Experiment Protocol

MICROSCOPE

by

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2.1 Lenses

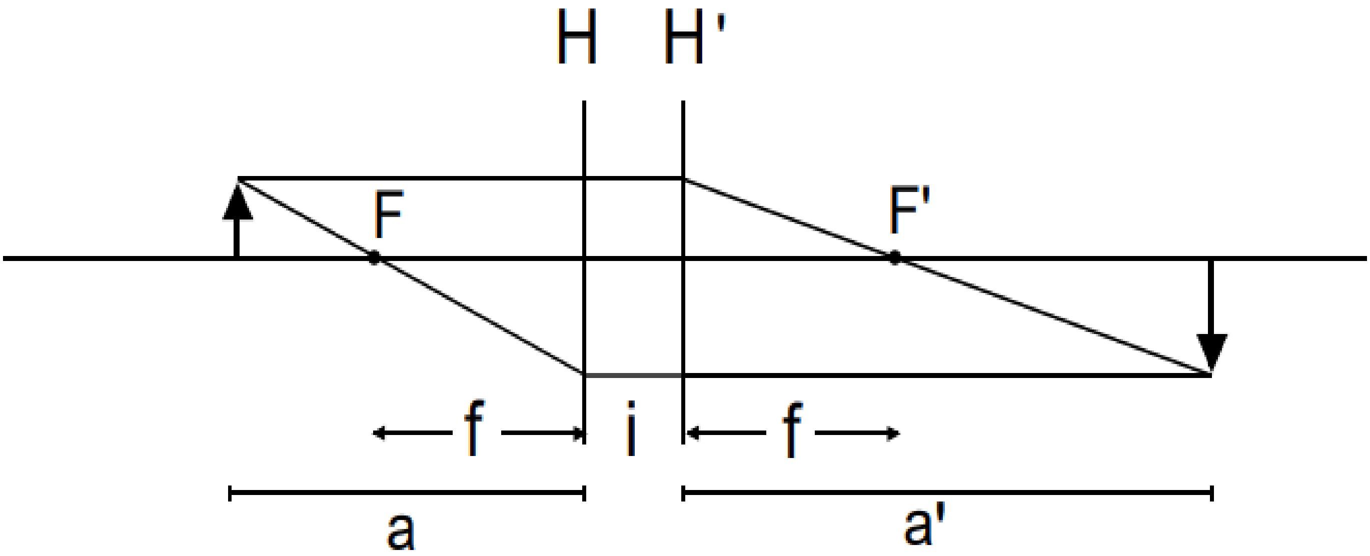


Figure 1: Imaging through Lenses

The thin lens formula describes, near the symmetry axis, the image of an object through a lens or a centered lens system for their rays of light:

$$\frac{1}{a} + \frac{1}{a'} = \frac{1}{f} \text{ with } \beta = \frac{a}{a'} \text{ being the image scale.} \tag{1}$$

With a and a' being distances the image scale is used to specify the the ratio between them. The f used in the formula is the focal length. H and H' are the two principal points of the system.

For most lenses the principal point interval i cannot be neglected and therefore a simple measurement of th focal length cannot be done. The Bessel method(2) is used in these cases to determine the focal length by moving a lens between a fixed object and a fixed image screen, with a distance of at least four times the focal length between them (e>4f). Two positions can be found in which the image is in focus, one is the magnified image and one the reduced image. e, the distance between the screen and the object, the distance between the two lens positions which is called a-a' and β are measured. Using the independent quantities, one can determine f and i using the following formula with the help of formula (1):

$$f = \frac{a - a'}{\frac{1}{\beta} - \beta} \tag{2}$$

$$i = e - (a + a') \tag{3}$$

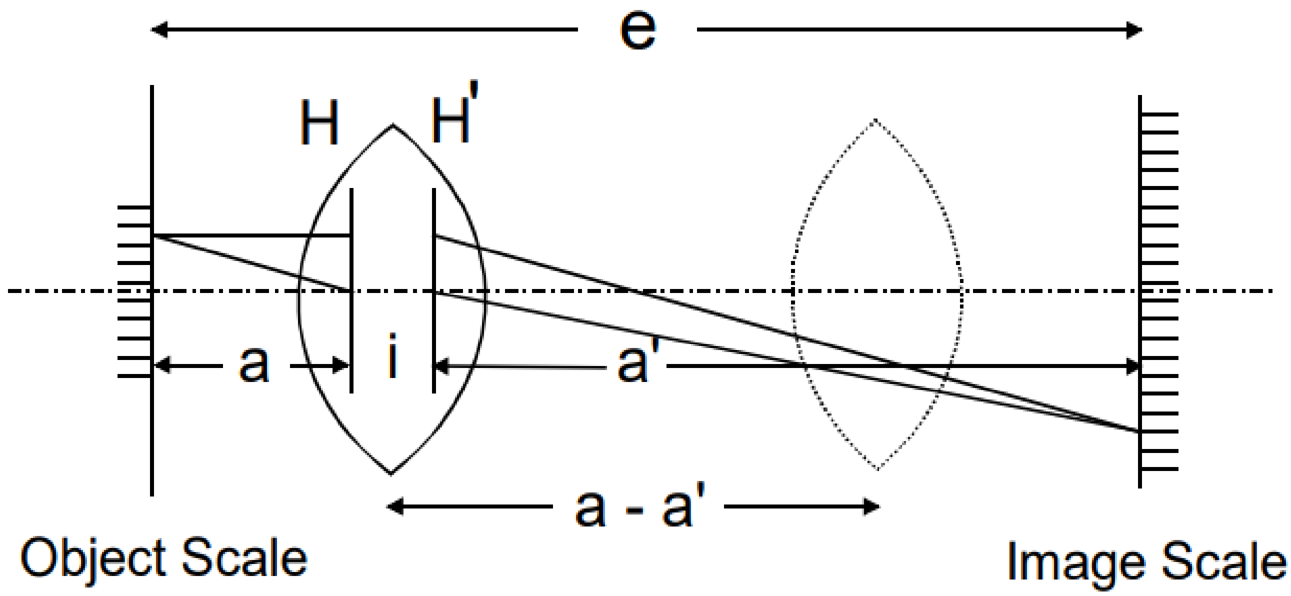


Figure 2: Bessel Method

2.2 Microscope

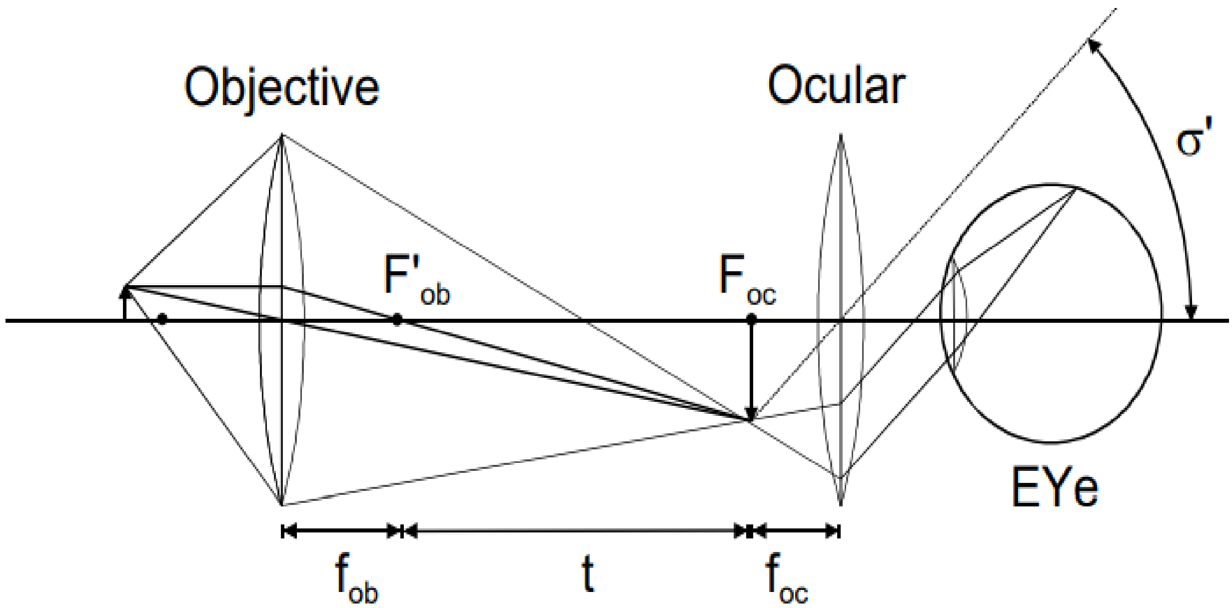


Figure 3: Microscope

A microscope has two lenses, one, the objective lens, which produces a real image and one, the ocular, to enlarge said image. The optical tube length t is the distance between the focus point of the objective lens and the ocular. The magnification of the angle of vision determines the size of the object being observed and is called the magnification of an optical instrument, which is defined as:

$$\Gamma = \frac{\tan\sigma}{\tan\sigma_0}. \tag{4}$$

The conventional near vision accommodation or angle of vision is $a_0 = 250\text{mm}$.
The product of the image scale β and the magnification of the ocular determines the total magnification of a microscope.

$$\Gamma = \beta_{Ob} \cdot \Gamma_{Oc} \tag{5}$$

It follows that the angle of vision in front of an ocular is given by:

$$\tan\sigma_{Oc} = \frac{y'}{a'} = \frac{y}{a} \tag{6}$$

Therefore the magnification is:

$$\Gamma_{Oc} = \frac{a_0}{a} \tag{7}$$

For the eye focused at infinity $a = f_{Oc}$:

$$\Gamma_{Oc}(\infty) = \frac{a_0}{f_{Oc}} \tag{8}$$

If the eye is accommodated to the near vision distance ($a_0 = a'$), a comparison scale is observed simultaneously, hence it follows:

$$\Gamma_{Oc}(a_0) = \frac{a_0}{f_{Oc}} + 1 \tag{9}$$

With decreasing focal length the ocular magnification increases. The resolving power is reduced because the small radius of the curvature results in a diminution of the lens diameter. The total magnification of the microscope, depending on the accommodation of the eye is:

$$\Gamma_\infty = \frac{t \cdot a_0}{f_{Ob} \cdot f_{Oc}} \tag{10}$$

$$\Gamma_0 = \frac{t}{f_{Ob}} \left[\frac{a_0}{f_{Oc}} + 1 \right] \tag{11}$$

2.3 Resolution of the Microscope

With the formulas (10) and (11) it should technically be possible to increase the magnification with sufficient tube length and small objective focal length. One does, however, observe a limitation in the resolution of the system. This phenomena can be explained with wave optics, there fore interference and diffraction should be taken into consideration.

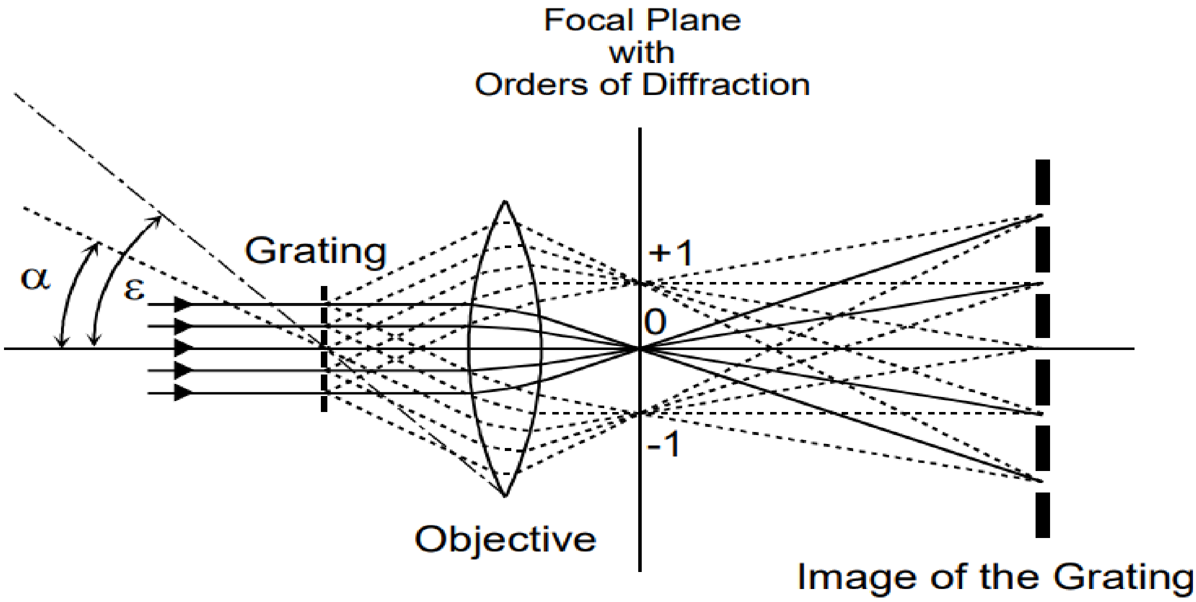


Figure 4: Focal Plane with Orders of Diffraction

A diffraction grating is used as the object which is illuminated by plane waves of light by Abbe's Theory of Imagining.
Due to interference effects a pattern of diffraction slits that appear in the focal plane of the lens according to the Huygens Principle. When the phase difference of the waves of neighbouring slits are whole multiples of the wave length λ a maximum occurs.

$$\frac{d \sin \alpha}{\lambda} = 0, \pm 1, \pm 2... \tag{12}$$

One should note that the diffraction angle α becomes larger the smaller the distance between object and objective lens.

The image of the grating can be observed on the image plane Z. The partial waves of at least two neighbouring orders of diffraction must be gathered by the lens in order to get an image with periodic intensity distribution. Therefore the minimum resolvable grating is:

$$d_{min} = \frac{1}{\sin \epsilon} \tag{13}$$

One can fill the space between the object and the objective lens with a medium with a refractive index n and thereby reduce the wavelength by the factor n. The resolution of the microscope is determined by the wavelength and the quantity, which is called the numerical aperature:

$$A = n \sin \epsilon. \tag{14}$$

3 Experimental Procedure

3.1 Tasks

3.1.1 Task 1

Determine the focal length of the objective lens using the Bessel Method.

3.1.2 Task 2

Determine the magnification of the microscope for a tubelength of 10cm, 15cm and 20cm.

3.1.3 Task 3

Insert a grit and determine its grating constant.

3.1.4 Task 4

Install a slit and determine the smallest opening radius with which the grit is still visible.

3.2 List of Devices

- objective lens with a focal length of 40 mm
- occular lens with a focal length of 40mm
- objective lens with a focal length of 50mm
- light source with scale
- slit
- grid
- mirror

- scale
- small scale

3.3 Illustration

3.4 Execution of the Experiment

At first one constructs the experiment as shown in the illustration and the focal length of the objective lense is determined by measuring the image scale and the distances between light souce and objective lens and ocular lens and the objective lens.

Then the theoretical magnification of the micorscope is calculated using formula (11) and the theoretical values of the lenses are used.
Afterwards the mirror and the second scale are installed and the tubelength of 10cm was set up. The focus length of the ocular lens is determined and using formula (11) the magnification of the microscope is calculated.
This process is repeated for the other tubelengths of 15 and 20 cm.

The grid is now inserted and using the small scale the width of the wire and the size of the holes is measured and with these values the grating conctant is determined.

Lastly the slit is inserted between the grid and the objective lens. One slowly closes the slit until the grid is no longer visible.

4 Data Collection and Analysis

4.1 Task 1

In Task 1, the focal lengths of two lenses (40mm and 50mm) are to be calculated. using formula (2).The errors of each measured quantity are listed in the tabel(5) The corresponding errors are to be calculated using Gaussian error propagation rules.

$$\Delta(f) = \sqrt{[\frac{\partial f}{\partial b}\Delta(b)]^2 + [\frac{\partial f}{\partial g}\Delta(g)]^2 + [\frac{\partial f}{\partial \beta}\Delta(\beta)]^2} \tag{15}$$

The data and the results are as follows:

	error	0.1cm	0.1cm	0.1				
Task1		b(cm)	g(cm)	beta	f(cm)	error(f)(cm)		
		10.5	10.2	0.7	0.41	0.20		
	for f=0.5cm	10.3	10.1	0.8	0.44	0.32	Average (f)	Average(error_f)
		11.4	11.1	0.7	0.41	0.20	0.42	0.23
	for f=0.4cm	11.2	11	0.7	0.27	0.20		

Figure 5: Task1

4.2 Task 2

In task 2, the total magnification of the microscope is to be experimentally calculated using formular:

$$\Gamma_{experimental} = \beta_{ob} \cdot (\frac{a}{f_{ok}} + 1) \tag{16}$$

Theoretically the total magnification is to be derived from :

$$\Gamma_{theoretical} = \frac{t}{f_{ob}} \cdot (\frac{a}{f_{ok}} + 1) \tag{17}$$

The data and calculated values are as follows:

	error	1	5mm						
Task2		beta	t(mm)	fob(mm)	fok(mm)	Theory	error	Experiment	error
		2.5	100	50	40	14.50	0.73	18.1	7.3
		4	150	40	40	27.19	0.91	29.0	7.3
		6	200	40	40	36.25	0.91	43.5	7.3
	average					25.98	0.85	30.21	7.25

Figure 6: Task2

The result:

$$\begin{aligned} \Gamma_{\text{theoretical}} &= 25.98 \pm 0.85 \\ \Gamma_{\text{experimental}} &= 30.21 \pm 7.25 \end{aligned} \tag{18}$$

4.3 Task 3

In Task 3, the grating distance and the thickness of the wire are to be determined.

The unit x used in observation is $(0.2 \pm 0.06) \times 10^{-2}$ mm. The observed grating distance is $0.3x$, and the width of the wire is $0.2x$ with an error of $0.1x$.
So the result is :

$$width_{wire} = (0.3 \pm 0.2) \times 10^{-2} mm \tag{19}$$

$$width_{grating\ distance} = (0.4 \pm 0.2) \times 10^{-2} mm \tag{20}$$

4.4 Task 4

The grid is still visible with a radius of 0.3mm until with a radius of 0.6mm. We take the middle value, 0.45mm, as the smallest opening radius with an error of 0.15mm.

$$B = 0.45 \pm 0.15 mm \tag{21}$$

5 Discussion

5.1 Task 1

The result of Task 1 is $f = (0.42 \pm 0.23)$ cm for a lens with a focal length of 0.5 cm and $f = (0.27 \pm 0.20)$ cm for a lens with a focal length of 0.4 cm. Therefore, the results seem plausible but off by one fourth of the theoretical value which can be explained by the fact that the minimum distance of e>4f might not have been adhered to. It is worth noting that the error in the results is comparatively large mainly due to the substantial uncertainty in the measurement of β.

5.2 Task 2

In task 2 we have obtained the result $\Gamma = 30.21 \pm 7.25$ experimentally , which is slightly outside the range of the theoretical expectation 25.98 ± 0.85.

6 Measurement Protocol

mzk

Task ① $f = 0.4\,cm$

$$f = \frac{b-g}{\frac{1}{\beta}-\beta} = 0.41\,cm$$

$$\Delta f = \sqrt{\left(\frac{1}{\frac{1}{\beta}-\beta}\cdot\Delta b\right)^2 + \left(\frac{-1}{\frac{1}{\beta}-\beta}\,\Delta g\right)^2 + \left[\Delta\beta\cdot(b-g)\frac{1}{\beta}\frac{1}{(\frac{1}{\beta}-\beta)^2}\right]}$$

$$= \left(\Delta\beta\,(b-g)\cdot\frac{1}{1-\beta^2}\right)^2$$

β	b cm	g cm
7/10	10.5cm	10.2cm
0.8	10.3	10.1
0.7 ~~g=~~	11.4	11.1

$f_{ob} = 0.5\,cm$ $f_{ok} = 0.4$

Task ② ~~(t+10)~~ $(t + f_{ob} + f_{ok})$

$$\Gamma = \beta_{ob}\cdot\left[\frac{a\,(250mm)}{f_{ok}} + 1\right]$$ exper

$t = 100, 150, 200\,mm$

$$\Gamma = \frac{t}{f_{ob}}\left[\frac{a}{f_{ok}} + 1\right)$$ the

~~50~~ 0.5 ~~40~~ 0.4 $f_{ob} = 50\,mm$ $f_{ok} = 40\,mm$

~~be β t fs~~

2.5 ~~90mm~~

~~140~~

β	t	f_{ob}	f_{ok}
2.5	100	50	40
4	150	40	40
	200	40	40

$(1.3 \pm 0.06)\cdot 10^{-2}\,mm$

$\boxed{0.2 \pm 0.1}$

Task 3

~~0.3x~~

$0.2x$ $0.3x$

wire grid

width

0.2 ± 0.1

~~x = 0.~~

$x = (1.3 \pm 0.06) \times 10^{-2}$ mm

Task 4

$0.3 < B < 0.6$

$B = 0.45 \pm 0.\cancel{1}5$ mm

Task 1: $\beta = \frac{7}{10}$ $g = 10.2$ cm

$b = 10.5$ cm

$s_1 = \dfrac{10.5 - 10.2}{\frac{10}{7} - \frac{7}{10}} = 0.412$ cm

$s(theo) = 0.4$ cm

g	b	β	s	
10.2	10.5	$\frac{7}{10}$	0.412	
~~9.7~~ 11	~~13~~	~~$\frac{6}{10}$~~	~~0.305~~ 3,09	theo: 0,5
10,3	10,1	0,8	0,644	
11,4	11,1	0,7	0,412	
11,12	11	0,90	~~0,47~~ 0,27	theo 0,4

Task 2: $\cancel{s(theo) = \frac{400mm}{400mm}\left[\frac{250mm}{400mm}\right.}$

$$s(theo_{100}) = \frac{100mm}{50mm}\left[\frac{250mm}{40mm} + 1\right]$$
$$= 2\left[\frac{25}{4} + 1\right] = \cancel{25mm}\ 14{,}5mm$$

$$\cancel{s(theo\,150) = \frac{150}{50}\left[\frac{250}{40} + 1\right]}$$
$$\cancel{= 3\left[\frac{25}{4} + 1\right] = 21{,}75}$$
$$\cancel{s(theo\,200) = \frac{200}{50}\left[\frac{250}{40} + 1\right]}$$
$$\cancel{= 4\left[\frac{25}{4} + 1\right] = 29}$$

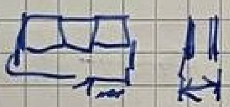
$\delta_{ok} = 40mm$ $a = 20mm$

β_{ob}	t	Γ	
2.5	100	18,125	
4	150	29.	
6	200	43,5	

$$\Gamma_{theo}(150) = \frac{150}{40}\left[\frac{250}{40}+1\right] = 27,188$$

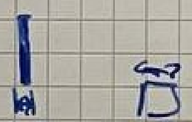
$$\Gamma_{theo}(200) = \frac{200}{40}\left[\frac{250}{40}+1\right] = 36,25$$

3)



3-4

distance b/w mix



Thickness = 0,2 x = ~~1~~ Δ0,1

grid = 0.3 x Δ0.1

4) not visible 0.6>

visible 0.6≤

$x = 0.3$
$y = 0.6$ => $0.3 < B < 0.6$

=> $B = 0,45 \pm 0,15$

7 References

- MIK script