PROPENSITIES and PAST-EVENTS
A look at I.J. Thompson's Quantum Ontology

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1 Preliminary Remarks

1.1 Introduction

Science is the activity of creating theories according to certain methodological standards. How those theories should be interpreted and, more specifically, what they are *about*, is a notoriously difficult question from the philosophy of science. If we adopt the realist viewpoint that scientific theories describe objective reality, it seems natural to wonder which entities really *exist*. Is the world made up of 'particles', as the 17^{th} century mechanists thought? Or was Aristotle closer to the truth, when he claimed that the world consisted of 'substance' shaped by 'form'? These questions belong to the part of philosophy known as 'ontology', which concerns itself with the *nature of being*.

The theory of quantum mechanics has changed the way we look at the world, and any modern ontology should allow us to make sense of its peculiar predictions. We will call an ontology which is explicitly created with this purpose a 'quantum ontology'.

1.2 The peculiarities of the quantum world

The conceptual problems accompanying quantum mechanics are many and various, so a quick outline of some of the more important ones will have to suffice here. Once, many thought the world was made of irreducible particles, called 'atoms'. There was nothing else, the atoms where the final and only building blocks of reality. Later, the theory of electrodynamics seemed to force us to accept the reality of fields, which influenced and were generated by the particles. The particles and fields, however, were distinct entities – something was *either* a particle *or* a field.

This is no longer clear in quantum mechanics. Particles are now described by wave functions, and display properties normally associated with waves or with particles depending on the context of measurement. It is no longer unproblematic to say that some entity is either a particle or a wave.

Furthermore, the quantum world appears to be, at first glance, indeterministic. It cannot be predicted where a photon moving through a slit will hit a photographic sheet. The outcome of many quantum experiments is seemingly random, with chances depending on the nature of the wave function. And not only is it indeterministic, it is also non-local. EPR-type experiments show that events can influence each other immediately, irrespective of the spatial distance between them.[1]

Nor is the concept of 'property' left unaffected. Where particles once had definite place and momentum, quantum mechanics brought us a strange principle of 'complementarity', which no longer allows us to claim that a particle can have a well-defined place and momentum at the same time.[2] It is very hard to visualise how this could be.

Finally, the infamous 'problem of measurement' has already puzzled physicists and philosophers for decades, and will probably continue to do so for many years to come. Quantum mechanics seems to require a 'reduction of the wave function', but how this can be fitted into our picture of nature is unclear. Many solutions to this problem have been proposed, but none of these has yet been widely acknowledged as the final answer.

1.3 Quantum ontologies

We would like to have an ontology in which the peculiarities of quantum theory can be fitted easily. By supplying us with a conceptualisation of the basic nature of the world around us, a successful ontology can increase our understanding of our theories and can be a source of inspiration for theoretical and foundational research. Because of this, even empiricists and instrumentalists might acknowledge the usefulness of ontological research – however, it is primarily a realist concern. What exactly is the quantum world like? Many, and widely differing, proposals have been made throughout the years. A quick look at some of those will illuminate the problems we have to face.[3]

1.3.1 Ontology of events

There really are no such things as particles, waves or fields: the only things which are real are *events*. What is quite unclear in this view is how causation works: if there are only events and no underlying substances, how do events cause other events? Furthermore, physical theories use notions like 'charge', 'mass', 'energy' and 'momentum', which have no counterpart in a world made of only events.

1.3.2 Ontology of particles

The fundamental building blocks of the universe are particles, just as the old atomists thought. However, these particles must have extremely strange properties for the peculiar features of quantum theory to arise. This is hardly an ontology in which quantum mechanics can be 'easily understood' or into which it can be 'naturally fitted'.

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[1] This is somewhat loosely stated; a fuller treatment of non-locality would take too much time.

[2] Unless we accept hidden-variable theories, which have their own share of problems. A recurring theme in the philosophy of quantum mechanics seems to be a variant of Murphy's Law: every solution to a problem creates new problems at least as big as the original one. Our present enterprise is also subjected to this problem-preserving conservation law.

[3] Here I am closely following I.J. Thompson's 'Philosophy of Nature and Quantum Reality', section 4.3.

1.3.3 Ontology of waves

The only thing which exists is a 'universal field', and the waves that propagate in it. Particles are simply localised concentrations of this field. The main problems of this ontology are firstly the fact that the wave-function of an n-particle system lives in $3n$-dimensions, not in our real 3-dimensional world; and secondly that the 'reduction of the wave packet' is extremely unnatural. In no ontology is the problem of measurement as incomprehensible as in this one.[4]

1.3.4 Copenhagen 'Ontology'

Niels Bohr once said: "There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find out how nature *is*. Physics concerns what we can say about nature." His idea of wave-particle complementarity destroys all hope the uncertain physicist might still have of a coherent and natural conceptualisation of quantum reality. In fact, Copenhagen's almost deontological claim that we cannot speak about quantum reality has probably driven many disillusioned scientists to a de-ontological world view. *We* do not wish to accept such restrictions, and look further.

1.3.5 Ontology of propensities

The really existing entities in our world are *forms of potentiality*, or 'forms of propensity'. The definition of 'propensity' will be given later, but it involves a notion of probability, of potentiality, which seems to fit nicely into the quantum mechanical scheme of non-deterministic evolution. However, this ontology suffers from an unallowable vagueness until the idea of 'forms of propensity' and the way in which they could be said to make up the world has been made sufficiently clear. That will be the aim of most of the remaining part of this essay.

1.4 'Philosophy of Nature and Quantum Reality'

This essay was written as part of the final examination of the 'Foundations of Quantum Mechanics'-course taught in 2002/2003 by Dr J.B.M. Uffink at Utrecht University. Because of the limited amount of time allotted to it, the scope of the present article is narrow. Instead of giving an overview of propensity ontologies, I chose to delve deeply into one book, professor Ian J. Thompson's unpublished 'Philosophy of Nature and Quantum Reality', wherein a quantum ontology is set forth that makes heavy use of them. Because of this narrow scope, comparisons with other schemes for such an ontology cannot be given, nor will I be able to draw any definite conclusions about the fruitfulness of searching for one.

What I *will* try to accomplish is giving a short but hopefully clear overview of I.J. Thompson's ontology as I understand it, and end with some tentative opinions of my own. Recasting a 140-page argument into a small fraction of that length will necessarily leave it somewhat mutilated and full of *ad hoc* postulates.

[4]The idea of not having a reduction of the wave function is pursued by Everett, Wheeler and Graham in their 'many worlds interpretation'. Unfortunately, this ontology forces us to accept that at every 'interaction' (whatever that may be) an infinitude of new universes is created. Although interesting and perhaps beautiful, this is a little far-fetched.

The interested reader is referred to the full text of the third draft of this book, currently living at `http://www.generativescience.org/books/pnb/`. In section 2 and 3 I will adopt the first person plural to describe what 'we' are doing. This is merely a writing device, and in no way either expresses my agreement with I.J. Thompson or his approval of my essay. My own comments will be in the form of footnotes.

The nature of the argument is explicitly hypothetico-deductive. We frame hypotheses about the nature of reality, deduce consequences for them and thus create a general scheme for ontologies. Only after that do we look to quantum mechanics to find out whether it does or does not fit naturally in our proposed scheme.

2 Philosophy of Nature: creating the concepts

2.1 Dispositions and Propensities

Dispositions are well known from the philosophy of science. The standard example of a dispositional property is the solubility of salt. In claiming that salt is soluble in water we are not claiming that any particular piece of salt is currently dissolving; nor are we claiming that any piece of salt will dissolve in the future. What we are saying is that *whenever* a piece of salt is placed in water (under the right conditions), *then* it will dissolve. Dispositions are notoriously difficult to formalise in non-modal logic, but it is intuitively clear what is meant by them.

Disposition Object S has the disposition P to do action $A \equiv$ *if* S is in some circumstance C, C depending on P and the character of A, *then* there will be a non-zero likelihood of S doing A.

The term 'character of A' was used rather than 'A' itself, since if the right situation never obtains, there may exist no action A. Furthermore, the definition allows both dispositions which are certain to generate an effect in the appropriate circumstances, and dispositions which only have a chance of doing so. These probabilistic dispositions, which will turn out to be handy in the description of quantum reality, are called 'propensities'.

Propensity Propensities are properties of objects which, in appropriate circumstances, give rise to *real* and *objective* probabilities. These probabilities, if they are truly the product of propensities, are not merely an expression of ignorance or partial knowledge on our part. In other words, a propensity is a probabilistic disposition.

Many scientists believe that dispositions are merely incomplete descriptions of reality. Surely, we can do away with a dispositional notion like 'solubility' by giving a description of the atomic structure of salt and the molecular make-up of water? Any disposition can be removed, according to this view, by giving a sufficiently detailed description of the system under consideration.

But this is a naive opinion. Yes, we can remove a disposition like 'solubility', but in the process we introduce new dispositions. For merely telling us what particles make up the system is not enough; we also have to know how these particles interact. All particles have, after all, a certain *ability to interact*, which is once again a dispositional property. Our laws of physics tell us that *whenever* two electrons are a distance r apart, *then* they will repel each other with a force $F(r)$ – thus ascribing dispositional properties to electrons. In the end, all descriptions of reality must contain abilities to interact, and these are necessarily dispositional.

2.2 Actualities

We now assume that there are in the world, independent of ourselves, various *particular* and concrete things.

Particular Particulars are concrete things in the world. These particulars have properties that describe them and distinguish them from other particulars.

We wish to talk about things which are 'actual', as distinct from things which are merely 'potential' or 'probable', or whatnot. The question which things, if any, can be thought of as 'actual' must be answered by any comprehensive ontology.

Actual Actual $\equiv$ existing as a complete and concrete fact (as distinguished from potential or possible).

Using our definition of 'particular', and somewhat elaborating on our definition of 'actual', we now define 'actual particulars'.

Actual Particular Actual Particulars are the fully determinate of the simple particulars.

'Fully determinate' means that all the characteristics of the particular are definite, fixed and precise; there is no element of chance, no uncertainty involved. 'Simple' means that the particulars are not dividable into smaller particulars – if that would be possible, than those constituent particulars would be the 'actual particulars'.

From this definition, as yet without any empirical content, we can deduce some facts about actual particulars. First of all, they are incapable of changing; for any change would change their properties and, because of their determinateness, this would change them into a different particular. Hence, the only change possible with respect to them is that they are created or destroyed. A little reflection will show that the actual particulars cannot be the cause of their own creation or destruction, but nothing disallows this process from being initiated by other means.

Now we turn to the question of whether actual particulars can be infinite or must always be finite. At first glance, infinities are somehow indefinite, and hence not fully determinate. But since Cantor mathematicians can do calculations with infinities and it is not impossible to claim that infinities can be fully definite.[5] However, we wish to develop an ontology where actual events must have non-zero time intervals between them – this will prove to be an assumption that allows us to realistically interpret quantum mechanics – and in that context we adopt the following postulate:

[5] The status of infinities in mathematics is highly controversial, with opinions ranging from the strict finitist view that they are meaningless to Cantor's equation of God with the Absolute Infinity. We do not wish to make our philosophy of nature dependent on a philosophy of mathematics, and hence do not claim that infinities are necessarily indefinite.

Finiteness Postulate Actualities, singly and in aggregates, are necessarily finite (in the Euclidean sense).

Euclidian Finiteness A set S is finite in the Euclidian sense iff any proper subset of S is smaller than S; in other words, iff there is no injective function which maps the elements of S to any proper subset of S.

Yet we do not adopt a strict finitist point of view with respect to nature. Though our Finiteness Postulate tells us that all actualities must be finite, it allows us to conceive of sets of possibilities which are infinite. We might claim, for instance, that there is a continuum of possible places on any line to place a particle. Though no particle ever actually occupies such a continuum, we can still talk about an infinity of possibilities.

Infinity in Nature We allow infinities only with respect to *possibilities*; the Finiteness Postulate tells us that all *actualities* are finite.

What kinds of things could be 'actual particulars'? I refer the reader to 'Philosophy of Nature and Quantum Reality', section 6.3, for reasoned rejections of many candidates for this highly sought-after title. In the end, Thompson only allows 'past-events' to be actual particulars in the sense defined above. They are fully determinate, since that which has happened will never change again.

Past-event A 'past-event' is an *actuality* that has been produced by a past *event*. The events themselves are the acts of becoming of the actual past-events.

We are here using a view of time where the past is fully determinate, whereas the future is not. As time goes by (a process to be looked at later), events occur, producing actual 'past-events'.[6]

2.3 Potentiality

Since we saw earlier that some kind of dispositions is necessary in any physical theory, we will now look at particulars that are not 'actual' in the sense of being fully determinate, but which are in some way potentialities.[7] The actual particulars we identified above alone cannot furnish us with a comprehensible account of change. For causality to be possible, a given actuality must in some way be related to a potentiality for other subsequent actualities.

As the basis paradigm of change we choose the process of actualising, which is the 'realising of a potentiality to produce a new actuality'. Thus, there is a potentiality for a certain actuality, and at some 'time' this potentiality actually produces the actuality.[8] We do *not* attribute real existence to an actuality

[6] I personally have doubts about the necessity of rejecting the 'block universe' account of time in this context. I see no reason to assume that the process of actualising of propensities, to be described later, is incompatible with the rejection of a moving present. These questions, however, fall beyond the scope of this essay.

[7] Thompson's use of the words 'power', 'potentiality' and 'propensity' in his section 7 is somewhat unclear. What is a 'potentiality' in subsection 7.1 seems to become a 'propensity' in section 7.2. For internal consistency, I will stick with the term 'potentiality'.

[8] By using the term 'potentiality' we wish to remain sufficiently general to encompass both deterministic and non-deterministic changes; we do not wish to imply at this point that all changes must be non-deterministic.

before it is realised, as Aristotle did when he claimed that a tree which had not yet grown from an acorn had 'potential being'. Indeed, this would violate our definition of actuality, since a potentiality is never entirely definite. Instead, we attribute real existence to the *potentiality*, to the possibility of actualising.

The process of Actualising There are really existing potentialities, which in the appropriate, as yet unspecified, circumstances produce an actual particular. Another name for this process, borrowed from Aristotle, is *kinesis*.

We will now give a schematic indication of this process of actualising. If an actual particular A causes an actual particular B, at least the following propositions must be true[9]:

1. The event B must have been possible, in other words, there must have been a real potentiality to make B happen.
2. There was a set of possibilities for the change, which might contain members apart from B, from which only one becomes actual.
3. These various possibilities are related to each other in some structure. (For example, the possibilities for different grains on a photographic plane to be hit by a photon are related to each other in the structure of our ordinary space-time.)
4. There was a form of distribution of the potentiality over the set of possibilities, allowing for different likelihoods of actualisation.[10]
5. Once B is actualised, there is a corresponding restriction of the distribution of potentialities for subsequent actualisations.[11]

The above is intended as a necessary framework for a theory of causation, but not a sufficient one. It should be compatible with many different physical theories.

[9]Compare 'Philosophy of Nature and Quantum Reality', section 7.2, where Thompson lists seven propositions. I have somewhat reduced the number. It seems to me that Thompson's first proposition makes the possibility for an actuality logically inequivalent to the existence of a potentiality to make that actuality happen – which contradicts, in my opinion, his rejection of Aristotelian 'potential being'. Rejecting potential being in favour of really existing potentialities seems to imply that the possibility for an event is logically equivalent to the existence of a potentiality for that event. In that context, the wording of the first two propositions by Thompson is at least strange. Furthermore, his third proposition seems to be a logical consequence of his second one; for how can we understand the phrase 'power or propensity to make B happen' without therefrom concluding that this is a power or propensity directed to the occurrence of B?

[10]How this 'set of possibilities' with the distribution defined on it is different from the potentiality itself is, to me, unclear. I suggest that 2-4 are really only elaborations on 1, and should have been presented as such.

[11]By claiming that this *follows* from the fact that an actual particular A causes an actual particular B, Thompson commits himself to the position that actualisation is *necessarily* accompanied by the redistribution of potentialities. If this is to be a fundamental aspect of actualisation, we might have preferred to see it in his original definition.

2.4 Space and Time

We will now develop a theory of space-time which we need for our ontology.[12]

Possibilities, Space and Time Possibilities are identified as *places in space-time*. An event is *at* a place when the corresponding possibility is being realised, and this results in that place being 'filled'. The space-time referred to need not be our usual space-time. (It might, for instance, have dimensions that behave like 'spin-space' or 'isospin-space'.)

An empirical fact from our world is that, in most situations, things tend to influence other things that are 'closer' more strongly than those that are 'far away'. There must be a kind of 'real extensiveness', some property of space, to account for this fact. Extensiveness is a relation that holds between all pairs of places, regardless of whether they are filled of not.

Extensive Continuum We adopt a view of space where space is the 'Extensive Continuum', which is an ordered manifold of places with a 'distance'-function defined on it. With our identification of possibilities with places, we claim that space is *the continuous order of possibilities for actuality.* Space itself is *not* an actual entity.

Quantum mechanics makes no fundamental difference between place-space and momentum-space. However, proximity in momentum space does not influence the ability of things to interact. For that reason, we wish to view place-space as real, and momentum-space as a mathematical abstraction.

What about time? We adopt a view of time where there is a *real* difference between past and future.[13] In the past, we have the past-events described earlier; in the present, we have potentialities; in the future, we only have possibilities for actualities. As the present 'moves', potentialities are actualised, thus creating past-events.

We are now in the position to define three relations between places: 'precedes', 'succeeds' and 'alternates with'. More precise definitions can be found in Thompson's book, but intuitively, using terminology from special relativity, we can say that *p precedes q* iff *p* is in the past light cone of *q*; *p succeeds q* iff *q precedes p*; and *p alternates with q* in all other cases. Since events have been identified with places, these relations on space-time define a partial ordering of events.[14] Using this partial ordering, we define the

[12] This is not an essay on the philosophy of space and time. Hence, I will allot but a small amount of space to what is in fact a substantial portion of Thompson's book. Readers who would like to see more detailed arguments for the ideas postulated here are referred to 'Philosophy of Nature and Quantum Reality', Chapter 8.

[13] As mentioned earlier, I am not convinced that this is necessary. The concepts of propensities and actualisations can be just as meaningful in a 'block universe' as in a Universe with a 'moving' present. I think that any ontology of change compatible with McTaggart's A series (a moving present) is also compatible with his B series (a block universe), simply by taking all the A series' 'presents' and putting them in an ordered string, which we then call the B series. Since nothing can happen in the 'future' or the 'past', *all* of the account of change in the A series must be contained in the description of those presents; hence, the account of change in the B series constructed in the way just described will be identical to that in the A series. A redefinition of terms like 'necessary' might be needed in the transition from the one to the other, but this should not be regarded as a fatal flaw. This is not the place to explore this conjecture, however.

[14] The two axioms of a partial ordering are 'For no a is $a < a$' and 'For every a, b and c, $a < b$ and $b < c$ implies $a < c$'. These axioms are evidently satisfied by our 'precedes' relation.

Principle of Definite Past An actualising at place p occurs *after* all places which precede p are either definitely filled or definitely not filled.

But our ontology is non-local: whenever a potentiality is actualised at place $\vec{x}_1$, the entire potentiality is instantly changed into a new one, as required by the fifth proposition of our account of actualising. Thus, an actualising event at $\vec{x}_1$ *immediately* changes the potentialities at $\vec{x}_2$, even if there is a large distance between them. This seems to indicate that there may be a full ordering of events after all: each actualising event resounds throughout the Universe as a tick of some ghostly clock. This nicely fits in with the intuition that past-events, being fully actual, should also be fully ordered. However, this ordering is not necessary, but contingent: no law of nature determines which of two alternating events happens first, this is merely a contingent detail of the process of actualising. Once the events have occurred, the ordering is definite, but it could not have been specified in advance.

This ordering of events defines a *discrete global 'process' time.*[15] And this is exactly what we wish to have, since we wanted our past-events to have non-zero time intervals between them. This is obviously satisfied in a discrete time where the moments are defined by the occurrence of events.

2.5 Continuants

Finally, we turn to the problem of *substance*. Since this term is highly ambiguous and has many connotations we wish to avoid, we use the term 'continuant' instead.

Continuant A continuant is that which continues to exist throughout some limited or unlimited period of time, during which its inner states or its outer connections may be altering or remain unaltered.

Past-events are obviously not continuants, since they exist only at a given time and do not 'continue' to exist. Yet maybe potentialities are in some way continuants. Our account of actualising and our theory of space-time allow us to think of these potentialities as 'propensity fields': distributions of potentiality over a set of possible events. Let's look once more at the causal process of actualising. We start considering an event A at some place $\vec{x}_A$ in space and time. The propensities which are responsible for making occur a successor event to A then extend and endure through the space-time continuum from the place $\vec{x}_A$, but only in the positive time-direction, over places where successor events *may* occur. This propensity field endures until a new event, B, happens at place $\vec{x}_B$. The propensity field 'collapses', and the new propensities extend from place $\vec{x}_B$. Etcetera.

In this scheme, the propensity field can be seen as the most basic continuant (or substance). The propensity fields emanating from A and B can be identified as successive stages of the *same* entity. There is an event, B, over which they are extensively continuous, which is the product of the earlier and the cause of

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The ordering is only partial, and not full, since some events are not related to each other by the 'precedes' relation at all. I have been quietly assuming that $p \neq q$.

[15] This process time is distinct from the continuous time which consisted of 'possibilities for actuality'. It is not clear to me what the ontological status of the process time is supposed to be.

the later field. Thus, a string of propensity fields can be formed which are all connected through subsequent actualisations, and form one entity, one enduring continuant.

The most basic nature of reality is this: there are continuants, which are propensity fields. By the process of actualising, as described in detail above, they create past-events, which are the only true actualities. We now turn to quantum mechanics and look at its compatibility with this ontology.

3 Quantum Reality: applying the concepts

3.1 Indeterminism

The wave-functions of quantum mechanics have been interpreted in a statistical fashion since Born suggested his ensemble interpretation. In this view, $|\psi^2|$ denotes the fraction of systems that have a certain property, given an infinite ensemble of equally prepared systems. However, instead of such a frequentistic interpretation, we might use a propensity interpretation of quantum mechanics: $|\psi^2|$ denotes a *real* and *objective* probability. Using this interpretation, quantum theory fits our ontology particularly well: our propensity fields naturally lead to the kind of indeterminism found in quantum mechanics. For although it is logically possible that our propensity fields are always localised in one point – the equivalent of determinism – nothing in our ontology forces us to regard this as being more natural than propensity fields extended in space-time.

3.2 Wave-particle complementarity

Quantum systems sometimes behave like waves, and sometimes behave like particles. In our ontology, there are two kinds of entities: propensity fields and past-events. This is exactly the kind of duality needed to explain the peculiarities of wave-particle complementarity. Propensity fields are like wave functions, and their 'time evolution' can be described by the wave equations of quantum mechanics.[16] But the actualising events which create past-events behave like particles: a propensity field is actualised at *one* photographic grain in a photographic place, etcetera. Thus, wave-particle complementarity is a logical consequence of our ontology.

Let's look at an example: the two-slit experiment. We emit a photon; this is an event, which generates a past-event and a propensity field. This propensity field evolves through time in a way dictated by the laws of quantum mechanics and the existence of the two slits, until it is actualised at one specific point on the photographic sheet. We get the kind of interference pattern we expect.

Now we place some kind of measuring device after one of the slits, so we can find out which slit the photon has moved through. We emit a photon; this is an event, which generates a past-event and a propensity field. This propensity field evolves through time in a way dictated by the laws of quantum mechanics and the existence of the two slits, until it is actualised at the *measuring device*.

[16] We are passing over the question whether the propensity field should be identified with ψ, with $|\psi^2|$ or with some other even more complicated function of the quantum mechanical wave functions. Though these would be important questions when working out the details of a particular quantum ontology, we are presently interested in the plausibility of the *general scheme of ontologies* we have set forth.

The propensity field is localised, and the subsequent actualisation at the photographic sheet will no longer exhibit an interference pattern.[17] The results of the two-slit experiment fit very naturally into our ontology.

3.3 The problem of measurement

Solving the problem of measurement is rather easy in our ontology. What is a measurement? Well, an actualising event. The 'reduction of the wave function' whenever any definite measurement takes places has been put into our ontology at the very beginning, so to speak. Using our ontology, it has to be *expected* that the wave-like fields of propensity are sometimes localised. Thus, it is easy to answer both the question 'What is a measurement?' and 'How is the wave function reduced when a measurement takes place?'

3.4 Non-locality

Non-local processes were seen as strange features of quantum mechanics. But our propensity fields behave in a non-local way whenever they are actualised, so some kinds of non-local processes are to be expected. However, the growing extension through space of a localised propensity field can be chosen not to exceed the speed of light. Hence, our ontology is *nearly-local*, exactly in the way the results of quantum mechanics are nearly-local: there are some marginal non-local effects, but these cannot be used to send messages faster than the speed of light. The EPR-paradox is not very paradoxical in our philosophy of nature.

3.5 Conservation of problems

Is it time to blow the trumpets and triumphantly announce that we have solved, be it in a qualitative and still relatively vague way, the philosophical problems of quantum mechanics? Unfortunately, no.[18] The most obvious problem, already mentioned in an earlier footnote, is that there should be a distinction between propensities which cannot and those that can be actualised. The propensity field often described as 'a photon flying through empty space' is qualitatively different from that often described as 'a photon reaching a photographic sheet'. In order to solve this problem, a new theory of propensity fields is needed, distinguishing propensity fields for 'virtual' events and for actual events. Thompson tries to do this in Chapter 11 of his book, but the result is greatly different from the

[17] This sounds initially plausible. But what if there is no actualisation at the measuring device, which should be the case for half of the emitted photons? In order to explain the empirical results, there should be a localisation of the propensity field at the other slit – but it is hard to see why this would necessarily happen. Furthermore, in some way the possibility for actualising in empty space must be qualitatively different from the possibility for actualising at the photographic sheet, since the photon is never actualised in empty space (this would destroy the interference pattern) but is always actualised at the photographic sheet. Thompson is aware of this problem, and creates a theory of two 'stages of propensity' in chapter 11, where he distinguishes between virtual and actual events. Since this takes place in the context of quantum field theory, I will not discuss it in detail.

[18] Maybe this is fortunate after all: philosophy of physics would become rather boring when all problems were suddenly solved.

ontology initially developed.[19] Furthermore, this approach leads to additional problems, for which Thompson himself claims he is 'at a loss' when it comes to solving them. As always, trying to solve some problems leads to many new ones.

4 Tentative Opinions

'He is wise who knows what he does not know', Socrates is supposed to have said. I make no claim to wisdom, but at least I hope to avoid the folly of feigning knowledge where I possess ignorance. The limited scope of my present researches does not allow me to draw authoritative conclusions about the ontology set forth by prof. Thompson. Please keep that in mind when reading my opinions, which I will formulate regardlessly.

The book 'Philosophy of Nature and Quantum Reality' itself suffers somewhat from over-ambitiousness. In many places it tries to summarise all the important philosophical positions taken with respect to a certain problem, which is sometimes helpful but more often only serves to obscure Thompson's own arguments. In this respect, the book could be improved by taking out some of the less relevant information and spending a little more time on the important issues. Additionally, the terminology is sometimes confusing. For instance, Thompson claims in Chapter 9 that we should use the term 'continuant' rather than 'substance', as the latter is too ambiguous. But later subsection 11.4 is called 'Quantum substances', and the term 'continuant' does not appear in it. Another example is the sudden change from 'potentiality' to 'propensity' in chapter 7.

The ontology developed is not *always* sufficiently clear either. The necessity of a moving present is postulated but not explained; the ontological status of the 'process time' is never elucidated; the account of actualisation suffers from a lack of clarity.

Still, these are minor problems. The overall ideas behind the developed ontology are communicated well, and the reader will certainly get a coherent picture of it. In my opinion, there were enough definitions and explanations to render the concepts used intelligible. Ontological treatises have a tendency to become excessively vague – I cannot resist mentioning Heidegger here – but prof. Thompson has succeeded in avoiding this to a very acceptable degree.

Although enough questions and problems remain, it is surely true that some aspects of the quantum world are more readily understandable when we accept the ontology of past-events and propensity fields. The natural way in which wave-particle complementarity follows from these notions is impressive, and certainly better than what particle-ontologies or wave-ontologies can give us. Although I don't advocate an unconditional acceptance of propensity fields, I do feel that ontologies using them are a promising field of research.

At the very least, 'Philosophy of Nature and Quantum Reality' is a thought-provoking book, which shows us a vision of the quantum world different from that taught to most of us. The notions and ideas introduced in it might be able

[19] Since this attempt makes heavy use of concepts of quantum field theory, which fall far beyond the scope of the 'foundations of quantum mechanics' course, I won't go into details. The interested reader should consult the chapter mentioned.

to stimulate us to do some interesting and fruitful foundational research. In the end, that is probably a more important virtue for any ontology than truth.[20]

[20]I would here like to thank Ian J. Thompson for kindly providing me with the figures that were initially missing in his document.