Interpretation of the double-slit experiment based on the quantum light

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The traditional understanding of the double-slit experiment, which serves as a classic demonstration of wave-particle duality, is being reconsidered due to new insights into the role of the central barrier between the slits. Contrary to the expectation of seeing two stripes on the screen when treating light as particles, the pattern can be more complex. This complexity arises from the interaction of light with the central barrier, where it is absorbed and re-emitted in the form of surface plasma polaritons (SPPs). These SPPs travel along the barrier's surface and contribute to the observed interference pattern. If their progress is interrupted by a Geiger counter, the pattern is altered, suggesting that the particle nature of light alone can sufficiently explain the phenomena. This challenges the traditional wave-particle duality interpretation and calls for a more nuanced understanding of quantum behavior.

I. INTRODUCTION

Since the duality of light has been found, scientists accept this concept, and it introduces foundation of various theory. Wave aspect of light is proved by double slit experiments. Generally, in the double slit experiments, there are two light patterns if the light is particle and there are specific patterns if the light is wave. When we use double slit experiment to prove the wave aspect of light, there may exist obstacle because of the limitation of this method. Especially, we need to recognize and solve the logical problem of analysis for double slit experiment when we observe several patterns by particles such as electrons. In other words, there is a logical error to recognize the wave and particle aspect of light by double slit experiments. The straightness and the wave aspect cannot be satisfied in double slit experiment. The several lined pattern should be analyzed by not an interference of light but an absence of the light[1–3].

II. THEORY

Light can travel along the boundary at the interface between air and a metal surface[4–6]. Surface plasmon waves have two modes. One is when the group velocity, ω/c, is less than the speed of light, c, and in this case, the light typically does not decay into photons and is called a non-radiative mode. However, when the group velocity is faster than the speed of light, coupling to photons occurs, and it is called a radiative mode. At this time, the surface plasmon is excited by light, and when the maximum plasma frequency is ${\omega_p}^2$, it emits light in all directions again[4]. Applying this to the double-slit experiment, the light that arrives at the central barrier of the double slit is absorbed, and the absorbed light travels along the surface of the barrier in the form of Surface Plasma Polaritons (SPPs). The SPPs that have traveled to the opposite side of the barrier are then emitted again in the form of light Fig. 1.

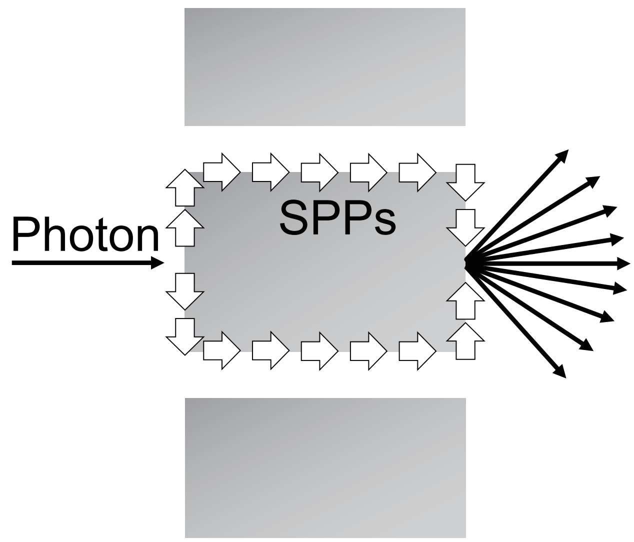

FIG. 1. A photon is absorbed in the form of a surface plasma polariton in front of the mask and then travels to the backside before being emitted.

In this paper, we will introduce a way to interpret the double-slit experiment based on the particle nature of light and explain the double-slit experiment. If the results of the double-slit experiment can be accurately explained based on the particle nature of light, then the fact that light has wave nature due to the results of the double-slit experiment can be reconsidered. And since the term "interference pattern" of light is based on the wave nature of light, it will be denoted as a sinc pattern.

$$sinc = A\frac{sin(kx)}{kx} \tag{1}$$

III. EXPERIMENTAL

The experiment is similar in configuration to the typical double-slit experiment as shown as Fig. 2. A LASER with a wavelength of 700 nm is used, and the width of the double slit is 100 μm. The distance between the slit and the screen is 3 meters. At this time, the screen is configured to be able to move back and forth in the direction of the laser. Three blocks were used to partially obstruct the light that passed through the double slit as the experiment progressed. The first block is

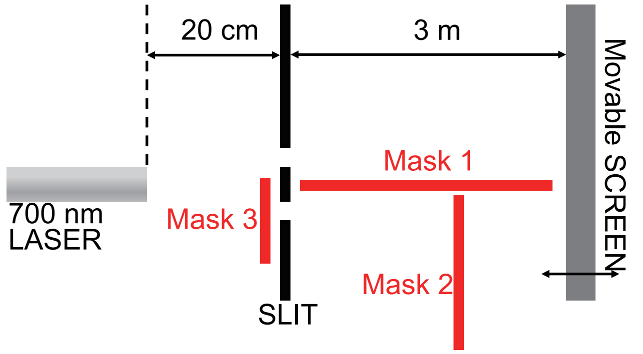

FIG. 2. Schematic of experiments. It is the setting of a typical double-slit experiment, where the distance between the laser and the double slit is 20 cm, and the distance between the double slit and the screen is 3 meters. A laser with a wavelength of 700 nm is used, and the screen is configured to move back and forth. Each of the masks is used only once in each experiment.

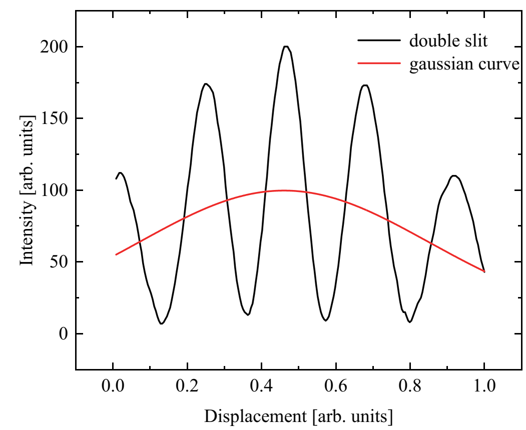

FIG. 3. Graph of arbitrary intensity versus generalized displacement.

perpendicular to the direction between the slit and the screen and is installed between them. The second block is parallel to the screen, and the experiment was conducted by moving it from the outside of the screen to the center. The third block was installed in front of the slit to obstruct it.

IV. RESULTS

If light is a wave, then when using a blocking mask before it reaches the screen, the screen should show a typical Gaussian distribution like the red line in Fig. 3. However, in actual experiments, a sinc pattern appears, and it is only affected by the straight line of the blocking mask. This can be seen as the light going straight, generating a sinc pattern, and shadows being created only on parts of the blocking mask due to its straightness. If the bright part appearing on the screen is due to the constructive interference of the waves coming from the two slits, then the bright part appears when the troughs of the two waves meet, or when the crests meet. In this case, if the screen is moved back and forth, the size of the trough or crest changes with distance, causing the size of the constructive interference to change, so the brightness of the bright part should change. However, in the experiment, such a change cannot be observed, and a constant brightness is observed as if the light is going straight. If the dark part appearing on the screen is due to the destructive interference of the waves coming from the two slits, then if the light coming from one slit is blocked, the dark part should brighten as the destructive interference does not occur. But in actual experiments, the dark part does not brighten Fig. 4. Ultimately, the dark part is not dark due to the destructive interference of the light coming from the two slits, but dark because the light does not arrive. Although the straight-line characteristic of light is well known, it cannot be proven that light has both this straight-line characteristic and wave nature at the same time in the double-slit experiment.

On the other hand, if the electrons within an atom are in orbital motion, the electrons on the surface of the slit will also be in orbital motion. Therefore, light or electrons passing by the slit will be influenced by the electrons making a consistent orbital motion on the slit surface, resulting in a consistent motion. As a result, they will appear on the screen in a consistent pattern. In this way, it is more desirable to anticipate the slit surface rotating rather than not rotating when light and electrons pass through the double slit. In this case, the smaller the experimental subject, the greater the influence it will receive, and this can be confirmed in actual experiments as the influence diminishes as the subject grows larger.

If light is a wave, then if the gap between the slits is widened, the sinc pattern should also appear in the same proportion if other conditions are maintained in the same ratio.

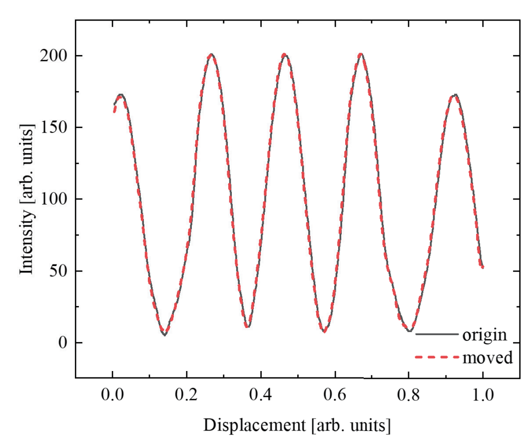

FIG. 4. Graph of arbitrary intensity versus generalized displacement.

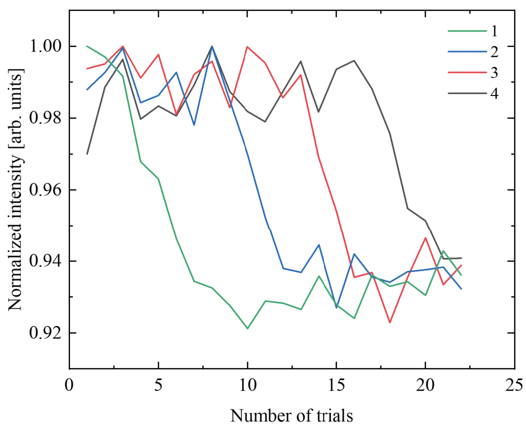

FIG. 5. The change in the brightness of each peak as the mask moves from the outside to the center. The direction is from the outside to the inside, from 1 to 4.

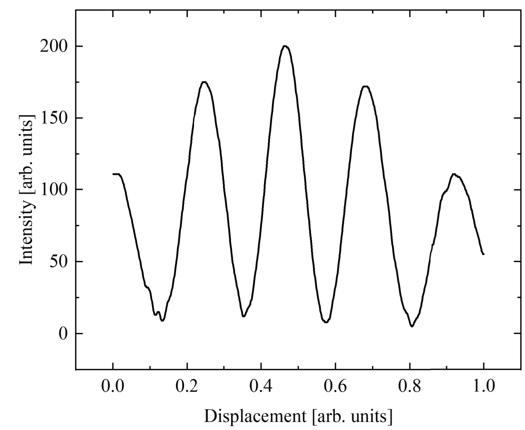

FIG. 6. Results with only the barrier, without the double slit.

However, if the width of the barrier included in the slit gap is increased, the straight-line characteristic of the light means that it cannot pass through the wide barrier. Therefore, there is a limit to the width of the barrier. If light is a wave, the spacing of the sinc pattern should be affected by the width of the slit, but in actual experiments, it is affected by the gap between the two slits, not the width of the slit. To verify whether the spacing of the sinc pattern is due to the gap between the slits, the barrier was placed in the middle, and the parts on both sides of the two slits were moved to observe the changes in the sinc pattern.

$$y = A\frac{\lambda L}{d} \tag{2}$$

Where y is the spacing of the pattern, λ is the wavelength of light, L is the distance between the slit and the screen, and d is the spacing between the two waves. If light is a wave, the spacing between the two waves is the distance to the center of the two slits, so if the width of the slit is increased, the centers of the two waves move apart, and the spacing d between the two waves increases. If the spacing between the two waves changes, the spacing of the sinc pattern appearing on the screen changes, but such a change is not observed in the experiment. Therefore, it can be said that the spacing of the sinc pattern is due to the width of the barrier, not the spacing between the centers of the slits. To confirm this, an experiment was conducted with only the barrier, and the sinc pattern was observed on the screen Fig. 6. The spacing of this sinc pattern is within the experimental error range when compared to the formula of the double-slit experiment.

In conclusion, there is an error in the interpretation of the double-slit experiment, which presupposes the passage of a wave through the slit to explain the double-slit experiment. In the above experiment, the change in the spacing of the sinc pattern according to the width of the barrier can be seen as being influenced by the position of the electrons within the atoms due to the width of the barrier. In the case of a narrow barrier width, the position of the electrons within the atoms is probabilistically determined while receiving the overall influence of the electrons at both edges, and the light is emitted at the position of these electrons, appearing as the spacing of the sinc pattern. If the barrier is above a certain width, the influence of the edge electrons does not reach the opposite edge electrons, and light is emitted from each edge, appearing to concentrate at each individual point. Therefore, it is necessary to verify whether the act of observation affects the movement of the barrier electrons.

Typically, a Geiger counter is installed in the double slit to make observations[7]. At this time, the Geiger counter comes into contact with the barrier, affecting the motion of the barrier electrons. This effect can be seen as the same as the effect of widening the barrier. As a result, the motion of the barrier electrons is transmitted through the Geiger counter, and the electrons move as if the barrier is wide, so the sinc pattern created by the narrow barrier disappears, and the two stripes created by the wide barrier appear. The same result occurs in slits with and without a Geiger counter, as regardless of which side the Geiger counter is installed on, it comes into contact with the barrier, so the barrier electrons are subjected to the same influence. Therefore, what determines the shape of the sinc pattern is not whether the observation is made through the Geiger counter, but because the Geiger counter comes into contact with the barrier and affects the motion of the electrons. To prove that the method of observation in which the Geiger counter comes into contact with the barrier is the cause of the appearance of the two stripes, an experiment was conducted to know which slit is passed through without coming into contact with the barrier.

In the experiment, when the light incident on one slit is blocked, the brightness of the bright part appearing on the screen is reduced by more than half, indicating that light has passed through the remaining slit. However, since the sinc pattern is observed in this case, it can be seen that the claim that the wave nature disappears, and two stripes appear when it is indirectly known which slit is passed through is incorrect. The light arriving at the barrier is absorbed by the vibrations of the electrons on the surface of the barrier and converted into the form of surface plasma polaritons (SPPs). The SPPs proceed in all directions along the surface of the barrier, and since the barrier has a long shape up and down, the components of the SPPs going up and down are canceled out. Therefore, only the SPPs proceeding in the direction perpendicular to the barrier remain. The SPPs proceeding in both directions turn half a circle around the barrier and meet on the opposite side where the light arrived, and then continue to proceed, converting back into the form of light. However, if the barrier becomes too long, the likelihood that the SPP will lose energy and disappear as it proceeds increases, so if the barrier becomes too long, it can be considered that such an interaction no longer occurs.

V. CONCLUSION

The interpretation of the sinc pattern that appears in the double-slit experiment can be explained not only by the wave nature of light but also by photons that interact with electrons. It can be anticipated that the electrons within the atoms constituting the double slit are rotating. In this case, the effect will be significant if the experimental subject is small, but the effect will be minimal if the experimental subject is large. This can be confirmed in experiments with objects of various sizes. In this process, it was confirmed that the sinc pattern is not due to the double slit but to the surface plasma polaritons (SPPs), and it can be anticipated that there will be an effect on the experiment if the motion of these electrons is influenced.

[1] P. Grangier, G. Roger, and A. Aspect, "Experimental evidence for a photon anticorrelation effect on a beam splitter: a new light on single-photon interferences," Europhysics Letters **1**, 173 (1986).

[2] M. O. Scully, B.-G. Englert, and H. Walther, "Quantum optical tests of complementarity," Nature **351**, 111–116 (1991).

[3] A. Zeilinger, "Experiment and the foundations of quantum physics," Reviews of Modern Physics **71**, S288 (1999).

[4] E. Kretschmann and H. Raether, "Radiative decay of non radiative surface plasmons excited by light," Zeitschrift für Naturforschung A **23**, 2135–2136 (1968).

[5] W. L. Barnes, A. Dereux, and T. W. Ebbesen, "Surface plasmon subwavelength optics," nature **424**, 824–830 (2003).

[6] J. Burke, G. Stegeman, and T. Tamir, "Surface-polariton-like waves guided by thin, lossy metal films," Physical Review B **33**, 5186 (1986).

[7] R. D. Bennett, "Some experiments on geiger ion counters," JOSA **16**, 339–354 (1928).