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Fast measurement of the lattice constant of smartphones with a laser pen

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Abstract: *Grating is one of the widely used optical elements in modern optics, and the grating constant determines many properties of the grating. The smart phone screen is a regular grating. Based on the grating formula, this paper improves and simplifies the experimental device, and measures the grating constant of the smart phone through the diffraction pattern reflected by the smart phone screen on the normal and grazing incidence of the laser pen. By comparing with the theoretical value, it is found that the measured value is in good agreement with the real value.*

Keywords: *grating diffraction; intelligent mobile phone*

1. Introduction

Grating is an optical element that diffracts light waves by using the (multi-slit) diffraction principle. It is composed of multiple equally spaced and parallel slits, and is widely used in spectrometer, optical communication, optical computing, optical information processing, laser warning system, spectral beam combination and other fields. Studying the diffraction law of grating is of great value of its application for engineering technology[1-4]. Because of the important value of grating, Therefore, the experiment of grating diffraction is indispensable to college physics experiments. However, in the process of traditional grating diffraction experiments, the transmission grating made of glass is often used for demonstration. Although this method can enable students to master the use of experimental instruments, the complexity of experimental instruments limits students' enthusiasm and creativity.

The smart phone screen is composed of tiny periodic arrangement of display units[5]. This periodic arrangement forms a grating. Therefore, this paper takes the smart phone screen as the research object to further to explore the law of grating diffraction and its potential application[6]. In the current experiment process of measuring smart phone screen based on the grating diffraction principle, it is mostly necessary to measure the incidence angle, diffraction angle and the inclination angle and incidence angle for the smart phone screen, the measurement of diffraction angle and inclination angle of smart phone screen increases the difficulty of completing the experiment.

For the above problems, this experiment will change to normal incidence and grazing incidence, and at the same time we use phyphox to maintain the constant inclination of the smartphone screen to achieve a more accurate measurement of the grating constant of the smartphone screen.

2. Theoretical basis

2.1 Experimental principle

Grating is an optical element composed of a large number of parallel slits in equal width and spacing. As shown in Figure1 (a) and Figure1 (b), the wavelength of incident light is λ and the grating constant is d. Let the Angle between incident light and the grating normal are θ, and the Angle between diffracted light and the grating normal be φ. According to single-slit diffraction and multi-slit interference, there are two cases in which incident rays diffract by grating to produce bright fringes: incident rays and diffracted rays are on the same side of grating normals, and incident rays and diffracted rays are on different sides of grating normals. When the incident ray and diffracted ray are on the same side of the normal line, when

$$d(\sin\theta+\sin\varphi)=k\lambda \quad (k=0,\pm1,\pm2\ldots) \quad (1)$$

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As shown in Figure1 (a), bright stripes will be produced. When the incident ray and diffracted ray are on different sides of the normal line, it is satisfied

$$d(\sin\theta-\sin\varphi)=k\lambda \quad (k=0,\pm1,\pm2\ldots)(2)$$

As shown in Figure1 (b), bright stripes will be produced[7].

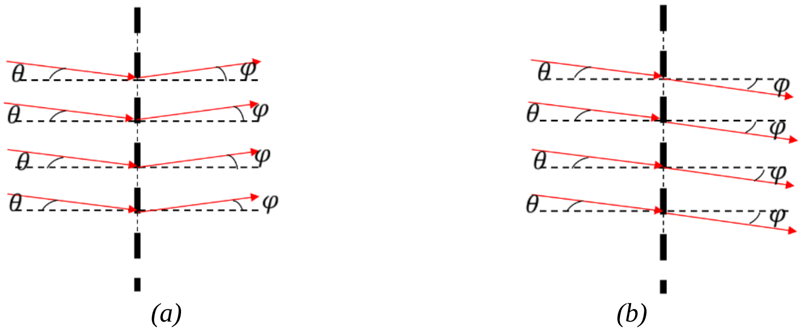

Figure 1: Grating diffraction (a) incident light and diffracted light on the same side of the normal (b) incident light and diffracted light on different sides of the normal

2.2 Experimental Scheme

Scheme 1

According to the above principles, the experimental optical path diagram is designed, as shown in Figure2, so that the laser is incident on the smartphone screen and generates diffraction. At this point, the smartphone screen is placed vertically on the ground and the incidence Angle $\theta\approx0$ is controlled, so $\sin\theta\approx0$. Then equation (1) can be obtained that the conditions for diffraction to produce bright fringe are:

$$d\sin\varphi=k\lambda \quad (k=0,\pm1,\pm2\ldots)(3)$$

Since the diffraction Angle φ is small, $\sin\varphi\approx\tan\varphi$ can be obtained

$$\sin\varphi\approx\tan\varphi=h/L(4)$$

Since the wavelength of incident light (green laser λ=532nm) is known; L is the distance between the incident point of the smartphone screen and the diffraction bright fringe plane, which can be measured experimentally. h is the distance between two adjacent bright fringes on the plane of diffraction bright fringe can be measured by experiment and the distance between adjacent diffraction bright fringes is equal, then it can be seen

$$d=L\lambda/h(5)$$

Scheme 2

Incident light grazes the screen of the smartphone. The experimental light path is shown in Figure3, and the grating normal is parallel to the screen of the smartphone. At this time, the incidence Angle $\theta\approx0$, $\sin\theta\approx0$, then the grating constant d can be determined according to equation (5) to determine the relevant data.

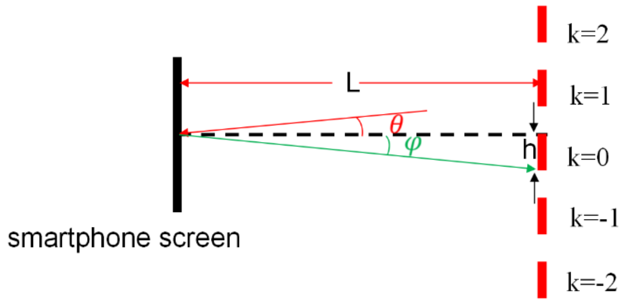

Figure 2: Experimental optical path diagram (normal incident mobile phone screen)

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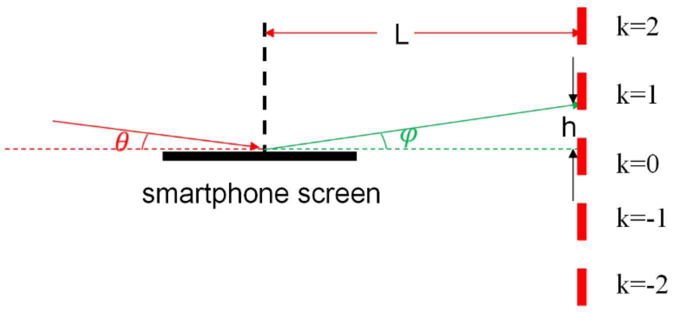

Figure 3: Experimental optical path diagram (grazing incident mobile phone screen)

3. Experimental Part

3.1 Experiment 1 Measures the grating constant of smart phone screen by normal incidence

3.1.1 Build the experiment platform

Experimental devices are shown in Figure 4, including green laser pointer, smart phone, graph paper, base and other devices.

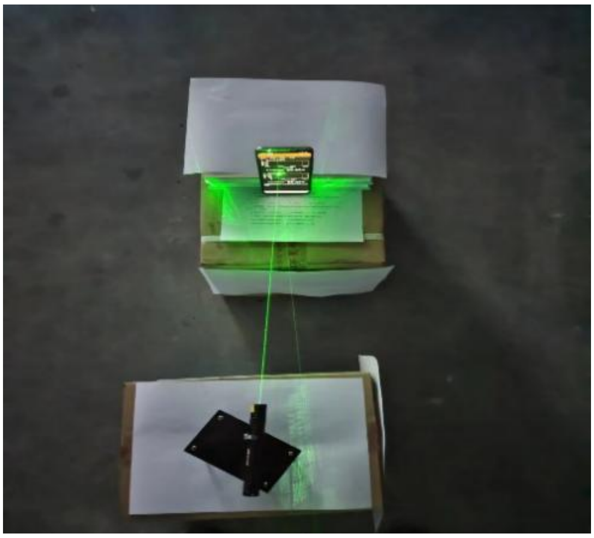

Figure 4: Layout of normal incidence instrument

3.1.2 Experimental procedure

(1) Fix the smart phone and green laser pointer on the base, and adjust the position of relevant instruments. IQOO NEO 5 dynamic version set as smart phone 1, RedmiNote8 set as smart phone 2.

(2) Turn on the smart phone and use the inclined plane function in phyphox to ensure that the smart phone is completely perpendicular to the ground, and then adjust the green laser pointer so that the incident light is vertically incident on the screen of the smart phone, and ensure that the incident light completely passes through the light outlet of the green laser pointer after it is emitted through the screen. At the same time, the green laser pointer is fine-tuned so that there is a small Angle between the incident light and the screen normal line.

(3) Ensure that the diffraction bright fringe plane can coincide with the coordinate paper plane, and record the coordinates of bright fringe on the coordinate paper plane.

(4) The distance between the incident point of the smartphone screen and the diffraction bright fringe plane is measured by meter ruler, and *L* is obtained. At the same time, the distance between two adjacent bright fringes on the diffraction bright fringe plane is measured according to the position of coordinates on the coordinate paper, and *h* is obtained.

(5) According to Formula (5), grating constant d can be obtained by placing data in sequence.

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3.1.3 Data measurement and data processing

Table 1: The distance between the incident light point of the screen of smartphone 1 and the plane of the coordinate paper (normal incidence)

n	L_{11}/cm	n	L_{11}/cm
1	150.5	4	149.9
2	150.4	5	150.2
3	149.8	6	150.2

Table 2: The distance between the incident light point of the screen of smartphone 2 and the plane of the coordinate paper (normal incidence)

k	L_{12}/cm	k	L_{12}/cm
1	150.3	4	149.8
2	150.0	5	150.2
3	149.9	6	150.0

(1) Measurement of the distance L between the incident point of the smartphone screen and the diffraction bright fringe plane. Experimental data are shown in Table. 1, Table. 2.

In experiment 1, coordinate paper was used to record the detailed information of the diffraction bright fringe plane. Therefore, the measurement of the distance between the incident light incident point of the smartphone screen and the diffraction bright fringe plane was the measurement of the distance between the incident light incident point of the smartphone screen and the coordinate paper plane. In order to reduce the experimental error, the experiment adopted the method of multiple measurements to reduce the experimental error. After averaging $\overline{L}_{11}$ = 150.2 cm, $\overline{L}_{12}$ = 150.0 cm.

(2) Measurement of diffraction bright fringe coordinates. The diffraction image is shown in Figure 5. The green laser pointer is normal incident on the smartphone screen, so that the plane of diffraction bright fringe coincides with the plane of the graph paper, and then the position of diffraction bright fringe is marked on the graph paper. Coordinates, such as a Table. The Table. 3, Table. 4, through calculation is more adjacent the interval between the two bright stripes and average worth $\overline{h}_{11}$ = 1.25 cm, $\overline{h}_{12}$ = 1.32 cm.

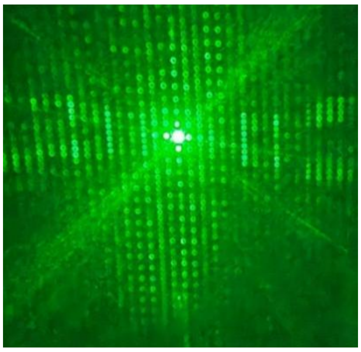

Figure 5: Diffraction pattern of smart phone screen (normal incidence)

Table 3: Bright Stripe Coordinates - Smartphone 1(normal incidence)

k	h_{11}/cm	k	h_{11}/cm
2	2.50	-1	-1.27
1	1.28	-2	-2.50
0	0		

Table 4: Bright Stripe Coordinates - Smartphone 2(normal incidence)

k	h_{12}/cm	k	h_{12}/cm
2	2.60	-1	-1.30
1	1.35	-2	-2.71
0	0		

(3) Calculate the grating constant. Known green laser wavelength λ = 532 nm, and $\overline{L}_{11}$ = 150.0 cm, $\overline{L}_{12}$ = 150.0 cm, $\overline{h}_{11}$ = 1.25 cm, $\overline{h}_{12}$ = 1.32 cm, then according to the formula (5) can be obtained $\overline{d}_{11}$ = 63.9 μm, $\overline{d}_{12}$ = 61.8 μm.

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3.1.4 Error analysis

Table. 5 shows the true value of grating constant d of smartphone 1, smartphon2.

Table 5: Data recording and analysis table (normal incidence)

Mobile phone model	True value d/μm	Measured value $\overline{d}$/μm	Relative error E_r	Absolute error Δd
IQOO NEO5 Dynamic edition	63.3	63.9	0.9%	0.6 μm
Redmi Note 8	62.1	61.8	0.5%	-0.3 μm

3.2 Experiment 2 measured the grating constant of smart phone screen by grazing incidence

3.2.1 Build the experiment platform

Experimental devices are shown in Figure 6, including green laser pointer, smart phone, graph paper, base and other devices.

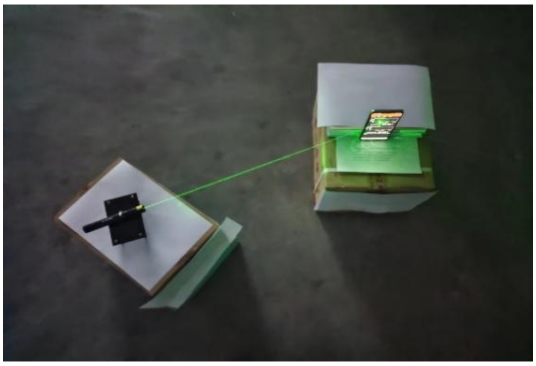

Figure 6: Layout of grazing incidence instrument

3.2.2 Experimental procedure

(1) Fix the smart phone and green laser pointer on the base, and adjust the position of relevant instruments. IQOO NEO 5 dynamic version set as smart phone 1, RedmiNote8 set as smart phone 2.

(2) Turn on the smartphone and use the bevel function in the phyphox to ensure that the smartphone is completely perpendicular to the ground, and then adjust the green laser pointer so that the incident light is parallel to the screen of the smartphone. After the incident light is parallel to the smartphone screen, fine-adjust the green laser pointer to make a small Angle between the incident light and the plane where the smartphone screen is located.

(3) Ensure that the diffraction bright fringe plane can coincide with the coordinate paper plane, and record the coordinates of bright fringe on the coordinate paper plane.

(4) The distance between the incident point of the smartphone screen and the diffraction bright fringe plane is measured by meter ruler, and L is obtained. At the same time, the distance between two adjacent bright fringes on the diffraction bright fringe plane is measured according to the position of coordinates on the coordinate paper, and h is obtained.

(5) According to Formula (5), grating constant d can be obtained by placing data in sequence.

3.2.3 Data measurement and data processing

Table 6: The distance between the incident light point of the screen of smartphone 1 and the plane of the coordinate paper (grazing incidence)

n	L_{21}/cm	n	L_{21}/cm
1	150.4	4	149.6
2	150.2	5	149.9
3	150.0	6	150.0

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Table 7: The distance between the incident light point of the screen of smartphone 1 and the plane of the coordinate paper (grazing incidence)

n	L_{22}/cm	n	L_{22}/cm
1	150.1	4	149.9
2	150.0	5	149.9
3	149.8	6	149.9

(1) Measurement of the distance L between the incident point of the smartphone screen and the diffraction bright fringe plane. Experimental data are shown in Table. 6, Table. 7.

In experiment 2, coordinate paper was used to record the detailed information of the diffraction bright fringe plane. Therefore, the measurement of the distance between the incident light incident point of the smartphone screen and the diffraction bright fringe plane was the measurement of the distance between the incident light incident point of the smartphone screen and the coordinate paper plane. In order to reduce the experimental error, the experiment adopted the method of multiple measurements to reduce the experimental error. After averaging $\bar{L}_{21}$ = 150.0 cm, $\bar{L}_{22}$ = 149.9 cm.

(2) The measurement of the diffraction light stripe coordinates. The diffraction image is shown in Figure7. The green laser pen is swept into the smart phone screen to make the diffraction light stripe plane coincide with the plane of the coordinate paper, and then the position of the diffraction light stripe is marked on the coordinate paper. The coordinates are shown in Table. 8, Table. 9. Through calculation, we can know the spacing between multiple adjacent two light stripes and calculate the average value of $\bar{h}_{21}$=1.29cm, $\bar{h}_{22}$=1.33cm.

Table 8: Bright Stripe Coordinates - Smartphone 1 (Grazing incidence)

k	h_{21}/cm	k	h_{21}/cm
2	2.59	-1	-1.30
1	1.28	-2	-2.58
0	0		

Table 9: Bright Stripe Coordinates - Smartphone 2 (Grazing incidence)

k	h_{22}/cm	k	h_{22}/cm
2	2.60	-1	-1.4
1	1.30	-2	-2.70
0	0		

(3) Calculation of grating constant. Known wavelength of green laser λ= 532 nm, and $\bar{L}_{21}$=150.0 cm, $\bar{L}_{22}$=149.9 cm, $\bar{h}_{21}$=1.29 cm, $\bar{h}_{22}$=1.33 cm, then according to formula (5), $\bar{d}_{21}$=61.9 μm, $\bar{d}_{22}$=60.0 μm.

3.2.4 Error analysis

Table. 11 shows the true value of grating constant d of smartphone 1, 2.

Table 10: Data recording and analysis table (Grazing incidence)

Mobile phone model	True value d/μm	Measured value $\bar{d}$/μm	Relative error E_r	Relative error Δd
IQOO NEO5 Dynamic edition	63.3	61.9	2.2%	-1.4 μm
Redmi Note 8	62.1	60.0	1.7%	-1.1 μm

Table 11: Smartphone screen raster constant real value

Mobile phone model	Pixel density /PPI	d/μm
IQOO NEO5 Dynamic edition	401	63.3
Redmi Note 8	409	62.1

4. Data analysis and feasibility verification

It can be seen from the literature that the grating constant of the smart phone screen is the same everywhere[8]. At the same time, it can be seen from Table 5, Table 10, Table 12 that the grating constant *d* measured in the experiment in two cases is approximately equal and at the same time is approximately equal to the real value, which shows that the experimental scheme is feasible.

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Table 12: Comparison table of data obtained from experiment 1 and experiment 2

Mobile phone model	True value d/μm	d_1/μm	d_2/μm
IQOO NEO5 Dynamic edition	63.3	63.9	61.9
Redmi Note 8	62.1	61.8	60.0

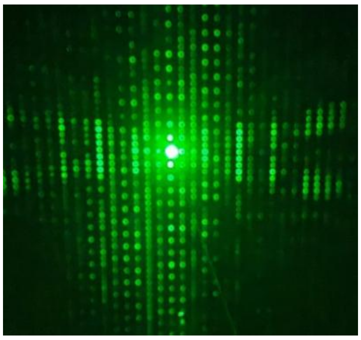

Figure 7: Diffraction pattern of smart phone screen (grazing incidence)

5. Conclusion

With the progress and development of the times, the useness of grating becomes more and more frequent. The experiment in this paper is a simple and fast method to test the grating constant of smart phone screen by changing the experimental instrument to simplify the experimental steps without unduly affecting the accuracy of the experiment.

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