Resolving power of optical devices

Task and equipment

Information for teachers

Additional Information

Optical devices are used to discern objects which are very far away or very small. Essentially, these instruments are designed to enlarge the visual angle. Whether this alone is sufficient to visualize the object depends on various factors, which the students should investigate.
Each ray emitted from an object point (point light source) is diffracted in the tube of the optical instrument. In this experiment, the two slits of a double slit represent the light sources (objects). Two diffraction peaks of 0th order are created, which can just be distinguished from each other when Rayleigh's Criterion is fulfilled. This criterion states that the distance between the diffraction peaks of 0th order may not be smaller than half of the distance between the diffraction troughs of 1st order (comp. Fig. 24).

Suggestions for Set-up and Performances

The experiments can be performed in a semi-darkened room.
Judgement of the limits of resolving power is highly dependent on the subjective perception of the investigator. Therefore, in experiment 1 we should expect fairly wide scatter of the measured values for s_{max}. The same will be true for the values in experiment 2.

Remarks

The equation

$\lambda = g \times b/s$ can be derived from Fig. 24 as follows:
$\sin(\alpha/2) \approx g / (2 \times s)$.
Since the visual angle α is very small, it is also true that:
$\alpha = g / s$.
The following applies to the diffraction trough of 1^{st} order for the diffraction from a single slit:
$\sin \alpha = \lambda/b \approx \alpha$.
In general we conclude that:
$\lambda / b = g / s \Leftrightarrow \lambda = g \times b / s$.

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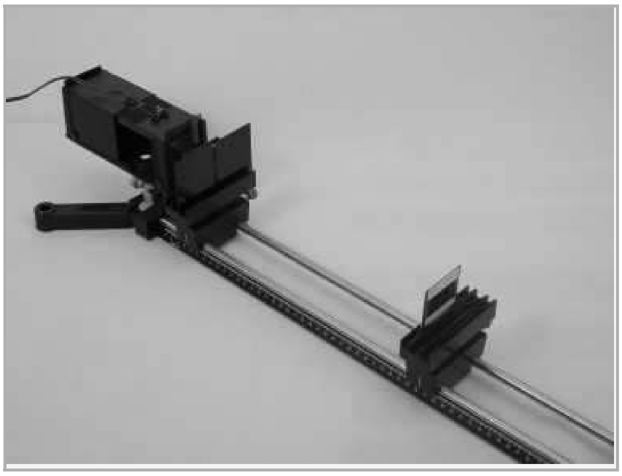
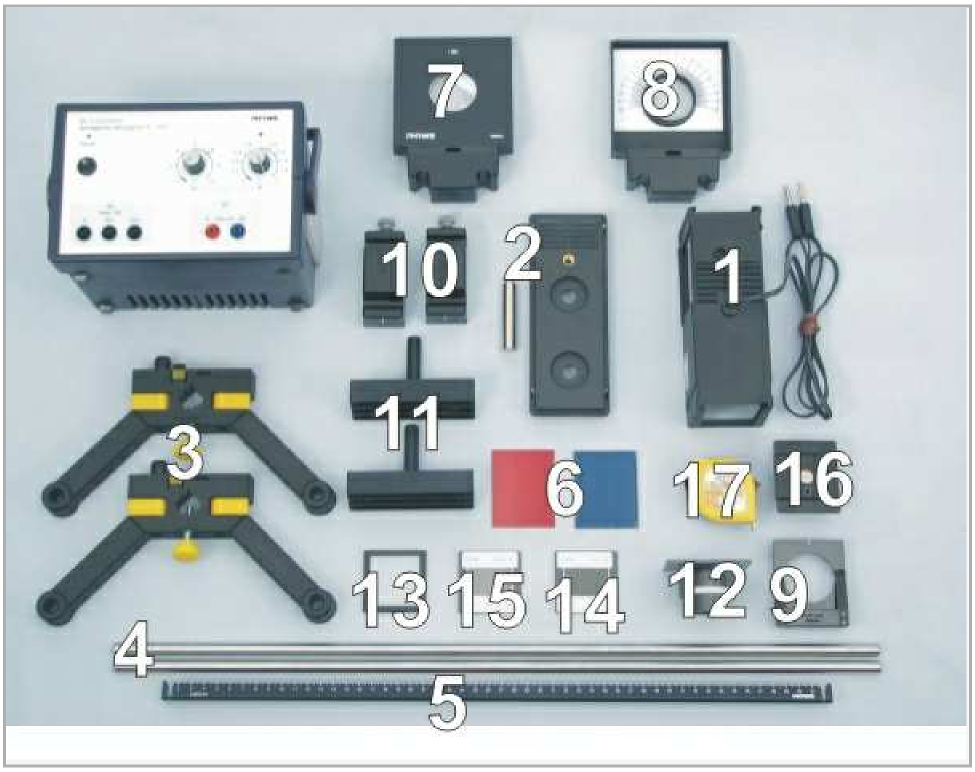
Task

On which factors does the resolving power of optical devices depend?

In a first experiment the conditions are investigated under which two objects (object points) can just still be perceived individually, i.e. resolved, with the aid of an optical device.
Afterwards, the validity of Rayleigh's Criterion $d = 1/2 \cdot d_1$ (comp. Fig. 24) for the resolving power of optical instruments is verified.



Equipment



Position No.	Material	Order No.	Quantity
1	Light box, halogen 12V/20 W	09801-00	1
2	Bottom with stem for light box	09802-10	1
3	Support base, variable	02001-00	1
4	Support rod, stainless steel, l = 600 mm, d = 10 mm	02037-00	2
5	Meter scale for optical bench	09800-00	1
6	Colour filter set, additive (red, blue, green)	09807-00	red, blue
7	Lens on slide mount, f=+50mm	09820-01	1
8	Mount with scale on slide mount	09823-00	1
9	Diaphragm holder, attachable	11604-09	1
10	Slide mount for optical bench	09822-00	2
11	Plate mount f.3 objects	09830-00	2
12	Measuring magnifier	09831-00	1
13	Ground glass screen,50x50x2 mm	08136-01	1
14	Diaphragm, 4 double slits	08523-00	1
15	Diaphragm, 3 single slits	08522-00	1
16	Slit, adjustable.up to 1 mm	11604-07	1
17	Measuring tape, l = 2 m	09936-00	1
-	PHYWE power supply DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
-	Cardboards 200x300mm,black,10 pcs	06306-01	(1)
Additional material			
	Scissors		1

Set-up and procedure

Experiment 1

- Using the two support rods and the variable support base (Fig. 1), assemble the optical bench (Fig. 2); place the meter scale against the front support rod.


Fig. 1


Fig. 2

- Place the bottom with stem under the light box (Fig. 3, 4) and clamp it onto the left part of the support base so that the lens end points away from the optical bench (Fig. 5).


Fig. 3


Fig. 4


Fig. 5

- Insert an opaque cover in front of the lens.
- Fix the plate mount onto the slide mount and place it at approx. 6 cm on the optic bench (Fig. 6). Attach the ground glass screen (Fig. 7) and the diaphragm with double slits (Fig. 8) on the mount.

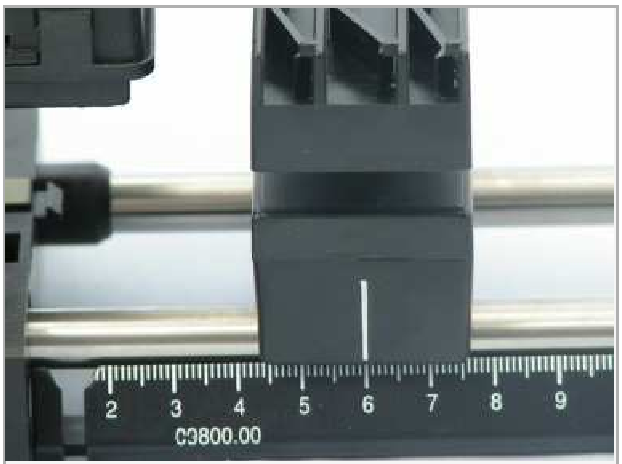


Fig. 6

Fig. 7

Fig. 8

- Fix the second plate mount onto another slide mount and place it to the right of the first. Attach the diaphragm with single slits on the mount (Fig. 9).

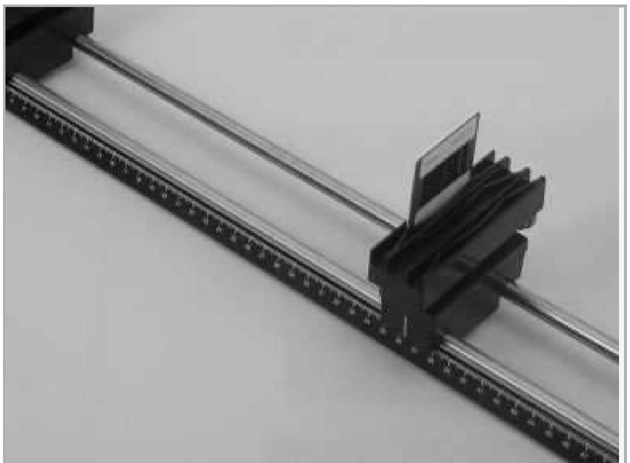


Fig. 9

- Insert the red filter into the shaft of the light box (Fig. 10), connect the light box to the power supply (12 V~) and switch it on (Fig. 11).

Fig. 10

Fig. 11

- First, move the double slit g = 1.00 mm into the optical axis (Fig. 12) and cover the other double slits with two opaque covers by attaching them on the plate mount (Fig. 13). (The two slits of the double slit represent the objets whose resolution is to be investigated.)

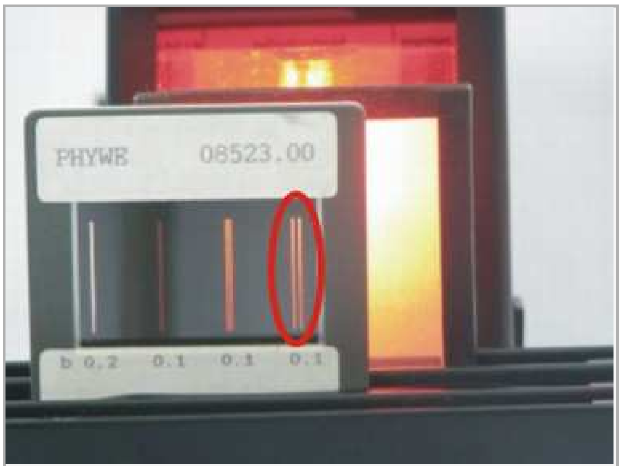


Fig. 12


Fig. 13

- Now, look at the double slit succesively through single slits of different widths. By moving the plate mount holding the single slits (Fig. 14), establish the respective maximum distance s_{max} at which the two slits of the double slit can just be distinguished from each other (resolved) (Fig. 15). (The single slits act as the lens diaphragm of an optical instrument, their width b corresponds to the lens diameter and the eye lens of the observer corresponds to the reproducing lens.)
- Note your results in table 1 in the report.

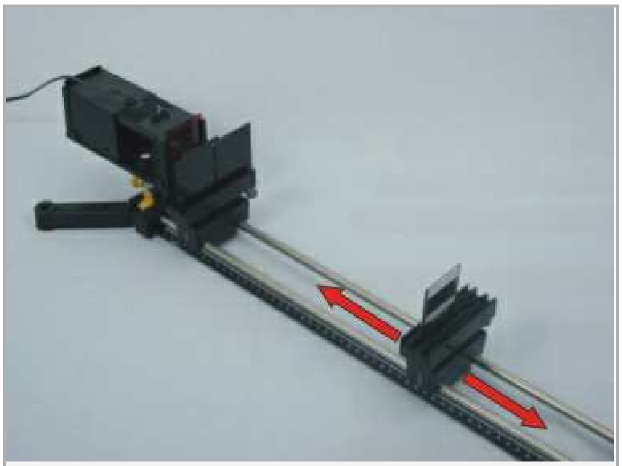


Fig. 14

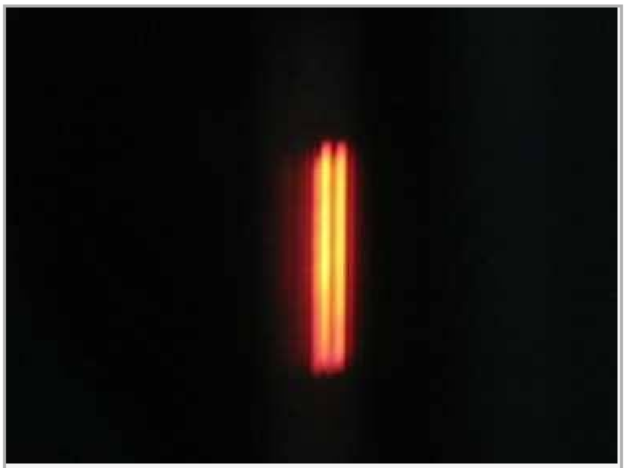


Fig. 15

- Next, observe double slit *g* = 0.50 mm and finally double slit *g* = 0.25 mm through the single slits and establish smax for each of these cases. Enter all values in table 1 in the report.
- After that, exchange the red filter for the blue filter (Fig. 16) and repeat the measurements. Again, enter all values in table 1.

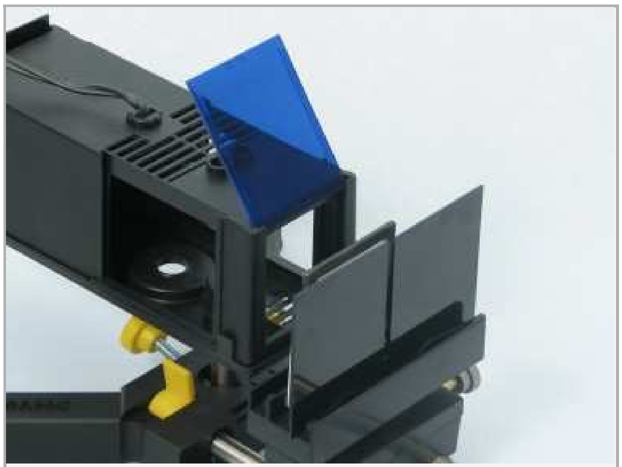


Fig. 16

- Switch off the power supply.

Experiment 2

- Leave the optic bench with light box as in experiment 1. Insert the red filter into the shaft of the light box and place lens *f* = +50 mm at 5 cm (Fig. 17).

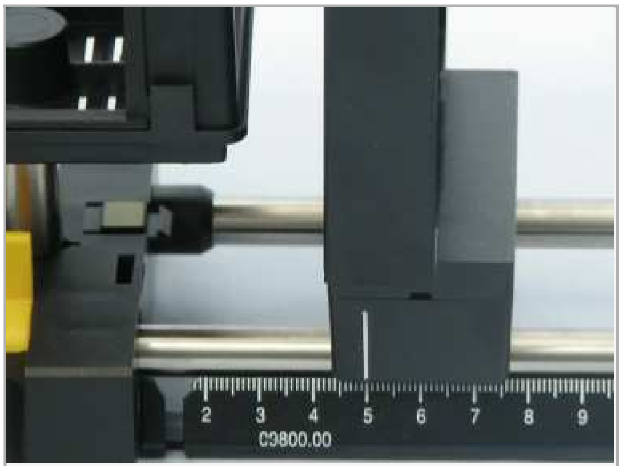


Fig. 17

- Position the plate mount with ground glass screen, diaphragm with double slits and opaque covers at 10 cm (Fig. 18).

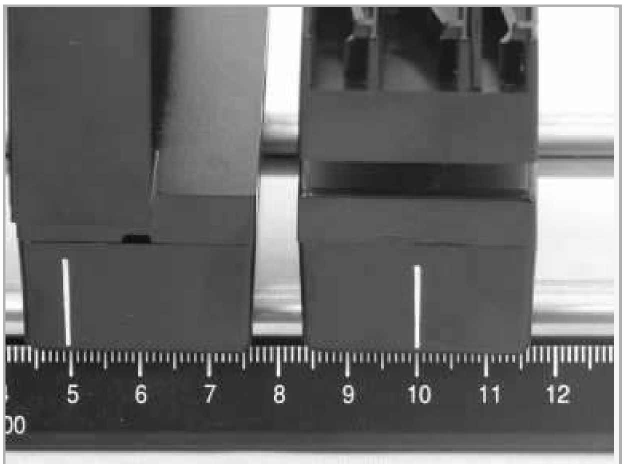


Fig. 18

- Fix the adjustable slit to the diaphragm holder (Fig. 19 and 20) and attach it to the mount with scale (Fig. 21).

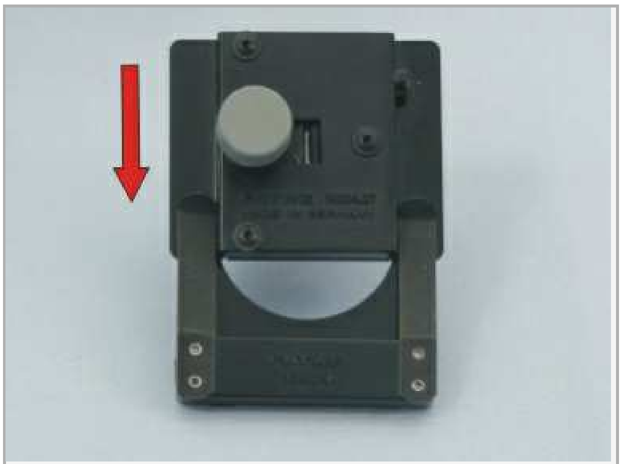


Fig. 19

Fig. 20

Fig. 21

- Position the mount with scale at approx. 48 cm. Attach the observation lens to the second plate mount and place it approx. 25 cm to the right of the adjustable slit (Fig. 22).

Fig. 22

- Switch on the power supply and move the double slit with g = 0.50 mm and b = 0.1 mm into the optical axis (Fig. 23). Cover the other double slits with the opaque covers.

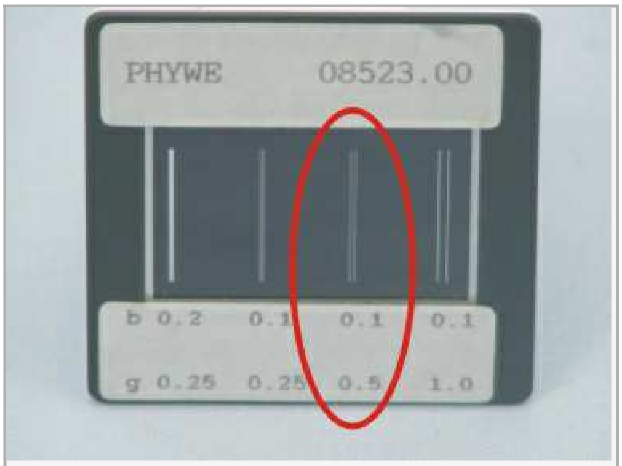


Fig. 23

- Observe the diffraction pattern through the observation lens. Start with a relatively large slit width *b* of the adjustable slit and gradually reduce *b*. Note your description of the diffraction pattern in the report.
- Finally, adjust the slit width *b* so that the two 0-order diffraction maxima can just be distinguished from each other. Measure the distance $d_{1.1}$ between the two 1^{st} order intensity troughs (comp. Fig. 24) and enter the value in table 2 in the report.

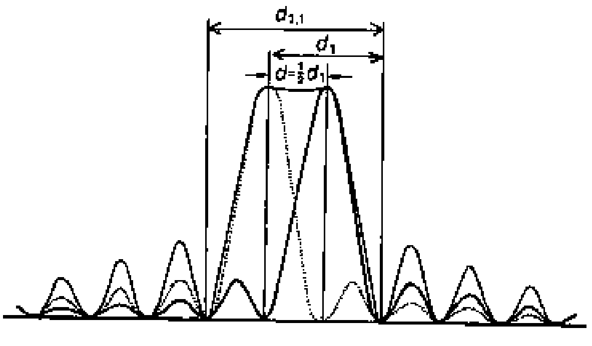


Fig. 24

- Exchange the double slit for a single slit with *b* = 20 mm and measure d_1 (comp. Fig. 24). Again, enter your measured value in table 2 in ther report.

- Switch off the power supply.

Report: Resolving power of optical devices

Result – Table 1

1. Record all your measured values in table.
2. Find the quotients $g \times b/s_{max}$ for each of the cases investigated in experiment 1 and enter the values in the last column of table.

Distance between slits of double slit	Width of single slit	Max. distance s_{max} in mm		g x b / s_{max} in nm	
g in mm	b in mm	Red	Blue	Red	Blue
1,00	0,1	1 ±0	1 ±0	1 ±0	1 ±0
1,00	0,2	1 ±0	1 ±0	1 ±0	1 ±0
1,00	0,4	1 ±0	1 ±0	1 ±0	1 ±0
0,50	0,1	1 ±0	1 ±0	1 ±0	1 ±0
0,50	0,2	1 ±0	1 ±0	1 ±0	1 ±0
0,50	0,4	1 ±0	1 ±0	1 ±0	1 ±0
0,25	0,1	1 ±0	1 ±0	1 ±0	1 ±0
0,25	0,2	1 ±0	1 ±0	1 ±0	1 ±0
0,25	0,4	1 ±0	1 ±0	1 ±0	1 ±0

Result – Observations 1

Describe the diffraction patterns with decreasing width b of the adjustable slit in Experiment 2:

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Result – Observations 2

Note down the distance between the 1st order intensity troughs:

Double slit: $d_{1,1}$ = ...mm
Single slit: d_1 = ...mm

Evaluation – Question 1

Which parameters are significant for the resolving power (see Table 1) and what kind of dependency exists between them in each case?

....

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....

....

Evaluation – Question 2

Calculate the respective mean values for $g \times b / s_{max}$, table 1:

red filter: .... nm
blue filter: .... nm

Evaluation – Question 3

What physical significance could the quotient $g \times b / s_{max}$ have?

Evaluation – Question 4

By analyzing Fig. 24 and Fig. 25, explain Rayleigh's Criterion.

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Evaluation – Question 5

Can the Rayleigh's Criterion be confirmed from measured values $d_{1,1}$ and d_1?