Teachers' hand-out

Student set

Optics 2.0

Propagation of light and formation of shadows

Reflections in mirrors

Light rays for a curved mirror

Refraction and total internal reflection

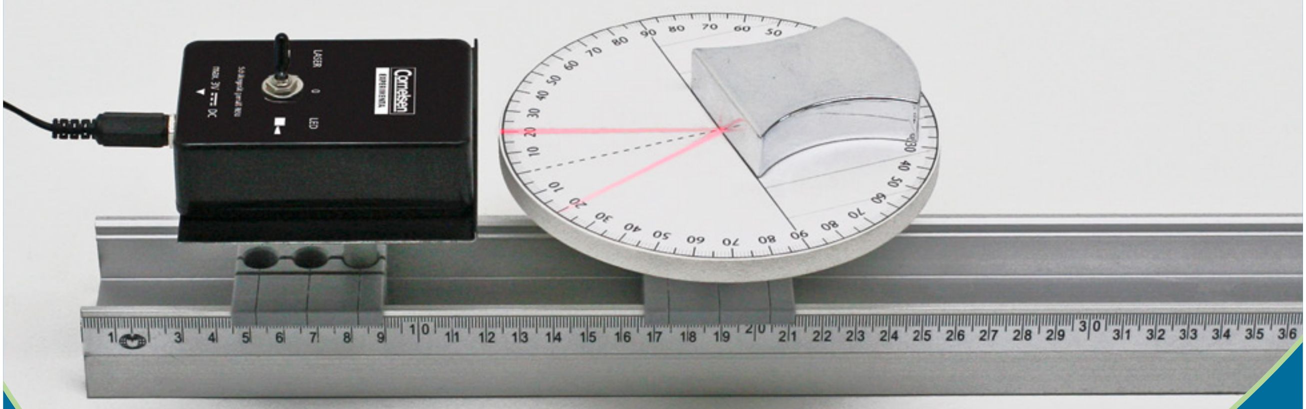
Focal length of a converging lens

Light beams with convex and concave lenses

Lens equation

Dispersion of white light

Optical instruments



Cornelsen
EXPERIMENTA

Student set

Optics 2.0

Order number 47530

Contents

Other Optics topics (e.g. optical functions of the eye, phases of the sun, lunar eclipses and much more) can be found in the following Cornelsen Experimenta products:

Human eye model
Order no. 47030

Tellurium *N*
Order no. 31115

Storage plan / Summary of parts *Optics 2.0* (47530)

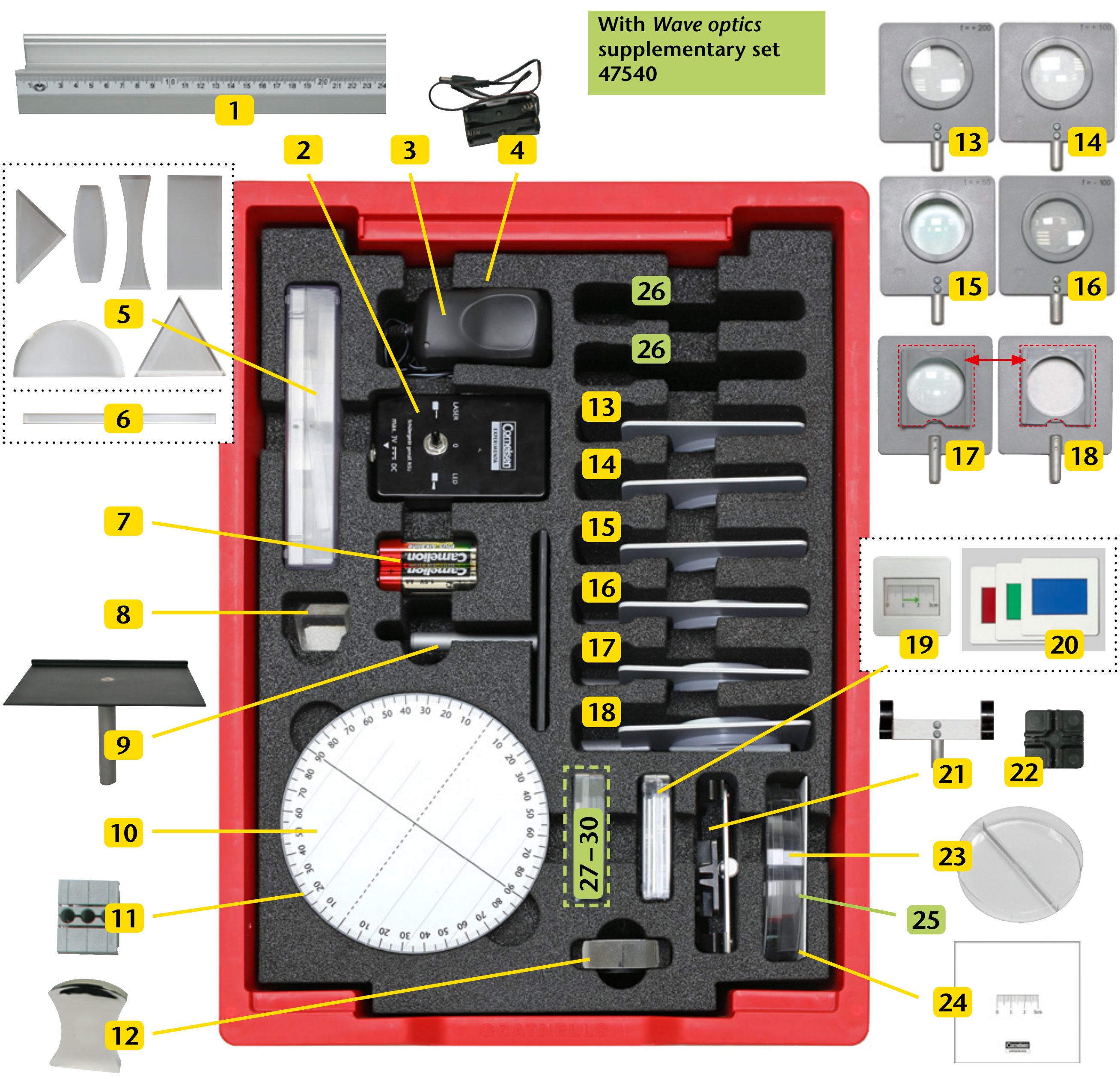


Fig. no.	Qty.	Item description	Order no.
–	1	Set of instructions for "*Optics 2.0*" student set	475306
–	1	Storage plan for "*Optics 2.0*" student set	4753036
1	1	Profile rail, aluminium, 500 mm	40810
2	1	Student lamp LED/LASER	47535
3	1	Plug-in power supply	68534
4	1	Battery holder	475351
5	1	Set of 6 *optical bodies*	47510
6	1	Perspex rod	47511
7		AA batteries, 1.5 V, alkaline, set of 4	51904
8	1	Prism, equilateral, 3 x 60°	47241
9	1	Lamp platform	47536
10	1	Measuring platform	47512
11	5	Clamp sliders	40820
12	1	Universal mirror	47094

Fig. no.	Qty.	Item description	Order no.
13	1	Lens, biconvex, f = +200 mm	47136
14	1	Lens, biconvex, f = +100 mm	47135
15	1	Lens, biconvex, f = +50 mm	47134
16	1	Lens, biconcave, f = –100 mm	47138
17	1	Condenser lens	475151
18	1	Apertures and slide holder	47517
19	1	*Slide scale*	47410
20	1	Colour filter, primary colours: red, green, blue,	47045
21	1	Screen and mirror holder	47256
22	1	Stand, black	13707
23	1	Petri dish with central ridge	17715
24	1	Screen, white, with scale	13733

Additionally required:
Opaque bodies (eraser, sharpener etc.), ruler (30 cm), water

Summary of parts *Wave optics supplementary set (47540)*

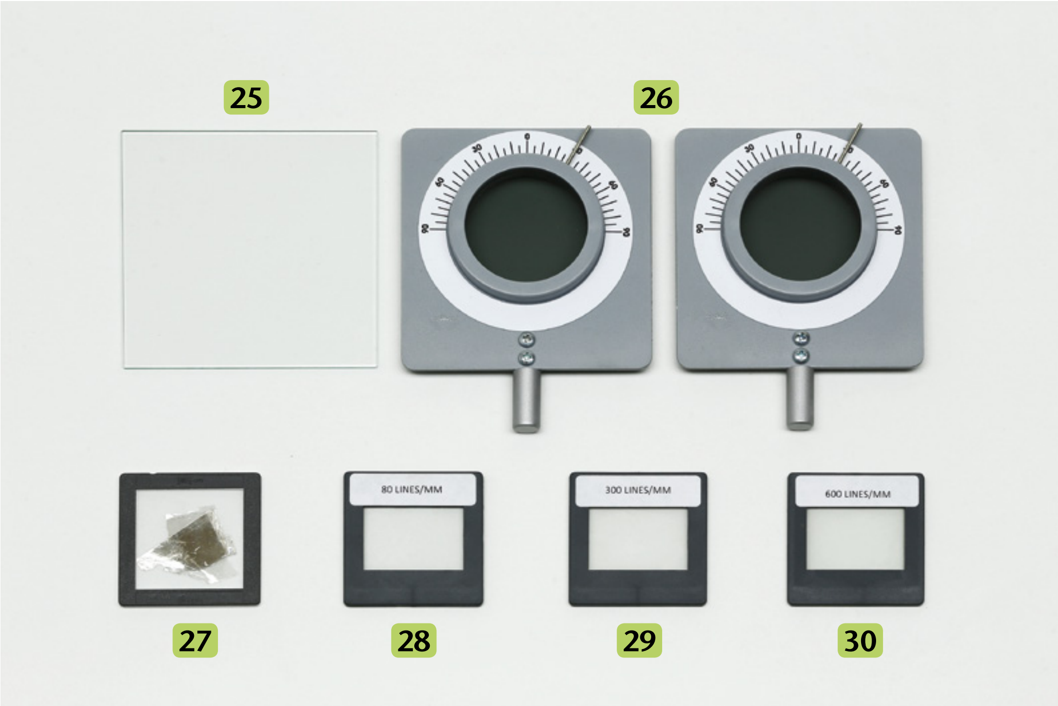
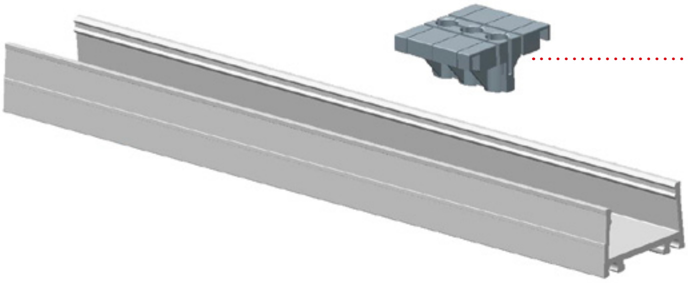


Fig. no.	Qty.	Item description	Order no..
25	1	Screen, plain glass	47065
26	1	Pair of polarisation filters with scale	47282
27	1	Slice of mica in slide frame	47407
28	1	Line grating, 80 lines / mm	47285
29	1	Line grating, 300 lines / mm	47282
30	1	Line grating, 600 lines / mm	47283

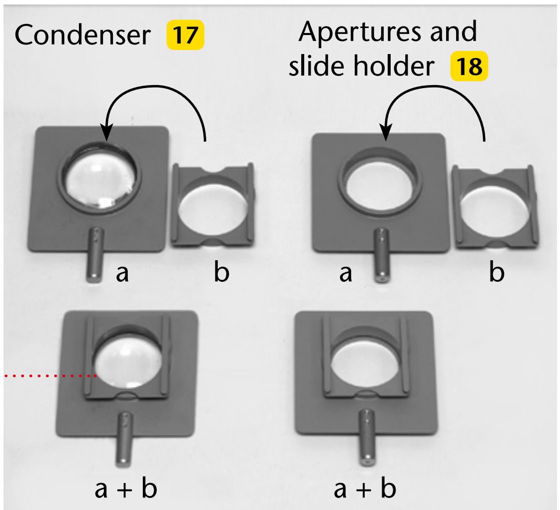
The **clamp sliders** 11 can be placed at any position along the profile rail. Their purpose is to accommodate and secure the stand rods.

The three sockets in the clamp sliders have different ways of clamping the rods.
When selecting the socket, make sure that the rod is pushed all the way into the socket and is held firmly.



The **apertures and slide holder** 18 and the **condenser** 17 with its apertures and slide holder are composed of two parts (a and b).

The holder (b) is only provided once in each box and can be swapped between parts 17 and 18 as needed.



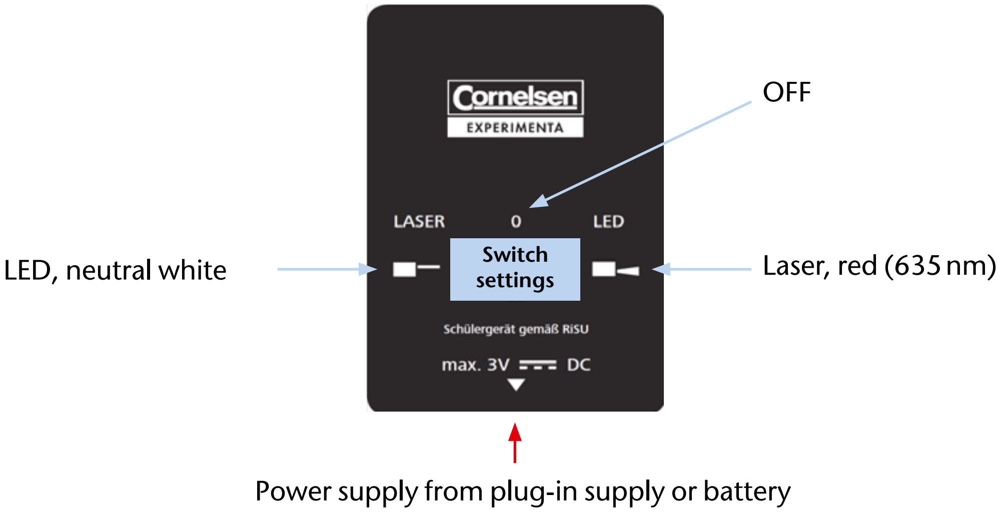
Notes on the hazards of the student lamps

The student lamps emit either white LED light or red laser light. It is possible to select between the two. They are both certified in the lowest protection class for their type, meaning that they conform to **risk group RG0** as per DIN EN 62471 and **laser protection class 1** as per DIN EN 60825.

- Operation of the lamps by students **does not require supervision of a teacher**.
- The area where experiments are taking place **do not need to be labelled** with laser warning signs **or cordoned off against unintentional entry**.
- Use of optically converging components (e.g. magnifying glasses, convex lenses) is permitted.

We recommend teaching students about the risks to their eyes from laser light before setting up and carrying out any experiments. They should be prohibited from looking directly into the laser beam or the LED, even if this is permissible at distances greater than the certified limit of 50 mm.

* The certificate can be requested in digital format from info@cornelsen-experimenta.de

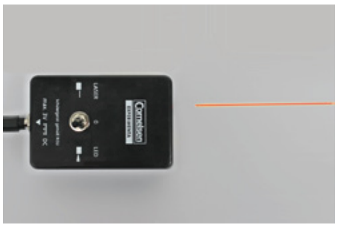


Instructions for use

The student lamps require a DC supply of 3 V. They can either be operated from batteries or the plug-in power supply provided. Switches allow you to swap between LED and laser modes.

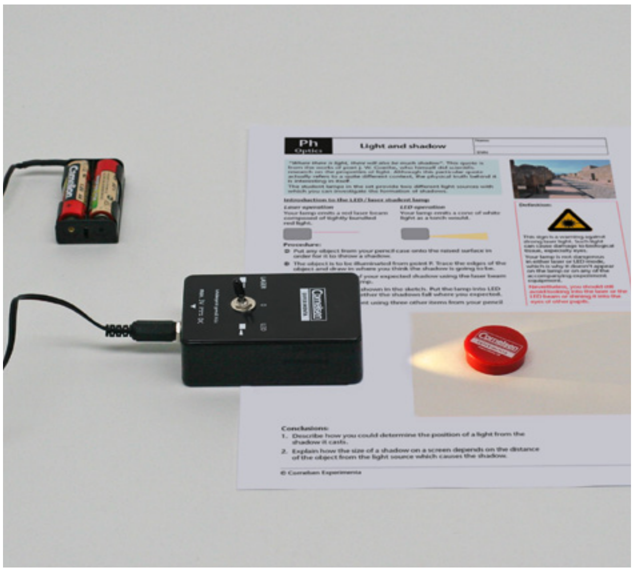
The laser only develops its maximum light output at temperatures below 40°C. When switching the student lamps from LED to laser modes, it is therefore necessary to be careful and plan for 5 minutes of cooling time for the LED to cool to room temperature.

The lamps themselves and their batteries supplies are magnetic so that they can be attached to the lamp platform or also to metal boards. The lamps are also suitable for the workbook optics experiments.



Op 1.1 Light and shadow

You can use the laser and LED light from your student lamp along with the accompanying worksheet to investigate the formation of shadows with the help of light ray models in workbook optics experiments.



Equipment

LED / laser student lamp 2
Light and shadow worksheet

Additionally required:
Ruler (30 cm)
Objects to throw shadows (eraser, sharpener, etc.)

Experiment procedure

At the start of this introductory experiment, students should be taught about safety. Even though both light sources are certified according to safety guidelines and are allowed to be used by students, looking directly at a laser diode or even an LED should be avoided in principle. An information panel with an appropriate warning is printed on the worksheet and is very suitable for use in instruction. When changing from LED to laser mode, it should be noted that the laser only develops its full brightness at temperatures below 40° C.
The experiments procedure starts with the positioning of an opaque body suitable for throwing a shadow (rubber eraser, pen cap, pencil sharpener, etc.) on the raised surface. Then you should trace the outlines of the object on the worksheet and the area you would expect to be in shadow when the body is illuminated by light from a point *P*.
The next thing is to check the limits of the shadow using laser light.
For the last step, the lamp is to be placed on the previously traced outline. Since *P* corresponds to the position of the LED inside the lamp, checking your expectations will only work with the lamp in LED mode.

Conclusions

This experiment focuses on discovering that light propagates in straight lines and thus forms shadows. While the LED does represent a very good approximate of a point light source, the narrow light beam from a laser can be treated as a light ray. Switching between the two light sources therefore offers the optimum requirements for experimental derivation of the optical ray model.
Observation of shadows leads to the understanding that projected shadows get bigger when the body throwing the shadow moves closer to the source of the light. The position of the point light source is the point where the shadow outlines all intersect and can be found by geometrically tracing the outlines back to source.
Since the LED is not actually a single point but covers a certain area, the shadows become less sharply defined as the distance from the light source decreases.
If opacity is to be determined as a specific property of a body, it is also recommended that shadows thrown by a transparent body be viewed. Also, more advanced students can get together in suitable groups to observe shadows thrown by light from multiple sources.

Supplementary to this experiment:

Light and shadow worksheet (page 9)

Light and shadow

Name
Date

"Where there is light, there will also be much shadow". This quote is from the works of poet J. W. Goethe, who himself did scientific research on the properties of light. Although this particular quote actually refers to a quite different context, the physical truth behind it is interesting in itself.

The student lamps in the set provide two different light sources with which you can investigate the formation of shadows.

Definition:

This sign is a warning against strong laser light. Such light can cause damage to biological tissue, especially eyes.

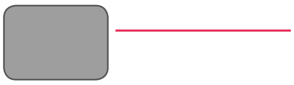
Your lamp is not dangerous in either laser or LED mode, which is why it doesn't appear on the lamp or on any of the accompanying experiment equipment.

Nevertheless, you should still avoid looking into the laser or the LED beam or shining it into the eyes of other pupils.

Introduction to the LED / laser student lamp

Laser operation

Your lamp emits a red laser beam composed of tightly bundled red light.

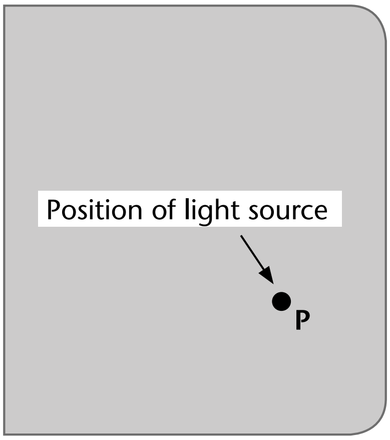


LED operation

Your lamp emits a cone of white light as a torch would.

Procedure:

- Put any object from your pencil case onto the raised surface in order for it to throw a shadow.
- The object is to be illuminated from point P. Trace the edges of the object and draw in where you think the shadow is going to be.
- Check the outlines of your expected shadow using the laser beam from your student lamp.
- Position the lamp as shown in the sketch. Put the lamp into LED mode and check whether the shadows fall where you expected.
- Repeat the experiment using three other items from your pencil case.

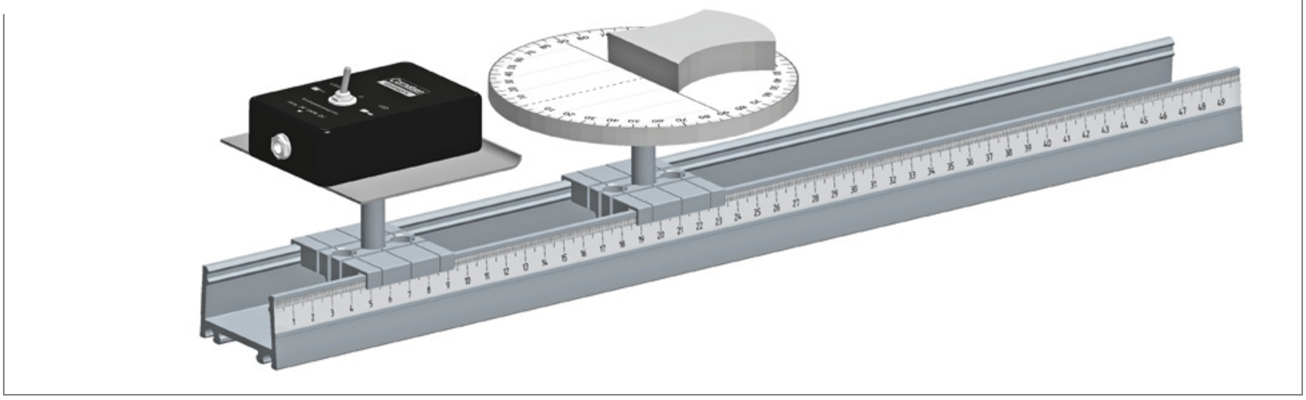


Conclusions:

1. Describe how you could determine the position of a light from the shadow it casts.
2. Explain how the size of a shadow on a screen depends on the distance of the object from the light source which causes the shadow.

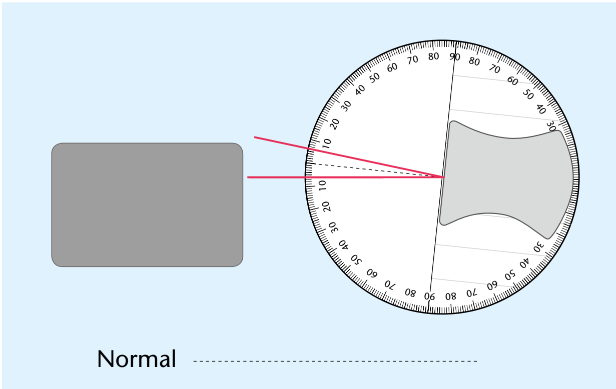
Op 1.2 Law of reflection

The expectation of a *law of reflection* is to be investigated using the laser in the student lamp.



Equipment

Profile rail 1
LED / laser student lamp 2
Lamp platform......................... 9
Measurement platform 10
Clamp sliders..............(2 x) ... 11
Universal mirror..................... 12



Experiment procedure

When you set up the experiment, you should pick a distance between the measurement platform and the lamp which results in the whole of the optical axis of the measurement platform being illuminated. The mirror is aligned with its flat side along a line across the diameter such that it is perpendicular to the dotted line along the optical axis.

The experiment then involves turning the measurement platform in order to change the angle of incidence α. For each new incident angle, the angle of reflection α' should then be measured.

You should be able to calculate whether the mirror is correctly situated from the first pair of results.

Conclusions

The measurements indicate the law of reflection

$$\alpha = \alpha'.$$

The law of reflection is valid for every single point on a curved mirror as well. This can be demonstrated using the curved surface of the universal mirror. The normal for the reflection law should coincide with a normal to the surface of the mirror at the point where the light ray strikes it.

If the mirror is placed on squared paper with its flat side facing the light, the mirror law can also be demonstrated. *"A mirror image is formed as far behind the mirror surface as the object being reflected is in front of it."* The symmetry between the original object and the mirror image can also be seen.

α	0	10	20	30	40	50	60	70	80
α'	0	10	20	30	40	50	60	70	80

Supplementary to this experiment:

Law of reflection worksheet (page 11)

Law of reflection

Name

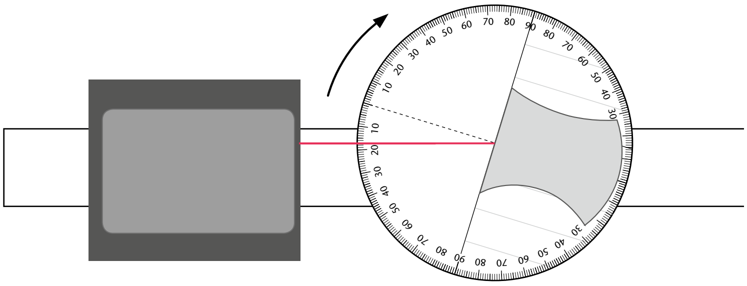
Date

We can use mirrors to see things which are not in our direct line of view or which are obscured by other objects. To choose the right size and position for a mirror, we need to know how an incident light beam is reflected.

Reflections from a plane mirror

Procedure/measurements:

- Write down what you expect the relationship to be between the angle of incidence and the angle of reflection.
- Set up the experiment as in the diagram.

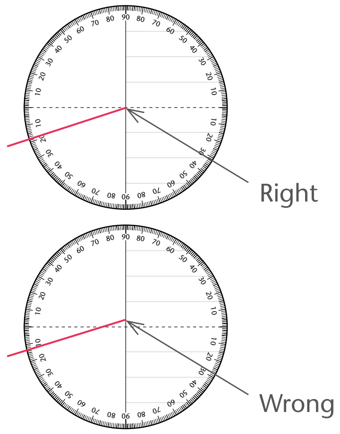


- Draw the reflected ray on the above diagram, label the angle of incidence α, the angle of reflection α' and the normal.
- Turn the measurement platform and measure the angles of reflection corresponding to angles of incidence from 0° to 80°. Enter your results into a table of measurements.

Angle of incidence α	0	10	20	...	70	80
Angle of reflection α'						

Take care when measuring

The laser needs to strike the start of the normal precisely.



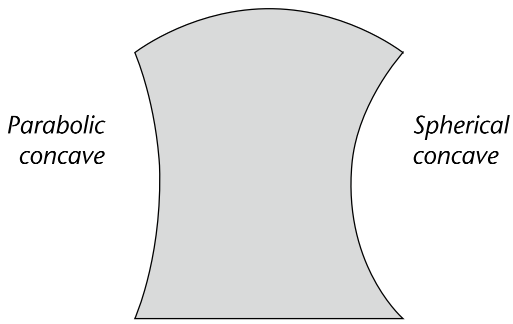
Conclusions:

1. Check to see if your expectations were confirmed.
2. Express your results in a sentence of your own and as a mathematical formula.

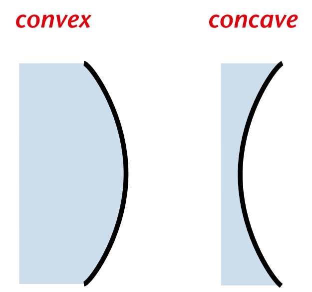
Reflection from curved mirrors

Exercise:

- Check whether the law of reflection also applies for mirrors of the following shapes.



Definitions:

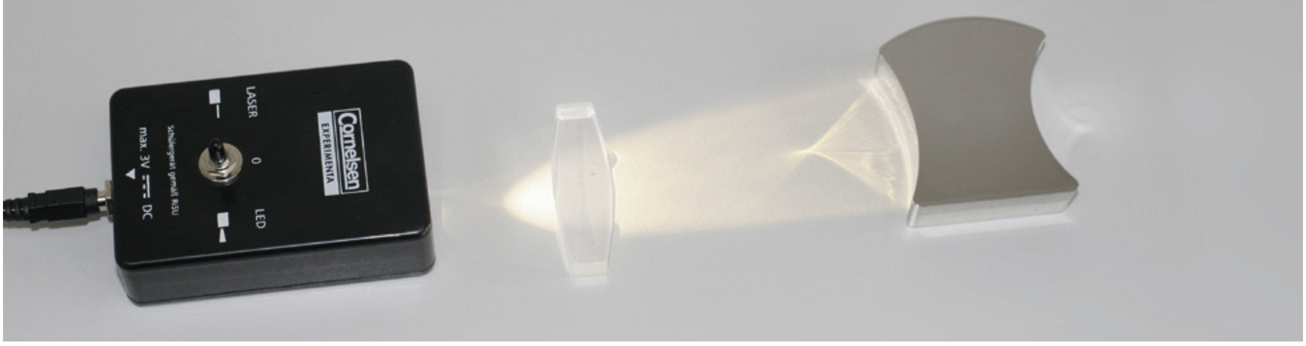


Spherical: *circular*

Plane: *flat*

Op 1.3 Curved mirrors

The light in a parallel beam is reflected by convex spherical, concave spherical and concave parabolic surfaces in a series of workbook optics experiments.

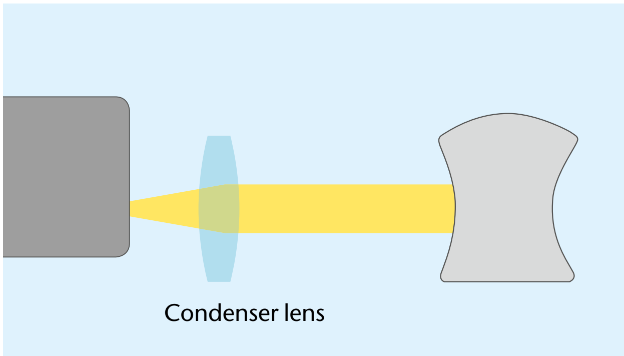


Equipment

LED / laser student lamp 2
Set of *optical bodies* 5
Universal mirror 12

Experiment procedure

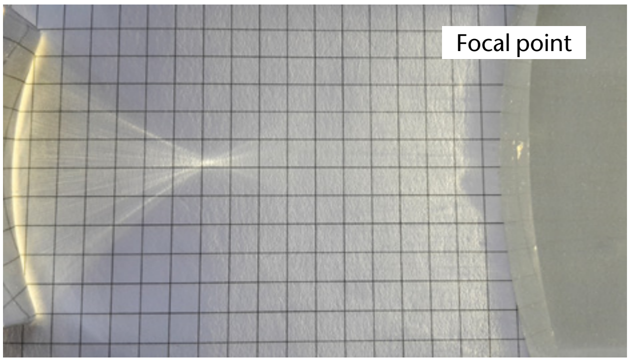
Use the lens object to generate a parallel light beam. Then you should check whether the three shapes of mirror cause the light to converge or diverge on reflection.

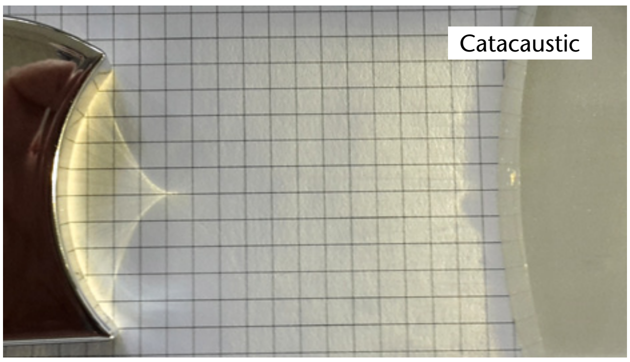


Conclusions

The two concave mirror shapes focus the light in different ways.
Whereas the parabolic mirror focuses the light to a clear focal point, the spherical concave mirror reflects the light along a so-called caustic without any visible point of maximum brightness.
The shapes of the reflections differ markedly as well. Whereas the outer edges of the reflection from a parabolic mirror are straight lines, the edges of the catacaustic from the spherical mirror are decidedly curved.

If parallel light is to be concentrated by a mirror to a specific point, then a parabolic mirror is best suited to the job.





Supplementary to this experiment:

Curved mirrors worksheet (page 13)

Curved mirrors

Name

Date

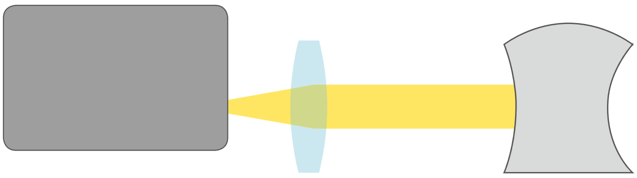
Curved mirrors are often used to make parallel light beams converge or diverge. They have an advantage over lenses in that they hardly dim the light at all.

Curved mirrors help to maintain traffic safety.

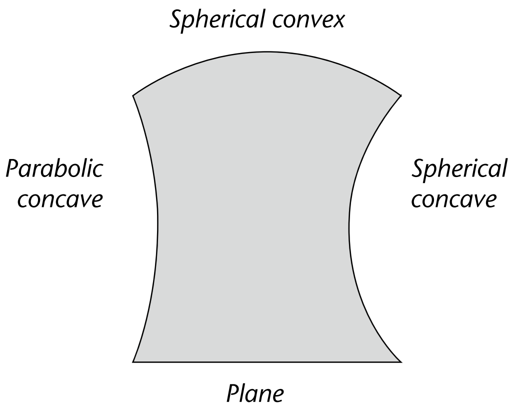
Reflection from curved mirrors

Procedure / measurements:

➲ Generate a parallel beam as shown in the diagram.

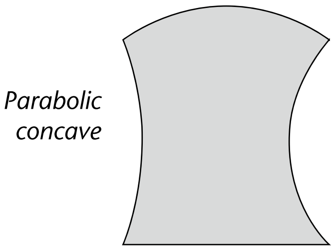


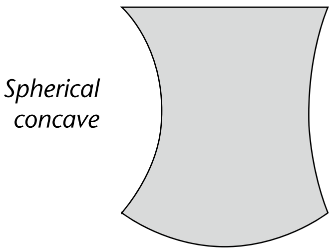
Mirror shapes:



➲ Guess whether the three mirror surfaces will cause a parallel light beam to converge or diverge.

➲ Sketch your observations for the parabolic and spherical curved concave mirrors.



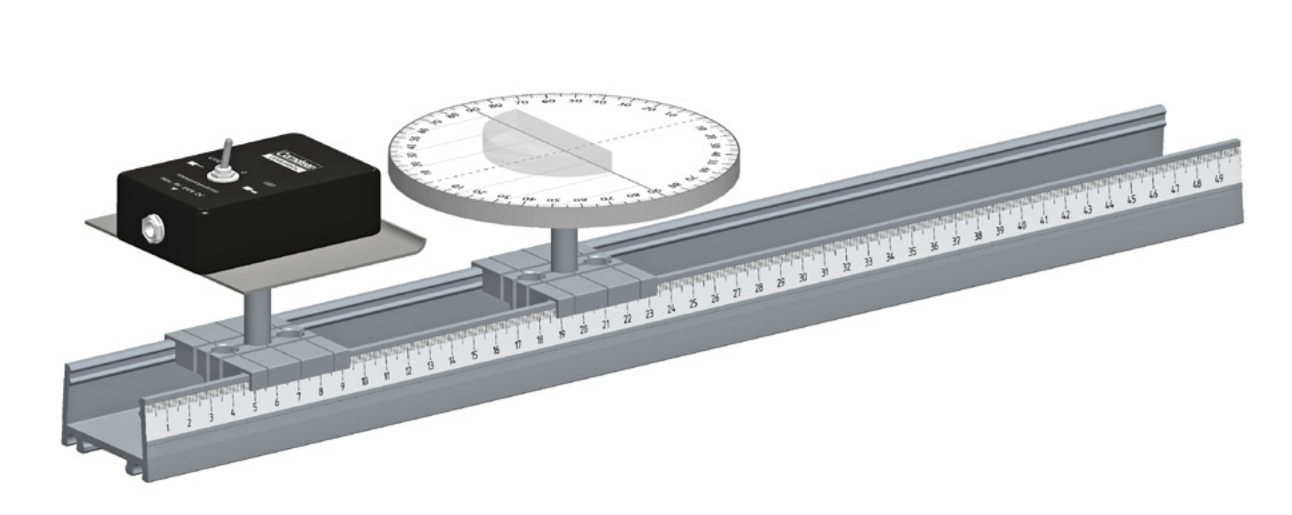


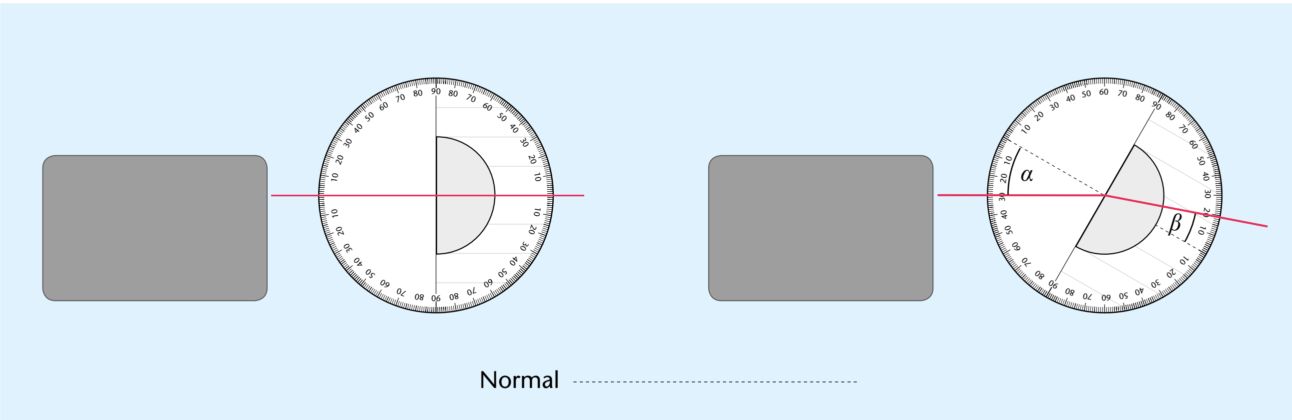
Conclusions:

1. Describe the difference between the two observations.
2. Discuss which of the two concave mirrors is better at concentrating the light.

Op 1.4 Snell's law of refraction

An investigation is to be made of what happens when light moves from air into glass. You should thereby discover *Snell's law of refraction* and experimentally determine the refractive index for light moving from air to glass.





Equipment

Profile rail 1
LED / laser student lamp 2
Set of *optical bodies* 5
Lamp platform......................... 9
Measurement platform 10
Clamp sliders ....(2 x) ... 11

Experiment procedure

When you set up the experiment, you should pick a distance between the measurement platform and the lamp which results in the whole of the optical axis of the measurement platform being illuminated.
Align the semi-circular glass body with its straight side along the diameter line such that the flat surface is perpendicular to the dotted line marking the optical axis. Check that the glass body is in the correct alignment before starting any measurements.

If the lamp and the glass body are properly aligned, the laser will shine through the glass body wholly along the optical without being refracted.

The experiment then involves turning the measurement platform to vary the angle of incidence α and then measuring the angle of refraction β.

Conclusions

The average of the quotients from the measurements results in the refractive index:

$$n_{\text{Air}\to\text{glass}} = \frac{\sin(\alpha)}{\sin(\beta)} \cong 1.55.$$

This represents a good approximation of the ratio between the speeds of light in the various media

$$\frac{c_{\text{Air}}}{c_{\text{Glass}}} = \frac{299711\ \text{km/s}}{190000\ \text{km/s}} \cong 1.57.$$

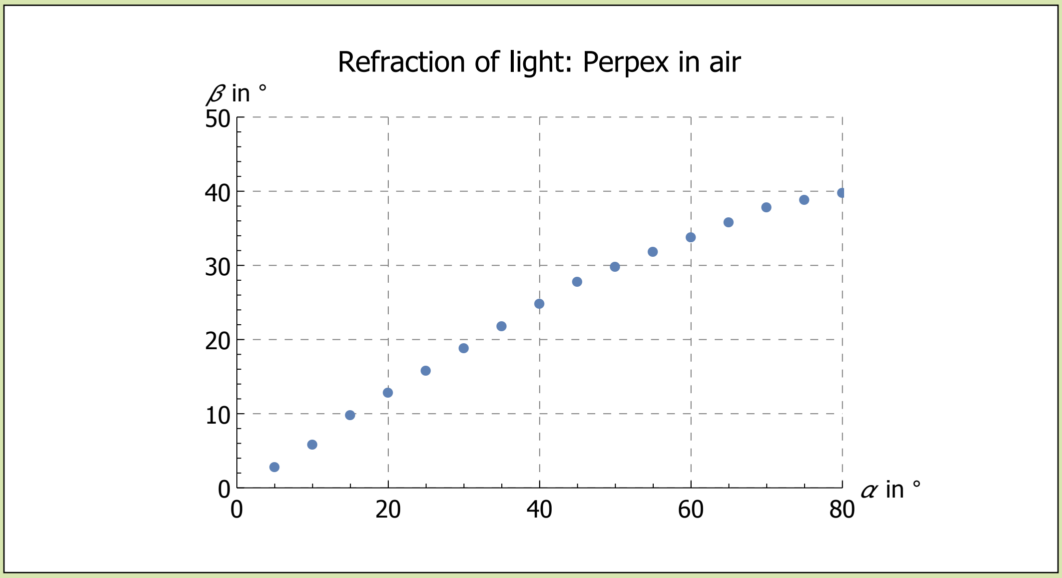
Snell's law of refraction can also be deduced from the results.

$$\frac{\sin(\alpha)}{\sin(\beta)} = \frac{c_1}{c_2} = n_{1\to2}$$

Advanced students can study whether there is a direct relationship between the density and the speed of light in a substance.
Here a comparison between water (1 g/cm^3), diamond (3.53 g/cm^3), glass (2.5 g/cm^3) and cooking oil (0.9 g/cm^3 shows that no such relationship exists.

$$\overline{n}_{\text{Air}\to\text{glass}} = \frac{1}{K}\sum_{k=1}^{K}\frac{\sin(\alpha_k)}{\sin(\beta_k)}$$

α	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
β	3	6	10	13	16	19	22	25	28	30	32	34	36	38	39	40
$\sin(\alpha)/\sin(\beta)$	1.67	1.66	1.49	1.52	1.53	1.54	1.53	1.52	1.51	1.53	1.55	1.55	1.54	1.53	1.53	1.53



Supplementary to this experiment:

Snell's law of refraction worksheet (page 16)

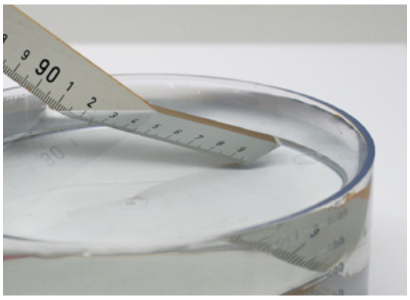
Ph
Optics

Snell's law of refraction

Name

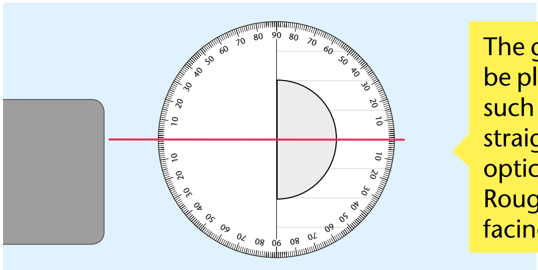
Date

When a ruler is held in water, it appears to bend at the water's surface. The reason for this is refraction of light, which this experiment will investigate.

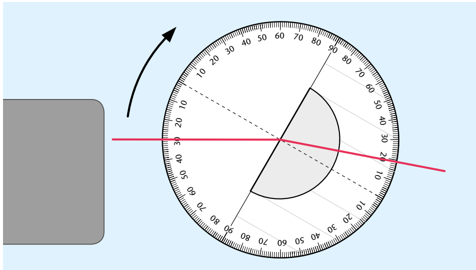


Procedure / measurements:

➲ Set up the experiment as in the diagram.



The glass body needs to be placed on the platform such that the laser shines straight along the optical axis.
Rough side should be facing down



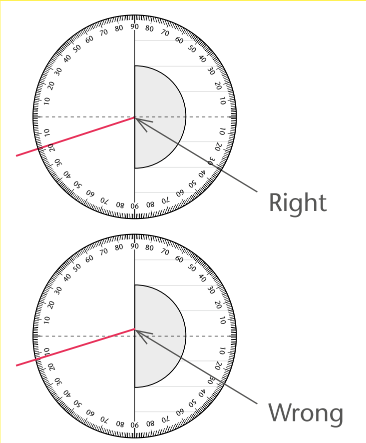
➲ In the illustration on the right, label the angle of incidence α, the angle of refraction β and the normal.

➲ Turn the measurement platform and measure the angle of refraction for six different angles of incidence. Enter your results in the table below.

Angle of incidence α						
Angle of refraction β						
$\sin(\alpha) / \sin(\beta)$						

Take care when measuring

The laser needs to strike the start of the normal precisely.



Conclusions:

1. For each pair of measurements, calculate the quotient $\sin(\alpha) / \sin(\beta)$ and enter the results into the third row of the table.
2. Calculate the average of the quotients.

3. Investigate how this quotient relates to the ratio of the speeds of light in air and glass.
4. *Snell's law of refraction* links the sines of the incident and refracted angles with the speeds of light in the respective media. Derive a formula for this law from your results in exercise 3.

Table of light speeds c

Medium	c in km/s
Air	299711
Water	225000
Diamond	125000
Glass	190000
Cooking oil	203000
Vacuum	299792

Op 1.5 Fermat's principle

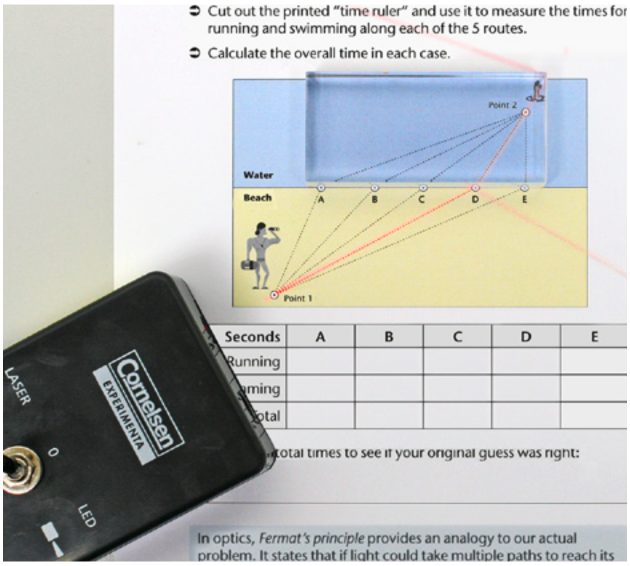
Now you will derive Fermat's principle in a worksheet optics experiment.

Equipment

LED / laser student lamp 2
Fermat's principle worksheet

Experiment procedure

Fermat's principle states that light if there are multiple paths which can be taken by light, the one the light actually follows will be the one which takes the most extreme time (usually the shortest time) to travel. On your worksheet this is exemplified by a rescue swimmer who has to help someone drowning as quickly as possible. First you need to guess which of the five possible routes from the beach to the water will represent the quickest route overall. This is measured by a "time ruler".
To find the time it will take to run or swim the various routes, you lay the "time ruler" beside it with the appropriate scaling.



When doing this experiment, you must take care to ensure the worksheet is lying flat on the table.

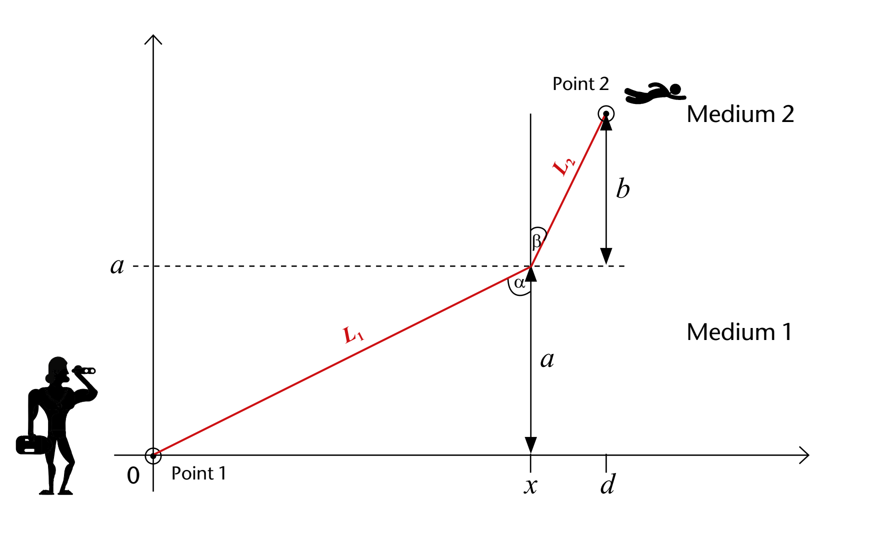
Conclusions

If you add up the overall times for each route, route **D** turns out to be the quickest. If you put the rectangular block over the water area, you can observe with the help of the laser that light takes the same route as the rescue swimmer.
There are other beams in the experiment, though, which arise through unwanted boundary effects. It is necessary to draw attention to the refracted beam which is of interest. Recognition of this can be used as an introduction to basing refraction of light on *Fermat's principle*.

Supplementary to this experiment:

Fermat's principle worksheet (page 16)

Fermat's principle as a maths lesson



$T(x) \triangleq$ „Total time as a function of water entry point x“

$$T(x) = t_1(x) + t_2(x)$$

If c_1 and c_2 are the speeds of light in the respective media as defined by

$$\Rightarrow T(x) = \frac{L_1(x)}{c_1} + \frac{L_2(x)}{c_2}$$

Use Pythagoras's theorem to work out the two distances.

$$\Rightarrow T(x) = \frac{\sqrt{x^2+a^2}}{c_1} + \frac{\sqrt{(d-x)^2+b^2}}{c_2}$$

Fermat's principle seeks out the minimum time as a function of x

$$\frac{dT(x)}{dx} = 0$$

Using the derivation rule from the analysis

$$\Rightarrow \frac{2x}{2c_1\sqrt{x^2+a^2}} + \frac{2(d-x)(-1)}{2c_2\sqrt{(d-x)^2+b^2}} = 0$$

This can be simplified

$$\Rightarrow \frac{x}{c_1\sqrt{x^2+a^2}} - \frac{(d-x)}{c_2\sqrt{(d-x)^2+b^2}} = 0$$

If $x = L_1 \sin(\alpha) = \sqrt{x^2+a^2}\,\sin(\alpha)$ and $(d-x) = L_2 \sin(\beta) = \sqrt{(d-x)^2+b^2}\,\sin(\beta)$

$$\Rightarrow \frac{\sqrt{x^2+a^2}\sin(\alpha)}{c_1\sqrt{x^2+a^2}} - \frac{\sqrt{(d-x)^2+b^2}\sin(\beta)}{c_2\sqrt{(d-x)^2+b^2}} = 0$$

By elimination and rearrangement, you eventually arrive at *Snell's law of refraction*

$$\Rightarrow \frac{\sin(\alpha)}{c_1} - \frac{\sin(\beta)}{c_2} = 0$$

$$\frac{\sin(\alpha)}{c_1} = \frac{\sin(\beta)}{c_2}$$

Fermat's principle

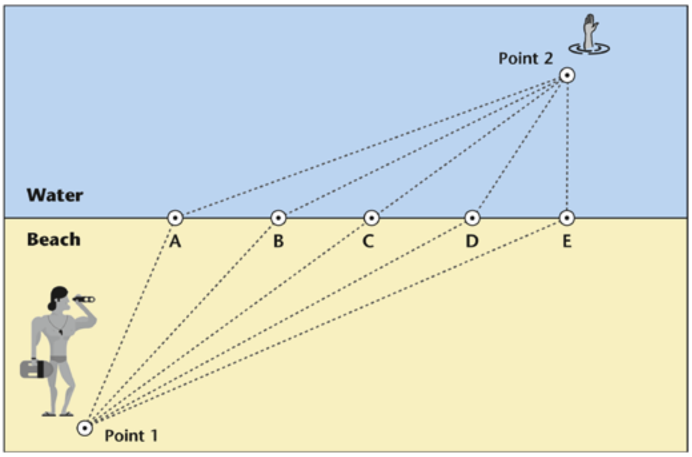
Name

Date

A coast guard rescue swimmer discovers a drowning person and wants to reach them by the quickest route. Since it is quicker to run than swim, it is necessary to find the best mixture of running and swimming to arrive at the quickest route, i.e. he has to find the best place to dive into the water from the beach.
Which route would you suggest?

➲ Cut out the printed "time ruler" and use it to measure the times for running and swimming along each of the 5 routes.

➲ Calculate the overall time in each case.



Seconds	A	B	C	D	E
Running					
Swimming					
Total					

➲ Check the total times to see if your original guess was right:

In optics, *Fermat's principle* provides an analogy to our actual problem. It states that if light could take multiple paths to reach its destination, the route it actually will take will be the quickest one.

Conclusions:

1. Show experimentally that a ray of red light takes the same route as the swimmer. Put the rectangular block on the page with its right-hand edge at the edge of the water (rough surface facing down) and see which route the laser beam takes from Point 1 to Point 2.
2. Explain your observations in exercise 1 by means of Fermat's principle.
3. In a medium with low optical depth, light travels faster than in one with higher optical depth. Use the example of air and perspex (which has an optical depth similar to glass) and discuss which of the two has the greater or smaller optical depth.

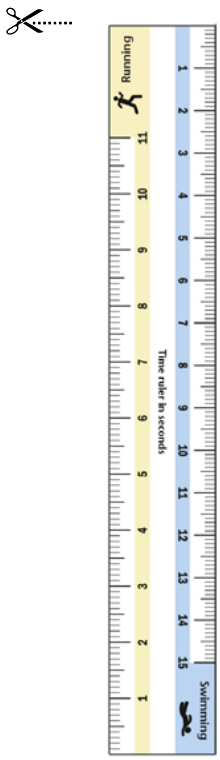
History: Fermat's place in mathematics

Pierre de Fermat (1607–1665)

Fermat was a **French mathematician** who made many contributions to mathematical knowledge. His correspondence with **Blaise Pascal** may be regarded as the very start of **probability theory**. He is perhaps best known for **"Fermat's last theorem"**, which states that the equation

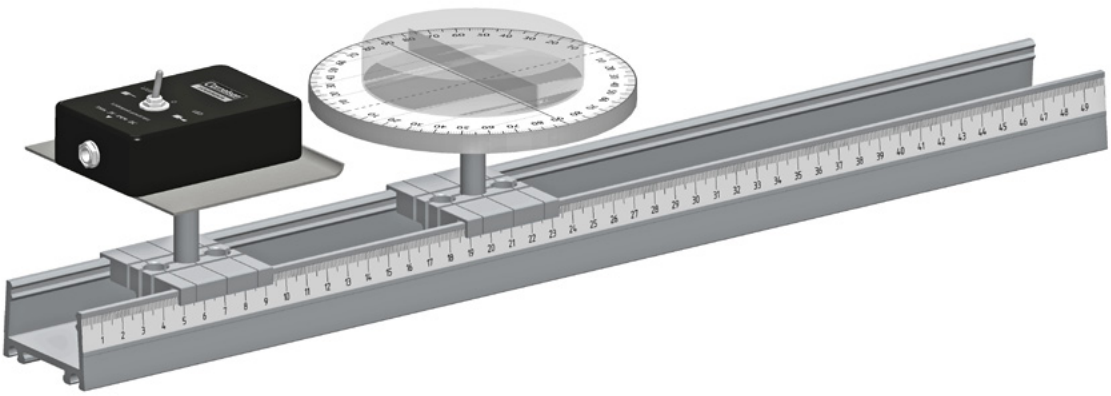
$$a^n + b^n = c^n$$

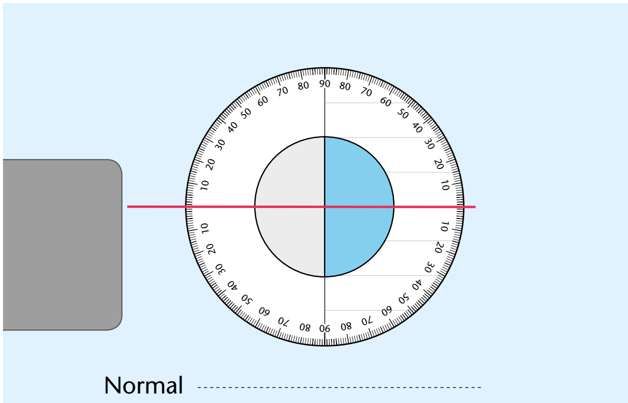
has no solution for natural numbers a, b and c if n > 2.

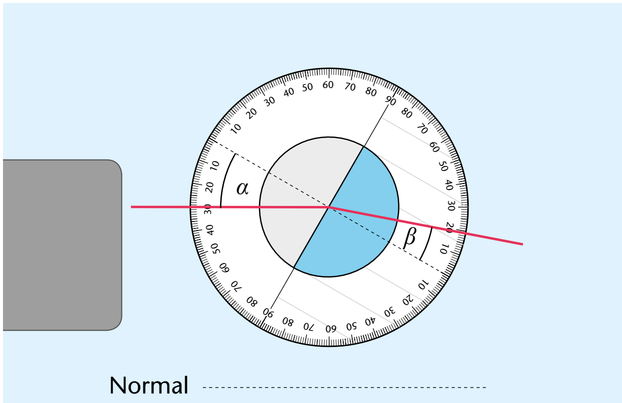


Op 1.6 Refraction and total internal reflection in water

An investigation is to be made of the transition of light from air to water. The refractive index of water and the critical angle for total internal reflection will both be determined.







Equipment

Profile rail 1
LED / laser student lamp 2
Lamp platform......................... 9
Measurement platform 10
Clamp sliders...............(2 x) ... 11
Petri dish with central ridge ... 23

Additionally required: Water

Experiment procedure

Put the petri dish onto the angle scale of the measurement platform as shown in the illustration and fill the right half of it with water. While doing this, make sure that the laser beam is not refracted by the petri dish and goes all the way along the optical axis.

Turn the measurement platform to vary the angle of incidence α and measure the corresponding angle of refraction β. If the refracted beam in the water gets too weak to see, adding a drop of condensed milk to the water can make it much clearer.

Conclusions

The average value for the refractive index obtained from the measurements is:

$$n_{\text{Air}\rightarrow\text{Water}} = \frac{\sin(\alpha)}{\sin(\beta)} \cong 1.36.$$

This value is a little bit higher than the value quoted in tables for pure water (1.33), but is nevertheless still plausible.
Comparing the trend line in the graph with the measurement points entered clearly demonstrates

the non-linear relationship between the angle of incidence and the angle of refraction. Determining from the graph the critical angle for total internal reflection between air and water gives the answer:

$$\beta_{crit} \approx 46° \,.$$

To derive the critical angle, substitute the refractive index you have measured, e.g. n = 1.36, and the angle of incidence 90° into Snell's law of refraction:

$$n = \frac{\sin(\alpha)}{\sin(\beta)}$$

This results in the following

$$1.36 = \frac{\sin(90)}{\sin(\beta_{crit})} \,.$$

By simplifying (sin (90°) = 1) and rearranging

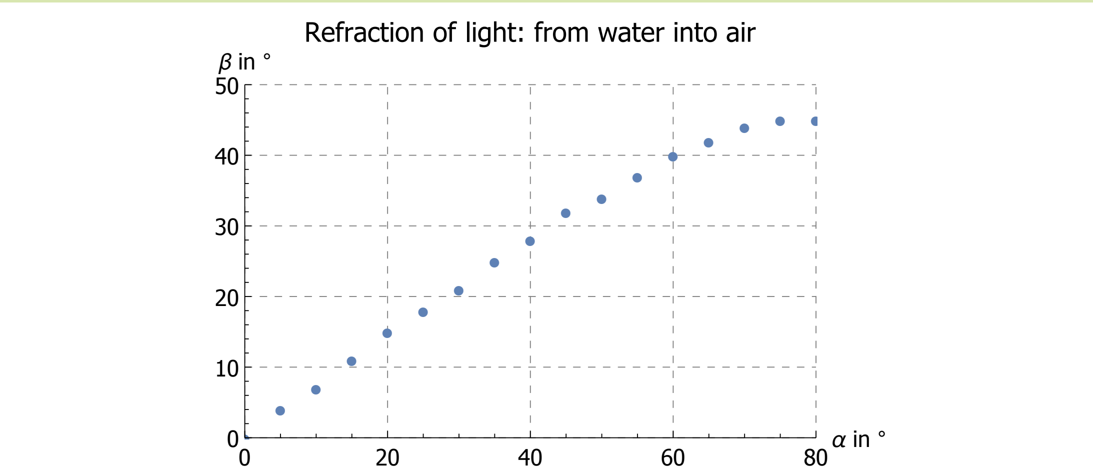
$$\beta_{crit} = \sin^{-1}\left(\frac{1}{1.36}\right)$$

the critical angle is obtained.

$$\beta_{crit} \approx 47°$$

This value agrees very well with the one obtained from the graph and can be verified in a follow-up experiment.
Advanced students can also determine the refractive index of another fluid (e.g. cooking oil or brine) or the refractive index between two fluids.

α	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
β	4	7	11	15	18	21	25	28	32	34	37	40	42	44	45	45
$\sin(\alpha)/\sin(\beta)$	1.25	1.42	1.36	1.32	1.37	1.40	1.36	1.37	1.33	1.37	1.36	1.35	1.35	1.35	1.37	1.39



Supplementary to this experiment:

Refraction of light in water worksheet (page 22)

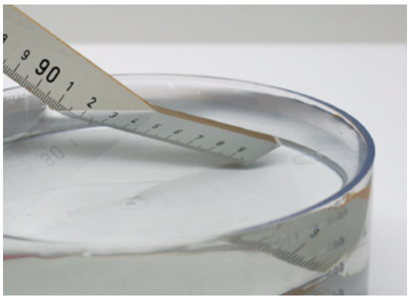
Ph Optics

Refraction of light in water

Name

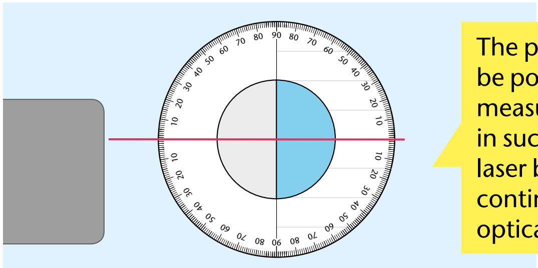
Date

When a ruler is held in water, it appears to bend at the water's surface. The reason for this is refraction of light, which this experiment will investigate.

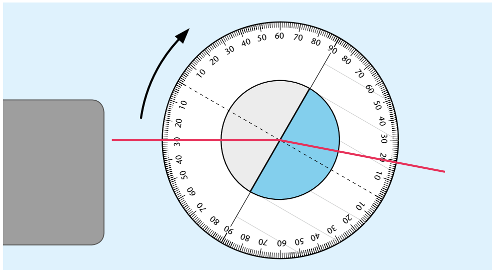


Procedure / measurements:

➲ Set up the experiment as in the diagram. Fill the right-hand side of the petri dish with water.



The petri dish needs to be positioned on the measurement platform in such a way that the laser beam strikes it and continues along the optical axis.



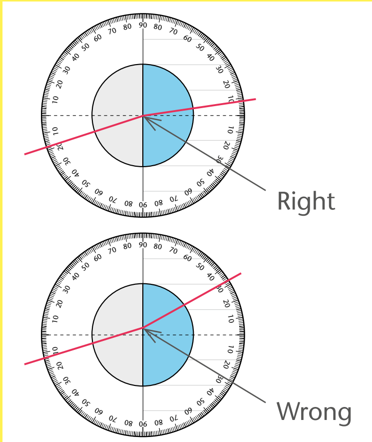
➲ In the diagram on the right, label the angle of incidence α, the angle of refraction β and the normal.

➲ Turn the measurement platform and measure the angles of refraction corresponding to angles of incidence from 0° to 80°. Enter the results into the table of measurements below.

Angle of incidence α	0	5	15	...	75	85
Angle of refraction β						
$n_{\text{Water}\rightarrow\text{Air}} = \sin(\alpha) / \sin(\beta)$						

Take care when measuring

The laser needs to strike the start of the normal precisely.



Conclusions:

1. For each pair of measurements, calculate the refractive index for light passing from water into air.
2. Calculate the average value of the refractive index and compare with the value quoted in table.
3. Plot a graph of angle of incidence against angle of refraction.
4. Interpret the graph considering the range of values of the angle of refraction.
5. Read about *critical angle* in your textbook.
6. Determine the critical angle experimentally using your experiment set-up and plot the results on your graph.
7. Calculate the critical angle with the help of the refractive index and Snell's law of refraction

Table of refractive indices

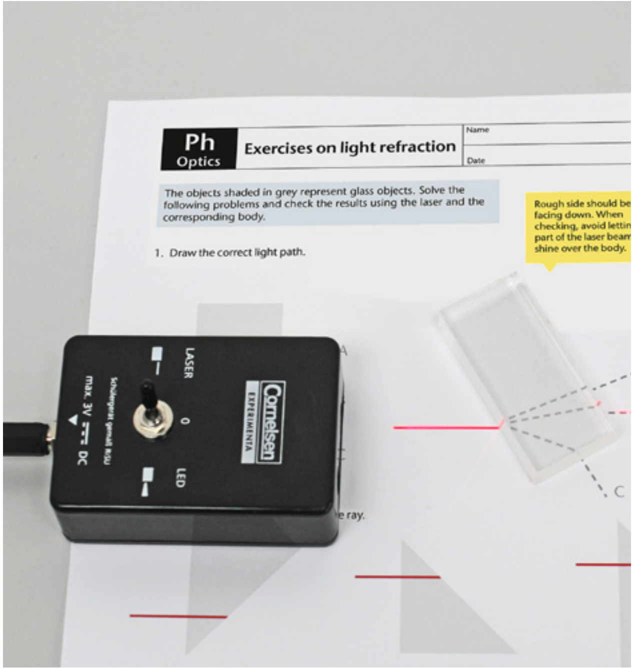
Medium	n
Air	1.000292
Water	1.33
Diamond	2.42
Glass	1.46 ... 1.65
Cooking oil	1.47
Vacuum	Exactly 1

To reiterate

Snell's law of refraction: $n = \frac{\sin(\alpha)}{\sin(\beta)}$

Op 1.7 Exercises: Refraction

Refraction of light in various bodies will be constructed in a workbook experiment and then checked using the laser light from the student lamp.



Equipment

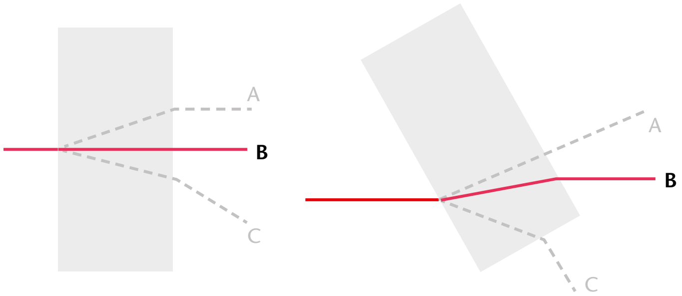
LED / laser student lamp........... 2
Set of *optical bodies* 5
Worksheet *Exercises on light refraction*

Experiment procedure

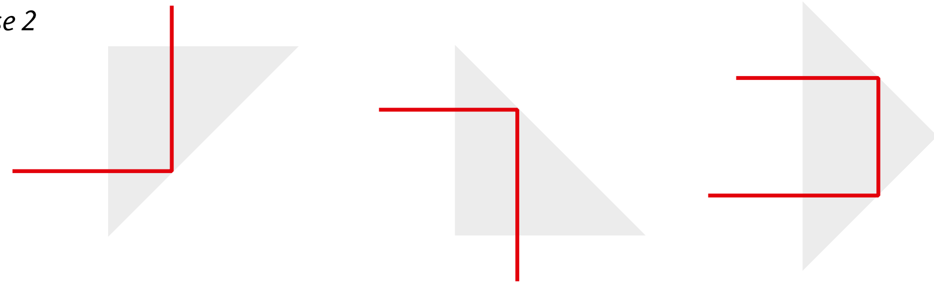
In each of these exercises, you will first complete the path of the illustrated light ray. Then the respective optical body will be laid on the paper with its rough edge in the stipulated position and the solution will be checked using the laser.

Solutions

Exercise 1



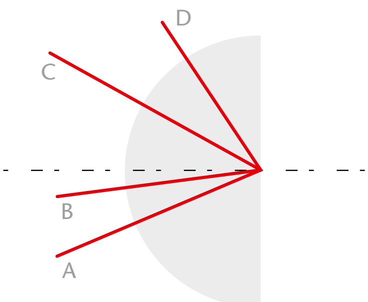
Exercise 2



Exercise 3

Assuming a refractive index of 1.55, the angle of refraction β is given by

$$\beta = \sin^{-1}(\sin(\alpha) \cdot 1.55).$$



Ray	Angle of incidence α	Angle of refraction β
A	25°	41°
B	10°	16°
C	30°	51°
D	55°	–

Supplementary to this experiment:

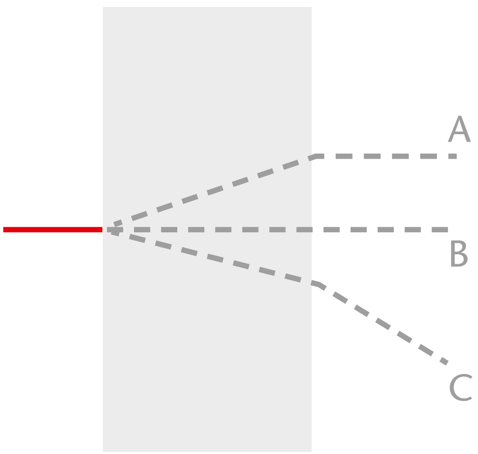
Exercises on light refraction worksheet (page 24)

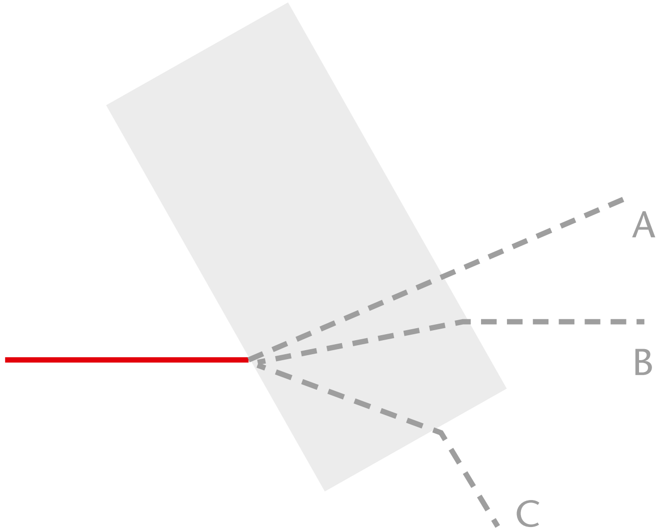
Ph Optics	Exercises on light refraction	Name
		Date

The objects shaded in grey represent glass objects. Solve the following problems and check the results using the laser and the corresponding body.

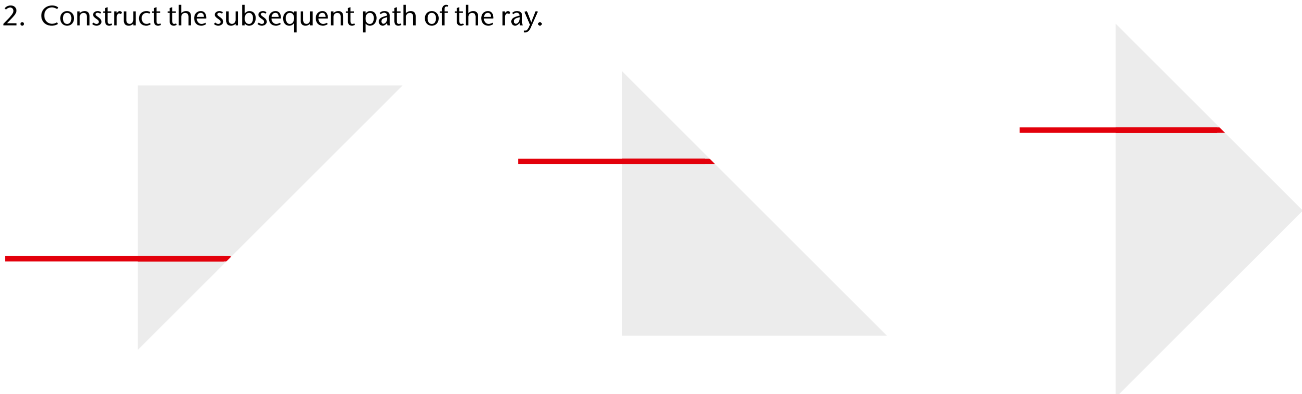
Rough side should be facing down. When checking, avoid letting part of the laser beam shine over the body.

1. Draw the correct light path.

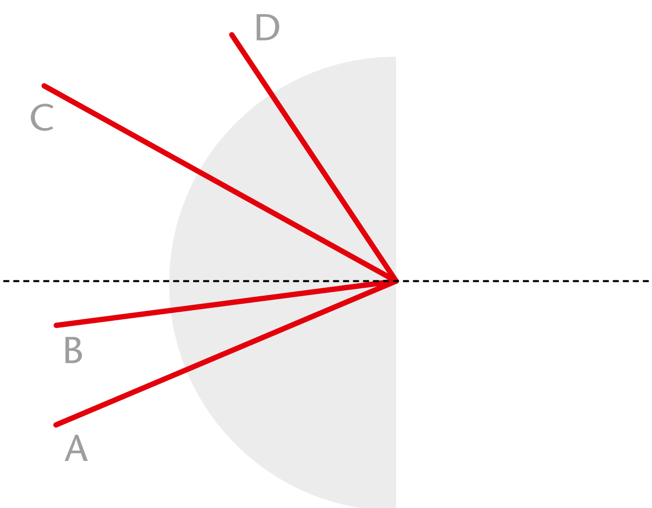




2. Construct the subsequent path of the ray.



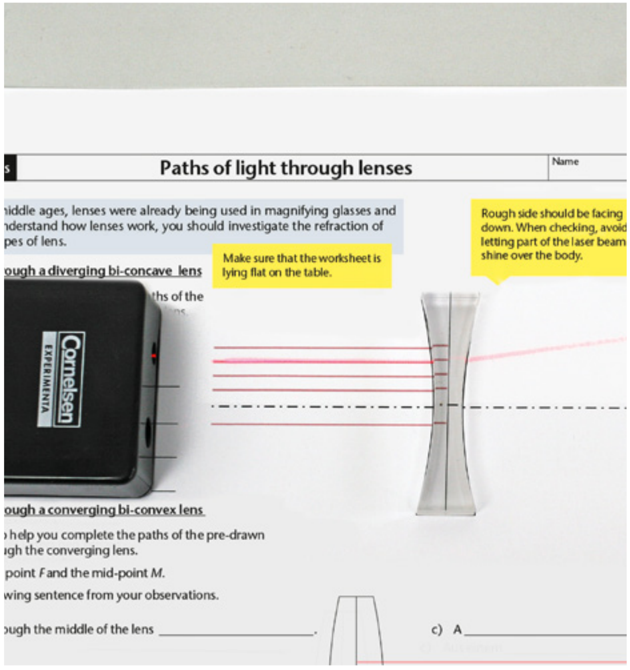
3. Measures the angles of incidence of the four rays. Determine the angle of refraction and use your result to construct the subsequent path of the ray.



Ray	Angle of incidence	Angle of refraction
A		
B		
C		
D		

Op 1.8 Paths of light through lenses

The paths light takes through convex and concave lenses will be investigated with a worksheet optics experiment.



Equipment

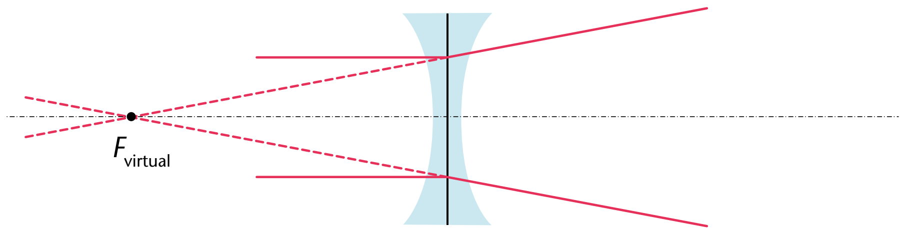
LED / laser student lamp 2
Set of *optical bodies* 5
Worksheet *Paths of light through lenses*

Experiment procedure

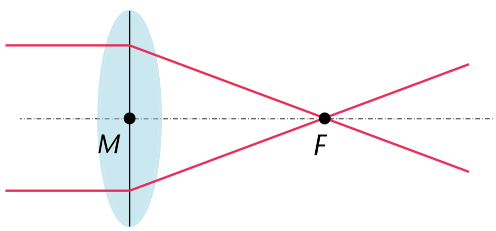
Take care during the experiment to ensure the lenses are initially situated at the stipulated positions. Afterwards the light paths drawn in red on the worksheet are traced by the laser and extended to their ends.

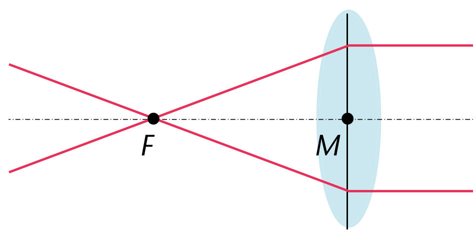
Conclusions

In the part of the experiment involving a concave lens, you can observe that parallel beams are diverged beyond the lens. The beams are actually refracted in such a way that they seem to be coming from a virtual focal point.



A convex lens, however, causes parallel light to converge to a focal point on the optical axis. Since the light paths are reversible, light rays emerging from this focal point are refracted by the lens in such a way that the rays become parallel. If the lens is thin enough, rays passing through the centre are not refracted at all.





M ≙ "Mid-point" *F* ≙ "Focal point"

Supplementary to this experiment:

Paths of light through lenses worksheet (page 26)

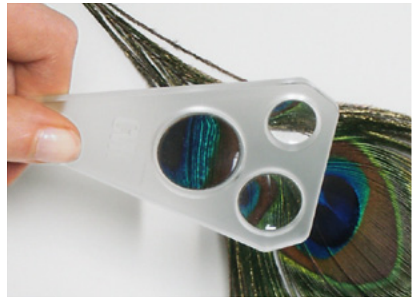
Paths of light through lenses

Name ____________ Date ____________

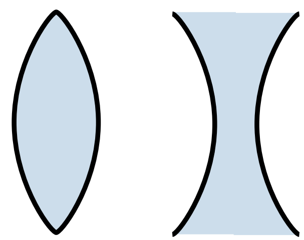
As early as the middle ages, lenses were already being used in magnifying glasses and spectacles. To understand how lenses work, you should investigate the refraction of light by two shapes of lens.

Make sure that the worksheet is lying flat on the table.

Rough side should be facing down. When checking, avoid letting part of the laser beam shine over the body.



Definitions:



Paths of light through a diverging bi-concave lens

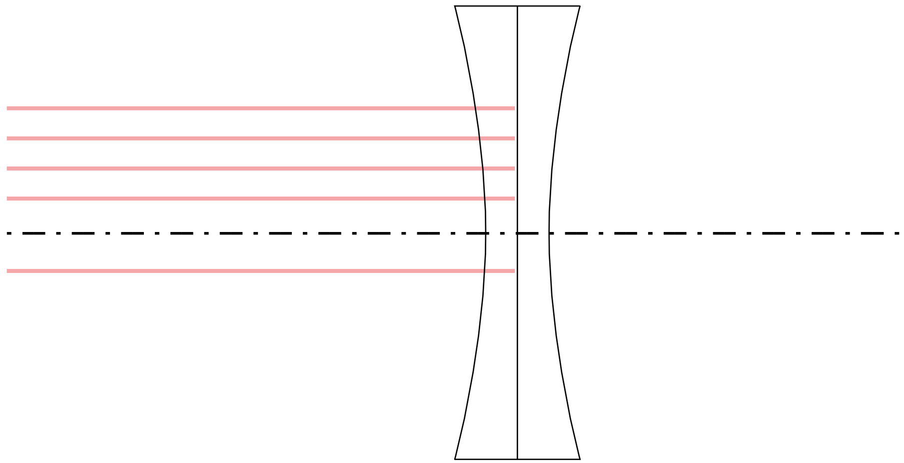
- Use the laser to help you complete the paths of the pre-drawn light rays through the diverging lens.
- Summarise your observations.

____

____

____

____



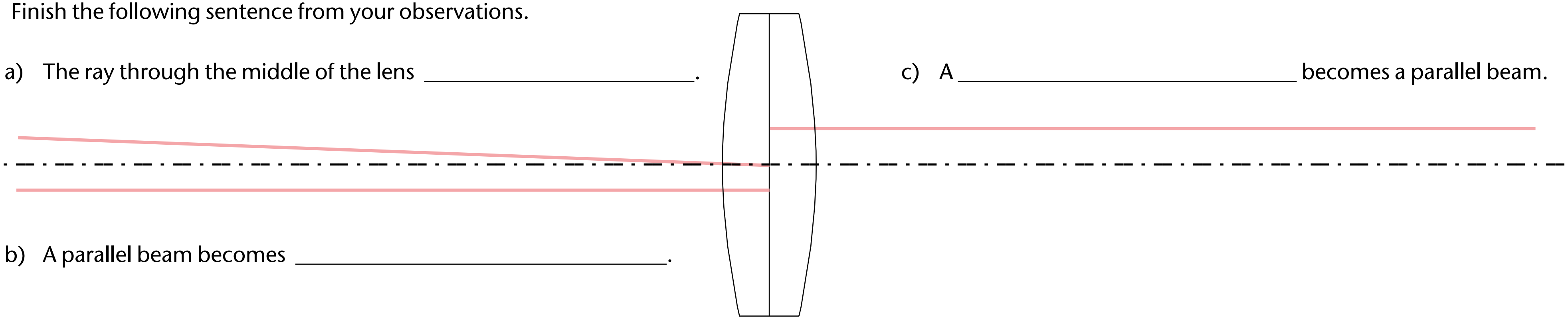
Paths of light through a converging bi-convex lens

- Use the laser to help you complete the paths of the pre-drawn light rays through the converging lens.
- Label the focal point *F* and the mid-point *M*.
- Finish the following sentence from your observations.

a) The ray through the middle of the lens ______________________.

b) A parallel beam becomes ______________________.

c) A ______________________ becomes a parallel beam.



Op 1.9 Focal point of a converging lens

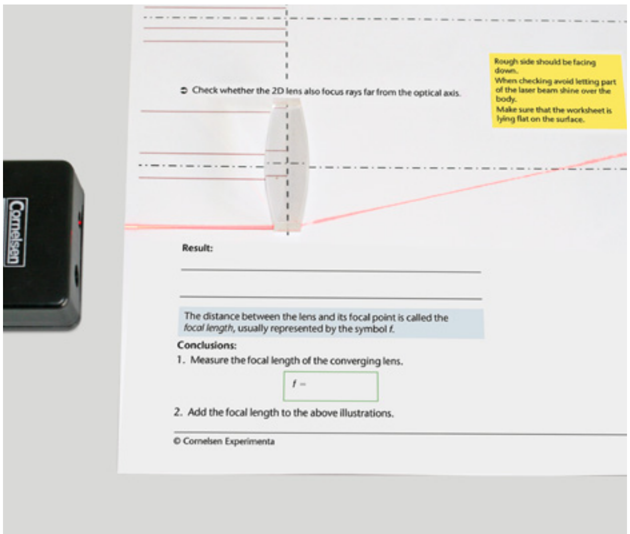
Op 1.9a 2D lens
Op 1.9b Lens on optical bench

An experiment is to be carried out in two parts. The first is to determine the focal point of a 2D converging lens in a worksheet optics experiment.
Then the focal length of a lens will be measured on the optical bench.

Op1.9a 2D lens

Equipment

LED / laser student lamp 2
Set of *optical bodies* 5
Worksheet *Focal point of a converging lens*



Experiment procedure

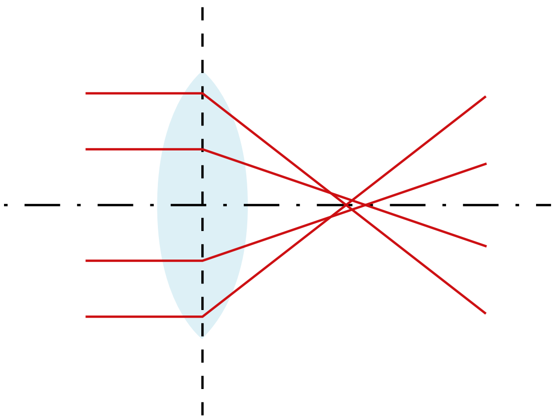
Take care during the experiment to ensure the lens is initially situated perpendicular to the optical axis. Afterwards the light paths drawn in red on the worksheet are traced by the laser and extended to their ends.

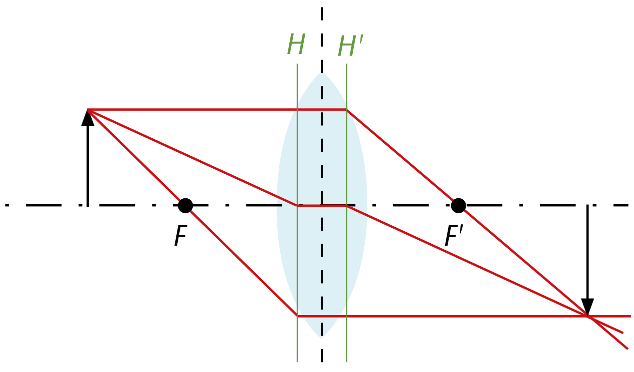
Conclusions

With a radius of curvature $r = 10\,\text{cm}$ a bi-convex lens made of perspex ($n = 1.49$) would have a focal length determined as follows:

$$f = \frac{n_{\text{lens}}}{n_{\text{lens}} - n_{\text{air}}}\left(\frac{r}{2}\right) = \frac{1.49}{1.49 - 1.00}\left(\frac{10\,\text{cm}}{2}\right) \cong 15.2\,\text{cm}.$$

Since the 2D lens is thick, the focal length needs to be measured from the principle plane of the lens *H'*. Due to spherical aberration, rays a long way from the centre are refracted in such a way that they intersect with the optical axis before the focal point.





F ≙ "Focal point" *H* ≙ "Principle plane"

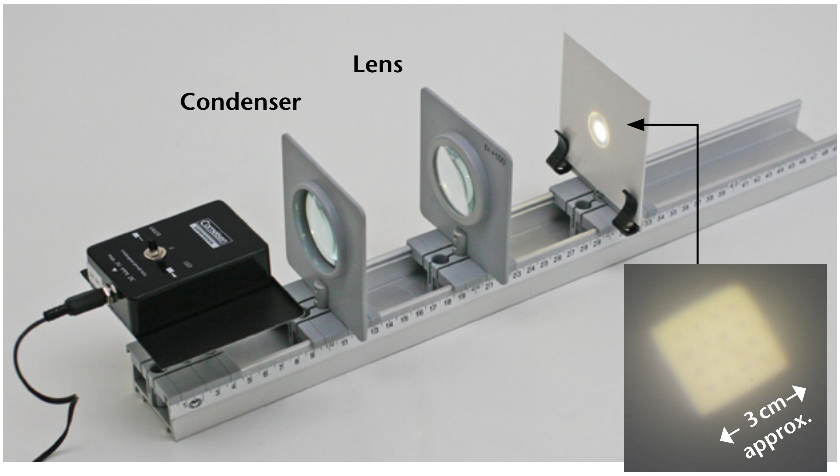
Supplementary to this experiment:

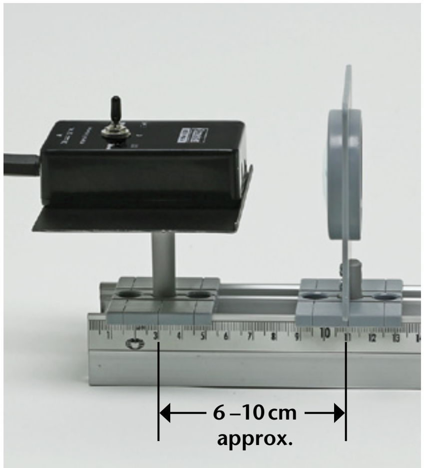
Focal point of a converging lens worksheet (page 29, 30)

Op 1.9b Lens on optical bench

Equipment

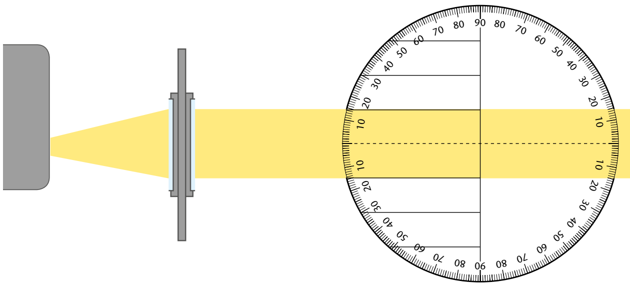
Profile rail 1
LED / laser student lamp 2
Lamp platform......................... 9
Measurement platform 10
Clamp sliders...............(4 x) ... 11
Lens, $f = +200$ mm 13
Lens, $f = +100$ mm 14
Lens, $f = +50$ mm 15
Condenser 17
Screen and mirror holder....... 21
Screen 24





Experiment procedure

This experiment requires a parallel beam. To make such a beam, the LED lamp should be positioned on the lamp platform in such a way that the condenser lens is fully illuminated by the cone of light from the lamp.



The condenser is then moved to the position relative to the lamp where the emerging beam is roughly parallel (typically 6 – 10 cm). You should check the shape of the beam using the measurement platform situated at a distance of about 20 – 25 cm from the lamp.
If the condenser is correctly configured, the platform can be replaced by the lens to be measured.
Next the screen is placed such that the image of the LED is well focused as shown.
Because the light from the LED is very bright when the screen is close to it, it is advisable to view the screen from the rear.

Conclusions

For lenses made by machine, the relative discrepancy in the curvature is about one per cent, which means there will be a roughly two per cent discrepancy in the focal length. The shape and path of the incident has a much greater influence on the measurement. As a rule, it is not quite parallel and usually strikes the lens at a slight angle (astigmatism).

f_{lens} in mm	$f_{measured}$ in mm	Δf in mm	δf	Tolerance range
50	56	6	12 %	43 … 58 mm
100	99	1	1 %	85 … 115 mm
200	220	20	10 %	170 … 230 mm
Condenser	52	2	4 %	43 … 58 mm

Supplementary to this experiment:

Focal point of a converging lens worksheet (page 29, 30)

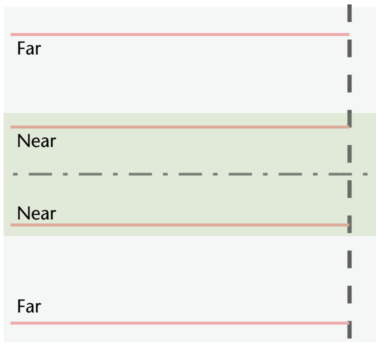
Ph Optics	Focal length of a converging lens (page 1)	Name
		Date

You should investigate the following definition:
"A converging lens focuses parallel incident rays to a specific point called the focal point."

Definitions:

Near means near the optical axis

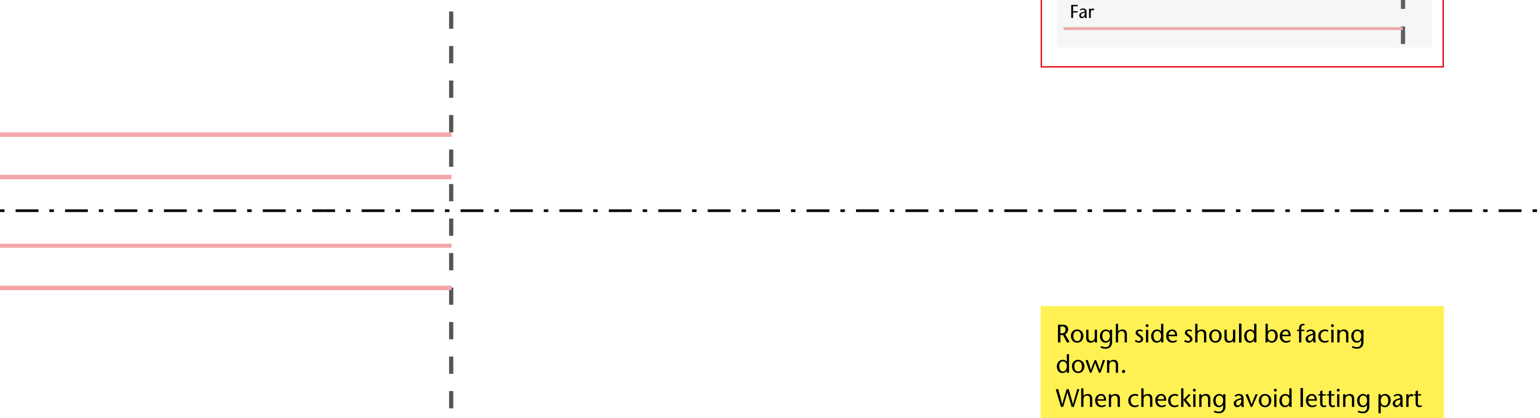
Far means far from the optical axis



Procedure:

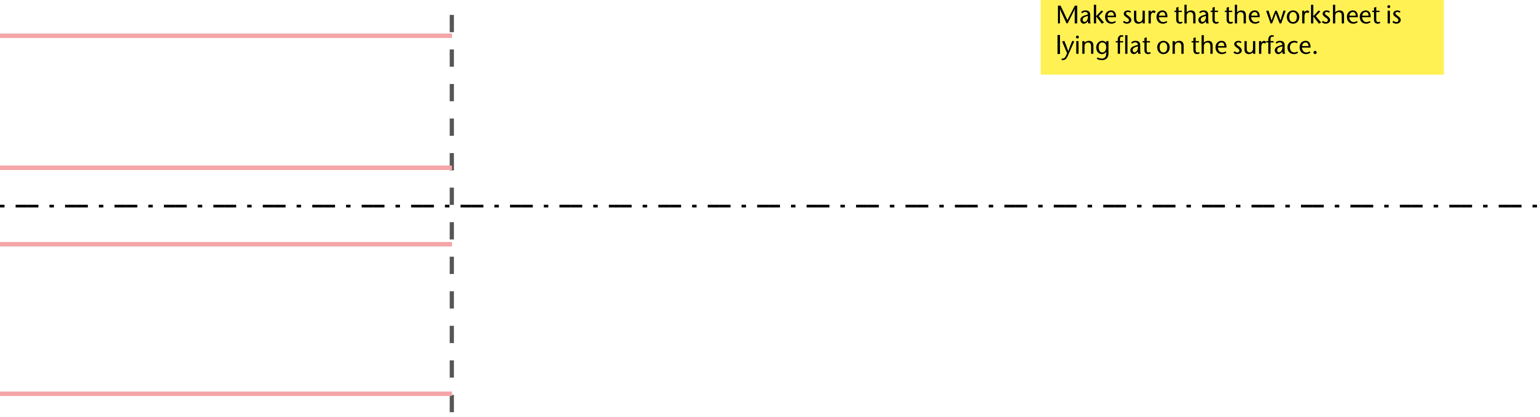
➲ Put the 2D lens down with its centre on the dotted line and the rough side facing downwards. If the lens is precisely positioned, a laser beam along the optical axis will not be refracted.
When the lens is properly aligned, you can start the experiment.

➲ Check experimentally whether the 2D lens has a focal point.



➲ Check whether the 2D lens also focus rays far from the optical axis.

Rough side should be facing down.
When checking avoid letting part of the laser beam shine over the body.
Make sure that the worksheet is lying flat on the surface.



Result:

____

____

The distance between the lens and its focal point is called the *focal length*, usually represented by the symbol *f*.

Conclusions:

1. Measure the focal length of the converging lens.

$f =$

2. Add the focal length to the above illustrations.

Focal point of a converging lens (page 2)

Name	
Date	

Introduction

You should now find the focal point of a converging lens experimentally. According to the definition:

"A converging lens focuses parallel incident rays to a specific point called the focal point."

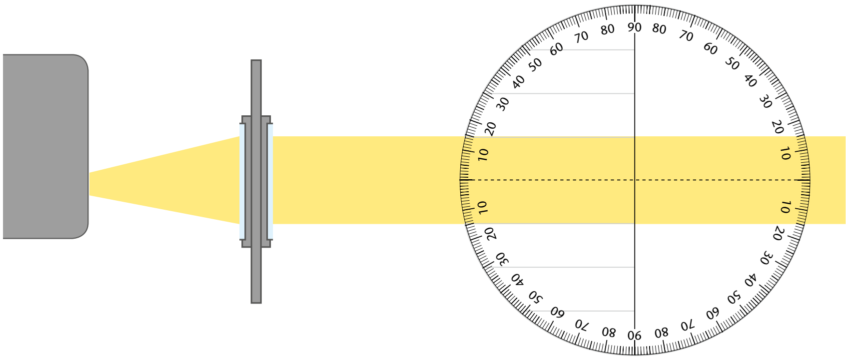
you need parallel light, which can be produced with the help of the condenser lens.

Definition:

The ***condenser*** is used to generate parallel beams of radiation. For visible light, the simplest kind of condenser is simply a converging lens. Use the unlabelled lens numbered **17** as the condenser.

Procedure

- Position the LED lamp and the condenser in such a way that the condenser lens is fully illuminated by the cone of light from the lamp.
- By moving and turning the condenser you can generate a parallel beam. Check your configuration using the markings on the measurement platform. The ideal configuration is shown in the illustration below.



- Now you can use the parallel light to find the focal point of the converging lens with the help of the screen. Since the light from the LED is very bright you should view the focal point on the screen from the rear.

Example:

Stated length $f_{150} = 150\,\text{mm}$

Measured length $f_{meas} = 158\,\text{mm}$

Absolute error Δf_{150}

$\Delta f_{150} = |\, f_{meas} - f_{150} \,|$

$\Delta f_{150} = |158\,\text{mm} - 150\,\text{mm}|$

$\Delta f_{150} = 8\,\text{mm}$

Relative error δf_{150}

$$\delta f_{150} = \frac{\Delta f_{150}}{f_{150}}$$

$$\delta f_{150} = \frac{8\,\text{mm}}{150\,\text{mm}}$$

$$\delta f_{150} \cong 0{,}05 = 5\,\%$$

Exercise:

1. Determine the focal length of these lenses.

Lens	Measured focal length	Absolute error	Relative error
$f = +50\,\text{mm}$	$f_{50} =$	$\Delta f_{50} =$	$\delta f_{50} =$
$f = +100\,\text{mm}$	$f_{100} =$	$\Delta f_{100} =$	$\delta f_{100} =$
$f = +200\,\text{mm}$	$f_{200} =$	$\Delta f_{200} =$	$\delta f_{200} =$

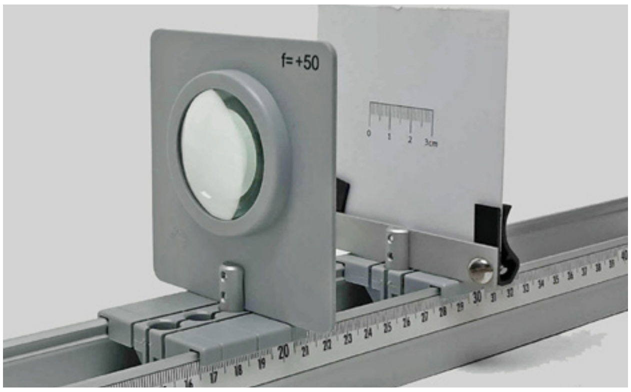
2. Calculate the absolute and relative error values from your measurements and enter the results into the table.
3. Determine the focal length of the condenser.
4. Assess the accuracy of the focal lengths quoted for the lenses.
5. Discuss possible reasons for discrepancies in the focal length.

Measurement tip for 3:

Use the lens with $f = +50\,\text{mm}$ as a condenser and reconfigure the set-up.

Op 1.10 Formation of images by a converging lens

You should observe how the image of a printed centimetre scale is formed on the screen by a converging lens (f = +50 mm).



Equipment

Profile rail 1
Clamp sliders ....(2 x) ... 11
Lens, f = +50 mm.................. 15
Screen and mirror holder....... 21
Screen 24

Supplementary to this experiment:

Formation of images by a converging lens worksheet (page 32)

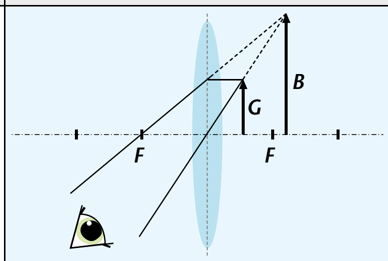
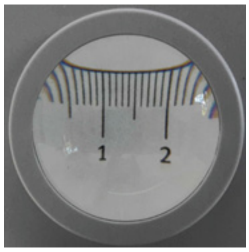
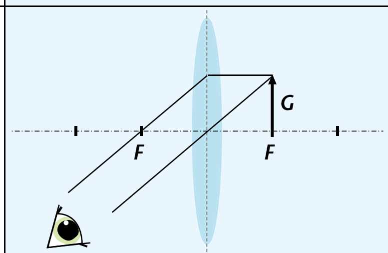
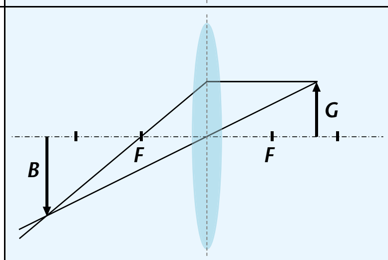
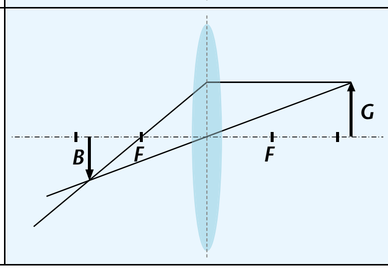
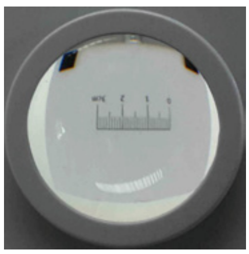
Experiment procedure

The lens and screen need to be placed in adjacent sockets of their respective clamp sliders so that the screen can be positioned inside the focal length. The screen is then slid to the required distances and the scale is observed on the screen.

Conclusions

The following observations are made:

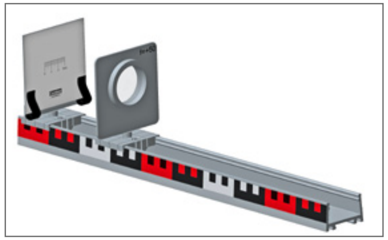
F ≙ „Focal point" *B* ≙ „Image" *G* ≙ „Object"

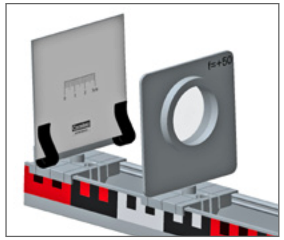
Lens-screen distance g	Nature of image	Construction	
Inside focal length **$0 < g < f$**	▪ Magnified ▪ Upright ▪ Virtual ▪ Right way round		
At the focal length **$g = f$**	▪ No clear image		
Between one and two times the focal length **$f < g < 2f$**	▪ Magnified ▪ Upright ▪ Real ▪ Mirror image		
More than twice the focal length of the lens **$2f < g$**	▪ Smaller than object ▪ Upside down ▪ Real ▪ Mirror image		

Formation of images by a converging lens – observation and construction

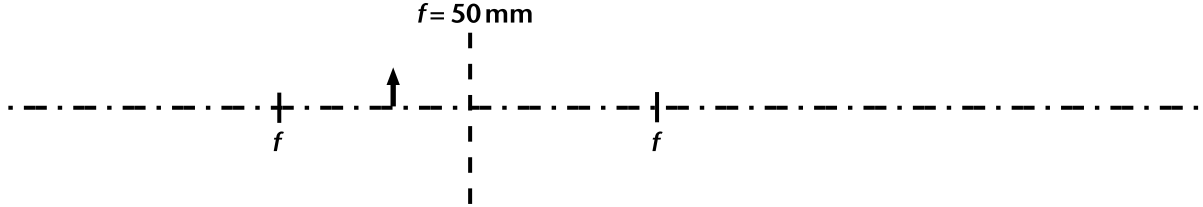
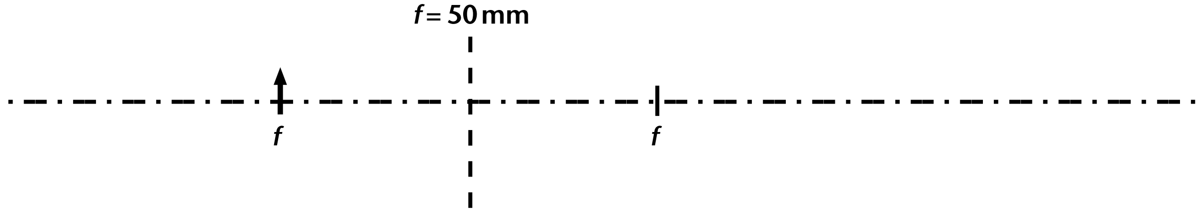
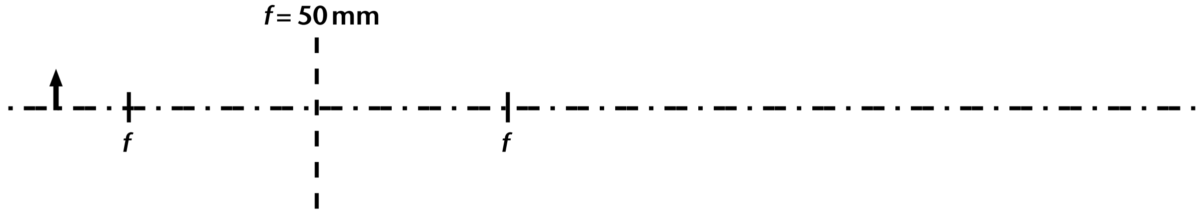
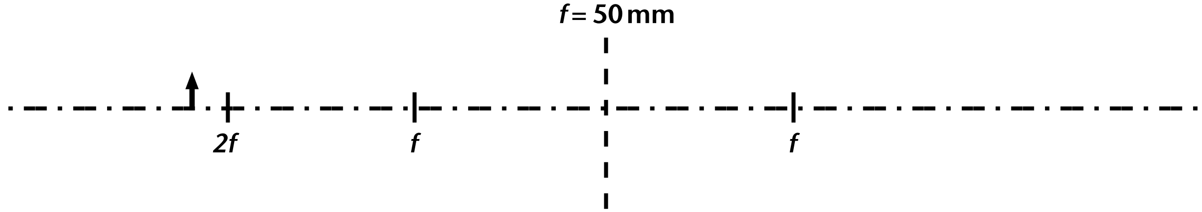
Name | Date

Procedure:



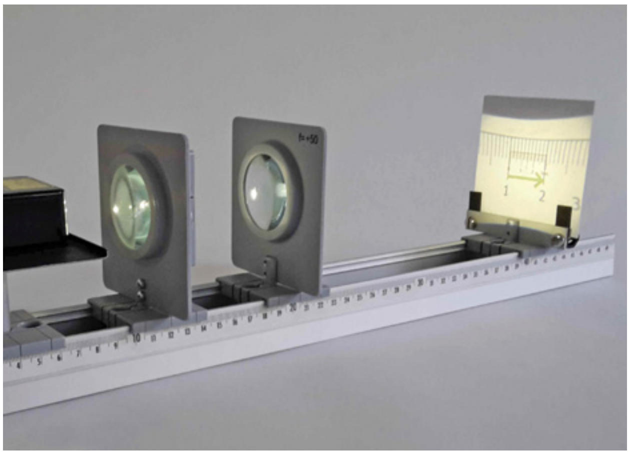


- ➲ Observe the printed centimetre scale on the screen using a converging lens $f = 50$ mm.
- ➲ Vary the distance between the lens and the screen as in the table and write down your observations.
- ➲ For each of your configurations, construct a ray diagram for rays through the converging lens.
- ➲ Compare your construction with your observations.
- ➲ Put a tick in the last column if the construction matches the observation.

Lens-screen distance *o*	Observations	Construction for image (scale 1:2)	correct
Inside focal length $0 < g < f$	☐ No image ☐ Upright image ☐ Inverted image ☐ Smaller image ☐ Same-size image ☐ Larger image		
At focal length $g = f$	☐ No image ☐ Upright image ☐ umgekehrtes Bild ☐ Smaller image ☐ Same-size image ☐ Larger image		
Between one and two times the focal length $f < g < 2f$	☐ No image ☐ Upright image ☐ Inverted image ☐ Smaller image ☐ Same-size image ☐ Larger image		
More than twice the focal length $2f < g$	☐ No image ☐ Upright image ☐ Inverted image ☐ Smaller image ☐ Same-size image ☐ Larger image		

Op 1.11 Lens equation

The lens equation will be derived from the scale of the image and experimentally verified using an image of an actual scale.

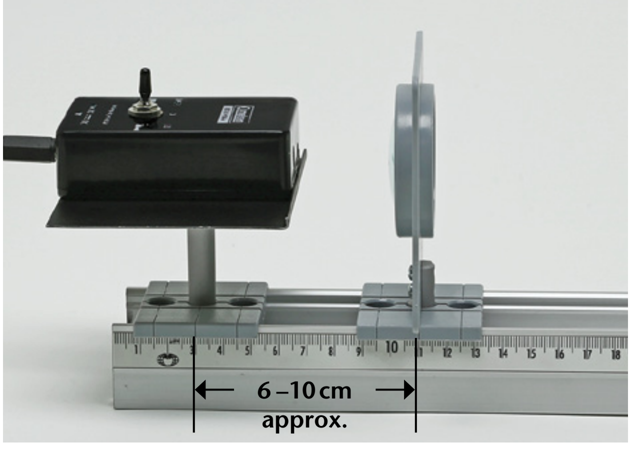


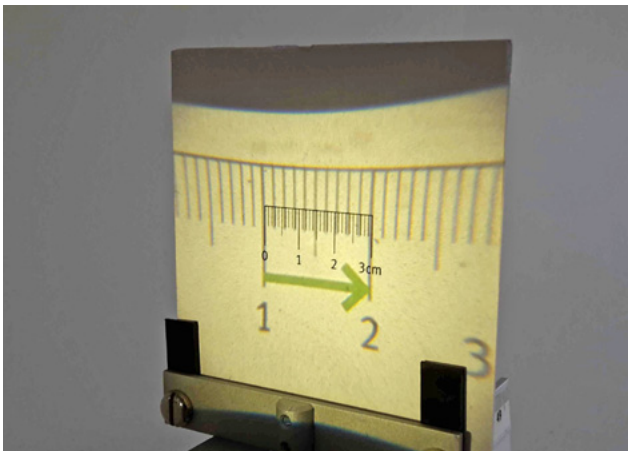
Equipment

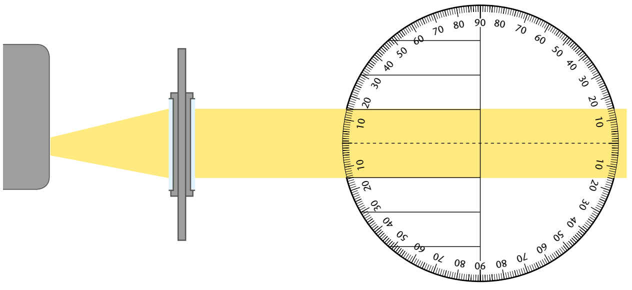
Profile rail 1
LED / laser student lamp 2
Lamp platform......................... 9
Measurement platform 10
Clamp sliders ....(4 x) ... 11
Lens, $f = +50$ mm 15
Condenser 17
Scale slide 19
Screen and mirror holder....... 21
Screen 24

Additionally required: Ruler

Experiment procedure







This experiment requires a parallel beam. To make such a beam, the LED lamp should be positioned on the lamp platform in such a way that the condenser lens is fully illuminated by the light from the lamp. The condenser is then moved to the position relative to the lamp where the emerging beam is roughly parallel (typically 6 – 10 cm). You should check the shape of the beam using the measurement platform situated at a distance of about 20 – 25 cm from the lamp.

If the condenser is correctly configured, the platform can be replaced by the lens to be measured.

If the condenser is set up correctly, the slide with the scale should be inserted into the slide holder and slotted next to the condenser. The measurement platform is then replaced by the lens ($f = +50$ mm).

For the measurement, the lens and screen should be placed such that the condenser is always outside the focal length and the image on the screen is well focused.

The green arrow, which is 1 cm long, is used as the object. The projection of it can be measured with the centimetre scale printed on the screen or with a ruler.

Conclusions

This experiment uses mathematics' intercept theorem to derive the conditions for a sharp image to be formed by a converging lens.
If you use the approach describe on the worksheet, and use the intercept theorem, it only takes a few steps to obtain the conditions for a good image from the object distance *g*, image distance *b* and focal length *f*.
The steps in the derivation which are not shown on the worksheet can be seen in the information panel.
As a result of this derivation the lens equation is very well verified.

From the worksheet:

$$\frac{b}{g} = \frac{b-f}{f}$$

Expand the difference:

$$\frac{b}{g} = \frac{b}{f} - \frac{f}{f}$$

Multiply all fractions by $\frac{1}{b}$ and cancel

$$\frac{1}{g} = \frac{1}{f} - \frac{1}{b}$$

Rearranging gives the lens equation

$$\frac{1}{g} + \frac{1}{b} = \frac{1}{f}$$

g in mm	b in mm	f in mm	$\frac{1}{g}$	$\frac{1}{b}$	$\frac{1}{g}+\frac{1}{b}$	$\frac{1}{f}$
68	220	50	0.015	0.005	0.019	0.020
100	116	50	0.010	0.010	0.020	0.020
67	291	50	0.010	0.000	0.020	0.020

Comparing the last two columns confirms the derivation of the lens equation

$$\frac{1}{g} + \frac{1}{b} = \frac{1}{f}.$$

The relationship being sought in exercise 3 of the worksheet is the initial equation used to derive the lens equation. It states that the scale of the image is as follows:

$$\frac{B}{G} = \frac{b}{g}.$$

This relationship can also be confirmed by measurements.

G in mm	g in mm	b in mm	B in mm	f in mm	$\frac{B}{G}$	$\frac{b}{g}$
10	68	220	31	50	3.1	3.2
10	100	116	12	50	1.2	1.2
10	67	291	45	50	4.5	4.3

Supplementary to this experiment:

Lens equation worksheet (page 35)

Ph Optics	Lens equation	Name
		Date

Lens equation

In geometrical optics, many light paths can be calculated with the help of the intercept theorem.
The *lens equation* is of key importance in this respect since it describes the relationship between object distance, image distance and focal length.

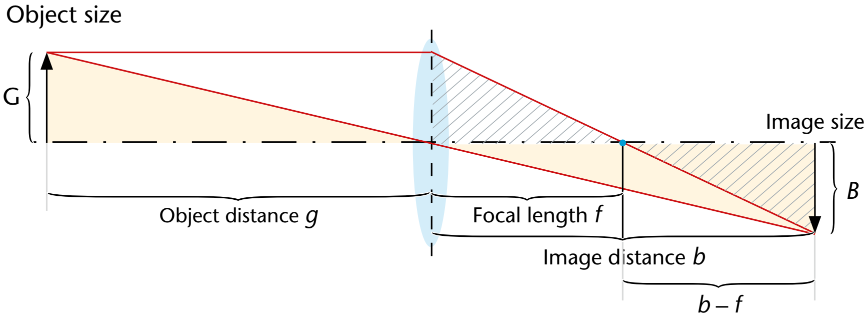


Photo reproduced with kind permission of Archenhold Observatory, Berlin

Approach to deriving the lens equation:

Intercept theorem with yellow triangles

$$\frac{B}{G} = \frac{b}{g}$$

Intercept theorem with shaded triangles

$$\frac{B}{G} = \frac{b-f}{f}$$

Equating the two right-hand sides

$$\frac{b}{g} = \frac{b-f}{f}$$

⋮

$$\frac{1}{g} + \frac{1}{b} = \frac{1}{f}$$

Procedure:

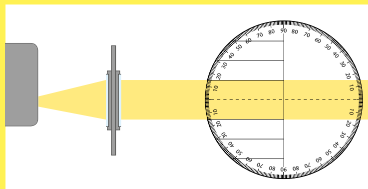
- Generate a parallel light beam as described in the condenser instructions.
- Insert the slide with the scale into the holder with the condenser.
- Now position the screen and lens ($f = 50$ mm) in such a way that the slide is not within the focal length and the image on the screen is well focused. Enter the object distance g, image distance b and the length of the 1-cm long arrow as seen on the screen (the image size B) into the table.
- Find other configurations which result in a sharp image and enter them into the table.

G in mm	g in mm	b in mm	B in mm	f in mm	$\frac{1}{g}$	$\frac{1}{b}$	$\frac{1}{g}+\frac{1}{b}$	$\frac{1}{f}$
10				50				
10				50				
10				50				
10				50				
10				50				

Instructions: Condenser

Position the LED lamp and condenser such that the condenser lens is fully illuminated by the cone of light from the LED lamp.

By moving and turning the condenser itself, you can obtain a parallel beam of light. Check your configuration using the markings on the measurement platform as shown.



Conclusions:

1. Discuss whether your findings verify the lens equation.
2. Calculate the ratio of the image size to the object size ($G = 10$ mm). in each instance. This ratio is called the scale of the image.
3. Check using your measured data whether there is a relationship between the scale of the image, the object distance and the image distance.

Op 1.12 Optical instruments

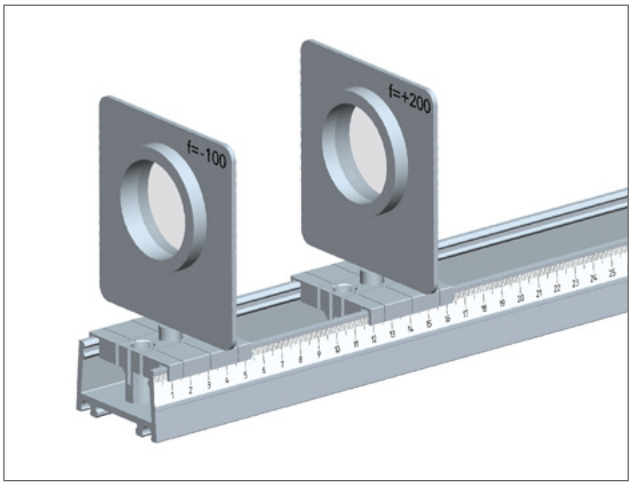
Op 1.12a Terrestrial telescopes
Op 1.12b Astronomical telescopes
Op 1.12c Projectors
Op 1.12d Optical microscopes

Demonstration of optical instruments makes a very good topic for student reports.
In the appendix there are suitable work assignments on terrestrial and astronomical telescopes as well as projectors and microscopes.
The following treatment provides an introduction.

Op 1.12a Terrestrial telescopes

Equipment

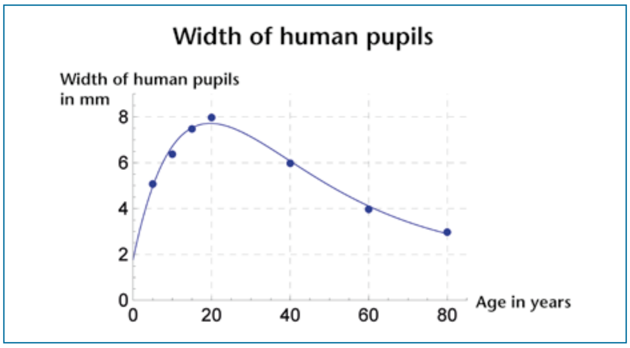
Profile rail 1
Clamp sliders ....(2 x) ... 11
Lens, $f = +200$ mm 13
Lens, $f = -100$ mm.................. 16



Terrestrial telescopes use a converging lens as an objective and come in various forms, one of which is known as the *Galileo telescope*.
Such a telescope causes light coming from a long distance away to be focused towards a focal point. Before it gets there, though, the light is then dispersed by a diverging lens located inside the focal length (the ocular). No intermediate image is formed. Instead the light is spread out again by the diverging lens acting as the ocular, creating a wider-angle image for the eye to see. The magnification is given by the quotient of the focal lengths of the objective and ocular:

$$V = \frac{f_{\text{Objective}}}{f_{\text{Ocular}}}$$

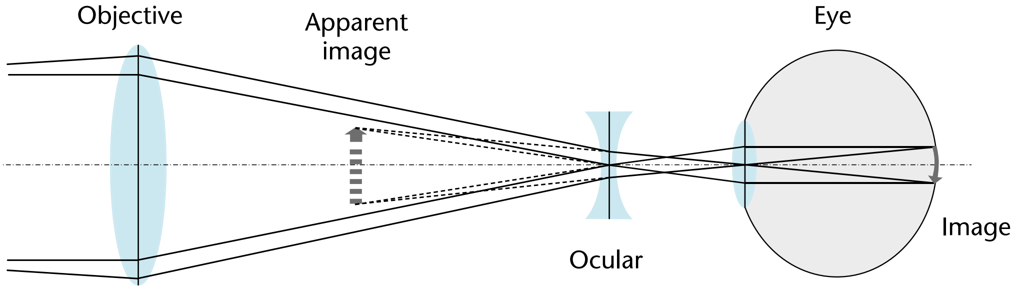
The image formed on the retina is upright and the right way round. This is an advantage for viewing objects on earth as opposed to astronomical telescopes, which show an inverted image.
Prismatic binoculars use a converging lens as the ocular in the same way as an astronomical telescope, but an inverting prism between the objective and the ocular turns the image back the right way up and reverts all mirroring while still maintaining a compact design.



Binoculars are usually characterised by their magnification factor and the diameter of the objective lens. To get the optimum image brightness for the eye, the exit openings from the equipment should be roughly the same size as the pupil of the human eye.

$$\textit{Exit opening} = \frac{\textit{Objective diameter}}{\textit{magnification factor}}$$

Continued overleaf



Continued from 1.12a: Since the width of human pupils varies widely and changes over the course of one's life, binoculars are sold with different sizes of exit openings.

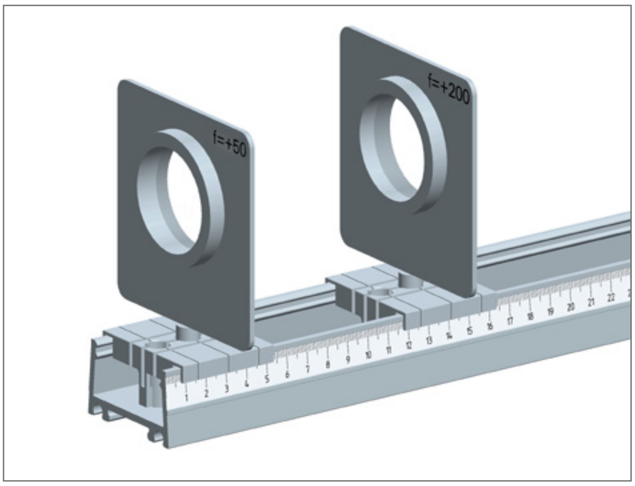
Supplementary to this experiment:

Terrestrial telescopes station card (page 40)

Op 1.12b Astronomical telescopes

Equipment

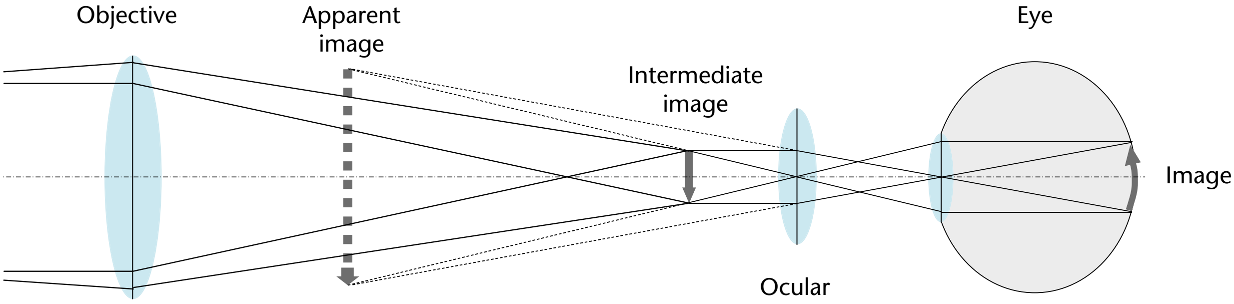
Profile rail 1
Clamp sliders...............(2 x) ... 11
Lens, f = +200 mm 13
Lens, f = +50 mm 15



The eye has a limited capacity for accommodation and can therefore only see over a restricted angle of vision. Telescopes are intended to increase that angle.
An astronomical telescope is a combination of an converging lens with a large focal length, which is used the objective, and another converging lens with a short focal length, which acts as the ocular. The ocular acts like a magnifying glass which magnifies the intermediate image produced by the objective.
The magnification of a telescope is given by the quotients of the focal lengths of its objective and ocular:

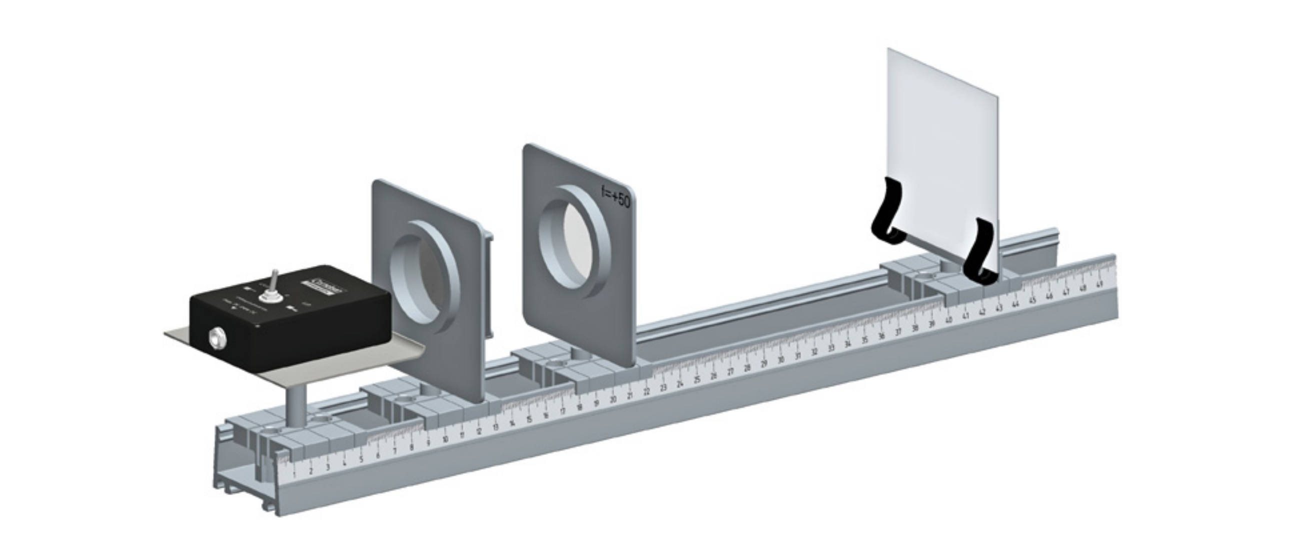
$$V = \frac{f_{\text{Objective}}}{f_{\text{Ocular}}}$$

The image produced on the retina is upside-down and mirrored. However, this is not a disadvantage when observing objects in space.
Telescopes with lenses usually offer better contrast and higher resolution.
The use of lenses does, however, have the disadvantages of chromatic (colour) aberration due to refraction and of higher price. Reflecting telescopes, by comparison, can have a much larger diameter for their objective (mirror) and therefore a larger opening to let in the light.
In practice, telescopes with lenses are used more for observations of planets, whereas reflecting telescopes are best for viewing so-called deep-sky objects such as galaxies and nebulae.



Supplementary to this experiment:

Astronomical telescopes station card (page 40)



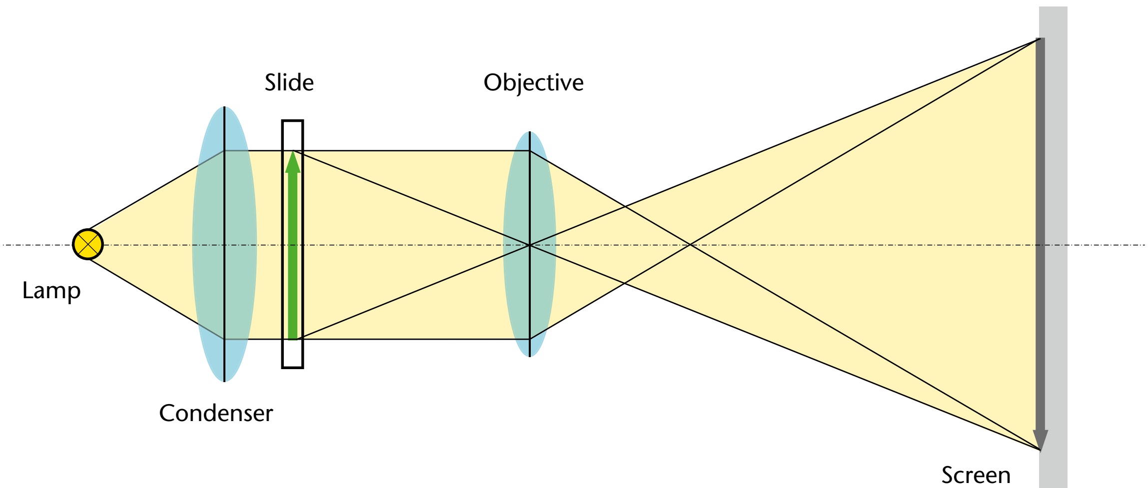
Op 1.12c Projectors

Equipment

Profile rail 1
LED / laser student lamp 2
Lamp platform......................... 9
Clamp sliders ....(4 x) ... 11
Lens, *f* = +50 mm 15
Condenser 17
Scale slide 19
Screen and mirror holder....... 21
Screen 24

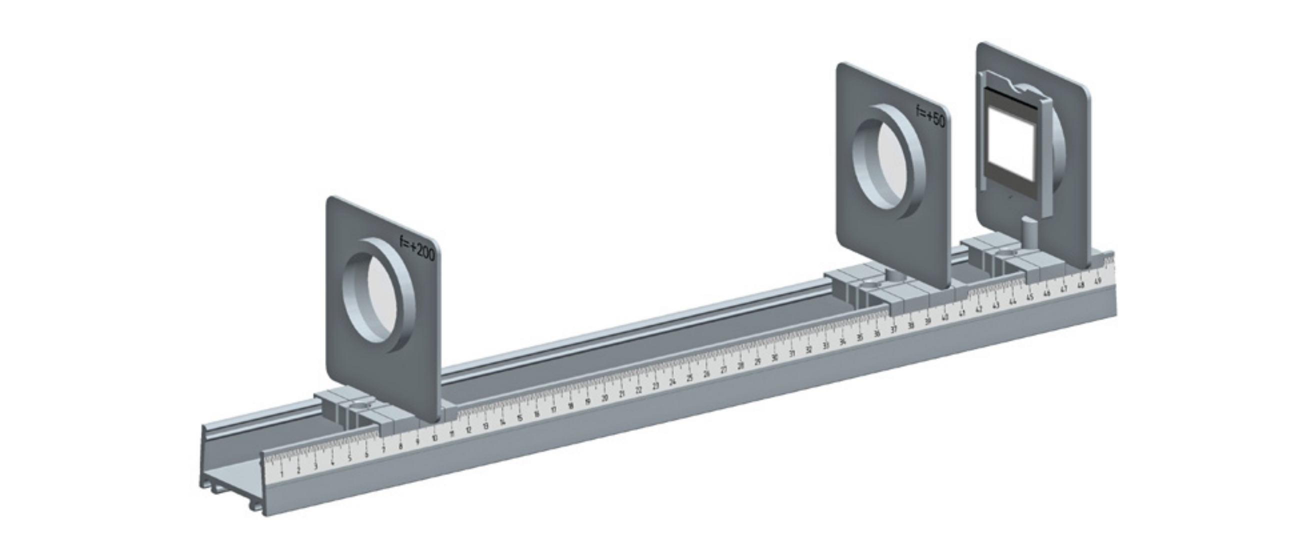
A slide projector needs to produce an image of a slide as large and as sharp as possible on a screen or a wall.

A parallel light beam produced by a combination of a light source and a condenser first illuminates the whole area of the slide. The light rays which are able to pass through the image on the slide are then focused to a focal point by the objective.
A real, greatly magnified, upside-down and mirrored image of the slide is then projected onto a screen located outside the focal length.
The size and sharpness of the image are dependent on the distances between the slide and objective and between the objective and the screen, as well as on the quality and refractive power of the objective lens.



Supplementary to this experiment:

Projector station card (page 41)



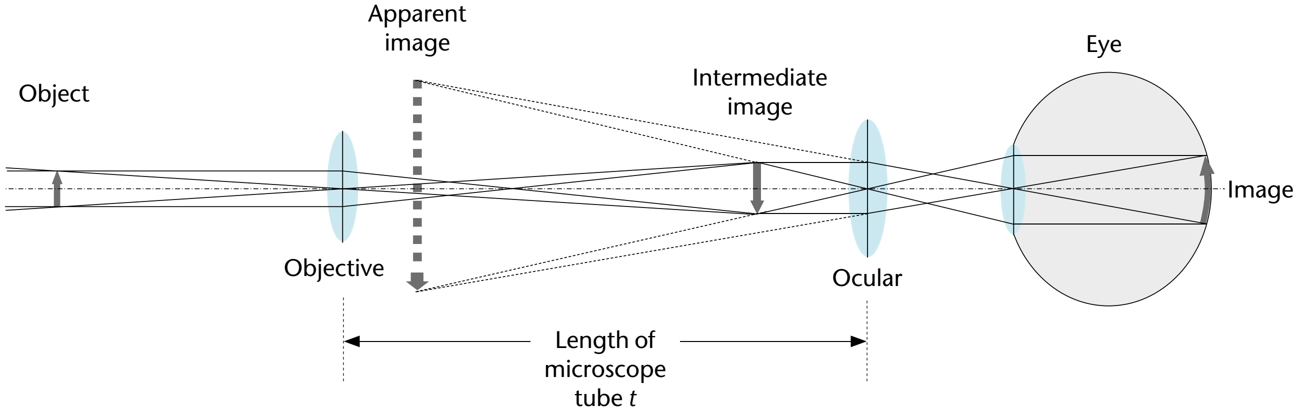
Op 1.12d Optical microscopes

Equipment

Profile rail 1
Clamp sliders .... (3 x) ... 11
Lens, f = +200 mm 13
Lens, f = +50 mm 15
Slide and aperture holder 18
Scale slide 19

An optical microscope is an instrument which helps to make highly magnified images of very small objects on the retina of the eye. The objective of a microscope produces a real and magnified intermediate image of the object being observed. This image is then viewed through the ocular, which acts like a magnifying glass and further magnifies the intermediate image to make a magnified virtual image.
The fact that the lens system magnifies twice means that it can be used to view very small objects.
In order to get as close as possible to the object being observed, the objective needs to have a very small focal length.
The magnification depends on the length of the tube t and the comfortable distance for viewing with the human eye which is about 25 cm.

$$V = V_{\text{Objective}} \cdot V_{\text{Ocular}} = \frac{t}{f_{\text{Objective}}} \cdot \frac{25\,\text{cm}}{f_{\text{Ocular}}}.$$



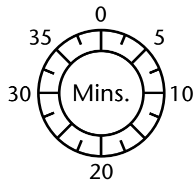
Supplementary to this experiment:

Optical microscopes station card (page 41)

Topic: Terrestrial telescopes

Deadline:

Length of report:



Work assignment

Write a report about terrestrial telescopes.

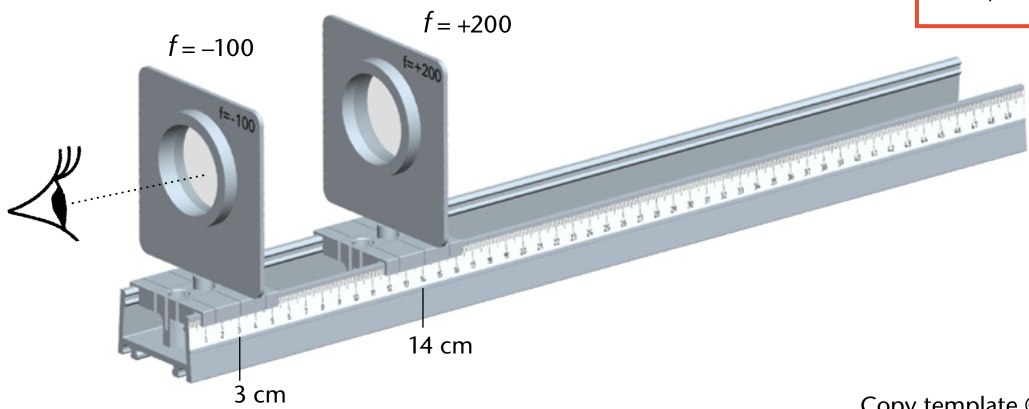
The following aspects need to be covered in the report:

- Introduction to terrestrial telescopes.
- Demonstration of the basic function by means of the experiment illustrated below.
- Explanation of how prisms are used in terrestrial telescopes.
- Discussion of the importance of magnification factor and the diameter of the objective in a terrestrial telescope.

Equipment

Profile rail 1
Clamp sliders.......... (2 x) 11
Lens, *f* = +200 mm 13
Lens, *f* = –100 mm 16

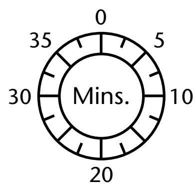
Demonstration experiment



Topic: Astronomical telescopes

Deadline:

Length of report:



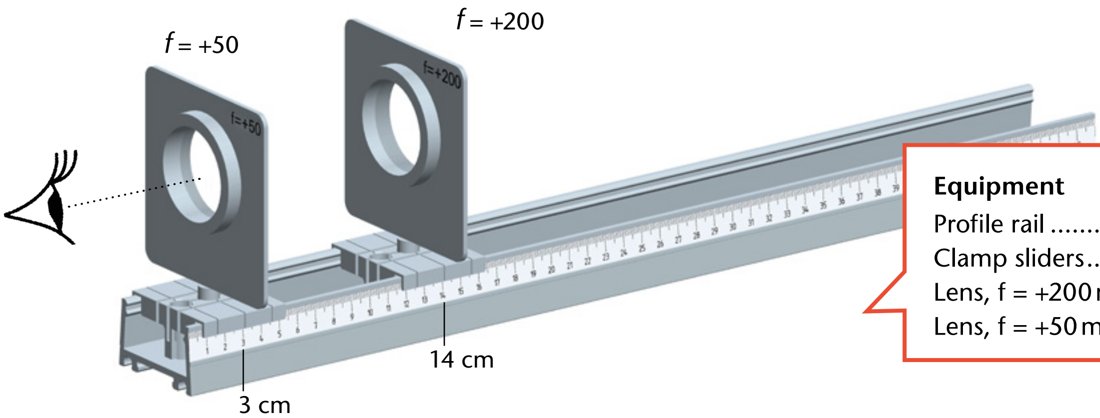
Work assignment

Write a report about astronomical telescopes.

The following aspects need to be covered in the report:

- Introduction to astronomical telescopes.
- Explanation of how the instrument works by means of the demonstration experiment below.
- Explanation of the functions served by the ocular and objective.
- Comparison between a refracting astronomical telescope and a reflecting telescope.

Demonstration experiment



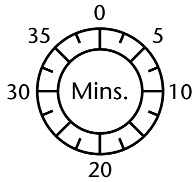
Equipment

Profile rail 1
Clamp sliders.......... (2 x) 11
Lens, f = +200 mm 13
Lens, f = +50 mm 15

Topic: Projectors

Deadline:

Length of report:



Work assignment

Write a report about slide projectors.

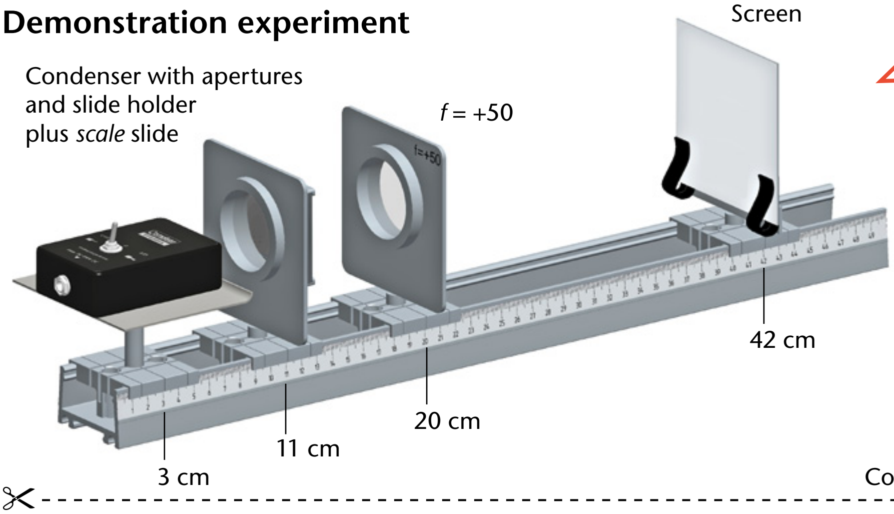
The following aspects need to be covered in the report:

- Introduction to slide projectors.
- Explanation of how the instrument works by means of the demonstration experiments below.
- Explanation of the function served by a condenser.
- Discussion of slide orientation and how the slide is projected onto the screen.

Equipment

- Profile rail 1
- LED / laser student lamp....... 2
- Lamp platform 9
- Clamp sliders.......... (4 x) 11
- Lens, f = +50 mm 15
- Condenser 17
- Apertures and slide holder.. 18
- Scale slide........................... 19
- Screen and mirror holder ... 21
- Screen 24

Demonstration experiment

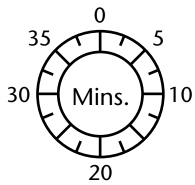


Ph Optics

Topic: Optical microscopes

Deadline:

Length of report:



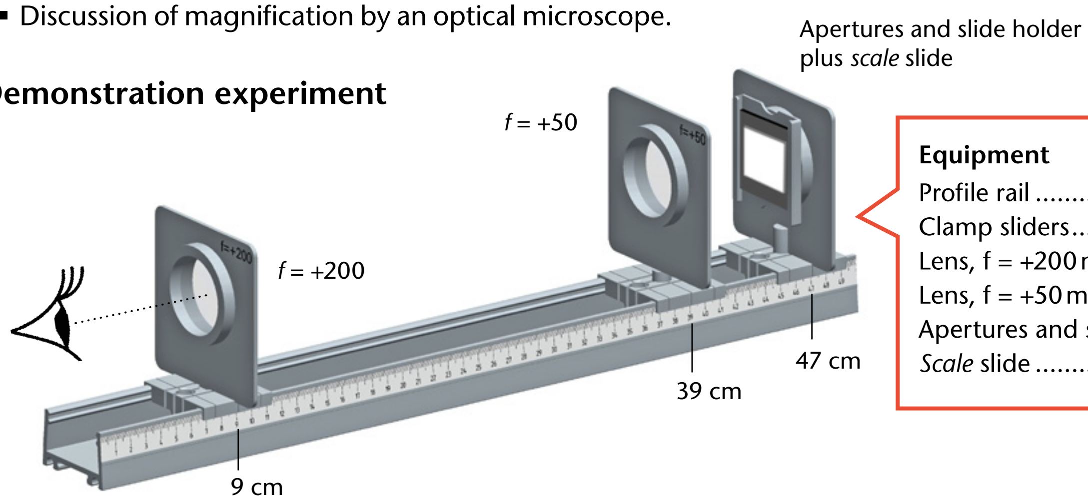
Work assignment

Write a report about optical microscopes.

The following aspects need to be covered in the report:

- Introduction to optical microscopes.
- Explanation of how the instrument works by means of the demonstration experiment below.
- Explanation of the functions served by the ocular and objective.
- Discussion of magnification by an optical microscope.

Demonstration experiment



Equipment

- Profile rail 1
- Clamp sliders.......... (3 x) 11
- Lens, f = +200 mm 13
- Lens, f = +50 mm 15
- Apertures and slide holder.. 18
- *Scale* slide 19

Op 1.13 Light and colour

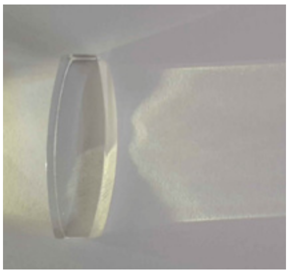
The light from an LED is to be dispersed into spectral colours by means of a prism. This is carried out as a workbook optics experiment.

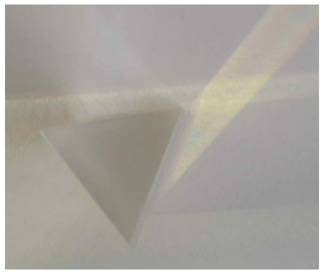
Equipment

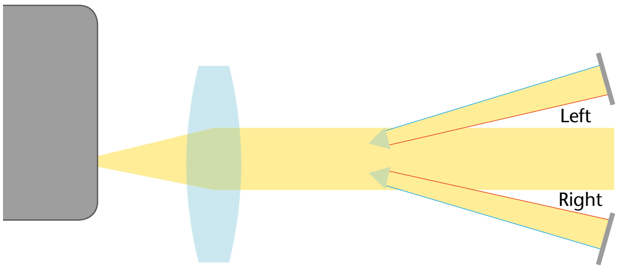
LED / laser student lamp 2
Set of *optical bodies* 5
Prism, equilateral 8
Stand 22
Screen 24

Experiment procedure

For this experiment, it is recommended that the surface on which you are doing the workbook experiment should be chosen such that the projection plane is at the same height as the LED.
The set-up uses a convex 2D lens to condense the light from the LED into a parallel beam. Then the prism is placed in the parallel beam in such a way the light emerges from the back of it with slight colouring around the edges.
The lamp is then moved slowly away from the lens until the light beam with its coloured edges becomes a complete colour spectrum. The lamp may need to be turned slightly to achieve this.
Tip: The disturbing direct light from the lamp can be blocked very well from the screen by standing the universal mirror next to the condenser.



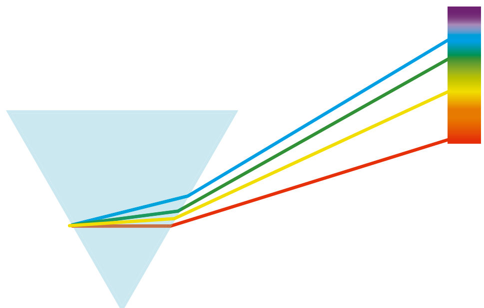


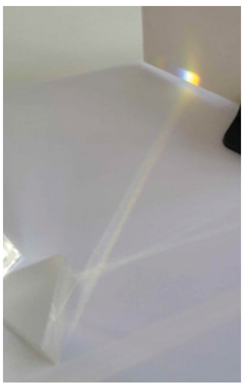


Conclusions

A prism refracts the light beam twice. The first time, as the light passes from air into perspex, it is refracted towards the normal. The second time, emerging from perspex into air, the light is refracted away from the normal. It is because of these refraction events that we can see the light being resolved into its spectral colours.
Since the various components of white light are refracted by differing amounts, the result is a continuous spectrum of light. The human eye can discern the following colour components: red, orange, yellow, green, blue and violet.

The red component of the white light is refracted the least, while the violet component is refracted the most. This means it is possible to observe the two results illustrated here.



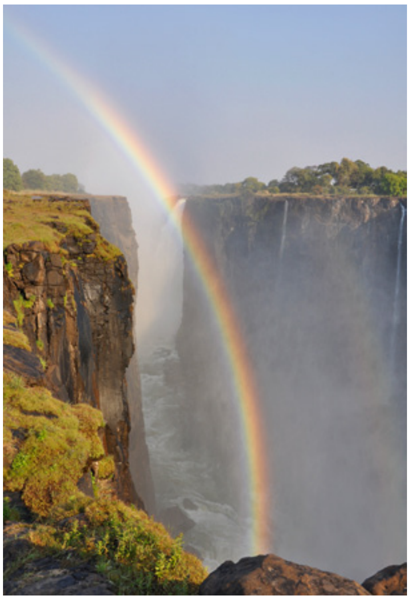


Supplementary to this experiment:

Light and colour worksheet (page 43)

Ph Optics	Light and colour	Name
		Date

A rainbow arises when a wall of rain is lit by the sun from behind. To understand how rainbows arise, it is necessary to know about *spectral dispersion*, as investigated in this experiment.



Definition:

The light of a ***spectral colour*** cannot be further dispersed into other colour components.

Spectral colours are also called *pure colours* or *rainbow colours*.

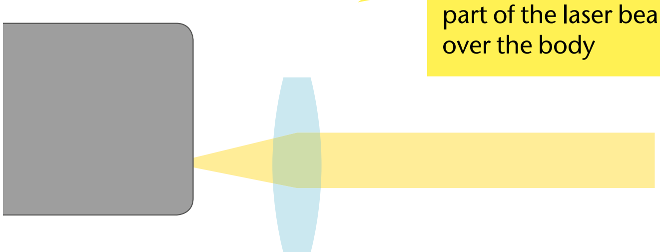
Procedure:

➲ Make a parallel light beam with the help of the LED light from your student lamp and the 2D lens body.

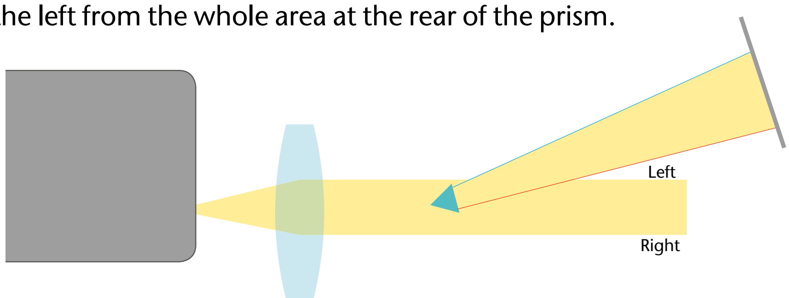
Rough side should be facing down.

Find the right distance between the lens and the lamp to obtain a parallel light beam.

When checking, avoid letting part of the laser beam shine over the body



➲ Put the prism in the parallel light beam in such a way that a beam of white light with slight colouring at the edges emerges towards the left from the whole area at the rear of the prism.



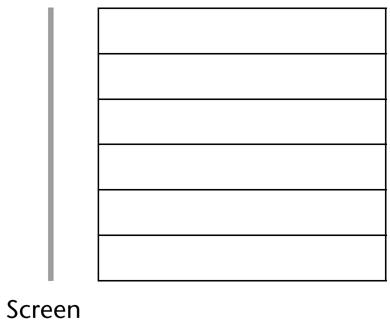
➲ Put the screen into the light beam such that it picks up the light beam with coloured edges.

➲ Now slowly move the lamp away from the lens until the light beam with coloured edges consists only of coloured light and no white can be seen on the screen at all. You may need to turn the lamp slightly to achieve this.

Conclusions:

1. The colours blue, yellow, green, orange, red, violet and more can be seen in the spectrum. Enter the colours into the list alongside as you observe them. ····················►

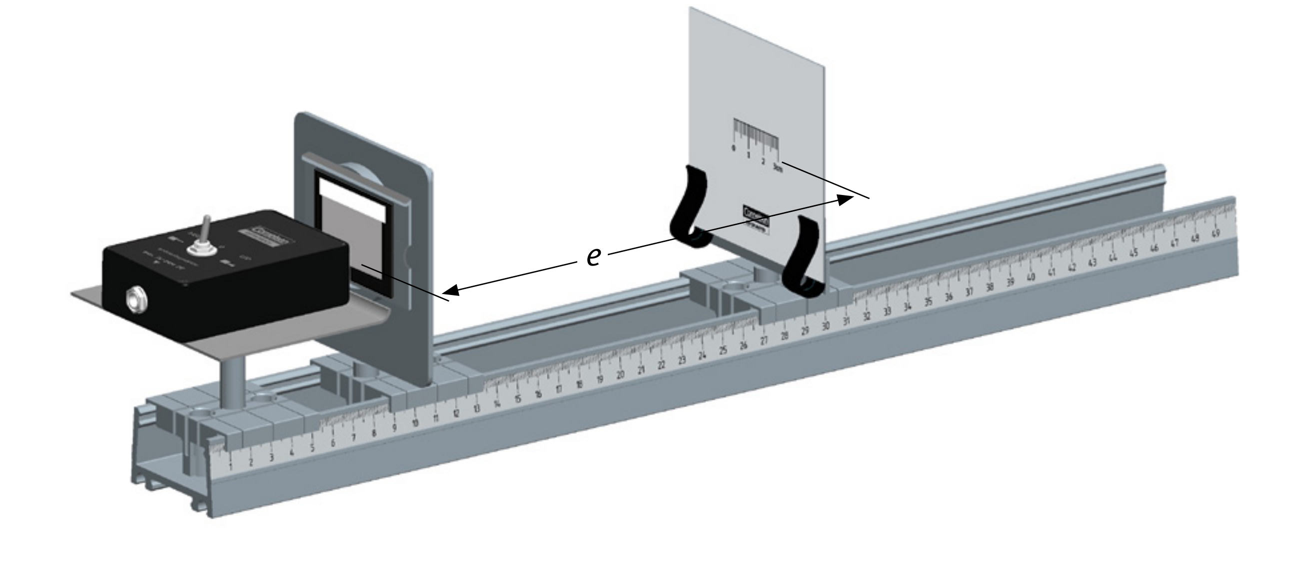
Spectrum of light:



2. State which colour is refracted most with respect to the incident white light beam.
3. A second experiment is to be performed where the light emerges from the prism towards the right. Guess what you will see on the screen and briefly justify your assumption.
4. Check to see if your guess was right by doing the experiment.
5. Use colour filters to investigate the paths the spectral colours take as they pass through the prism.

Op 2.1 Interference from a grating

The wavelength of the light from the laser in the student lamp is to be determined experimentally with the help of an optical diffraction grating.

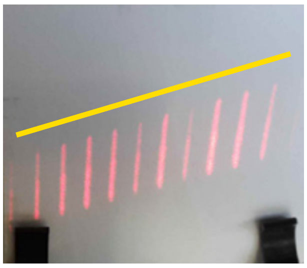


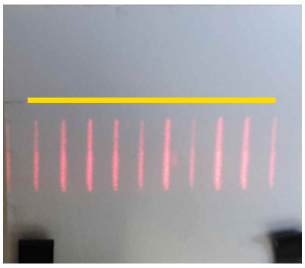
Equipment

LED / laser student lamp 2
Lamp platform 9
Clamp sliders .... (3 x) ... 11
Apertures and slide holder 18
Screen and mirror holder 21
Screen 24
Line grating,
80; 300; 600 lines / mm 28–30

Experiment procedure

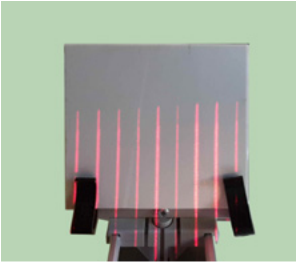
Light from the lasers illuminates a line grating as shown. The grating should be tuned such that the lines on the screen are in a horizontal band. Then the interference patterns on the screen will be measured using the printed scale.
The distance between the screen and the grating should be large enough so that the approximation for small angles can apply.


Wrong

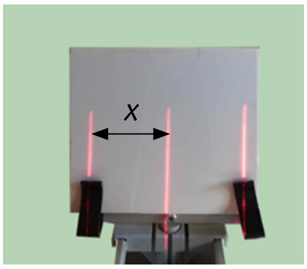

Right

Conclusions

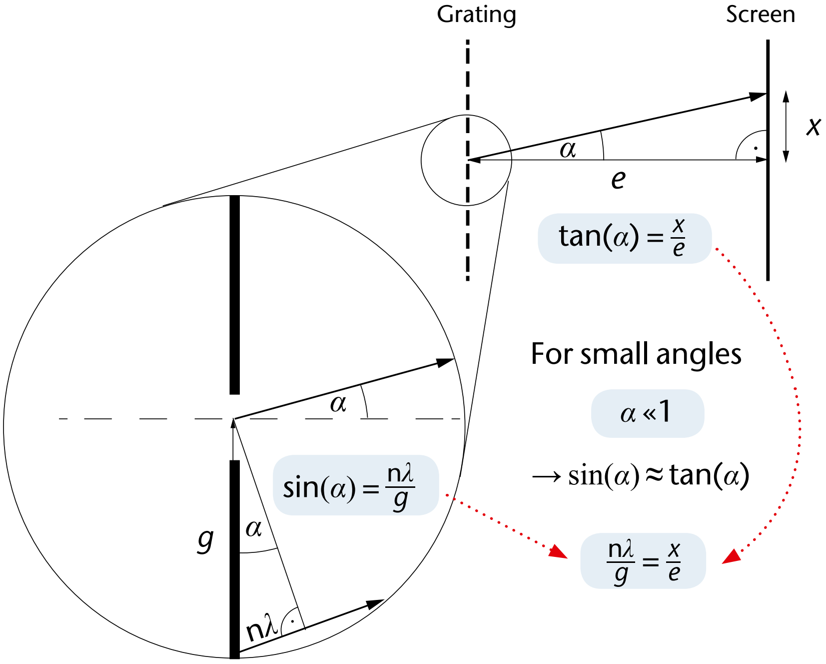
With increasing density of lines on the grating, the maxima in the interference pattern become increasingly widely separated. Observation of how the intensity decreases for higher-order maxima is disrupted by the optical characteristics of the laser diode. Nevertheless, it is possible to calculate the wavelength of the laser diode with very good accuracy using the derived relationship $\lambda = g\frac{x}{e}$. This is verified by comparing the results of your measurements with the wavelength quoted on the rating plate, 635 nm.



Grating, 80 lines / mm



Grating, 300 lines / mm



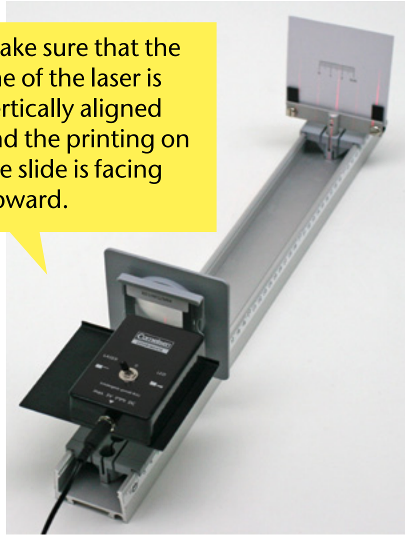
Grating type	80 lines / mm	300 lines / mm	600 lines / mm
Line separation g in µm	12.50	3.33	1.67
Distance to screen e in m	0.33	0.33	0.14
Separation of maxima x in m	0.017	0,064	0.058
Wavelength λ in nm	644	646	692
Error $\delta\lambda$ in %	1	2	9

Supplementary to this experiment:

Interference from a tansmission grating worksheet (page 46)

Ph **Optics**	**Interference from a transmission grating**	Name
		Date

When light rays from a laser are superimposed on one another having covered different paths, specific interference patterns arise. With the help of these patterns, it is possible to determine the wavelength of the light using only a ruler, even though the wavelength is exceedingly short.



Make sure that the line of the laser is vertically aligned and the printing on the slide is facing upward.

Procedure:

➲ Set up the experiment as shown in the illustration.

➲ Calculate the grating constants *g* for the following three gratings.

Grating type	80 lines / mm	300 lines / mm	600 lines / mm
g in mm			

➲ Investigate the effect the grating constants have on the interference patterns. Position the screen in such a way that you can see at least three interference bands on the screen.

Conclusions:

1. Sketch a section of the interference pattern for each of the gratings. For each of them, make a note of the separation of the maxima and the distance e between the screen and grating and add the values to your sketch.

g =

e =

g =

e =

g =

e =

2. Mark the positions of constructive and destructive interference on your sketch.
3. Use your data to calculate the wavelength of the lasers.
   Check your results against the data on the rating plate.

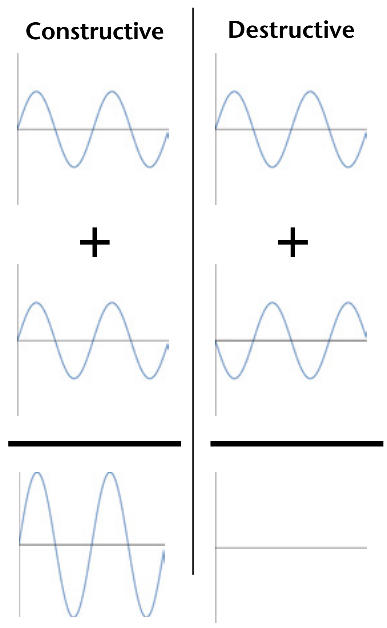
Measuring tip

To improve the accuracy of the measurement you can…

… measure the separation of multiple maxima.

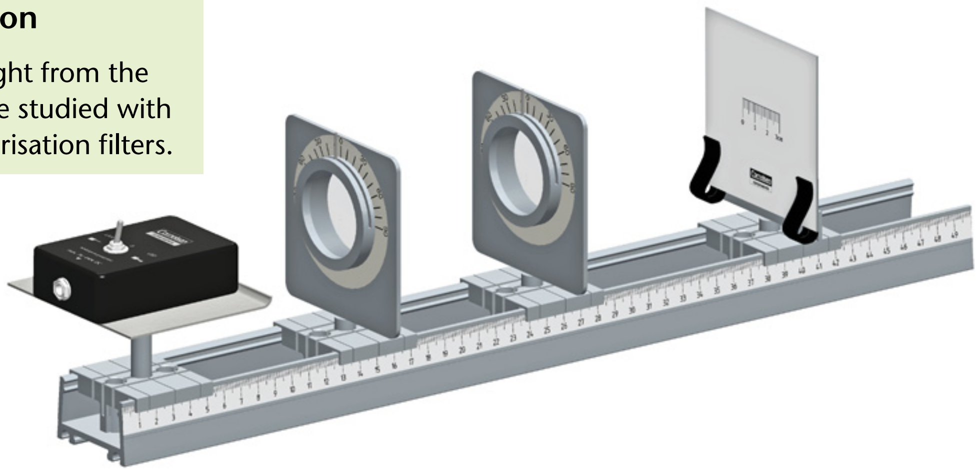
… increase the distance between the screen and grating.
Don't forget to write down the distance on your sketch.

Reiteration of *interference*



Op 2.2 Polarisation

The laser and LED light from the student lamp is to be studied with the help of two polarisation filters.



Equipment

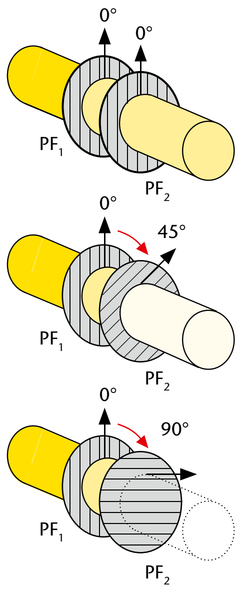
Profile rail 1
LED / laser student lamp 2
Lamp platform........................ 9
Clamp sliders .... (4x) ... 11
Screen and mirror holder....... 21
Screen 24
Polarisation filters.................. 26

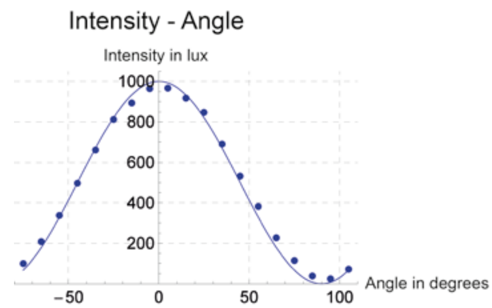
Experiment procedure

Set up the experiment as shown in the illustration. The first part of the experiment to investigate the polarisation of the laser light only requires one polarising filter. To dim the light of the lamp altogether, two polarising filters are needed.

Conclusions

The adjustment lever of the polarisation filters shows the direction of the transmission axis. If the incident light is polarised in this direction, almost all of it will be allowed to pass through the filter.
Since the LED light is not polarised, the brightness is markedly dimmed even after the first filter.
If a second filter is then placed in the subsequent beam to be used as an analyser, the intensity of the transmitted light depends on the relative angle between the transmission axes of the two filters. When the transmission axes are parallel, the intensity will be at its maximum, whereas if they are perpendicular, to one another, the light will be blocked off entirely.





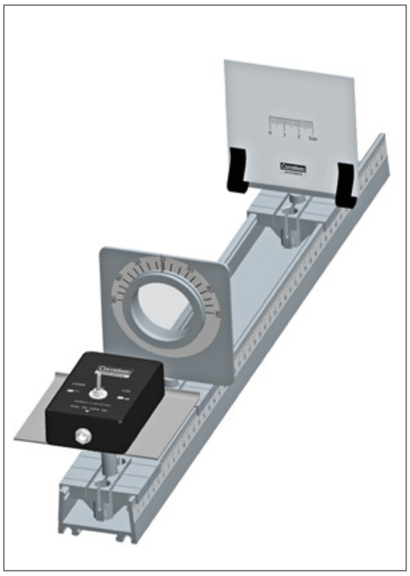
Unlike the LED, the light from the laser diode already exhibits good linear polarisation and can therefore be investigated using just one polarisation filter. The polarisation plane of the laser light is parallel to the p-n boundary layer of the diode. If the filter is perpendicular to this, the residual intensity arises from the small unpolarised component of the light, which is due to spontaneous emission.
An extension of this experiment involves measuring the light intensity with a lux sensor as a function of the orientation of the filter (angle α with respect to the direction of maximum intensity I_{max}).
By this means, the relationship $I(\alpha) = I_{max} \cdot \cos^2(\alpha)$ can be verified.

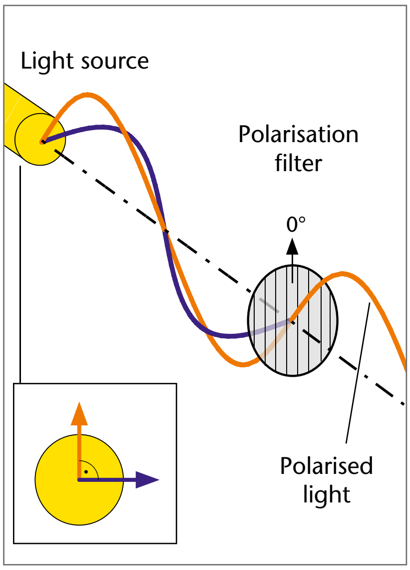
Supplementary to this experiment:

Polarisation of light worksheet (page 48)

Ph Optics	Polarisation of light	Name Date

Light can be regarded as an electromagnetic wave. In the case of polarisation, the key aspect is the direction of oscillation of the electric field. If the electric field always oscillates in the same direction, the light is said to be *linearly polarised*.





Procedure:

➲ Set up the experiment as shown in the illustration.

➲ Observe the light from the laser after it has passed through a polarisation filter. Make a note of your observations for various angles of the polarisation filter.

Filter angle	Observations

➲ Repeat the experiment with light from the LED.

➲ Compare the intensity of light from an LED with and without it passing through a polarisation filter.

➲ Add a second polarisation filter to the set-up.

➲ Find various settings of the polarisation filters for which maximum dimming of LED light occurs.

Configurations for maximum dimming of LED light:

Filter angle 1					
Filter angle 2					

Definition:
A polarisation filter only allows light with a certain polarisation direction to pass through it, i.e. light in which the electric field oscillate in a specific direction.
Beyond the filter, the light is therefore linearly polarised.

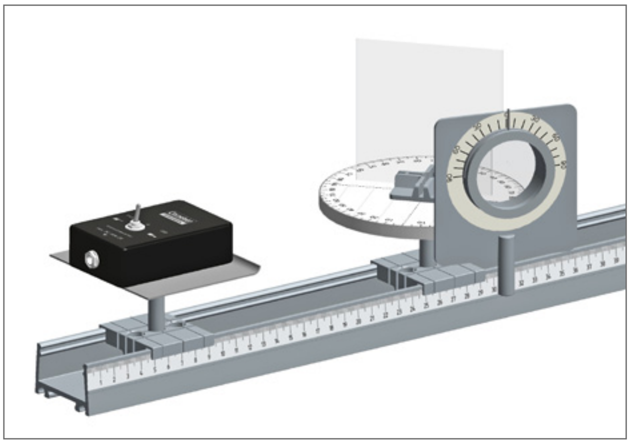
Conclusions:

1. Formulate a condition for which the maximum dimming of light occurs after the light passes through two polarisation filters.
2. Discuss on the basis of your observations what the light from lasers and light from LEDs have in common in terms of polarisation and what the differences are.

Op 2.3 Effects of polarisation

Three experiments on *polarisation*.

Op 2.3a Polarisation due to reflection (Brewster's angle)
Op 2.3b Birefringence due to tension
Op 2.3c Chromatic polarisation (LCD screens)



Op 2.3a Polarisation due to reflection (Brewster's angle)

Equipment

Profile rail 1
LED / laser student lamp 2
Lamp platform........................ 9
Measurement platform 10
Clamp sliders ....(2 x) ... 11
Stand.................................... 22
Screen, clear glass.................. 25
Polarisation filters.................. 26

Experiment procedure

The image of the LED as reflected from a glass plate is to be studied with the help of a polarisation filter for various angles of incidence. For each incident angle, the polarisation filter is adjusted in such a way as to obtain the minimum brightness of the reflected light. To measure the angle as easily as possible, the LED, the observed image and your eye should all be at the same height as far as possible.

Conclusions

For the angles of incidence α which have been set up, which must be neither too shallow or too steep, a brightness minimum needs to be found for the position to which the filter is turned, whereby the transmission axis is in the plane spanned by the incident and emergent ray of light.
The trough of the minimum depends on the angle of incidence. The angle for which the lowest trough in the brightness is observed is called *Brewster's angle* Θ_B. At this angle, the light reflected from the glass plate is polarised completely at right angles to the incident plane. As the angle deviates from this one, the linearly polarised component decreases.
For a glass reflector ($n_{Glass} \approx 1.5$) in air ($n \approx 1.0$) Brewster's angle Θ_B is as follows

$$\Theta_B = \arctan\left(\frac{n_{Glass}}{n_{Air}}\right)$$

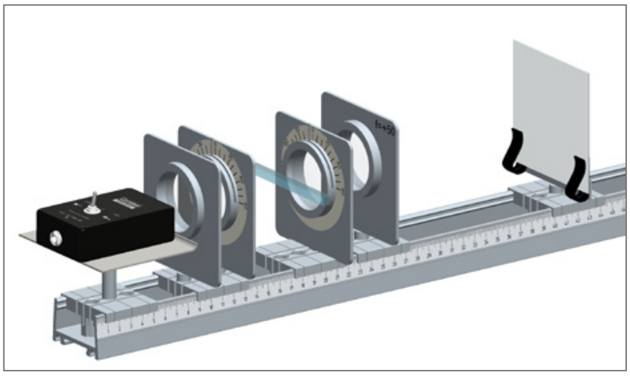
$$\Theta_{B,Glass} \cong \arctan\left(\frac{1{,}5}{1}\right)$$

$$\Theta_{B,Glass} \cong 60°.$$

Op 2.3b Birefringence due to tension

Equipment

Profile rail 1
LED / laser student lamp 2
Perspex rod 6
Lamp platform........................ 9
Clamp sliders ....(5 x) ... 11
Lens, $f = +50$ mm 15
Condenser 17
Screen and mirror holder....... 21
Screen 24
Polarisation filters.................. 26

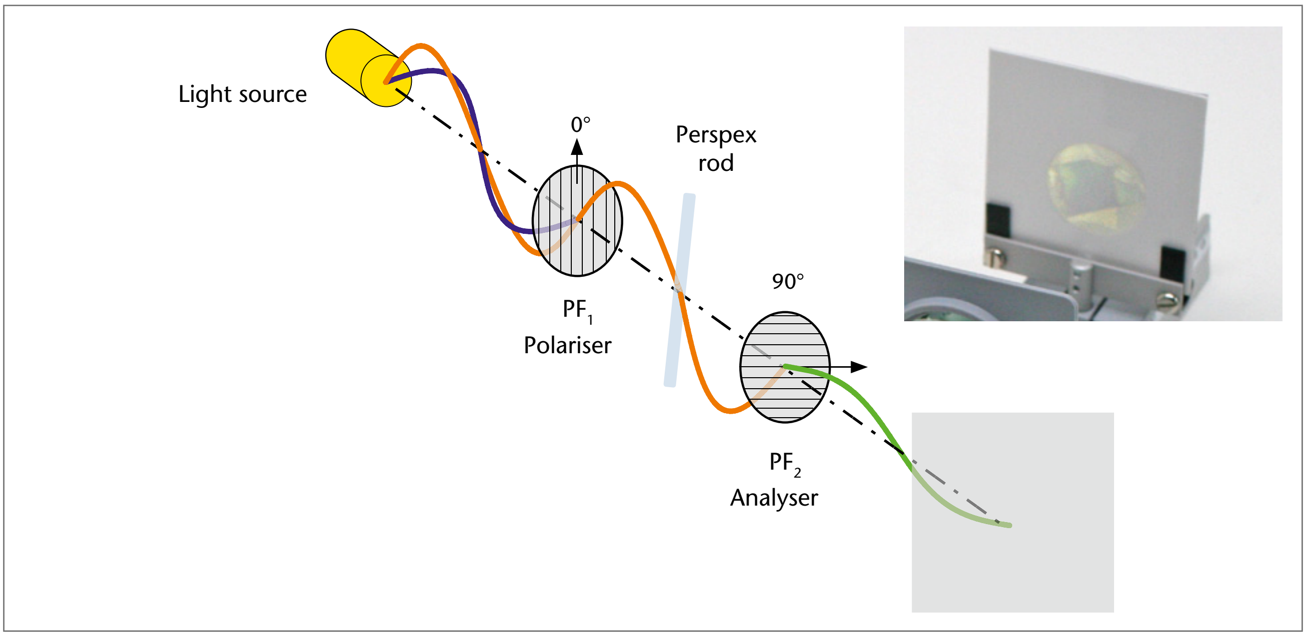


Experiment procedure

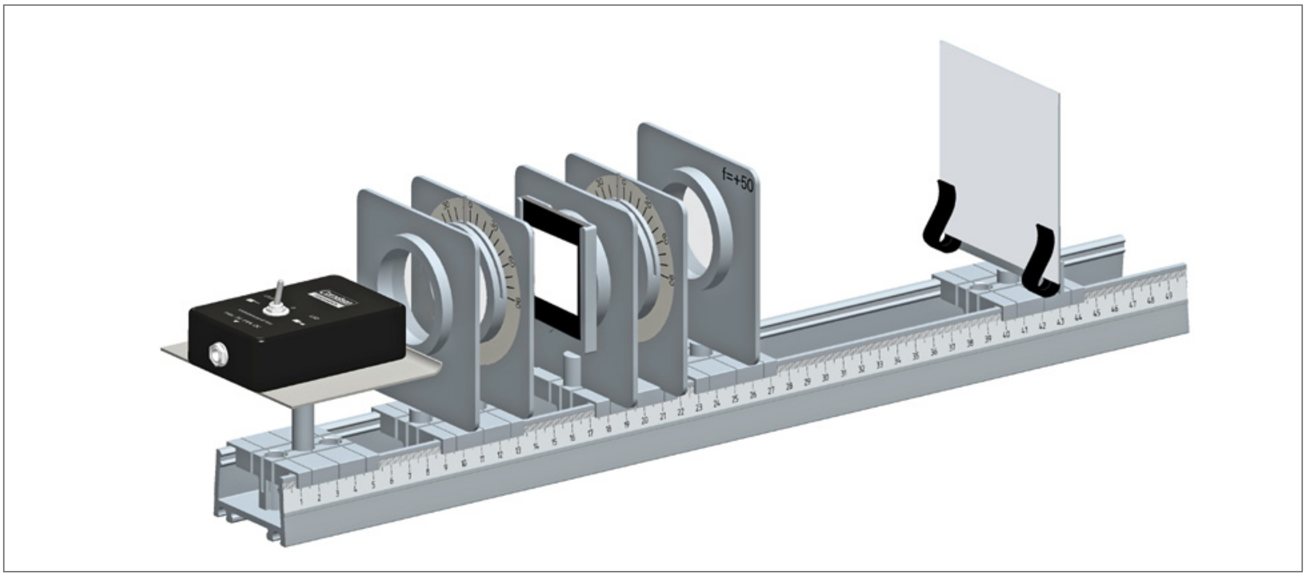
This experiment requires a parallel beam of light. To obtain such a beam, the LED lamp is placed on the lamp platform in such a way that the condenser lens is fully illuminated by its light. Then the condenser is moved to a position relative to the lamp for which the emerging beam is roughly parallel (typically 6–10 cm). The shape of the beam can be checked using the measurement platform at a distance of about 20–25 cm from the lamp.
Once the condenser has been positioned correctly, the measurement platform should be replaced with the screen, in front of which another convex lens should be placed at exactly its focal length (f = +50 mm) away from the screen. The two polarisation filters are now placed between this lens and the condenser with enough space between them to allow for the object through which the light is to pass.
The transmission axes of the filters are set up perpendicular to one another so that all the light is filtered out. Now the perspex rod should be held between the polarisation filters and slowly placed under mechanical tension by bending it. The image on the screen can be put into focus by moving the second lens slightly.

Conclusions

As you will already have observed in the experiment on polarisation, when two polarisation filters are set up with their transmission axes perpendicular to one another, then no light passes through them.
If a perspex body is introduced between the two filters and put under mechanical tension, it is possible to observe coloured patterns on the screen. The reason for this is a property of perspex whereby tension causes it to become optically anisotropic at certain places. This causes the polarisation of the portion of light passing through the rod at these places to be altered. A beam with altered polarisation cannot then be entirely blocked by the second polarisation filter and thus contributes to the image on the screen.
Since all parts of the light in the beam are shown together on the screen at once, interference colouring arises which is characteristic of the mechanical tensions arising locally in the piece of equipment.



Tip In addition to birefringent materials, optically active substances, such as a sugar solution, can also cause a polarisation plane to rotate.
If you fill an optical cell with concentrated sugar solution and put this between two polarisation filters that are perpendicular to each other, then the screen will exhibit a slight brightening. The optically active sugar solution causes the polarisation plane to rotate by an angle dependent on the concentration of the solution. Only when the analyser filter is adjusted by the same angle, is the light fully filtered out again. The angle by which the polarisations plane is rotated can be used as a measure of optical activity and concentration of the sugar solution.

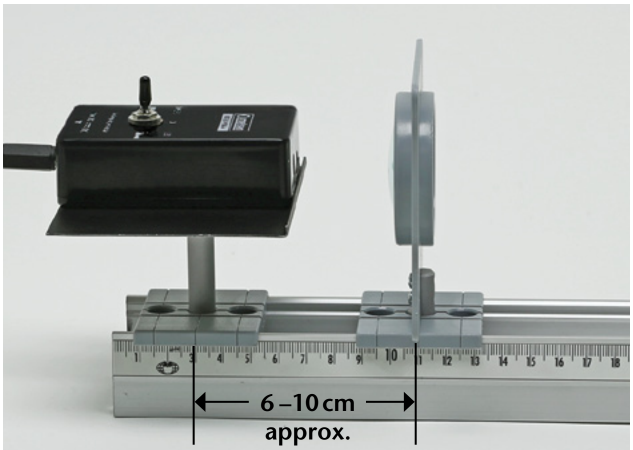


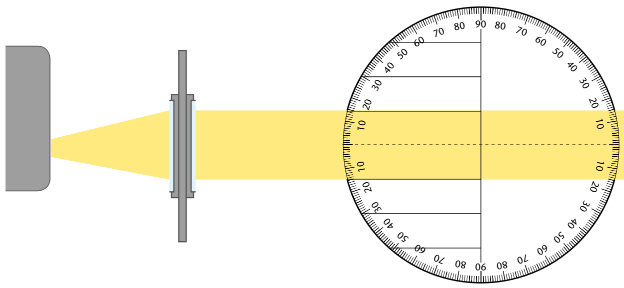
Op 2.3c Chromatic polarisation (LCD screens)

Equipment

Profile rail 1
LED / laser student lamp 2
Lamp platform......................... 9
Clamp sliders ....(5 x) ... 11
Lens, $f = +50$ mm 15
Condenser 17
Apertures and slide holder 18
Screen and mirror holder 21
Screen 24
Polarisation filters.................. 26
Mica slide 27

Experiment procedure





This experiment requires a parallel beam of light. To obtain such a beam, the LED lamp is placed on the lamp platform in such a way that the condenser lens is fully illuminated by its light. Then the condenser is moved to that position relative to the lamp for which the emerging beam is roughly parallel (typically 6 – 10 cm). The shape of the beam can be checked using the measurement platform. Once the condenser has been positioned correctly, the measurement platform should be replaced with the screen. Next the two polarisation filters and the lens are set up between the screen and the condenser.

The adjustment levers of the two polarisation filters are set up such that they are aligned at 90° to one another. The filters are then put in the specified positions on the clamp sliders for the condenser and the lens.

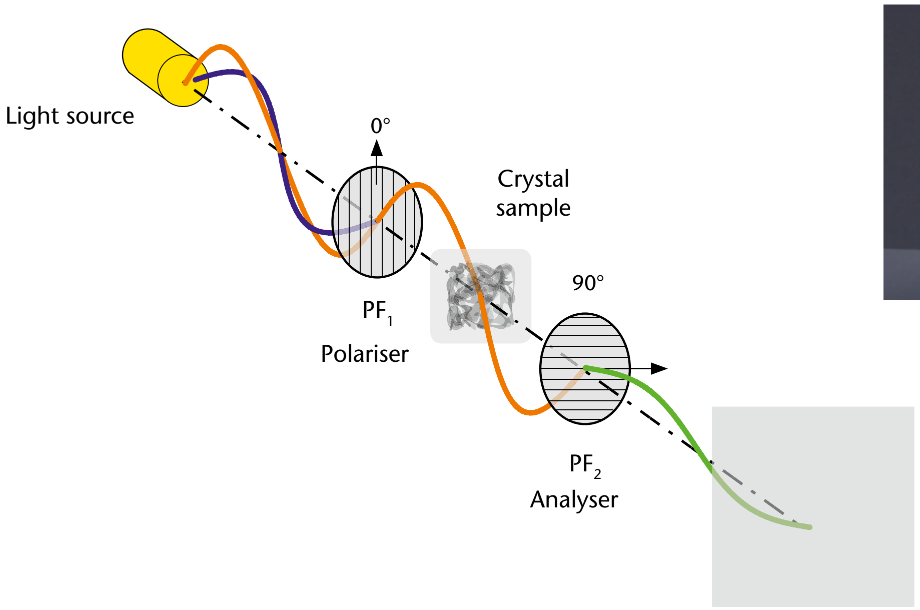
The apertures and slide holder is inserted into the empty clamp slider between the polarisation filters and the mica slide is slotted into it.

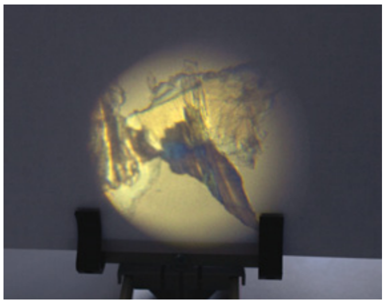
The image on the screen can be focused and assessed by moving the lens slightly. One of the polarisation filters is then rotated slowly from its initial configuration in both directions. You should carefully observe the effects on the screen.

Conclusions

If a crystal sample (mica slide) is put into the path of a polarised light beam, birefringence occurs. This happens with differing intensity at certain places on the mica slide depending on the thickness of the layer and its crystalline structure as well as various path differences.

Depending on how the polariser and analyser are set with respect to one another, there will be corresponding increases or decreases in brightness and colours resulting from interference in the image of the crystal slide on the screen.

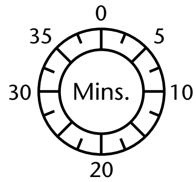




Supplementary to this experiment:

Effects of polarisation worksheet (page 53, 54)

Ph Optics | **Station: Polarisation due to reflection (Brewster's angle)** | Time:



Work assignment:

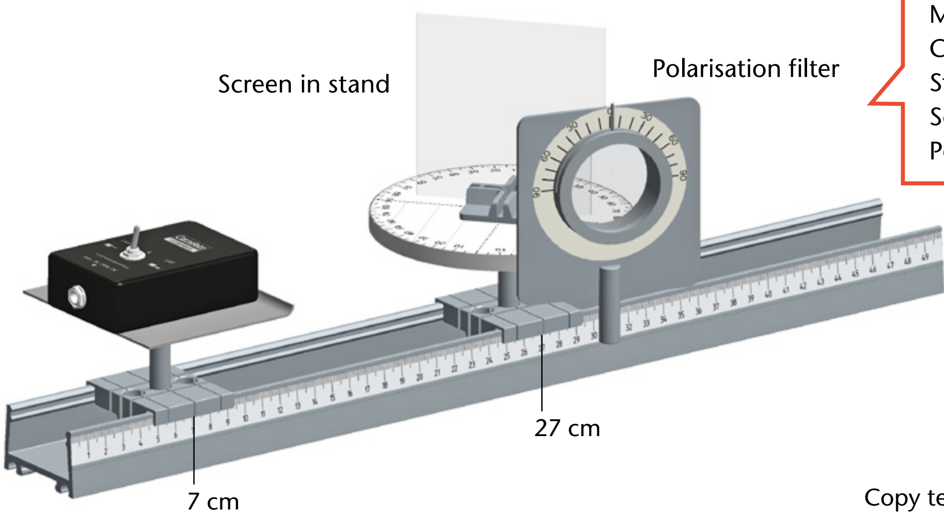
➲ Set up the experiment as shown in the illustration.

➲ Observe the LED light reflected from a glass plate with the help of a polarisation filter. Observe the image of the LED for various angle settings of the polarisation filters, and write down your observations.

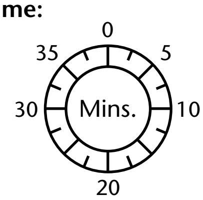
➲ Check experimentally that Brewster's angle for glass is 60°.

Equipment

Profile rail	1
LED / laser student lamp	2
Lamp platform	9
Measurement platform	10
Clamp sliders (2 x)	11
Stand	22
Screen, clear glass	25
Polarisation filters	26



Ph Optics | **Station: Birefringence due to tension** | Time:



Work assignment:

➲ Set up the experiment as shown in the illustration.

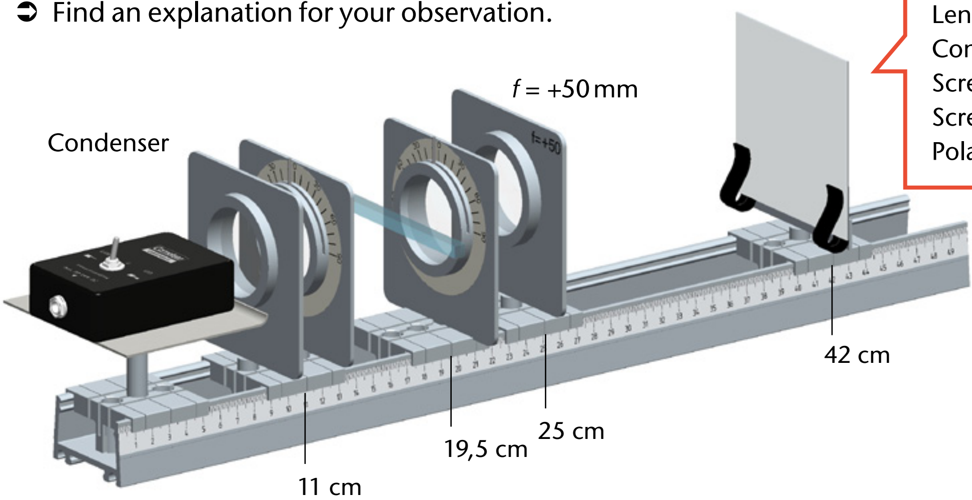
➲ Set up the two polarisation filters in such a way as to cause maximum dimming of the light from the LED.

➲ Hold the perspex rod between the two polarisation filters. Observe the image on the screen while you bend the rod.

➲ Find an explanation for your observation.

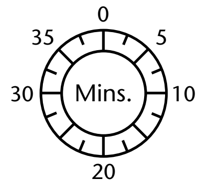
Equipment

Profile rail	1
LED / laser student lamp	2
Perspex rod	6
Lamp platform	9
Clamp sliders (5 x)	11
Lens, $f = +50$ mm	15
Condenser	17
Screen and mirror holder	21
Screen	24
Polarisation filters	26



Ph	Optics	Station: Chromatic polarisation (LCD screens)

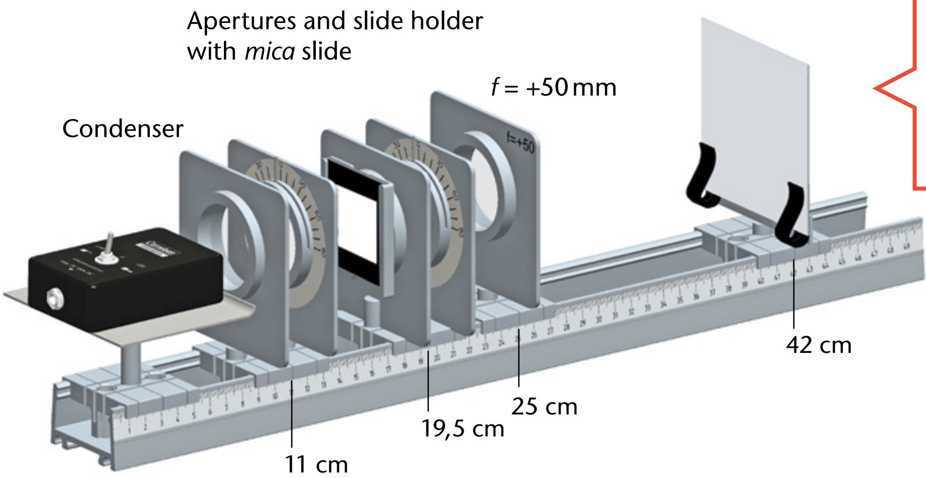
Time:



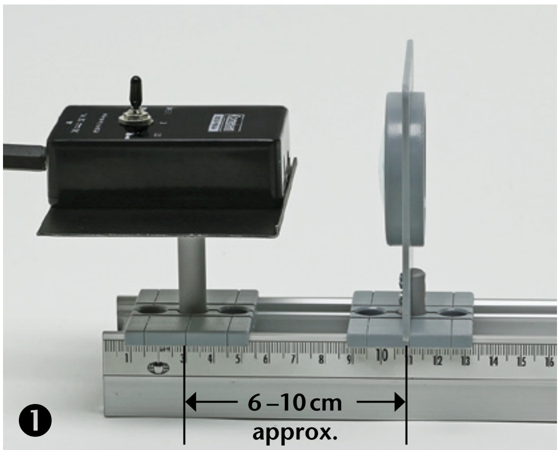
Work assignment:

- Set up the experiment as shown in the illustration.
- Observe the image of the mica for various setting of the polarisation filters.
- Discuss the relationship between wavelength and polarisation.

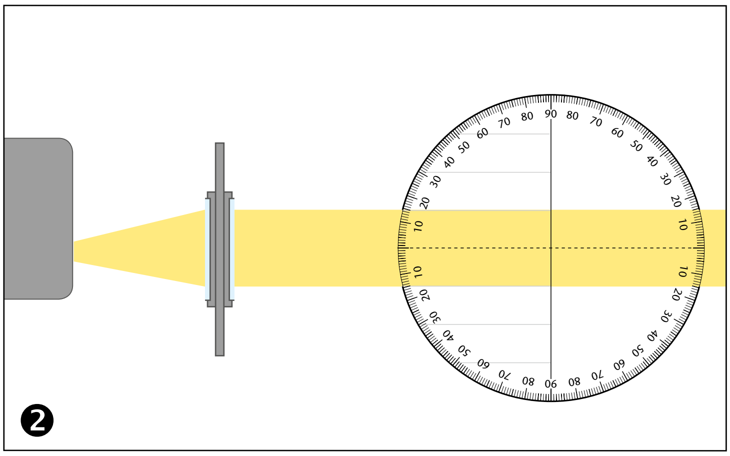
Profile rail 1
LED / laser student lamp....... 2
Lamp platform 9
Clamp sliders.......... (5 x) 11
Lens, $f = +50$ mm 15
Condenser 17
Apertures and slide holder..18
Screen and mirror holder....21
Screen 24
Polarisation filters 26
Mica slide 27



Ph	Optics	Help for condenser



1



2

- Position the LED lamp and condenser such that the condenser lens is fully illuminated by the cone of light from the LED lamp.
- By moving and turning the condenser itself, you can obtain a parallel beam of light. Check your configuration using the markings on the measurement platform as shown.
  The optimum configuration is shown in Figure 2.

Definition:

A ***condenser*** is used to generate parallel beams of radiation.

For visible light, the simplest kind of condenser is a converging lens.

Use the unlabelled lens numbered **17** as the condenser.

Op 2.4 LEDs and lasers – coherence, polarisation and monochromaticity

Carrying out the experiments on wave optics can involve a comparison of the two light sources, the laser and LED. The properties of *coherence*, *polarisation* and *monochromaticity* are to be investigated again and entered into a table.

Solutions

	Definition	Experiment	Assumption and result: LED	Assumption and result: Laser
Coherence	If two waves have a fixed phase relationship with one another, they are described as *coherent* or *capable of interference.*	*Gratings* experiment	NO	YES
Polarisation	If the planes of oscillation of the electric field are parallel for all of the photons in a beam of light, then that light is linearly polarised. Circularly polarised light involves the direction of polarisation changing at constant angular velocity.	*Polarisation* experiment	NO	MOSTLY
Monochromaticity	Monochromatic light is light with a specific wavelength, frequency and colour. Since perfect monochromaticity is not achievable, in practice a small range of wavelength or frequency is treated as single spectral colour.	*Spectrum with laser and LED light* experiment	NO	YES

Supplementary to this experiment:

LEDs and lasers – coherence, polarisation and monochromaticity worksheet (page 56)

Ph **Optics**

LEDs and lasers – coherence, polarisation and monochromaticity

Name	Date

Exercise

➲ Investigate the light from the LED and the laser for the properties of *coherence*, *polarisation* and *monochromaticity*. Proceed as follows:

1. Explain the above properties in your own words.
2. Guess which properties the light from the various sources will possess.
3. Plan an experiment to test the properties in question.
4. Check your assumption with the result of the experiment.

			Assumption and result	
	Definition	**Experiment**	**LED**	**Laser**
Coherence				
Polarisation				
Monochromaticity				

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