THE PROBLEM OF THE OBSERVER IN PHYSICS [DRAFT]

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ABSTRACT. In this short paper I present a new approach to the problem of measurement, based on the difference between language (reality) and meta-language (meta-reality). This way, it will be shown that the measurement is a meta-sentence on a real event. It is no longer necessary to split up the world into subject and object with a shifty boundary, but starting with an holistic event (the phenomenon) in which everything is entangled, and make meta-assertions on this. This possible way out stops von Neumann’s chain and explains the real meaning of the concept of measurement.

1. Symbolic Notation

First of all, some considerations on the notation used. Consider the eigen-value problem \( \mathcal{O}|\varphi_i\rangle = \lambda_i|\varphi_i\rangle \), where \( \mathcal{O} \) is an hermitian operator (a particular linear operator) representing mathematically an observable \( \mathcal{O} \). An observable is anything which we can measure. It is what von Neumann called Grösse. \( |\varphi_i\rangle \) is an eigenvector, representing the eigen-state in which the wave-function collapses after a measurement. Finally, \( \lambda_i \) is a real number: the measure of \( \mathcal{O} \). I will write the wave-collapase this way:

\[
m_i(\mathcal{O}) \rightarrow |\varphi_i\rangle \models m_i(\mathcal{O}) = \lambda_i
\]

I.e. the measurement \( m_i \) on \( \mathcal{O} \) collapses the wave-function of \( \mathcal{O} \) in one of its eigenstates \( |\varphi_i\rangle \) in which it is true that \( m_i(\mathcal{O}) = \lambda_i \); it is true that \( \mathcal{O} \) measures just \( \lambda_i \). I would insist on this notation. The arrow \( \rightarrow \) suggests an implication from the measurement to the collapse. Obviously, this arrow is a meta-linguistic sign. The formulation of the consequent suggests a parallel with Model Theory. The eigenvector is a sort of model in which a formula is true or false (in this case, true). In fact, we can speak of measurement only in the context of an eigen-state.

One could argue that we have neglected the amplitude of probability associated to a possible eigen-state. As you can see below, we can express that a measurement implies a collapse with a probability \( P = r_i \) in the following manner:

\[
m_i(\mathcal{O}) \xrightarrow{P=r_i} |\varphi_i\rangle \models m_i(\mathcal{O}) = \lambda_i
\]

2. How the Problem arises in Quantum Mechanics

We shall start with a quotation of one of the fathers of Quantum Mechanics, Erwin Schrödinger:

Man kann auch ganz burleske Fälle konstruieren. Eine Katze wird in eine Stahlkammer gesperrt, zusammen mit folgender Höllenmaschine (die man gegen den direkten Zugriff der Katze sichern muß): in einem GEIGERSchen Zählrohr befindet sich eine winzige
Menge radioaktiver Substanz, so wenig, daß im Lauf einer Stunde *vielleicht* eines von dem Atomen zerfällt, ebenso wahrscheinlich aber auch keines; geschieht es, so spricht das Zählrohr an und betätigt über ein Relais ein Hämmerchen mit Blausäure zertrümmert. Hat man dieses ganze System eine Stunde lang **sich selbst überlassen**, so wird man sagen, daß die Katze noch lebt, *wenn* inzwischen kein Atom zerfallen ist. Der erste Atomzerfall würde sie vergiftet haben. Die \( \psi \)-Funktion des ganzen Systems würde das so zum Ausdruck bringen, daß in ihr die **lebende und die tote Katze** (...) zu gleichen Teilen gemischt oder verschmiert sind.

One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following hell-machine (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that in the course of one hour *perhaps* only one of the atoms decays, but probably none of them; if it happens, the counter tube discharges and through a relay releases a little hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would tempted to say that the cat still lives *if* meanwhile no atom has decayed. The first atomic decay would have poisoned it. The \( \psi \)-function of the entire system would express this by having in it the living and the dead cat (...) mixed or smeared out in equal parts.

In this famous example, Schrödinger notes that at a quantum level we have a superposition of states, in which a cat, considered as an elementary particle, is at the same time live and dead. This is inferred from the wave-function of the cat-particle. This function gives us all possible information about the particle, and for any space point, it gives the amplitude of the probability that the particle is at that point. Quoting again Schrödinger:

\[
(\ldots) \text{“Sie” [i.e. the wave-function] ist nämlich eine Summe von Kentnissen(...).}
\]

*The wave-function is indeed a sum of knowledge.*

Let us make this point precise; let the cat be represented in the formalism of quantum mechanics as an hermitian operator \( \mathbb{C} \); its wave function is noted as \( |\psi_C\rangle \), and its two possible states are *live* and *dead*, which we represent as two vectors \( |\psi_l\rangle \) and \( |\psi_d\rangle \), respectively. So, what Schrödinger says in the first quotation is:

\[
|\psi_C\rangle = c_1|\psi_l\rangle + c_2|\psi_d\rangle, \quad \text{for} \quad c_1, c_2 \in \mathbb{C}
\]

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1. [Sch35a, p. 812]. The embolding is mine.
2. [WZ83, p. 157]. The translation was corrected by me. In the original translation by Trimmer Schrödinger speaks of *diabolical device*. I preferred *hell-machine* to maintain the humoristic tone of this passage.
3. [Sch35b, p. 827]. The translation is mine. See also [WZ83, p. 161].
4. For the scope of this paper, it is sufficient to note that an hermitian operator is a type of linear operator, i.e. a linear function.
So, the cat has an amplitude of probability \( c_1 \) of being in the state 'live' and an amplitude \( c_2 \) of being in the state 'dead'. Note that a wave-function is a linear sum, not an alternative. I would insist on this point. The cat, in the closed box, is not 50% live and 50% dead, but he is live and dead. Set-theoretically, our element-cat belongs at the same time both to the set of dead things and to the set of live things. All this is paradoxical, but in order. Now, we can decide to open and by this act we decide the destiny of the cat. Once the box is opened, the cat is live or dead, but it is no more live and dead. What does this mean? Does the observer collapse the super-position into one of the two states? Yes. It does.

**Sentence 1.** The observer, opening the box, collapses the wave-function associated with the cat into one and only one of its possible states.

The state in which we see the cat is called an eigen-state of the cat. The act of opening the box corresponds to an act of measurement of the cat-observable; algebraically, this corresponds to an appropriate eigen-function. In fact, an object exists in mathematics only as measured. The measure confers the status of reality upon an object. So let us make another step, and let us reformulate our problem in these terms.

**Sentence 2.** (Eigen-value problem) We must find all possible solutions \( \lambda \), for this equations: \( C|\psi\rangle = \lambda |\psi\rangle \), for \( \lambda \in \mathbb{R} \).

\( \lambda \) (a so called eigen-value) is the result of our measurement, \( C \) is the operator which represents our cat, and \( |\psi\rangle \) are the possible eigen-states in which the cat measures just \( \lambda \). So, our act of measurement (opening the box) corresponds to an eigen-function \( m_i \) s.t.:

\[
(4) \quad m_i(C) \rightarrow \begin{cases} 
|\psi_l\rangle \vdash m_i(C) = \lambda_l \quad (P_1(|\psi_l\rangle = |c_1|^2) \\
|\psi_d\rangle \vdash m_i(C) = \lambda_d \quad (P_2(|\psi_d\rangle = |c_2|^2)
\end{cases}
\]

In other words, in the first case, opening the box \( m_i \) causes the cat to be alive with a given probability \( P_1 \), in the second case, our opening of the box kills the cat (alas!) with a probability \( P_2 \). In this sense, we can assert that the observer collapses the wave-function into only one of its states. And this remains valid for any other observable.

This is extremely surprising, since it suggests that the observer has an immense power. He modifies in a drastic manner the observed reality, the object of knowledge. One could almost say that he creates the reality. But we would underpin another aspect of this situation. We understood that the rôle of the observer is a very creative one. But there is another lesson from this example: it tells us that there is not a sharp distinction between object (the cat) and subject (the observer).

The simple act of knowing an object induces a modification on it. The simple

\[\footnote{We speak of amplitude of probability and not of probability tout-court, inasmuch as the \( c_i \) associated to the states are complex numbers and not real ones. Of course, we obtain the probability for a state from his weight \( c_i \) making the square of the modulus of \( c_i \) which transforms the \( c_i \) in real numbers. How it can happen? The modulus of \( c_i \), \( |c_i| \) equals \( \sqrt{\text{Re}^2 c_i + \text{Im}^2 c_i} \). This square root is a real, as the sum of the squares of two reals. In fact, assuming that \( c_i = a + ib \), where \( i = \sqrt{-1} \), the real part of \( c_i \) is \( a \) (real) and its imaginary part is \( b \) (real). So the function modulus applied to a complex number leaves out the problematic \( i \), transforming a complex number into a real one. At this point, we can speak of probability.} \]
knowledge, before any interpretation or manipulation, modifies the object. Therefore, it is better to consider the act of measurement as relation which _ontologically_ founds subject and object, avoiding to consider the subject as passive tabula rasa (who plays a neutral rôle) on whom the object exerts an influence (at least, increasing the knowledge of the subject). On one hand, the subject is not a black box who receives inputs and sends outputs, and on the other it is the precise context that determines what is in that situation subject and object. There is no subject in absolute, but a subject only relative to a given context. In this sense, the relation, the context, the _event_, the model, etc, founds subject and object, because it is only starting from a given context that everything receives a meaningful sense. So it is this context, the act of measurement, which decides what is subject and what is object. Subject and object do not be, except in a relation which founds them.

Obviously, this doesn’t solve our problems. Also in an holistic situation, we perceive a direction from the subject to the object. The subject is that which causes an action. Surely, the object in this reading is no more pure passivity, but notwithstanding a difference between subject and the object continues to persist. Well, where can we situate this boundary between subject and object? In a sense, such boundary is shifty. Using von Neumann’s words:

Daß diese Grenze _beliebig_ tief ins Innere des Körpers des wirthchlichen Beobachters verschoben werden kann, ist der Inhalt des Prinzips vom psychophysikalischen Parallelismus (...).[6]

That this boundary can be pushed arbitrarily deeply into the interior of the body of the real observer is the content of the principle of the psycho-physical parallelism (...).[7]

So, the line between subject (observer) and object is fuzzy. We could in this way imagine two extrema:

1. The subject/object division is pushed _outwards_ to infinity

2. The subject/object division is pushed _inwards_ to infinity

In the first case, the totality of the universe is absorbed by the mind. It is a pure illusion. The mind plays with itself, not acknowledging the external objects as its own creations. The mind is a theatre in which the totality of the external world is playin. But, adopting this point of view, we are going far beyond Berkeley: not _esse est percipi_, but _esse est cogitari_. This is absolute solipsism.

In the second case, the division is pushed outwards from the subject until it encompasses the entire universe. The universe is an immense laboratory. But, if in the first case, there is no room for the object (understood as _Gegen-stand_, i.e. what it is opposite [gegen] the subject), now there is no place for the observer:

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6 Consider model theory, where a sentence has a meaning only according to a function-interpretation. There is no sentence which is true or false, but sentences may be true in one model and/or false in another. This way, it is the totality of the model which determines the meaning of any part of a language.

7 [vN32, p. 224]. The bold is mine.

8 [WZ83, p. 622]. I corrected the translation, translating _wirthlichen_ with real in place of the original _actual_. I would underpin with this choice that the observation is possible only inserted in an appropriate real phenomenon. It is not only a matter of mathematical computation. I don’t see a particle, but a spot on a sliver plate.
It is easy to imagine a state vector for the whole universe, quietly pursuing its linear evolution through all of time and containing somehow all possible worlds. But the usual interpretative axioms of quantum mechanics come into play only when the system interacts with something else, is ’observed’. For the universe, there is nothing else, and quantum mechanics in its traditional form has simply nothing to say.

These are the words of J.S. Bell in *The Moral Aspect of Quantum Mechanics*. This splitting of the universe into two parts, subject and object, is dangerous in both the above cases. Consider the universe as a *Denkbereich* which we split into two complementary sets: $S$ (the subject) and $\neg S = O$ (the object). Given that this splitting is purely arbitrary, using von Neumann’s worlds, *beliebig*, we can decide to put $S = \emptyset$ or $\neg S = \emptyset$. In the first case, we remain without subject (as essentially distinct from the object), in the second case we have no object. But, without observer how can the wave-function collapse? Perhaps we must question this way of splitting and adopt another point of view.

3. The Measurement

One other problem to face is the following: as the observer collapses the wave-function, deciding the fate of the cat, another observer may observe this observation producing another result, and it could be another observer again who observes the second observer producing a third result, and so on to infinity. **So, the crucial question is:**

Sentence 3. *Where in space-time does the wave-function collapse?*

We begin to wrestle with this conundrum, distinguishing the interaction between the observable and the system of observation on one side and the observer on the other. I.e. we have an event composed of three parts: an observer (subject), an object and an instrument of observation. Object and instrument of measurement can be regarded as two systems interacting with each other. So we have on one side this interaction and on the other side the observer. The interaction between observable and instrument of observation happens *one and only one time* and it is this interaction that collapses the wave-function. The observer can at most read the result of this interaction, calling it a *measurement*, but when he intervenes, the wave-function is yet collapsed and the interaction between the two systems is lost. Ignoring for a moment the presumptive reality of the interaction, Masanao Ozawa proved that in no case does the reading of measurement coincide with the interaction between the observable and the system of observation, because they happen in two distinct times, and because the reading of the measurement can occur only after the interaction.

The orthodox view [of the wave-collapse] confuses the time at which the outcome of measurement is obtained and the time at which the object is left in the state determined by the outcome. (…) it confuses the time just after the reading of the outcome and the time just after the interaction between the object and the apparatus.**[11]**

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[9]Bell04, p. 26. The embolding is mine.
[10]Bell66, now in Bell04, pp. 22–28.
[11]Ozawa03, p. 117.
In fact, the interaction between the observable and the apparatus starts at a time $t$ and lasts for a time $\Delta t$. At $t + \Delta t$ the two systems disentangle themselves. Now, the observer can read the result of measurement only at a time $t + \Delta t + \tau$ and there is no situation in which $\tau = 0$, as Ozawa carefully shows. So, the act of measurement and the act of interaction are two different acts.

I would also stress that in this situation we are unable to stop the regress to infinity caused by infinite measurements. Also, if there is only one interaction, it is possible to have an infinite number of acts of observation; I who read the result of interaction (i.e. I find the value of $\lambda$ in the eigen-value problem above), my friend who reads my reading, another guy reading the reading of my friend, etc. This is a false problem. Really, we have before us an event: the physical, perceived experiment, the click of a detector, the rotation of some polarizing filters, etc. My measurement\textsuperscript{12} is on another level in relation to this object-level; the measurement is a meta-event which asserts that in the event the cat is dead or alive. I.e. the measurement is a sentence about a state of affairs, represented by the interaction.

For example, returning to our sentence (2) above, let us state:

**Sentence 4.** The value of $\lambda$ in $C|\psi\rangle = \lambda|\psi\rangle$ equals a number $r_i \in \mathbb{R}$.

Well, we have two sentences: one formulated in the language-object and one in the meta-language:

1. $C|\psi\rangle = \lambda|\psi\rangle$
2. The value of $\lambda$ in . . . equals a number $r_i \in \mathbb{R}$

The first sentence refers to the event-object and it is formulated in the language, while the second, formulated in the meta-language, asserts something about the first sentence. It says that $\mathfrak{1}$ has a certain truth value; that it satisfies the property of being true.\textsuperscript{13} So, the act of measuring is a meta-act, based upon the interaction between systems.

Obviously, in this case too, we have an infinite hierarchy of meta-levels: the level-object, the meta-level, the meta-meta-level, etc., where any level, apart the first, is a meta-level in relation to its immediate predecessor. Surely, the totality of these levels could be problematic, but not the passage from a level to its successor. The consideration of $\aleph_0$ is problematic, but not the function-successor. In any subset of $\aleph_0$ is definite and harmless the passage from $n$ to $n + 1$.

We can imagine the meta-level as a level which is a function of its predecessor. In this sense, our sentence above could be rewritten in the following manner:

$$\mathfrak{M} \models \lambda = r_i, \text{ for } r_i \in \mathbb{R},$$

where $\mathfrak{M}$ is the model pertaining to our event, in which the eigen-value problem has a given result. Or, expressed in another way, in this model-event, the function-interpretation $\mathcal{I}$ maps $\lambda$ to $r_i$, and maps the sentence $\lambda = r_i$ to the truth, 1. This

\textsuperscript{12}I consider measurement and reading of a measurement synonymous, because it makes no sense speaking of a measurement without a measure.

\textsuperscript{13}This type of distinction (language/meta-language) is usual in mathematics. In fact we say that a derivative of a function $f(x)$ in the point $x_0$ conceptualizes at a mathematical level the tangent of the graph of the function at the point $f(x_0)$. But a derivative, a number, cannot be a straight line or a tangent. In this situation, the event-object is given from the geometrical graph of the function, while the meta-level is the place where the derivative lives. The derivative tells something about a geometrical situation; it is not a geometric being.
way, we avoid splitting the world into two contiguous parts, subject and object, considering as apriori, a primitive fact, the experiment, the model, the event, which gives values to any component of it. The division is not between two sections of the real, but between the language and the meta-language. It makes no sense, attributing a status of reality to Quantum Mechanics, inasmuch as it is a meta-level on which we make assertions about a level-object.

4. Events

Only the experiment is real. And this experiment is an event.

Sentence 5. *The experiment is an event, which we can decompose into sub-events, or which we can stretch, without losing its singular quality.*

All I perceive is the phenomenon of the experiment with its components. No other. Obviously, it is the observer who stipulates what is an event and what pertains to this event. So, this totality is, in a sense, fuzzy. We can modify it at pleasure, but without leaving out the fundamental tracts which make of an event *this* event. Its components are parts, in a mereo-topological sense, not in a set-theoretic one. For example, let \( C \) be our cat. I decide with an act of *free will* to consider \( C \) as an event. For whatever reason, I may to choose to split up this cat; so our cat can be regarded as the collection of his head and the rest of his body, as the collection of his legs plus his trunk, the left part of his head and the right part of his head. There is no unique way to decompose the cat, but an infinity, and the decision of how to split the cat belongs only to the subject.

I would stress this point. \( C \) is not a singleton. Otherwise, there would be a unique manner in which to decompose it: picking up its elements. If \( C \) were regarded as a singleton, we would have only one element and the cardinality of this set equals 1. If we consider the cat as an event, we have a totality which can be split in an infinity of ways. In fact, not only the event ‘cat’ belongs to the cat, but also any part of him. For this reason, treating an event not as a set, but as collection, we must renonce to attribute to an event a cardinality, and renonce to a unique possible splitting up.

Only the observer can stipulate how to arrange an experiment-event, taking for granted that in an event everything is entangled. I cannot separate sharply one thing from another. It is only a pure matter of convenience to focus on this sub-event, instead of another.

5. Conclusion

Summing up our discourse. The experimental arrangement is a totality only in which it makes sense to speak of subject and object, and so to speak of an arrow from the observer to the observable. On the other hand, it is undeniable that such a difference takes place, i.e. that in the experiment we distinguish an interaction from a measurement. Yes. But we avoided splitting up the real in two adjacent parts, exploiting the difference language/meta-language. The observer is in a meta-level in relation to the interaction object/instrument of measurement. We cannot put subject and object on the same level. Schrödinger’s cat belongs to a level, while the observer to a meta-level.
However, a problem may arise here. How can the observer collapse the wave-
function if it is on another level? Obviously, the observer cannot influence the
cat directly. Remember Schrödinger’s words:

Hat man dieses ganze System eine Stunde lang sich selbst über-
lassen (…)\textsuperscript{14}

[If one has left this entire system to itself for an hour
(…).\textsuperscript{14}]

The box containing the cat is left to itself; it is out of reach of the observer. Neither
the cat is in condition to alter the system where he is:

(…) man [the system] gegen den direkten Zugriff der Katze si-
chern muß (…)\textsuperscript{15}

[(…) [the system] must be secured against direct interference
by the cat (…).\textsuperscript{15}]

Does it mean that the rôle of observer is insignificant? No. It is only the observer
who may arrange an experiment in one way or in another, and doing so he influences
the possible outcomes of the experiment. The experiment is the \textit{apriori} of any
measurement. It makes sense to speak of a measurement only within the context
of a precise experiment and this is built up from the subject. It is he who sets up
the radioactive source, the polarizing filters, a detector. A simple change in the
filters bars the path of an electron. So, also, indirectly, through the experimental
arrangement, the subject modifies the object in a drastic manner, collapsing the
wave-function. It is true that the collapse occurs in the interaction between object
and instrument of measurement, but if the subject doesn’t place the object and
instrument of measurement in interaction with each other, does the wave-function
collapse?
So designing the experiment, Schrödinger decided the fate of the cat. That stresses
the important rôle of the subject. He does not read the \textit{mathematical signs in
Nature}, he creates the reality.

6. Appendix

For the sake of clarity, I wish to return to Schrödinger’s hell experiment, applying
in an appropriate manner the distinction language/meta-language. For simplicity,
we assume that the is box split into two parts: in the first, there are Schrödinger’s
hell instruments, in the second, the cat. The elements of these parts belong to two
ground-levels, \(L_1\) and \(L_2\), respectively. The relation obtaining between them, i.e.
the system in its totality is on a meta-level with respect to \(L_1, L_2\), inasmuch as it
establishes a link between them. The act of opening the box is on a meta-meta-
level, because it states something about the meta-level precedent, saying that the

\textsuperscript{14}Ozawa would say that he arrives too late.
\textsuperscript{15}[Sch35a, p. 812].
cat is dead, or is alive. We can formalize the process this way:

\[ f : \{L_1, L_2\} \rightarrow \{S_i\}_{0 \leq i \leq n}, \quad (\text{where } S_i \text{ is a possible system}) \]

\[ g : \{S_i\}_{0 \leq i \leq n} \rightarrow \{r_i\}_{i \in \mathbb{R}} \]

\[ h : \{r_i\}_{i \in \mathbb{R}} \rightarrow \{r_k\}_{k \in \mathbb{R}} \]

(9) etc.

In other words, \( f \) maps \( L_1 \) and \( L_2 \) to a system \( S \) (\( f \) establishes a relation \( S \) between \( L_1 \) and \( L_2 \)); \( g \) measures the system; \( h \) measures the \( g \)-measurement and so on.

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