Curved Diffraction Patterns of 2D-Cross-Grating Experiments —Double Slit Still Has Much to Offer

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Research Article

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Curved Diffraction Patterns of 2D-Cross-Grating Experiments ---Double Slit Still Has Much to Offer

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Abstract Young's double slit experiments represent the mystery of quantum mechanics. To explore the mystery, varieties of the single slit, double slit, cross-double slit and 1D-grating experiments were performed, which show the universal phenomena that the interference/diffraction patterns are curved, expanded and inclined. In this article, we show novel phenomena that the diffraction patterns of the 2D-cross-grating experiments can be curved, expanded and inclined simultaneously and continuously.

Those experiments provide comprehensive data for developing/testing a theoretical model.

Keywords: grating experiment, cross-grating experiment, diffraction pattern, curved diffraction pattern, expanded diffraction pattern, inclined diffraction pattern

Declaration: The author declares that there are no potential conflicts of interest

1. Introduction

Young's double slit experiment was performed in 1801 [1] [2], which, 100 years later, led to wave-particle duality. Feynman called it "a phenomenon [...] has in it the heart of quantum mechanics. In reality, it contains the only mystery [of quantum mechanics]" [3]. Moreover, the nature of photons truly puzzled Einstein. He wrote to M. Besso: "All these 50 years of conscious brooding have brought me no nearer to the answer to the question: What are light quanta?" [4]. A. Jogalekar explained: "Yet

we have no clue how any of the fundamental facts of quantum mechanics including wave-particle duality, ..., or the double-slit experiment, that disarmingly simple setup which ...- actually work.” [5]. The double slit experiment still has much to offer (Pinner, 2021).

To further explore the mystery, the 1D-double slit-AB (Figure 1) has been extended to 2D-cross-double slit-ABCD (Figure 2) [6].

Figure 1. 1D-double slit-AB experiment and its pattern

Figure 2. 2D-cross-double slit-ABCD experiment and its pattern

The universal phenomena of the curved, expanded and inclined patterns of the dynamic double slit, cross double slit and 1D-grating experiments have been shown [7] [8].

2. Curved Patterns of 1D-Grating and 2D-Cross-Grating

It has been shown that the photons' behaviors depend on the orientations of the diaphragms of the 1D-grating [7]. In this article, we study further the orientation dependance of the diffraction patterns of the 2D-cross-grating experiments. Let us compare the 1D-Grating (Figure 3) and the 2D-cross grating (Figure 4). The 1D-Grating is referred to the grating with multiple parallel slits (Figure 3), where the vertical slits S2 may be more than four. With a laser source, the diffraction pattern of the 1D-grating experiment is shown in Figure 3.

Figure 3. 1D-grating and its pattern

The cross-grating consists of the multiple vertical slits S2 and the multiple horizontal slits S1, and is referred as 2D-cross-grating. For simplicity, in Figure 4, we draw only four vertical slits, referred as S2, and 4 horizontal slits, referred as S1.

Figure 4. 2D-cross-grating and its pattern

The patterns P1 and P2 are created by the horizontal slits S1 and vertical slits S2 respectively.

3. Curved and Expanded Diffraction Pattern

To further compare the 1D-grating/pattern with 2D-cross-grating/pattern, we arrange both gratings and patterns side by side. Hereafter, simply denoted the “diffraction patterns” as “patterns”.

3.1. Rotating 1D-Grating: Curved Pattern

In Section 3.1 and 3.2, rotating the 1D-grating. Then in Section 3.3, rotating 2D-cross grating.

Experiment-1 (Figure 5): The curved patterns of 1D-Grating experiments.

The experiments utilize a laser source, a 1D-grating (Figure 5a) and a protractor. Figure 5a shows the 1D-grating and its pattern created when the grating is at the original orientation, i.e., the laser light is perpendicular to the plan of the 1D-grating.

Figure 5. 1D-grating and its pattern

Figure 5b shows the curved pattern created when the 1D-grating rotating around Y-axis counterclockwise. The direction the pattern curved toward obeys the left-hand rule [9]. While Figure 5c shows the curved pattern created when the 1D-grating rotating around Y-axis clockwise. The direction the pattern curved toward obeys the right-hand rule [9]. The spacings between fringes keep the same.

3.2. Rotating 1D-Grating: Expanded Pattern

Experiment-2 (Figure 6): The expanded patterns of 1D-Grating experiments.

Figure 6a shows the 1D-grating and its pattern when it is at the original orientation.

(b)

Figure 6. 1D-Grating and its pattern

Then rotating the 1D-grating around Z-axis, either clockwise or counterclockwise, the pattern expands as shown in Figure 6b.

3.3. Rotating 2D-Cross-Grating: Curved and Expanded Patterns

Experiment-3 (Figure 7): The experiments utilize a laser source, a 2D-cross-grating and a protractor.

(a)

(b)

Figure 7 Patterns of 2D-cross-grating rotating around Z-axis

Rotating the 2D-cross-grating around Z-axis clockwise and counterclockwise respectively with a discrete angle, for example, 75° .

Observation (Figure 7a): the 2D-cross-grating rotates around Z-axis counterclockwise

- (1) the vertical patterns, P1, are curved towards the right continuously, which obey the left-hand rule.
The larger the rotation angle, the larger the curvature of the patterns.
- (2) The spacings between the fringes of the horizontal patterns, P2, expanded continuously. The larger the rotation angle, the larger the spacings.
- (3) The patterns are curved and expanded simultaneously.

Observation (Figure 7b): the 2D-cross-grating rotates around Z-axis clockwise

- (1) the vertical patterns, P1, are curved towards the left continuously, which obey the right-hand rule.
The larger the rotation angle, the larger the curvature of the patterns.
- (2) The spacings between the fringes of the horizontal patterns, P2, expanded continuously. The larger the rotation angle, the larger the spacings.
- (3) The patterns are curved and expanded simultaneously.

The 1D-grating rotates twice around two perpendicular axes to observe the curved and expanded patterns as shown in Experiment-1 and Experiment-2. The 2D-cross-grating rotates once around one axis and observe the both phenomena (Experiment-3).

3.4. Rotating 2D-Cross-Grating Continuously: Curvatures and Expansions of Patterns Change

Continuously

To see the continuously change of the patterns during the grating rotates clockwise and counterclockwise, please see the Video:

“0-video-20211109_curved patterns of cross grating.mp4”.

4. Curved, Expanded and Inclined Pattern

In this section, first, for the sake of the comparison, rotating the tilt-1D-grating.

4.1. Rotating Tilt 1D-Grating: First Orientation

Rotating the 1D-grating around its normal vector counterclockwise a discrete angle, say 60° , such that the A-axis is vertical. Thus, the 2D-Cross-Grating is tilted.

Experiment-4 (Figure 8): Then rotating the grating around the A-axis counterclockwise (Figure 8b) and clockwise (Figure 8c). respectively.

Figure 8. Rotating Tilt-1D-Grating and Curved, Expanded and Inclined Patterns

Observation: Figure 8b shows that the pattern is curved upward, expanded and inclined towards the horizontal axis simultaneously. Figure 8c shows that the pattern is curved downward, expanded and inclined towards the horizontal axis simultaneously.

4.2. Rotating Tilt-1D-Grating: Second Orientation

Rotating the 1D-grating around its normal vector clockwise a discrete angle, say 60° , such that the A-axis is in the vertical direction (Figure 9a). Thus, the 1D-Grating is tilted.

Figure 9. Rotating Tilt-1D-Grating and Curved, Expanded and Inclined Patterns

Experiment-5 (Figure 9): Then rotating the grating around the A-axis counterclockwise (Figure 9b) and clockwise (Figure 9c). respectively.

Observation: Figure 9b shows that the pattern is curved downward, expanded and inclined towards the horizontal axis simultaneously. Figure 9c shows that the pattern is curved upward, expanded and inclined towards the horizontal axis simultaneously.

4.3. Rotating Tilt-2D-Cross Grating at Discrete Angles

Rotating the 2D-Cross-Grating around its normal vector clockwise a discrete angle, say 45° , such that the A-axis is vertical (Figure 10). Thus, the S1 and S2 of the 2D-Cross-Grating are tilted.

Figure 10. 2D-cross-grating experiment and its pattern at original position

Figure 10 shows the pattern, the pattern P1 is created by S2, while P2 by S2.

Experiment-6 (Figure 11): Rotating the 2D-cross-grating clockwise around A-axis with angles 45° , 60° and 75° , respectively. The tilt cross-grating contain slits of both orientations, S1/P1 and S2/P2.

. (a) rotating 45°

.(b) rotating 60°

(c) rotating 75°

Figure 11. 2D-cross grating rotating around A-axis clockwise

Observation (Figure 11):

- (1) the spacings between fringes of the pattern P1 created by S1 is expanded, while the spacings between the fringes of the pattern P2 created by S2 is expanded;
- (2) the pattern P1 is curved upward, which obeys the right-hand rule, while the pattern P2 is curved downwards, which obeys the right-hand rule; the green line and the orange line show that the P2 and P1 are curved;
- (3) the pattern P1 and P2 are inclined towards the horizontal direction, respectively.
- (4) the pattern is curved, expanded and inclined simultaneously.

Experiment-7 (Figure 12): Figure 12a shows the pattern when the cross-grating rotates 0° . The pattern P1 is created by S1, while P2 by S2. Next, rotating the 2D-cross grating counterclockwise around A-axis with angles 45° , 60° and 75° , respectively (Figure 12). The tilt cross-grating contain both orientations of slits.

(a) Rotating 0°

(b) Rotating 45°

(c) Rotating 60°

(d) rotating 75°

Figure 12 2D-cross-grating rotating counterclockwise around A-axis

Observation (Figure 12):

- (1) the spacings between fringes of the pattern P1 created by S1 is expanded, while the spacings between the fringes of the pattern P2 created by S2 is expanded;
- (2) the pattern P1 is curved downwards, which obeys the left-hand rule, while the pattern P2 is curved upwards, which obeys the left-hand rule; the green line and the orange line show that the P2 and P1 are curved;
- (3) the pattern P1 and P2 are inclined towards the horizontal direction, respectively.
- (4) the patterns are curved, expanded and inclined simultaneously.

The 1D-grating rotates twice around two different axes to observe the curved, expanded and inclined patterns as shown in Experiment-4 and Experiment-5. The 2D-cross-grating rotates once around one axis and observe all three phenomena as shown in Experiment-6 and Experiment-7.

4.4. Rotating Tilt 2D-Cross-Grating Continuously: Curvatures and Expansions of Patterns

Change Continuously

To see the continuously change of the patterns during the tilt Cross-grating rotates clockwise and counterclockwise, please see the Video:

“0-video-20211109_curved patterns of tilt cross grating.mp4”.

5. Summary

We show that the diffraction patterns of the 2D-cross grating depend on the orientation of the grating. More specifically, the patterns are bended by rotating the grating around Z(Y)-axis.

The experiments of the 2D-cross grating in this article show the phenomena of the curved, expanded and incline patterns attributing to the rotations of the 2D-cross-grating, which confirm that the phenomena of the curved, expanded and incline patterns attributing to the rotations of the single slit, 1D-double slit, 2D-cross-double slit, 1D-grating and 2D-cross-grating are universal (Table) [8] [10].

Table: Universal Phenomena

Pattern	Single slit	1D-Double slit	2D-Cross-double slit	1D-Grating	2D-Cross-Grating
Curved	yes	yes	yes	yes	yes
Expanded	yes	yes	yes	yes	yes
Inclined	yes	yes	yes	yes	yes

It is a challenge to interpret the phenomena/experiments consistently.

The significances of the above-mentioned experiments are to disclose new phenomena and provide comprehensive phenomena/data for developing theoretical model to explore the mystery of the double slit experiments.

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- [0video20211109curvedpatternofcrossgrating.mp4](#)
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