

A Mechanism of Wavefunction Collapse and Modified Double Slit Experiment

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Abstract

We restudy the particle double slit experiment and wave-particle duality of matter. We argue that: (1) a particle moving with acceleration has no wave-like behavior; thus (2) it is the acceleration of particle caused by the photons during an optical observation that collapses a matter wave; (3) This mechanism does not affect the history of the particle's movement prior to the observation takes place. Modified double slit apparatus with various configurations covering different ways of accelerating particle is propose to investigate the wave-particle duality of accelerating matter and test the mechanism. Also we propose: (1) a free falling double slit experiment in a gravitational field. (2) An experiment in which, relative to an observer in Lab, the slit wall and detection screen are accelerated and the particle keeps constant speed. We raise a question that if, after the acceleration, the particle continuously flies with a constant speed before reaching the detection screen, would it regain wave-like behavior automatically? We also design an experiment to test this possibility.

Key words: wavefunction collapse, wave particle duality, double slit experiment, decoherence, delay choice experiment

1. Introduction

The particle double slit experiments show the wave-like behavior of matter, which confirms the wave-particle duality. This duality was a profound principle in quantum mechanics, and allows one to use wavefunction to describe phenomena of matter. In the ordinary double slit experiment, a beam of particles is directed towards a slit wall with two slits. Put a detection screen on the other side of the slit wall, an interference pattern will be observed. Even shooting one particle at a time, the interference pattern is still formed. The displacement on the detection screen satisfies, $y \approx \frac{nD}{d} \lambda = \frac{nD}{d} \frac{h}{p}$. The interpretation of the interference pattern is that each particle passing through the slits interferes with itself, and, therefore, in some sense the particles are going through both slits at once.

This experiment was advanced to Wheeler's delay choice experiment [1], which is as a way of exploring the counterintuitive aspects of particle-wave duality. This Gedanken experiment has been realized photon [2] and massive particle [3]. For its particle double slit version, if particle detectors are positioned at the slits, which shows through which slit a particle goes, the interference pattern would disappear. This which-path experiment shows that the observation of the particles inevitably disturb them and destroy the interference pattern, called the wave function collapse. The presence or absence of the observation would determine "wave or particle" manifestation. This "observation interpretation" implies that quantum particles seem to have some kind of "quantum level intelligent". To eliminate the effects of observations on quantum system, recently, "track unobserved quantum particles" [4] has been reported.

Decoherence [5] was utilized to explain the wave function collapse that the quantum nature of the particle lost into the surrounding, i.e., components of the wave function are decoupled from coherent, and acquire phases from their classical surrounding. However, decoherence cannot provide what generates wave function collapse.

The mystery remains: what is the mechanism of the observation collapsing a wave into a particle?

In this article we focus on the particle double slit experiment.

2. An Accelerating Particle Has No Wave-like Behavior

To explore this mystery, we emphasize two facts:

- (1) The concept of the de Broglie matter wave was proposed for free particles moving with *constant speed*, de Broglie wavelength is given by $\lambda = h/p$.
- (2) During the optical observation, photons apply force on the particle, i.e., the photons *accelerate* the particle. Note the acceleration is defined to relative to the detection screen.

So, let's consider whether accelerating particles have the wave particle duality. First, we ask:

- (1) Whether the de Broglie matter wave can be applied to an accelerating particle.
- (2) Whether an accelerating particle has wave-like behavior, and thus has the wave-particle duality.

For those questions, we argue that there are two possible answers:

First possible answer: the concept of the de Broglie matter wave is still applicable on an accelerating particle, since at any given time, the instant speed of an accelerating particle can be considered as a constant. However, the wavelength continuously changes with the continuous changes of the momentum as

$$\lambda_t = h/p_t. \quad (1)$$

Then there is no interference pattern, since the displacement at a particular time t varies with instant speed p_t ,

$$y_t \approx \frac{nD}{d} \lambda_t = \frac{nD}{d} \frac{h}{p_t}. \quad (2)$$

Therefore even if the de Broglie matter wave relation held, the accelerating particle has no wave-like behavior.

Second possible answer: the concept of the de Broglie matter wave is not applicable to an accelerating particle; therefore, an accelerating particle has no wave-particle duality. Then one cannot utilize wave function to describe an accelerating particle, namely an accelerating particle is a classical particle.

Both possibilities indicate that since an observation applies a force on the particle and accelerates it, the accelerated particle has no wave-like behavior, thus no wave particle duality, i.e., becomes a classical particle. The process is the following,

Observation \longrightarrow force \longrightarrow acceleration \longrightarrow not a matter wave

We argue that to accelerating particle is a direct cause of wave function collapse

Hypothetical statements: An accelerating particle, whether or not satisfies the de Broglie matter wave relation, does not have wave-like behavior. We can convert an uniformly moving quantum object having both wave- and particle-like behavior to that only having particle-like behavior by accelerating it, namely, collapsing a matter wave to a particle, and vice versa. Thus, in this sense an accelerating particle can be thought as a classical particle than a wave. We argue this is a possible mechanism that a quantum particle is transformed to a classical particle and obey classical probability rules when interacting with optical observation.

3. Modified Double Slit Experiment with External Electric Field

In order to gain a more complete picture of the wave-particle property of a particle and to test the proposed mechanism of wave function collapse, we modify the double slit apparatus by introducing external forces, which change the motion of particle. This allows us to identify whether the acceleration destroy interference pattern. Comparison of the various configurations gives us insight into the applicability of the standard concepts and assumptions. This also provides the context for a more general discussion regarding the interpretations in quantum physics.

Methods of accelerating a particle include both “observation” by throwing photons on it and “non-observation” by putting it in an external field.

To test experimentally the above hypothetical statements, we propose modified double slit apparatus, which have two categories of configurations:

First category: utilize an external electric field to accelerate electrons. Although we do not “observe” electrons, but electrons are accelerated and precisely controlled. Note in this category, a physicist and the detection screen are at rest to each other

Second category: accelerating whole double slit apparatus relative to a physicist.

Let’s study the first category in this section. A modified double slit apparatus (MDSA) contains an electron source that emits non-relativistic electrons one at a time, a double slit wall, a detection screen, an electric voltage V applied between the source and the detection screen as shown in Fig. 1 to Fig. 7 below.

We propose different configurations of MDSA to investigate wave-particle duality of particles, determine whether an accelerating particle has wave-like behavior, and detect where the interference takes place, when a particle decides whether to act

as a wave or a particle in the experiment.

Configuration 1: the electric voltage V is applied between the source and the detection screen (Fig. 1).

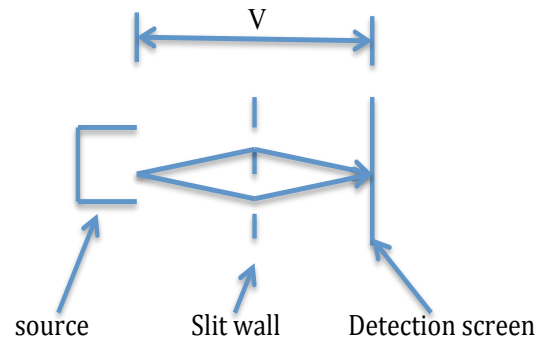


Fig. 1

We expect that there would be no interference pattern, which would show that an accelerating particle has no wave-like behavior.

Configuration 2: the electric voltage V is applied between the source and the left side of the slit wall (not applied on the slit wall) (Fig. 2).

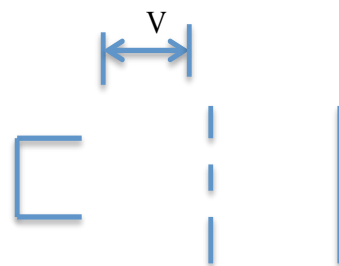


Fig. 2

This configuration is essentially the same as the ordinary double slit apparatus with an extended source. We expect to have an interference pattern described by the displacement on the detection screen, $y \approx \frac{nD}{d} \lambda = \frac{nD}{d} \frac{h}{p}$, where $p = mv$, v is the speed after the particle left the electric voltage area.

Configuration 3: the electric voltage is applied on the slit wall only (Fig. 3).

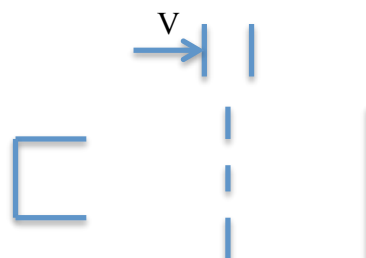


Fig. 3

The purpose of this configuration is to investigate the role of the slit. The thickness of

the slit wall varies from that of one atom layer to that of a macroscopic bulk.

Configuration 4: the electric voltage is applied between the right side of the slit wall and the detection screen (not applied on the slit wall) (Fig. 4).

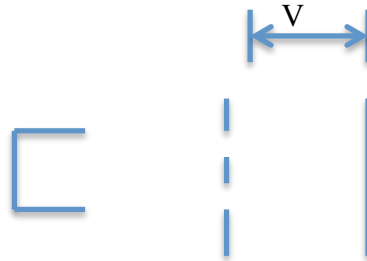


Fig. 4

The particle is accelerating until it hit the detection screen. We expect there is no interference pattern.

Configuration 5: the electric voltage is applied between the right side of the slit wall and before the detection screen (Fig. 5).

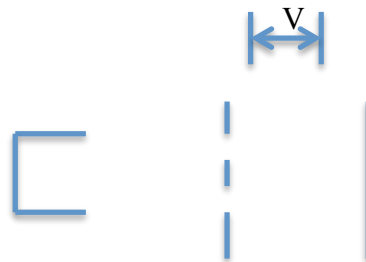


Fig. 5

The purpose is to investigate experimentally where/when a particle decides whether to act as a wave or a particle. Assume the area of the electric voltage is restricted, after passing the acceleration area, particles still fly a distance with a constant speed before hitting the detection screen.

Configuration 6: Then the question is: whether the wave-like behavior would restore, i.e., the classical particle transforms back to a quantum particle after the interaction? For detecting it, let's modify configuration 5 by adding a second slit wall between the first slit wall and the detection screen (Fig. 6).

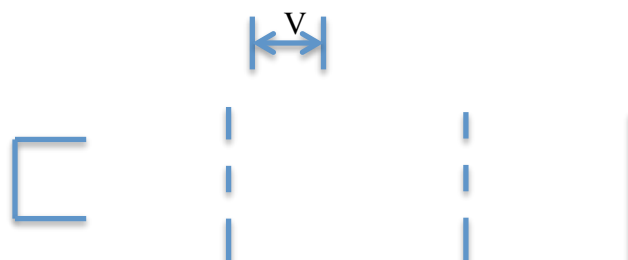


Fig. 6

Configuration 7: the electric voltage is applied between the source and the right side of the slit wall (Fig. 7).

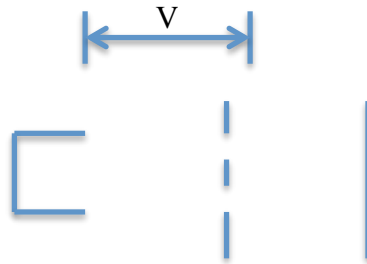


Fig. 7

This is the combination of configuration 2 and 3.

Configuration 8: the electric voltage is applied between the left side of the slit wall and the detection screen, i.e., applied on the slit wall as well (Fig. 7).

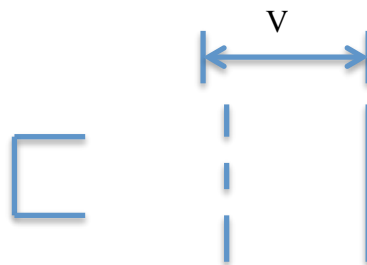


Fig. 8

This is the combination of configuration 3 and 4. Like configuration 1, there is no interference pattern.

4. Modified Double Slit Experiment: Accelerating the Slit Wall and Detection Screen

To test an accelerating particle's wave-like behavior, instead accelerating the particle, let's accelerating the slit wall and the detection screen together with the a same acceleration a (Fig.9).

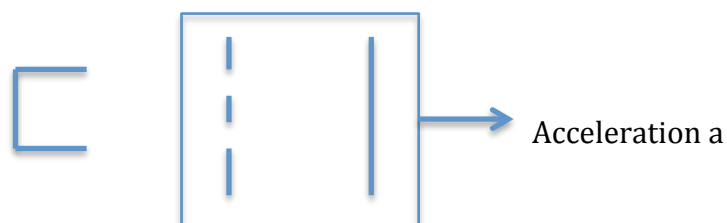


Fig. 9

5. Modified Double Slit Experiment: Free Fall in a Gravitational Field

As mentioned above, an accelerating particle has no wave-like behavior, and thus can be described by classical physics. Now let's define "accelerating". Note, in above

sections, the acceleration is relative to a physicist sitting next to the detection screen.

Now let's consider an elevator with both a double slit apparatus and physicist A sit in it. The elevator is free falling in the gravitational field of the Earth. Considering a physicist B who is at rest on the Earth (Fig. 10).

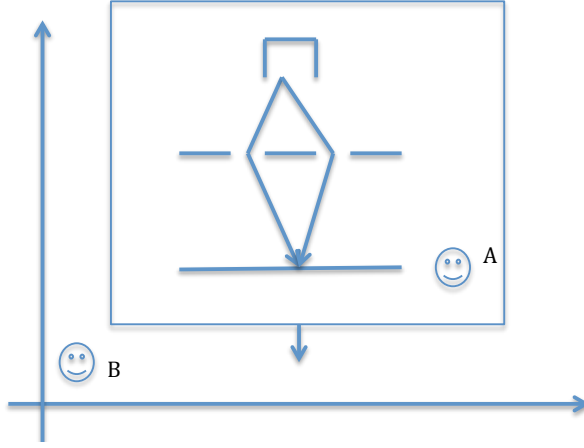


Fig. 10

Physicist A sees that a particle emitted by the source is uniformly moving toward to the detection screen, and thus an interference pattern is expected. On the other hand, physicist B sees that the particle is accelerating by the gravitational field. However, physicist B sees that the particle is uniformly moving toward to the detection screen. Therefore physicist B expects an interference pattern either.

5. Discussions and Conclusion

We argue that an accelerating particle has no wave-like behavior and thus is a classical particle. According to this argument, a possible mechanism of collapsing wavefunction is that the photons of an optical observation accelerate the quantum particle and transform it to a classical particle. This mechanism does not affect the history of the particle's movement prior to the observation takes place.

To test the argument, we proposed modified double slit experiment with various configurations covering different ways of "accelerating" particle: (1) introducing an electric field for accelerating electrons; (2) let's the whole double slit apparatus free falls in the gravitational field. To thoroughly test the argument, we also propose an experiment in which, relative to an observer in a Lab, the slit wave and detection screen are accelerated and the particle keeps constant speed.

We describe the process of the collapse of wave function as the following: For a quantum particle, the wave function is initially a combination of the eigenstates.

When an external force, which is due to either photons of observation or external field, acts on the particle, the particle is accelerated; therefore the particle no longer has wave-like behavior. Without the wave-like behavior, the quantum particle turns to classical particle. Namely, before interaction with the force, the particle acts as a matter wave; during the interaction, the particle is accelerated, thus lost the wave-like behavior and transferred to a classical particle. We argue the interaction does not change the wave-like behavior of the particle prior to the interaction. In terms of ordinary interpretation, once the wave function collapses, the particle behaves like a classical particle since it left the source.

We raise a question that if, after the acceleration, the particle still flies at a constant speed before reaching the detection screen, would it regain wave-like behavior automatically? We also design an experiment to test this possibility.

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