when it is applied. That is why time appears only in the form of that notorious parameter t. Usually we imagine time as represented by a horizontal line on paper with an arrow to the right: Again a spatial representation of time. We cannot expect that this line represents all aspects of time. And apparently there is no feature of a horizontal line nor of equations that could stand for the present—and for that much, there is no feature for past and future either.

Physicists tend to consider the aspect of time we describe as present, past, and future as something that isn't objective: Thus, in the language of physicists, it is subjective. And consequently physics is not supposed to deal with it.

Still, occasionally there arises a necessity to talk about aspects of time that cannot be represented by that parameter t; we will consider such occasions later. In order to have an opportunity to talk and to think of the structure of time in view of the objectivity of physics, physicists grew accustomed to using words like "flow of time" or "arrow of time." But when you look a bit closer you can see that this is rather misleading: A river can flow (through space!) *in* time, as we are accustomed to say; so time cannot be the stuff that flows as well. But even that image of a river flowing in time seems to be rather queer: How can anything be *in time*? Is time something like a container?—We see that even this seemingly harmless metaphor transforms temporal relations into spatial ones thereby distorting them.

Thus, even though for many purposes a spatial representation of time is practical, we have to admit that the character of time is fundamentally different from the character of space. This tends to be forgotten in the context of natural science—hence "the forgotten present."

2 Time in Ancient Philosophy

2.1 Parmenides

Time was a favorite subject of philosophy since philosophy began in sixth century (BC) Greece. Parmenides, after whom our hosting society is named, gives that discussion a rather strong start in denying that time really existed at all; time belongs, according to Parmenides, to "δόξα" (*doxa*), to the realm of appearance and illusion. I think it is important for understanding the history of philosophy to see the truth that is in the enigmatic text of Parmenides. Let me give you a short and rather bold account of what I think I understand of it: The subject Parmenides is talking about is “being,” in Greek he says “εἶναι,” “ἐστίν,” or “ἐόν.” A characteristic sentence in his didactic poem is, to my advice: “οὔτε γάρ ἂν γνοίης τό γε μὴ ἐὸν (οὐ γὰρ ἀνυστόν) οὔτε φράσαις.”[1]: “For you cannot know what is not – that is impossible – nor utter it.” This sounds rather self evident, at first glance. But Parmenides—and following him, a lot of classical philosophy—took “being” very seriously as being in eternal presence, as not at all changing; and hence, many concluded like Parmenides that it is impossible to think or to talk in truth of anything but the eternal. Thus the question how to describe change became a major problem for Greek philosophy.

This problem seems to be solved in modern physics by the introduction of equations that include the parameter t already mentioned. Still from time to time we hit on questions in physics which show that the problems of time are not solved entirely with equations.

Now this touches philosophy. Time is a major theme through all of philosophy. The article “Time” in the Historical Encyclopaedia of Philosophy [2] extends over 78 columns. So there is no chance to cover this here. But let me indicate a few highlights.

2.2 Plato

We started with Parmenides, who practically denies the “real” existence of change, i.e., of time altogether. Plato greatly esteemed Parmenides—he devoted one of his dialogues to Parmenides’ philosophy; but still, Plato tries to cope with the problem of change. He gives his famous definition of time:

> εἰκὼ δ′ ἐπενόει κινητόν τινα αἰῶνος ποιῆσαι, καὶ διακοσμῶν ἅμα οὐρανὸν ποιεῖ μένοντος αἰῶνος ἐν ἑνὶ κατ′ ἀριθμὸν ἰοῦσαν αἰώνιον εἰκόνα, τοῦτον ὃν δὴ χρόνον ὠνομάκαμεν. (*Plato*, *Timaeus 37d*)
>
> In English: But he took thought to make, as it were, a moving likeness of eternity; and, at the same time that he ordered the Heaven, he made, of eternity that abides in unity, an everlasting likeness moving according to number—that to which we have given the name time.[2]

---

[1] Parmenides [1]. I am quoting in Greek knowing that many readers will not readily understand the quotation. But I want to emphasize the importance of referring to the original text since every translation is an interpretation. If one really wants to find out what the text says there is no better way than studying the original.

[2] Cornford [3], p. 98.

Plato uses “moving” (or, more literally, “going”) in order to define time: A rather unusual approach, in our modern thinking, since we would consider time as more fundamental than movement. But Plato with his approach seems to be closer to modern physics than to modern philosophy, especially with the other ingredient of his definition, namely number: For time he considers essential counting the revolutions—of the sun or of planets. Thus he apparently formed already the image of time we use now in physics. Heisenberg, in his dialogue-book “Der Teil und das Ganze,”[3] suggests that Plato had already anticipated in his Timaeus dialogue the fundamental nature of mathematics for physics as we understand it today.

Plato describes his thoughts, not quite as mythical as Parmenides, but still in the form of a myth: the “He” he is talking about is the Demiurge, the god-like craftsman who composes the universe from primitive materials. This seems to be Plato’s way of describing the structure of the universe, in telling a tale.

2.3 Aristotle

You will notice the contrast between Plato’s text and texts we have from Aristotle’s works. This contrast is partly accounted for by the difference between the addressees: Plato writes for a broader public, and he emphasized that it is impossible to write the truth directly—hence, I think, the myth. Aristotle’s text, by contrast, might have been notes for his lectures or notes taken by one of his students from a lecture: Short, very sober outlines of a line of argument. But it is, in my impression, not only the difference in addressees, but also a difference in the style of thinking between Plato and Aristotle: Plato was an aristocrat, mainly interested in good governance for his state, and a poet; whereas Aristotle was, from his roots, a biologist, a scientist, who later led a large research institution—to put it in modern terms.

Aristotle introduces time, much like Plato does, dependent on change (κίνησις). And change, in Aristotle’s system, is derived from possibility (δύναμις), which in turn is part of the fundamental pair, according to Aristotle, actuality–possibility (ἐνέργεια—δύναμις). Aristotle defines change, depending on possibility, as follows: “ἡ τοῦ δυνάμει ὄντος εντελέχεια, ᾗ τοιοῦτον, κίνηςίς ἐστιν.” (“The actuality of that which potentially is, *qua* such, is change.” Phys. 201a10–11).[4] I am not going to dwell any further on that very intricate formulation and its afterlife in Aristotle exegesis. The essential feature of Aristotle’s argument is the fundamental role of possibility, not of time. But let me still quote his definition of time: “τοῦτο

---

[3] Heisenberg [4].

[4] Hussey [5], p. 2; In German cf. Wieland [6], 298^{25}.

γὰρ ἐστὶν ὁ χρόνος, ἀριθμὸς κινήσεως κατὰ τὸ πρότερον καὶ ὕστερον.” (“For that is what time is: a number of change in respect of the before and after.” Phys. 219b2–3).[5] So we see that his definition is closely akin to Plato’s.

But Aristotle does more than that. He talks about the present as well! He introduces his chapter on time with a very interesting consideration, whether time “is” at all:

> Ἐχόμενον δέ τῶν εἰρημένων ἐστὶν ἐπελθεῖν περὶ χρόνου· πρώτον δὲ καλῶς ἔχει διαπορῆσαι περὶ αὐτοῦ καὶ διὰ τῶν ἐξωτερικῶν λόγων, πότερον τῶν ὂντων ἐστίν ἢ τῶν μὴ ὂντων, εἶτα τίς ἡ φύσις αὐτοῦ. ὅτι μὲν οὖν ἢ ὅλως οὐκ ἔστιν ἢ μόλις καὶ ἀμυδρῶς, ἐκ τῶνδέ τις ἂν ὑποπτεύσειεν. τὸ μὲν γὰρ αὐτοῦ γέγονε καὶ οὐκἔστιν, τὸ δὲ μέλλει καὶ οὔπωἔστιν. ἐκ δὲ τούτων καὶ ὁ ἄπειρος καὶ ὁ ἀεὶ λαμβανόμενος χρόνος σύγκειται. τὸ δ’ ἐκ μὴ ὂντων συγκείμενον ἀδύνατον ἂν εἶναι δόξειε μετέχειν οὐσίας. Aristotle, Physics 217b29–218a3
>
> English: “After what has been said, the next thing is to inquire into time. First, it is well to go through the problems about it, using the untechnical arguments as well [as technical ones]: whether it is among things that are or things that are not, and then what its nature is. That it either is not at all or [only] scarcely and dimly is, might be suspected from the following considerations. Some of it has been and is not, some of it is to be and is not yet. From these both infinite time and any arbitrary time are composed. But it would seem to be impossible that what is composed of things that are not should participate in being.”[6]

This is a nice specimen of the style of Aristotle’s texts. In his system there follows a longer consideration where he gives the definition of time quoted above, and then he adds that in this case he means the number that is counted, not the number by which we count. For our consideration of the forgotten present, the only part that seemed to me to be helpful is his question whether time, being present, past or future, “is” at all.

2.4 Augustine

We find that very same question in Augustine’s famous essay on time in his “Confessions.” But Augustine’s solution is quite different from Aristotle’s: He finds past and future “being” in my memory or in my expectations, respectively. Augustine, therefore, is considered the first philosopher of “Subjectivity.” The following quotation from “Confessions” gives a good idea of Augustine’s thinking and writing: In his philosophical argument he is, at the same time, praying, arguing with God. And one still sees his tradition of a classical rhetorician[7]:

---

[5] Hussey [5] p. 44.

[6] Hussey [5], p. 41.

[7] Augustinus [7] ch. 11.18.23.

> "Sine me, domine, amplius quaerere, spes mea; non conturbetur intentio mea. si enim sunt futura et praeterita, volo scire, ubi sint. quod si nondum valeo, scio tamen, ubicumque sunt, non ibi ea futura esse aut praeterita, sed praesentia. nam si et ibi futura sunt, nondum ibi sunt, si et ibi praeterita sunt, iam non ibi sunt. ubicumque ergo sunt, quaecumque sunt, non sunt nisi praesentia. quamquam praeterita cum vera narrantur, ex memoria proferuntur non res ipsae quae praeterierunt, sed verba concepta ex imaginibus earum quae in animo velut vestigia per sensus praetereundo fixerunt. pueritia quippe mea, quae iam non est, in tempore praeterito est, quod iam non est; imaginem vero eius, cum eam recolo et narro, in praesenti tempore intueor, quia est adhuc in memoria mea. utrum similis sit causa etiam praedicendorum futurorum, ut rerum, quae nondum sunt, iam existentes praesentiantur imagines, confiteor, deus meus, nescio. illud sane scio, nos plerumque praemeditari futuras actiones nostras eamque praemeditationem esse praesentem, actionem autem quam praemeditamur nondum esse, quia futura est." –

> Permit me, Lord, to seek further. O my hope, let not my purpose be confounded. For if times past and to come be, I would know where they be. Which yet if I cannot, yet I know, wherever they be, they are not there as future, or past, but present. For if there also they be future, they are not yet there; if there also they be past, they are no longer there. Wheresoever then is whatsoever is, it is only as present. Although when past facts are related, there are drawn out of the memory, not the things themselves which are past, but words which, conceived by the images of the things, they, in passing, have through the senses left as traces in the mind. Thus my childhood, which now is not, is in time past, which now is not: but now when I recall its image, and tell of it, I behold it in the present, because it is still in my memory. Whether there be a like cause of foretelling things to come also; that of things which as yet are not, the images may be perceived before already existing, I confess, O my God, I know not. This indeed I know, that we generally think before on our future actions, and that that forethinking is present, but the action whereof we forethink is not yet, because it is to come.

This was to show from the philosophy of antiquity how time was treated at least in some sense different from space. Our glance into classical philosophy might also serve to see a bit clearer the same problem in the way it has been renewed by modern physics.

3 Time in Modern Physics

We'll do a large jump now from Augustine to physical thought of modern age. There I will not deal with "time" in general, but with time in the framework of physics.

3.1 Laws of Nature

Physics, as I mentioned above, deals with “laws of Nature,” mostly in the form of equations; and those equations are eternal in the sense that they do not change in time. Time is represented in the equations by the parameter t.

But what does a law of Nature, represented by an equation, mean?—It is in some way a description of the inner workings of Nature; it gives us an objective picture of reality. How does it do that?—“Objective” in this context means that it is valid at any time at any place, independently of individuals. I can always verify (pace Karl Popper!) its truth by looking in reality, by looking in an experiment whether what the law says really comes out. That means that the law of nature can give me predictions about what will come out when I perform a certain experiment. So this ability to make predictions from a law of Nature is indispensable for its character of being objective.

A law of Nature gives me also the possibility to use it for predictions in order to get a result that is useful for me. That is, I can use it for a technical application; namely when I am able to manipulate the situation of applying the law of Nature in such a way that the predicted result is what I wanted to achieve.

So prediction is a decisive feature of any law of nature—and there it is, the structure of time: Predicting means saying something about the future. So we can conclude that, even though it does not look like that, and even though physicists usually do not talk about it, the structure of time beyond that parameter t lies at the basis of modern science. If we ever “forget” the present, this is only a subjective event; the present still forms an important part of the fundament of the building of science.

3.2 “Classical” Ontology

I might use the equations, e.g., of astronomy, as well to “retrodict” certain events: Astronomy works for the past as well as for the future. It has been calculated, e.g., that the solar eclipse Thales of Miletus is supposed to have predicted occurred on May 28, 585 BC (according to our modern calendar). This seduced classical astronomers to assuming that “in themselves” all events were predetermined. P.S. Laplace, the great astronomer and mathematician, considers that assumption in his work on probability. He says that only we, limited humans we are, depend on probability considerations. A superhuman spirit could do without[8]:

> Une intelligence qui, pour un instant donné, connaîtrait toutes les forces dont la nature est animée, et la situation respective des êtres qui la composent, si d’ailleurs elle était assez vaste pour soumettre ces données à l’analyse, embrasserait dans la même formule,

---

[8] Laplace [8], p. 2.

> les mouvements des plus grand corps de l'univers et ceux du plus léger atome: rien ne serait incertain pour elle, et l'avenir comme le passé, serait présent à ses yeux.
>
> English: An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

Please note the last words: "...would be *present* before its eyes." That point of view of classical astronomy would really abandon time in reality—it might be kept as some subjective superstition—; everything would be drawn into the present. There, you see it, the present is by no means forgotten. But, not any better for time, the universe consists of the present alone.

Our considerations above have shown that Laplace cannot maintain his view consistently: If there were only the present, no predictions existed; thus objectivity would break down, and with it the whole nice construction of Laplace's intellect.

3.3 Probability

So we must now turn Laplace's argument around, it works the other way: Since there is future, probability is one possible way to deal with it.

The past is factual. We cannot change facts any more, they are henceforth eternal. So in some respect we can deal with past facts like with mathematical truths. But for the future it is different, the future is open. For the future there are many possibilities; future "facts" are facts only potentially. Thus predictions may have the form: "This and that will happen." But predictions may also have the form: "This possibility may become a fact, but that other possibility may as well become a fact. We might only be able to predict the relative frequency of occurrences of one or the other." And that is what probability is when it is applied in natural science: Predicted relative frequency.

With this definition in mind, we can solve several puzzles of probability theory.

First, the definition of probability we have given here: For a long time it seemed impossible to define probability. All attempts at a definition seemed to fail, from Laplace's "classical" one with his "ratio of the number of cases favorable, to the number of all cases possible," to Richard von Mises' limit of relative frequency. Kolmogorov's axiomatic was so successful because he explicitly avoided any attempt at defining probability in its use in science; his theory is a purely axiomatic system, and he leaves the hard questions to the "application" of his theory.

It is true, our definition does not look very mathematical. And with its term "predicted," it looks awfully subjective to any physicist. But if you followed my argument so far, you should not be really surprised: Predictions are in the foundations of physic, in any case.[9]

There is a serious problem with that definition that has, I suppose, kept people from adopting it so far: it cannot give exact values to probability that would correspond to exact measurements. But this is a problem of probability itself, not of talking about it or of defining it. This impossibility lies in the concept of probability. In Kolmogorov's axiomatic system as well as in any other serious theory of probability it is possible to derive positive probabilities for different possible outcomes of a test series of probabilities—i.e., for different relative frequencies. Thus the theory itself excludes the possibility of an exact definition, analogous to the definition of length or charge. And this is another difficulty of the concept of probability: Almost all propositions about probability use the concept of probability again. Thus there is in probability a kind of infinite recursion of probability of probabilities. But again this is not a fault of the definition of probability but a feature of probability itself. We can understand more of it when we seriously make use of the structure of predictions. Again I must end this discussion here, in order not to be too long. One can find more detail in the texts referred to above.

On these grounds one may ask whether probability and whether time is objective at all. A first answer to this question is given by the facts: Objective science is working very successfully with probability. But probability theory itself gives us good arguments why this is so: In spite of the recursive structure of "probability of probabilities," one can always cut off the infinite process and get measurable frequencies in a good approximation. This might not be satisfactory for a mathematician or logician, but that's the way physics is; approximation is at its roots! Thus probability is an objective property of physical systems in so far as probability predictions can be verified independently of time, space, and subject.

And is time itself, in its structure of present, past, and future, objective? Time is, as we know, a fundamental concept. The concept of time is more fundamental than the concept of objectivity: A proposition is objective if it can be corroborated empirically, i.e., if a prediction derived from it can be verified. Thus we presuppose the concept of prediction in order to define what we mean by "objective." So it is not really possible to ask whether time itself is objective.

This is not the right place to delve into the subject any more. I mentioned it to hint at an example where we run into trouble when we "forget the present," i.e., when we try to stick to the description of time solely as that real parameter t.

---

[9] cf. the treatment of that definition in Drieschner [9]. For more detail cf. Drieschner [10].

3.4 Statistical Thermodynamics

We run into real trouble as well with the question how time asymmetry comes in, when we deal with statistical thermodynamics.

Statistical thermodynamics is a wonderful achievement of nineteenth century physics: There was classical (Newtonian) mechanics, which was considered the fundamental theory of everything—as we saw in quoting Laplace's intellect. And there was thermodynamics, originally a theory of steam engines, that turned out to be of interesting mathematical elegance and generality. The achievement of statistical thermodynamics was the proof that thermodynamics can be reduced to mechanics, namely to the mechanics of a large ensemble of molecules, in using statistical methods. In a quantity of gas that can be treated by humans—say, a few liters—there are as many as about 10^{23} molecules. This is a huge number, much larger than anybody could imagine. Statistics of such huge numbers is rather precise. Statistical thermodynamics turned out to be an extremely successful story.

But there remained a fundamental problem that haunts foundational research till today: Mechanics is a reversible theory. That means: if you have a solution to a mechanical problem, i.e., a function that describes the change of your system correctly, then there is always another solution under the same circumstances that would be correct as well, namely the reverse order of states with the reverse direction of changes. For example, for the system of planets revolving around the sun it would be an equally good possibility to revolve the other sense. This is what "reversible" means: you can reverse the order and still have a valid solution according to the theory. But thermodynamics is irreversible. When you leave your cup of hot coffee on the table for awhile, it will cool down until it has acquired room temperature; but when you leave a cup of cold coffee on the table, it will never become hot by itself. This is represented in thermodynamics: The temperature of bodies in contact will equalize, according to thermodynamics, the pressure of amounts of gas that are connected will equalize, etc. This is a fundamental feature of thermodynamics, deeply rooted in its equations. Now the big question: How is it possible that thermodynamics, which is "really" mechanics, according to statistical thermodynamics, becomes irreversible? How can a reversible theory just by not being looked at so closely (namely by using statistics) become irreversible?

Already Ludwig Boltzmann, one of the "fathers" of statistical thermodynamics, proposed a solution to that problem in using the possibility of fluctuations within a system at equilibrium. His solution has been reproduced through the decades again and again, e.g., in the famous treatise by Adolf Grünbaum,[10] until recent textbooks on the subject. Boltzmann expressed it so nicely that I cannot but quote it here—again in the original German and in an English translation[11]:

---

[10] Grünbaum [11].

[11] Boltzmann [12]; especially vol. II; § 90 (pp. 256–259).

> Man kann sich die Welt als ein mechanisches System von einer enorm grossen Anzahl von Bestandteilen und von enorm langer Dauer denken, so dass die Dimensionen unseres Fixsternhimmels winzig gegen die Ausdehnung des Universums und Zeiten, die wir Aeonen nennen, winzig gegen dessen Dauer sind. Es müssen dann im Universum, das sonst überall im Wärmegleichgewichte, also todt ist, hier und da solche verhältnissmässig kleine Bezirke von der Ausdehnung unseres Sternenraumes (nennen wir sie Einzelwelten) vorkommen, die während der verhältnissmässig kurzen Zeit von Aeonen erheblich vom Wärmegleichgewichte abweichen, und zwar ebenso häufig solche, in denen die Zustandswahrscheinlichkeit gerade zu- als abnimmt. Für das Universum sind also beide Richtungen der Zeit ununterscheidbar, wie es im Räume kein Oben oder Unten giebt. Aber wie wir an einer bestimmten Stelle der Erdoberfläche die Richtung gegen den Erdmittelpunkt als die Richtung nach unten bezeichnen, so wird ein Lebewesen, das sich in einer bestimmten Zeitphase einer solchen Einzelwelt befindet, die Zeitrichtung gegen die unwahrscheinlicheren Zustände anders als die entgegengesetzte (erstere als die Vergangenheit, den Anfang, letztere als die Zukunft, das Ende) bezeichnen und vermöge dieser Benennung werden sich für dasselbe kleine aus dem Universum isolirte Gebiete, “anfangs” immer in einem unwahrscheinlichen Zustande befinden. Diese Methode scheint mir die einzige, wonach man den 2. Hauptsatz, den Wärmetod jeder Einzelwelt, ohne eine einseitige Aenderung des ganzen Universums von einem bestimmten Anfangs- gegen einen schliesslichen Endzustand denken kann.
>
> English: One can think of the world as a mechanical system of an enormously large number of constituents, and of an immensely long period of time, so that the dimensions of that part containing our own “fixed stars” are minute compared to the extension of the universe; and times that we call eons are likewise minute compared to such a period. Then in the universe, which is in thermal equilibrium throughout and therefore dead, there will occur here and there relatively small regions of the same size as our galaxy (we call them single .worlds) which, during the relative short time of eons, fluctuate noticeably from thermal equilibrium, and indeed the state probability in such cases will be equally likely to increase or decrease. For the universe, the two directions of time are indistinguishable, just as in space there is no up or down. However, just as at a particular place on the earth’s surface we call “down” the direction toward the center of the earth, so will a living being in a particular time interval of such a single world distinguish the direction of time toward the less probable state from the opposite direction (the former toward the past, the latter toward the future). By virtue of this terminology, such small isolated regions of the universe will always find themselves “initially” in an improbable state. This method seems to me to be the only way in which one can understand the second law—the heat death of each single world—without a unidirectional change of the entire universe from a definite initial state to a final state.

I suppose that you feel, similarly as I did when I first read this proposal, that something must be wrong with it. Closer inspection shows, again, that the point is the structure of time: Boltzmann explicitly draws on an analogy with space (“up or down” with “two directions of time”). But that makes no sense: If you start out with fluctuations (in time), what could it mean that “a living being will... distinguish the direction of time...”? Should a living being live “backwards” in time? More recent authors don’t express that idea in such naïve terms, but you always find the distinction of “beginning” and “end,” that was supposed to come out of the argument, introduced by hand in some hidden way.

There is a really convincing solution introduced by C.F. v. Weizsäcker in 1939, which does not seem to have been recognized much[12]: It is not that time asymmetry *comes out* of using statistics, but we introduce that asymmetry ourselves—apparently without noticing it—in going over from mechanics to statistical thermodynamics. The point is that we introduce probability in that process. And the natural area of application of probability is predictions. This is probably the reason that it went almost unnoticed that in the argument for statistical thermodynamics probability is applied only to the future, but not to the past. Small wonder, thus, that the result bears an asymmetry between past and future.

The ingenious Josiah Willard Gibbs noted in his work on statistical thermodynamics as early as 1902 a faint suspicion that this might be the reason for the much discussed puzzle. He wrote[13]:

> But while the distinction of prior and subsequent events may be immaterial with respect to mathematical fictions, it is quite otherwise with respect to the events of the real world. It should not be forgotten, when our ensembles are chosen to illustrate the probabilities of events in the real world, that while the probabilities of subsequent events may often be determined from the probabilities of prior events, it is rarely the case that probabilities of prior events can be determined from those of subsequent events, for we are rarely justified in excluding the consideration of the antecedent probability of the prior events.

Still there are occasions where we give past events a probability. One field of such occasions is history. For instance we could say that it is highly probable that the apostle Jacob went to Spain. What does that mean? It is quite certain that, in fact, he went to Spain or he went not. The uncertainty arises only that we do not know for sure. So actually we can again refer that probability to the future, namely to the possible event that somebody will find out how it really was. Another field of application of probability to past events is in statistical thermodynamics itself: We might know (or we might suppose) that the system considered is in thermal equilibrium, i.e., that there is no permanent change in its state. Then the only possible changes are fluctuations caused by the "statistical" movement of the molecules. Now let me say that, to make it short, in a bit more technical terms: If we find a state that does not have maximal entropy, we can conclude with high probability that it is the extreme of a fluctuation. In that case looking backward in time gives the same result as looking forward in time, namely that entropy probably was lower than at present, and probably will be lower than at present. But this is a very intricate statistical argument. It can be discussed rather clearly with the non-realistic model that has first been proposed by Paul and Tatjana Ehrenfest in 1906 and has been used many times since.[14] The point of the argument is that for a system

---

[12] Weizsäcker [13].

[13] Gibbs [14].

[14] Ehrenfest [15].

in equilibrium there is no asymmetry of time; conclusions for the future are just as valid for the past. But if there is no thermal equilibrium, we do predict for the future, but there is no sense in "predicting" the past. Since this would become too lengthy, let me again refer to Drieschner loc. cit.

3.5 *Quantum Mechanics*

After that long run-up let me turn, finally, to Quantum Mechanics. The run-up was necessary in order to make clear the role of time for the interpretation of probability. Since quantum mechanics is indeterministic, in fact the first truly indeterministic theory in history, probability is the one concept that is most intimately connected with the new features of quantum mechanics. The notorious interpretation problems of quantum mechanics turn out to be for the most part connected with interpretation problems of probability.

Quantum mechanics is fundamentally indeterministic. Before the invention of quantum mechanics probability was already used in physics; we saw it in the example of statistical thermodynamics. But in classical (i.e., pre-quantum) physics one could always think of an underlying deterministic theory so that the use of probability became only necessary when it was too hard or too laborious to get an exact description. We saw that in Laplace's description of his use of probability, and this is usually supposed for statistical thermodynamics: The processes could in principle be described with the mechanics of 10^{23} molecules, but practically we depend on probability.

This is different in quantum mechanics. Quantum mechanics is a *fundamentally* probabilistic theory. Even if one knows all that can be known about a quantum mechanical object, according to its theory, there remain always more than one possibility for the further development; the most one can do about that is, attaching a probability value to each possibility. The situation is fundamentally different from the situation in statistical thermodynamics. For if you assume that there is an underlying deterministic theory in quantum mechanics as well, you run into serious trouble.

Since the invention of quantum mechanics in 1925, there have been attempts at finding "Hidden Parameters" of a deterministic theory for quantum mechanics, but the success of those attempts is rather doubtful. This is not the place to describe the long and tedious story of Hidden Parameters. One remark only: There is a way to introduce a deterministic theory with hidden parameters into the way of speaking about quantum mechanics; David Bohm invented it as in 1950. But the consequences of that way of speaking about quantum mechanics are rather queer and contradict principles that have been well established, e.g., the principle that the speed of light is the maximum speed for the movement of particles. So the overwhelming majority of scientists and philosophers of science consider Bohm's experiment just a curious side effect of the discussion about the consequences of the great discovery of the quantum world.

One motive for seriously discussion Bohm's and similar proposals has always been the fact that the interpretation of quantum mechanics seems so difficult. Quantum mechanics has so many features that contradict traditional ideas of classical physics that sheer desperation may lead physicists to think of rather strange ways out. But I shall try to show that the culprit for many problems is "the forgotten present." It must suffice here to pick out the two most serious examples, namely the "Collapse of the wave function" and the "EPR paradox."

3.5.1 Collapse of the Wave Function

Usually the dynamics of a quantum mechanical system is described as following two entirely different laws:

One law is the Schrödinger equation that describes the development of the wave function in a deterministic way, just like any other field equation, e.g., of electrodynamics.

The other law is the "collapse of the wave function." The latter describes the effect of a measurement: Before the measurement several outcomes are possible, with probabilities implied by the wave function; and after the measurement the one outcome, that was unpredictable before, determines which wave function describes the further development. That means that the measurement induces a sudden change in the description of the system that does not conform to the Schrödinger equation. In a measurement of position this would mean that the wave function, which was spread out in space before the measurement, is concentrated in a small volume afterwards—hence the name "collapse of the wave function."

Let us look at this description a bit closer: The wave function or, more generally, the "state" of the system under consideration, represents a catalogue of probabilities for all possible measurements of the system. So, according to the description above, it is a collection of predictions. This state develops in time according to the Schrödinger equation. This development is deterministic; the indeterminism comes in through the fact that what develop are probabilities. In general, none of the predictions bears probability 1, which would mean certainty. But there are in general several possible outcomes of the measurement; it is not predetermined which one of the possibilities will come true: This is the indeterminism of quantum mechanics.

Most theorists express regret about the fact that not all developments can be described by the Schrödinger equation. Some of them even try to develop the description of some interaction of the system under consideration with its environment that takes care of *all* changes in the framework of the Schrödinger equation, including the "collapse." In the light of the considerations above we can unmask those considerations as founded in a misunderstanding: If you accept an indeterministic theory at all, it is the unavoidable consequence that you will have two entirely different descriptions of the development.

For if a theory is not deterministic, the best you can have from it are probabilities. So the dynamics of the theory must consist in a development of the probabilities. This dynamics might even be indeterministic itself, but it can be deterministic as well, as in the case of quantum mechanics. Probability means prediction of relative frequency. So what the dynamics of the theory gives us is a prediction of relative frequency in the outcomes of like measurements. If the predicted frequency is positive but less than one, the single outcomes *must* be unpredictable. So if you continue predictions—the dynamics of the system—after the measurement, you can either continue the original dynamics, keeping all possible outcomes of the experiment with their respective probabilities within your scope. Or you take the result of the experiment into consideration. That means that from the experiment on you drop whatever could follow from the other results that were possible before the experiment, and follow only the consequences of the result that really came out. But since this very result was unpredictable, according to our basic assumption that the theory is indeterministic, there *cannot* be a way to derive that result, i.e., the further dynamics, from a theory.

This means that, in an indeterministic theory, something like the collapse of the wave function must necessarily occur. The collapse of the wave function is a necessary ingredient of any indeterministic theory.

How can we incorporate this consequence into our understanding of physical theories? In early discussions of quantum mechanics there was a strong tendency towards a subjectivist way of description. C.F.v.Weizsäcker e.g., the most philosophical thinker of the traditional ("Copenhagen") school of interpretation,[15] says in an early essay: "Dies wird besonders deutlich durch den allgemeinen Formalismus der Quantenmechanik. Er beschreibt *unser Wissen* über ein Objekt durch die Angabe einer abstrakten 'ψ-Funktion'" [17]. In English: "This becomes especially clear through the general formalism of quantum mechanics. It describes *our knowledge* about an object through an abstract 'ψ-function'." This tendency culminates in an entirely subjective interpretation of quantum mechanics by London and Bauer [18], which was not supported, though, by "Copenhagenians."

Calling the wave function ("ψ-function") a description of our knowledge is possible, if you interpret it in the right way. But you can use a more "objective" language as well. Because the wave function (the state of the system) is actually a collection of probabilities, and probability, being predicted frequency, is as objective as any prediction: If the theory is correct then you will be able to corroborate the prediction quite objectively.

Applying this argument to the case of the collapse of the wave function, we have the following situation:

- You can continue using the state before the measurement, calculated according to the Schrödinger equation, in order to predict the probabilities that apply after the

---

[15] The "Copenhagen interpretation of quantum mechanics" is, to my mind, still the only acceptable way of talking about quantum mechanics, mainly because of its modesty: it does not try to give more than it has. Cf. Drieschner [16].

measurement. You will then corroborate the relative frequencies implied by that state within the ensemble of all single systems you had before the measurement.
- But you might as well apply the collapse of the wave function after measurement, keeping only those single systems for further predictions of relative frequency that belong to a certain result of the measurement. Then you use a smaller ensemble, and you will corroborate the predictions for the "collapsed" state within this smaller ensemble.

Thus it becomes clear that the notorious collapse of the wave function is nothing but a *decision* of the one who makes the predictions. And usually he will act wisely in taking the result of every measurement into account for his predictions, i.e., to apply the collapse of the wave function. But nobody *has* to do that!

3.5.2 EPR[16]

The authors "EPR" give an example of a quantum mechanical correlation of two objects that have interacted before, but are separated afterwards. In 1951 David Bohm gave a simpler example that is usually discussed instead of the one by EPR because it is easier to understand and can be (and has been) realized experimentally[17]: Take a physical system with spin 0 that decays into two subsystems ("particles") with spin ½ each. The two subsystems have to have their spins oriented in opposite directions to conserve angular momentum. So when one measures the angular momentum of one of the particles one can conclude what the angular momentum of the other one is, even if the particles have moved apart in the meantime for a distance of light years. This is the same in quantum mechanics as in classical mechanics. But now a quantum mechanical specialty comes in: The orientation of the spin cannot be measured as some "objective" property, as in classical mechanics. What can only be measured is, whether the orientation of the angular momentum (spin) is parallel or antiparallel a certain direction fixed by the measuring apparatus.[18] Thus the result of the measurement will to a large part depend on a decision of the experimenting physicist, namely on the decision how he orients his measuring apparatus.

Let us, in order to facilitate communication, call the experimenter at one measuring apparatus "Alice," and the one at the other apparatus "Bob" (a quite common practice). The conservation of angular momentum implies that, if the measuring apparatuses are parallel, the orientations measured must be opposite. But, what sounds quite strange, not only will Bob find the opposite orientation when he orients his measurement in the same direction as Alice, but at any orientation of his experiment he will find that very frequency distribution that follows from the result

---

[16] The acronym refers to the paper Einstein et al. [19].

[17] Bohm [20].

[18] Stern and Gerlach [21, 22].

of Alice's experiment. Quantum mechanically, the state of Bob's particle always is anti-parallel to the state Alice has measured, even if Alice decides only milliseconds before her particle arrives how she wants to orient her experiment—or rather, even if she decides a time so short before that it is impossible that a signal can reach Bob before his own measurement. Einstein called this "spooky action at a distance."[19]

Actually this is not a spooky action, but it is no action at all. In order to see this we have to look a bit closer at that experiment. Bob, e.g., will see as results of his experiment (approximately) equal numbers of outcomes on both sides of his apparatus, whichever orientation he gives it, and whichever orientation Alice gives to her apparatus. What EPR talk about is the *correlation* between the results of Alice and Bob, i.e., something that somebody can find out only when he has information from both, Alice's and Bob's experiments: He has to *compare* the results. Thus, without knowing a lot about Alice's experiment, Bob cannot find out anything about it from the results of his experiment. Nothing happens on his side of the world that would depend on what Alice does on her side.

Whence, then, the whole question?

The reason for the trouble with EPR is the fact that the *state* of Bob's particle is changed by what Alice finds out.

The state is the collection of all predictions for possible measurements. But if these predictions change, why is it that Bob cannot measure that change?

The predictions are probability propositions. Probability presupposes, as we know, a certain ensemble from which the single cases for the measurement of relative frequency are taken. Let us assume for our case that Alice's apparatus is oriented vertically. Thus Bob's particle would assume the state "up" the instant when Alice measures "down" at her particle. But Alice's results are a mix of ups and downs, with an about equal number of both. So if Bob wants to do any statistics on his state "up," he can do so only if he selects the cases where Alice found "down." If he does not use information about the sequence of Alice's results, he sees nothing but his random sequence of ups and downs, about equally distributed.

Thus the change of the state of Bob's particle by Alice's measurement is actually a change of the ensemble under consideration. And Bob can effect this change only when he uses information about Alice's experimental setup and, most important, about the sequence of Alice's single results.

Thus that change of state is no action at a distance; it is no action at all. It is rather a decision, again, of the experimenters.

Physicists who call themselves realists—mainly the Bohmian school[20]—regret very much that the state of a system is not "real" in their sense. In German there is the beautiful word "Wirklichkeit" for reality. It is related to the verb "wirken,"

---

[19] "spukhafte Fernwirkungen": Born and Einstein [23], letter 84, p. 210.

[20] cf. the very interesting book Passon [24].

which means “to act” in English. In English you can imitate this relationship by the words “act” and “actual world”: Something is actual if it *acts* somehow. And since there is no action in the EPR effect, the EPR effect is not “actual”; it cannot be a *real* effect.

4 “Timeless”?

Concepts are “timeless,” eternal. In order to have concepts, there must be something that bridges time and connects present with past and future. Without that, experience would not be possible. Plato introduces that with his world of ideas, which he considers the only *real* world.

CFv Weizsäcker gives an approach from the other side. He considers time as fundamental. According to Weizsäcker, logic is fundamentally temporal logic; the “timeless,” mathematical logic we are used to is a theory that is derived from temporal logic.

Now, to be sure, we are using *concepts*, which are time bridging, and we are talking about the *structure* of time, and structures are time bridging; and we are talking about *physical theory*, which is time bridging. Truth is time bridging. So the emphasis of philosophy on the eternal is quite all right. But sometimes—i.e., at certain *times*—it is necessary to bethink oneself of the fundamental role of time, e.g., in order to understand what the eternal physical theory tells us.

What time is has been a great question of philosophy through the ages. Although this seems an abstract, rather dry subject, fundamental philosophical themes underlie our discussions of truly practical matters. So an important point in the political discussions about the environment, about sustainable economy, and similar subjects, is the question how we see the world around us, our “reality.” And for our image of reality it is decisive how we understand the picture quantum mechanics draws of this reality, although it seems so remote at first glance. And in order to understand that, we must not forget the present.

References

1. Parmenides (2012) http://philoctetes.free.fr/parmenidesunicode.htm. English translation by John Burnet (1892) [(2005) Parmenides of Elea. Kessinger, Whitefish]
2. Ritter J et al (eds) (1971–2007) Historisches Wörterbuch der Philosophie, 13 vols. Schwabe, Basel/Stuttgart
3. Cornford FM (1935) Plato’s cosmology. Kegan Paul, London (many reprints)
4. Heisenberg W (1969) Der Teil und das Ganze. Piper, München [English: Physics and beyond: encounters and conversations. A.J. Pomerans, trans. New York 1971]
5. Hussey E (1983) Aristotle’s physics, books III and IV. Clarendon, Oxford
6. Wieland W (1962) Die aristotelische Physik. Vandenhoeck & Ruprecht, Göttingen [2nd edn, 1970]

7. Augustinus A (1946) St Augustine's confessions, 2 vols [with an English translation by William Watts]. Heinemann, London (Loeb Classical Library)
8. de Laplace PD (1814) Essai philosophique sur les probabilités. Paris [English translation from the original French 6th ed. by Truscott FW and Emory FL. New York 1951; p 4]
9. Drieschner M (2002) Moderne Naturphilosophie. Mentis, Paderborn
10. Drieschner M (1979) Voraussage –Wahrscheinlichkeit – Objekt. Über die begrifflichen Grundlagen der Quantenmechanik (Lecture notes in physics). Springer, Berlin
11. Grünbaum A (1963) Philosophical problems of space and time. Knopf, New York [Boston Studies in the Philosophy of Science, 2nd edn. Reidel, Dordrecht/Boston, 1973]
12. Boltzmann L (1896/1898) Vorlesungen über Gastheorie, 2 vols. Leipzig [English translation by Stephen G. Brush: Ludwig Boltzmann, Lectures on gas theory. Dover, New York 1995 (© University of California Press, 1964)]
13. von Weizsäcker CF (1939) Der zweite Hauptsatz und der Unterschied von Vergangenheit und Zukunft. Annalen der Physik 36:275 [Reprinted in: von Weizsäcker CF (1971) Die Einheit der Natur. Studien, München (Hanser) pp 172–182]
14. Gibbs JW (1902) Elementary principles in statistical mechanics, developed with especial reference to the rational foundations of thermodynamics. Scribner's sons, New York, xviii, 207 p [Reprint Woodbridge, 1981. pp 150–151]
15. Ehrenfest P, Ehrenfest T (1906) Über eine Aufgabe aus der Wahrscheinlichkeitsrechnung, die mit der kinetischen Deutung der Entropievermehrung zusammenhängt. Mech.-Naturw. Blätter 3(11, 12) [Reprinted in Ehrenfest P (1959) Collected scientific papers. In: Klein MJ (ed). Amsterdam (North-Holland)/New York (Interscience)]
16. Drieschner M (2002) Eine Lanze für Kopenhagen. In: Eusterschulte A, Ingensiep HW (eds) Philosophie der natürlichen Mitwelt. Festschrift für K.M.Meyer-Abich. Königshausen & Neumann, Würzburg, pp 171–179
17. von Weizsäcker CF (1941) Das Verhältnis der Quantenmechanik zur Philosophie Kants. Die Tatwelt 17:66–98 [Reprinted in Zum Weltbild der Physik. Stuttgart 1943; augmented editions and reprints 1944–2002]
18. London F, Bauer E (1939) La Theorie de l'Observation en Mechanique Quantique. Hermann, Paris
19. Einstein A, Podolski B, Rosen N (1935) Can quantum mechanical description of physical reality be considered complete? Phys Rev 47:777
20. Bohm D (1951) Quantum theory. Prentice Hall, New York
21. Stern O, Gerlach W (1922) Der experimentelle Nachweis des magnetischen Moments des Silberatoms. Zeitschrift für Physik 8:110–111
22. Stern O, Gerlach W (1922) Der experimentelle Nachweis der Richtungsquantelung im Magnetfeld. Zeitschrift für Physik 9:349–355
23. Born M, Einstein A (1969) Albert Einstein, Max Born. Briefwechsel 1916 – 1955. Nymphenburger, München
24. Passon O (2004) Bohmsche Mechanik: Eine elementare Einführung in die Deterministische Interpretation der Quantenmechanik. Harri Deutsch, Frankfurt/M