'tHooft predeterminism and Einstein nonseparability

Han Geurdes

Abstract In the paper we employ entangled particles from a source. The question is asked if it is possible to maintain the view that only measured phenomena are to be considered phenomena and that 'tHooft his predetermination avoids the paradox.

1 Introduction

It is well known that Einstein was not very pleased [2] with what we now know under the name EPR [3] paradox . Einstein's main criticism on the completeness of quantum theory is beautifully explained in his Dialectica paper [4]. As far as the present author can understand, it is the conflict between the Grundsatz II [4, p. 321] and the accepted interpretation of the wave function ψ in Ib [4, p. 320]. In [5] the philosophical and historical basis of Einstein's own incompleteness argument is further presented. The present author believes that the key to understanding Einstein here is the non-separability of quantum theory. Einstein describes this clearly in his Dialectica paper. According to Don Howard, Einstein already worried about it in 1909 [2]. Briefly viewed Einstein his worries come down to: if two spatial separated particles with respectively wave functions $\psi_A^{(1)}, \psi_A^{(2)}, \dots$ and $\psi_B^{(1)}, \psi_B^{(2)}, \dots$ arise from a common wave function ψ then the following curious situation occurs. Suppose at A we measure $\psi_A^{(1)}$, then the particle at distant point B has $\psi_B^{(2)}$, while if we decided at A to measure $\psi_A^{(2)}$ then at distant B we have e.g. $\psi_B^{(1)}$. The A and B belong to spatial regions R_A and R_B such that, in Einstein's wording: äussere Beeinflussung von A hat keinen unmittelbare Einflusz auf B; dies is als

F. Han Geurdes
GDS appl math BV
E-mail: han.geurdes@gmail.com

"Prinzip der Nahewirkung" bekannt. Therefore if $\psi_B^{(1)}, \psi_B^{(2)}, \ldots$ contains one wave function that descibes the situation for the particle at B, it is impossible to influence it by measurement of one of the $\psi_A^{(1)}, \psi_A^{(2)}, \ldots$ for the particle at A. However, the quantum theory exactly predicts that $\psi_A^{(1)}$ for A entails $\psi_B^{(2)}$ for B, while $\psi_A^{(2)}$ for A entails $\psi_B^{(1)}$ for B.

The response of Bohr, in my own simplified version of it, was complementarity. A discrimination between different experimental procedures allows the unambiguous use of complementary classical concepts. When one measures $\psi_A^{(1)}$ for A one uses another experimental procedure than when one measures $\psi_A^{(2)}$. This implies that in the quantum domain: no elementary phenomenon counts as phenomenon until it is a registered phenomenon.

2 Mathematical preliminaries

Let us start with the Dirac equation such as can be used in the study of relativistic quantum mechanics of electrons [1]. The free particle equation is:

$$i\hbar \frac{\partial}{\partial t}\psi = \left(-ic\hbar \left(\alpha_1 \frac{\partial}{\partial x_1} + \alpha_2 \frac{\partial}{\partial x_2} + \alpha_3 \frac{\partial}{\partial x_3}\right) + \beta m c^2\right)\psi \tag{1}$$

Here, we take ψ a 1×4 vector, the α_k with $k = 1, 2, 3$ are 4×4 matrices and β is a 4×4 matrix as well. For the matrices we have, $j, k = 1, 2, 3$,

$$\begin{aligned} \alpha_j \alpha_k + \alpha_k \alpha_j &= \delta_{j,k} 1_{4\times 4} \\ \alpha_j \beta + \beta \alpha_j &= 0 \\ \alpha_j^2 = \beta^2 &= 1_{4\times 4} \end{aligned} \tag{2}$$

Here we have 4×4 matrix multiplication and $1_{4\times 4}$ is the 4×4 unity matrix. This information can be found in [1] The unity of the integral is defined by

$$\int \overline{\psi}(\mathbf{x})\psi(\mathbf{x})d\tau = 1 \tag{3}$$

where $\overline{\psi}(\mathbf{x}) = \psi^\dagger(\mathbf{x})\beta$ and $\psi^\dagger(\mathbf{x})$ is complex conjugated of $\psi(\mathbf{x})$ and then transposed. The $\mathbf{x}$ is the three dimensional space vector.

2.1 One dimension

Suppose in the first place we are looking at a stationary state, with energy eigenvalue E, in only one dimension, the x axis. Therefore, equation (1) is written

$$\left(\frac{i}{\hbar c}\right)\left(E - \beta m c^2\right)\psi = \alpha_1 \frac{\partial}{\partial x_1}\psi \tag{4}$$

Perform subsequently the operation $\alpha_1 \frac{\partial}{\partial x_1}$ left and right of (4). This gives

$$\left(\frac{i}{\hbar c}\right)\left(E+\beta mc^2\right)\alpha_1 \frac{\partial}{\partial x_1}\psi = \frac{\partial^2}{\partial x_1^2}\psi \Rightarrow \tag{5}$$
$$\frac{-1}{\hbar^2 c^2}\left(E^2 - m^2c^4\right)\psi = \frac{\partial^2}{\partial x_1^2}\psi$$

In the subsequent splitting into two particles with $\psi_1(\mathbf{x}_1)$ and $\psi_2(\mathbf{x}_2)$. The split occurs such that:

$$\alpha_1 \frac{\partial}{\partial x_1} \to \alpha_1 \frac{\partial}{\partial x_{1,1}} + \alpha_2 \frac{\partial}{\partial x_{2,2}} \tag{6}$$

and because $\alpha_1^2 = 1_{4\times 4}$

$$\frac{\partial^2}{\partial x_1^2} = \left(\alpha_1 \frac{\partial}{\partial x_{1,1}} + \alpha_2 \frac{\partial}{\partial x_{2,2}}\right)^2 \tag{7}$$

We have, $\mathbf{x}_1 = (x_{1,1}, x_{1,2}, x_{1,3})$. Therefore, $x_{1,1}$ is the first, or x, coordinate of particle 1. Similarly, $x_{2,2}$ is the second, or y, coordinate of particle 2. Then, looking at (2), it follows that

$$\frac{\partial^2}{\partial x_1^2} = \frac{\partial^2}{\partial x_{1,1}^2} + \frac{\partial^2}{\partial x_{2,2}^2} \tag{8}$$

The way we view the split into two particles is a hypothetical physical one where use is made of (7) and the conception that coordinates and matrices can be coupled in the Dirac theory.

2.2 Two particle wavefunction vectors

Suppose we may write for the two separate particles

$$\frac{-1}{\hbar^2 c^2}\left(E_1^2 - m_1^2c^4\right)\psi_1(x_{1,1}) = \frac{\partial^2}{\partial x_{1,1}^2}\psi_1(x_{1,1}) \tag{9}$$
$$\frac{-1}{\hbar^2 c^2}\left(E_2^2 - m_2^2c^4\right)\psi_1(x_{2,2}) = \frac{\partial^2}{\partial x_{2,2}^2}\psi_2(x_{2,2})$$

Subsequently let us introduce the $\otimes$ product of two 1×4 wavefunction vectors. Hence when writing $\psi_1(x_{1,1})\otimes\psi_2(x_{2,2})$ we mean to say, $\xi = x_{1,1}$ and $\eta = x_{2,2}$,

$$\psi_1(\xi)\otimes\psi_2(\eta) = \tag{10}$$
$$\left(\psi_{1,1}(\xi)\psi_{2,1}(\eta), \psi_{1,2}(\xi)\psi_{2,2}(\eta), \psi_{1,3}(\xi)\psi_{2,3}(\eta), \psi_{1,4}(\xi)\psi_{2,4}(\eta)\right)$$

Let us introduce $\psi(x_1) = \psi_1(\xi) \otimes \psi_2(\eta)$ and then see, maintaining the (ξ, η) notation

$$\frac{-1}{\hbar^2 c^2}\left(E_1^2 - m_1^2 c^4\right)\psi_1(\xi) \otimes \psi_2(\eta) = \psi_2(\eta) \otimes \frac{\partial^2}{\partial \xi^2}\psi_1(\xi)) \tag{11}$$
$$\frac{-1}{\hbar^2 c^2}\left(E_2^2 - m_2^2 c^4\right)\psi_1(\xi) \otimes \psi_2(\eta) = \psi_1(\xi) \otimes \frac{\partial^2}{\partial \eta^2}\psi_2(\eta)$$

And so, using $\frac{\partial^2}{\partial x_1^2}\psi(x_1) = \left(\frac{\partial^2}{\partial \xi^2} + \frac{\partial^2}{\partial \eta^2}\right)\psi_1(\xi) \otimes \psi_2(\eta)$, it follows that

$$E^2 = E_1^2 + E_2^2 + m^2 c^4 - m_1^2 c^4 - m_2^2 c^4 \tag{12}$$

Therefore looking at the square of $E_1 + E_2 + \Delta E$ gives

$$E^2 = E_1^2 + E_2^2 + (\Delta E)^2 + 2\left(E_1 E_2 + E_1 \Delta E + E_2 \Delta E\right) \tag{13}$$

This implies

$$(\Delta E)^2 + 2(E_1 + E_2)\Delta E + 2E_1 E_2 - (m^2 - m_1^2 - m_2^2)c^4 = 0 \tag{14}$$

If, $(m^2 - m_1^2 - m_2^2)c^4 > 2E_1 E_2$, the $\Delta E > 0$,

$$\Delta E = -E_1 - E_2 + \sqrt{E_1^2 + E_2^2 + (m^2 - m_1^2 - m_2^2)c^4} \tag{15}$$

2.3 The experiment

Suppose that

- The ΔE is a photon with energy $\hbar f$ and f its frequency.
- The E_1 for particle 1 and E_2 for particle 2 can be measured.
- A $\delta \in \{0, 1\}$ is possible in the (expected) trajectory of particle 1. $\delta = 0$ does not change the E_1, but $\delta = 1$ represents a physical condition that can change E_1.

Then the following experiment can be imagined with $t_0 < t_1 < t_2$. At $t = t_0$ we measure $\Delta E = \hbar f$. At $t = t_1$ we decide if $\delta = 0$ or $\delta = 1$ and we measure E_2. At $t = t_2$ we measure E_1. Let us define $m' = m - \frac{1}{2}(m_1 + m_2)$ and obviously stress that $f > 0$.

Then it appears as though there are certain instances where a contradiction arises when, at $t = t_0$, the $\Delta E = \hbar f$ is based on $\delta = 0$ but, at $t = t_2$, we selected $\delta = 1$. Or even $\Delta E = \hbar f$ is based on $\delta = 1$ but, at $t = t_2$, we selected $\delta = 0$. It is fixed with the expression $f \approx \frac{1}{\hbar}\sqrt{E_1^2 + E_2^2 + (m^2 - m_1^2 - m_2^2)c^4} - \left(\frac{E_1 + E_2}{\hbar}\right)$, but of course the *order* in which the measurements are made allow the E_1 dependence on δ where $f \approx \frac{1}{\hbar}\sqrt{E_1^2 + E_2^2 + (m^2 - m_1^2 - m_2^2)c^4} - \left(\frac{E_1 + E_2}{\hbar}\right)$ is determined *before* the experimenter determines δ which in turn determines E_1, denoted with $E_1(\delta)$.

Or must we say that measuring $\Delta E = \hbar f$ destroys the relation and after determining $\Delta E = \hbar f$ we no longer will have equation (12). But how does this disentanglement work if not by first having (mathematical) inseparability. Is it the inseparability that Einstein already was complaining about [4]?

Of course we only know: $f \approx \frac{1}{\hbar}\sqrt{E_1^2 + E_2^2 + (m^2 - m_1^2 - m_2^2)c^4} - \left(\frac{E_1+E_2}{\hbar}\right)$ when we measure the photon's f. But then measuring the E_2 does not change the f anymore. So δ may work out to give a contradiction in f and E_2. This contradiction occurs despite: "no elementary phenomenon counts as phenomenon until it is a registered phenomenon". Or is this phrase perhaps suggesting that elementary phenomena only exist when *all relevant* measurements are performed. Then one cannot establish f *before* $E_1(\delta)$ is determined. This view looks as though this totality of measurement is clearly not true. Why would one not be able to measure f and E_2 but e.g. never measure $E_1(\delta)$?

According to tHooft: Predeterminism is [here] defined by the assumption that the experimenters free will in deciding what to measure [.], is in fact limited by deterministic laws, hence [is] not free at all [6]. Therefore another possibility is that, like 'tHooft suggested, there is <u>no</u> free selection of δ. It is predetermined. Hence, f and δ are *always* connected by predetermination.

3 Conclusion

In the present paper the Dirac theory was used to try to describe the fission of a quantum relativistic particle. The direction of propagation, after the split, is one new particle along the x-axis and the other along the y-axis.

If people object to the expression of the split in (6) the *reason* must be given. Obviously, this reason must be why this coordinate split is wrong. It preferably must not be motivated by the opinion, that in this case Einstein's critique on the completeness of quantum theory will re-emerge from the grave and the reader does not like that.

The experiment that could be derived from the split is based on conservation of energy. If people disagree with conservation *in this case* they should provide the reason. Here, as for the previous remark, it must be so that the discussion is clean and not contaminated with preferences of the mainstream idealism.

The temporal sequence in the experiment allows first, at $t = t_0$, the determination of the frequency of the photon ΔE. Then later, at $t = t1$, the E_2 is measured and so f and E_2 fix the value of E_1 looking at
$f \approx \frac{1}{\hbar}\sqrt{E_1^2 + E_2^2 + (m^2 - m_1^2 - m_2^2)c^4} - \left(\frac{E_1+E_2}{\hbar}\right)$.

However after measurement of E_2 and f we are free to implement in the experiment a factor δ that can change E_1. This then can give rise to a contradiction. The contradiction cannot be avoided with the usual "only measured phenomena are to be considered phenomena" axiom unless of course people are implying that *only* measurement creates phenomena. If we chose not to measure E_1 at $t = t_2$ then there is another phenomenon. How would the phenomenon do that? We know f, we know E_2, then we know what E_1 must be without measuring it. Is the theory all of the sudden wrong because we don't measure?

This implies in addition that experiments where two photons are entangled don't prove a damn thing about nature. There are no photons before measurement and we can hardly say anything about the entities we measure. Wait a minute the reader might want to say. There are things before measurement. No there are not in a genuine honest truthful representation of the axiom, is my answer. There is no entanglement before measurement. The Schrödinger equation refers to nothing but an ideal in the researcher's head. An ideal that is passed on through generations of researchers but is meaningless. The Dirac equation is dealing with similar mental images that are absolutely not related to anything out there. If that is too much vagueness for you, e.g. choose Einstein and admit incompleteness. You will not die from that.

The author for his part prefers the view of 'tHooft where predeterminism plays a crucial role. It draws from the necessity to look at a larger aspect of physical nature, i.e. the wave function of the universe. I read 'tHooft like: god plays the dice in a universe, not just in your laboratory. Quantum cosmology allows the beginning of corroboration observations that can be done outside the entanglement domain to support the interpretation. The present paper might suggest an experiment to find out if predeterminism is a good philosophy of physics.

Conflict of interest

The author declares that he has no conflict of interest.

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