Notes for teachers
on Module 3

Lenses and Telescopes

Lenses are a basic optical component. However, understanding how they work is non-trivial! They have a wide variety of applications. One such use is in telescopes to allow us to look at astronomical objects. In this module, students will get to work with lenses and learn about interesting effects for themselves.

Summary: Students learn how concave and convex lenses focus light. They also build their own Galilean and Kepler telescopes to look at distant objects.

The module consists of one worksheet:

- The Light Way worksheet

Designed for: lower secondary level (age ca. 12 to 14)

Duration: The chapter is designed for one lesson of ca. 40 min.

What students should already know:

- Basic concepts about lenses
- Concave and convex lenses

What students will learn:

- How different lenses focus light
- The physical concept of ”focal point”
- The difference between real and virtual images
- How to build two types of telescopes
- How to work out the magnification of a telescope
- The concept of field-of-view

Skills your students will foster:

- Teamwork
- Working with lenses and ray diagrams
- Building their own experimental setups and relating observations to theories

This module includes:

- 1 worksheet
- 1 fact sheet

Chapter 1| The Light Way

Suggested lesson outline

Students study concave and convex lenses and learn about how and where lenses focus light. They also learn about real and virtual images.

Timing in minutes	Activity	Material
0-20	Group work: Finding out how different lenses focus and about properties of the image. Creating and filling out the table. Working through Q 2)	3 lenses (+30 mm, -30 mm and 150 mm focal lengths) LED module *Not provided* An object to use like a bottle cap or a smiley drawn on a page.
20-35	Building Galilean and Kepler telescopes	
35-40	Class discussion on results	
homework	None	

Description of suggested lesson

To begin the lesson, ask your students to ”investigate” the lenses on their own. Tell them to note their findings in a table like the one shown on the worksheet. The main idea is for them to *qualitatively* analyse the images. For this experiment, it is best that students use an object that has ann obvious orientation so they can easily identify when it is inverted. e.g. a soft drink bottle cap with writing on it or a smiley face drawn on card or paper.

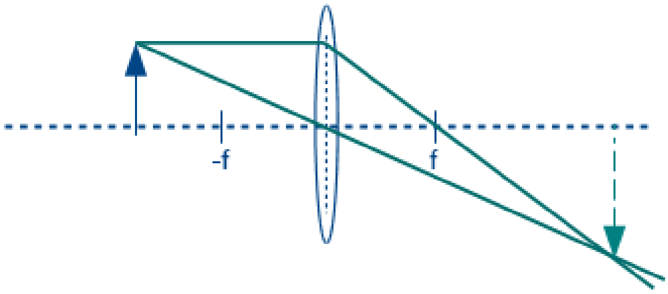
Once the students have worked through this experiment they should be able to summarise the properties of each type of lens in a table as shown below. e.g. is the image upright or inverted, bigger or smaller, etc.

Type of Lens	Focal Length	Object position	Image distance	Image orientation	Image Size
bi convex	+30 mm				
bi Convex	+150 mm				
bi Concave	-30 mm				

The students should also test the significance of the focal length and focal point to understand what happens to images when the object is placed at, near, or away from the focal point of the lens. Two questions that the students might have after working through this part is what happens when the object is up close to the concave lens and how come the image turns upright when the object is up close to the convex lens. Leave these as points for discussion and tell them to work through the next part to find out the answers themselves.

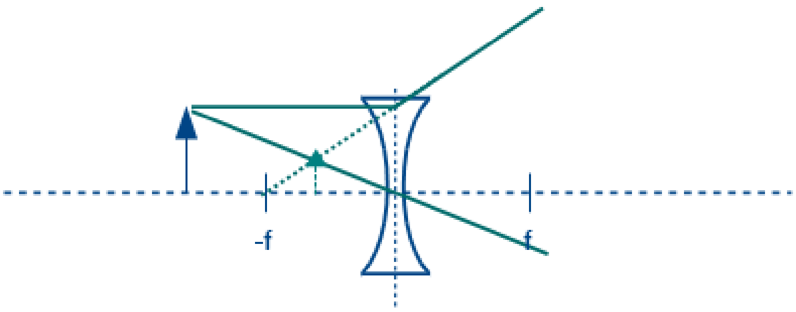
Real and Virtual Images

In Question 2), students work with the bi-concave and bi-convex lenses to see that they can actually make a sharp image on the screen with the first lens but not with the second lens. In 3), they are provided with an explanation of what is a real image and what is a virtual image. You can enhance their understanding of these concepts using ray diagrams. Two cases are shown below;

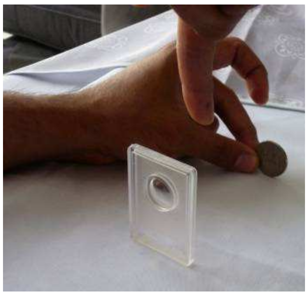


With the bi-convex lens a larger, real image is formed when the object is placed >f away from the lens. This kind of image can be seen on a screen

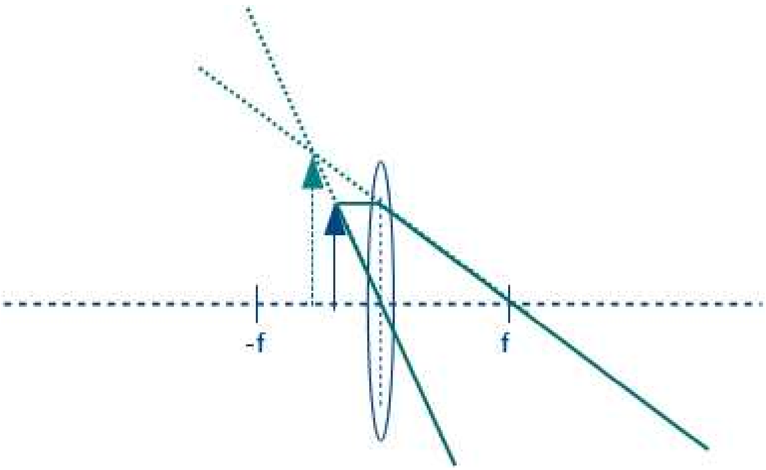
With the bi-concave lens a smaller, virtual image is formed when the object is placed >f away from the lens. This kind of image is not seen on a screen. The light rays can be traced back to behind the lens and appear as if they are coming from this point.



Time permitting, you can do a simple experiment with the class to illustrate this effect. Take the -30 mm focal length lens and place it on a table. Hold a small object >30 mm behind the lens and ask a student to look at the object through the lens with both eyes open. Now ask them to line up their finger above the object while still looking through the lens at the object. It is important that the student does not see their finger through the lens. Their finger should be just above the lens. Ask them to say ”NOW” and hold their finger steady. Now tell them to look behind the lens at their finger above the object. If done correctly, the student’s finger should always be between the lens and the object. *This is the position of the virtual image.*



In Part 4), students work with the bi-convex lens to find out that when the object is placed before the focal point (< 30 mm away from the lens) then no sharp image is seen on the screen. The rays diverge as shown in the ray diagram below and a virtual image is formed.



Galilean and Kepler Telescopes

There are several ways to take your students through this part of the worksheet. Two options are as follows:

1) The stories of Galileo and Kepler are full of interesting historical facts, so it might be interesting to add historical context to the lesson. Students could learn why the problem needed to be solved and what it meant in that period in history to solve this problem. *If time is short,* you can divide the class into Galileo groups and Kepler groups and make each work on only one kind of telescope. Once they have ”built” their respective telescopes, they should demonstrate how it works to the other group and compare and contrast both types of telescopes. They should also talk about what each might be useful for.

2) Divide your class into groups of 2-3 and let them work through questions 5-7 on WS 3.1 together to build both types of telescope setups. You then have an open discussion where you jot down the qualities for each type of telescope on the board.

NOTE: Please note that for this part of the worksheet, students need to focus on a distant object (at least 5-6 metres away). Ideally, they should look out a window at distant building. However, if this is not an option then put a poster on the farthest wall in the classroom for students to focus on. Make sure that the poster has words or letters on it so that they can easily work out the vertical orientation.

In Part 5), students discuss whether or not they can make a telescope with one lens. This may lead to the question of whether or not a magnifying glass is essentially a telescope because it makes objects look bigger. A magnifying glass is a bi-convex lens that magnifies objects that are at the distance of about one focal length away from it. A telescope on the other hand uses a minimum of two lenses to magnify very distant objects. Therefore, a minimum of two lenses is needed to build a telescope.

In Part 6), students build a *Galilean telescope*. Students should see that this combination of lenses provides a smaller field of view (they can see less area) and the image is upright. The distance between the lenses for a Galilean setup should be the *sum of the focal lengths* ~ 120 mm.

In Part 7), students build a *Keplerian telescope.* This provides a larger field of view but the image is inverted. The distance between the lenses needed to see a clear image is once again the sum of the focal lengths ~ 180 mm.

In Part 8), students calculate the magnification of their telescopes using the formula provided. They should see that both telescopic setups have the same magnification but that the Kepler telescope has a negative sign. This indicates the orientation of the image and that the Kepler telescope setup gives an inverted image.

Background Information

Some interesting history: Galileo and Kepler

Galileo's full name was Galileo di Vincenzo Bonaiuti de' Galilei. He was born in Pisa in 1564 and he was a renowned physicist, mathematician, astronomer and philosopher who played a key role in the "Scientific Revolution". In 1589, he was appointed to the chair of mathematics in Pisa. In 1592, he moved to the University of Padua and taught geometry, mechanics, and astronomy until 1610. During this period, Galileo made significant discoveries in both pure fundamental science (for example, kinematics of motion and astronomy) as well as applied science (for example, strength of materials and improvement of the telescope). His multiple interests included the study of astrology, which at the time was tied to the studies of mathematics and astronomy. He is perhaps best known for his support of the heliocentric view, which placed the sun, not the earth, at the centre of the universe.

In 1609, Galileo made significant improvements to the first version of the telescope demonstrated by Hans Lippershey the previous year. Galileo constructed telescopes with three to thirty times magnification. For a period of time, he was the only one able to make telescopes powerful enough to look at celestial objects in the night sky. In 1610, Galileo observed three of Jupiter's four orbiting moons, which created a revolution in astronomy. This observation contradicted the theory that all celestial objects orbit the earth. Galileo continued to observe the satellites over the next eighteen months, and by mid 1611 he had obtained remarkably accurate estimates for their periods—a feat which Kepler had believed impossible.

Among several other observations, Galileo was also the first to observe the phases of Venus, which, along with the observations of orbiting moons, contributed greatly towards the change from geocentrism (placing the earth at the centre of the universe) to heliocentrism.

Johannes Kepler, born in 1571, was a German mathematician, astronomer and astrologer. A key figure in the 17th century scientific revolution, he is best known for his laws of planetary motion. Kepler lived in an era when there was no clear distinction between astronomy and astrology, but there was a strong division between astronomy and physics. Kepler also incorporated religious arguments and reasoning into his work. He nurtured a great love for astronomy and as a child of six he observed the Great Comet of 1577 and at nine he observed a lunar eclipse.

In 1601, Kepler began working for Tycho Brahe. Kepler was appointed Brahe's successor as imperial mathematician and spent 11 years in this position. He worked extensively to develop some of the first theories on the cause of eclipses, the inverse-square law that governs the intensity of light, reflection by flat and curved mirrors, and principles of pinhole cameras.

He systematically studied the supernova of 1604, and, continuing Brahe's work, developed the three laws of motion that we know today:

- The orbit of every planet is an ellipse with the Sun at one of the two foci.
- A line joining a planet and the Sun sweeps out equal areas during equal intervals of time.[1]

- The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.

After hearing of Galileo's observations with his telescopes, he too worked with telescopes and discovered that using two convex lenses could give a larger magnification than the Galilean telescope.

Reflecting telescopes

A reflecting telescope (also called a reflector) is an optical telescope which uses a single or combination of curved mirrors that reflect light and form an image. The reflecting telescope was invented in the 17th century as an alternative to the refracting telescope that, at that time, was a design that suffered from severe chromatic aberration. Although reflecting telescopes produce other types of optical aberrations, it can be designed with very large objectives. A large objective in a refractive telescope involves accurately grinding the lens whereas a reflecting configuration involves the simpler process of polishing a mirror. Almost all of the major telescopes used in astronomy research are reflectors. Isaac Newton has been generally credited with building the first reflecting telescope in 1668. It used a spherically ground metal primary mirror and a small diagonal mirror in an optical configuration that has come to be known as the Newtonian telescope.

Because the primary mirror focuses light to a common point in front of its own reflecting surface, almost all reflecting telescope designs have a secondary mirror, film holder, or detector near the focal point. This partially obstructs the light from reaching the primary mirror. Not only does this cause some reduction in the amount of light the system collects, it also causes a loss in contrast in the image due to diffraction effects.

The use of mirrors avoids chromatic aberration but they produce other types of aberrations. A simple spherical mirror cannot bring light from a distant object to a common focus because the reflection of light rays striking the mirror near its edge do not converge with those that reflect from nearer the centre of the mirror. This defect is called spherical aberration. To avoid this problem most reflecting telescopes use parabolic shaped mirrors, a shape that can focus all the light to a common focus. Parabolic mirrors work well with objects near the centre of the image they produce where the rays are parallel the optical axis. However, towards the edge of that same field of view they suffer from off-axis aberrations.

Students might ask

How many lenses do telescopes have and why?

In reality, no lens is perfect. There are several problems with the image from a two-lens telescope system. For instance, the image is curved and has chromatic aberration because refracting lenses bend light based on wavelength or frequency and the telescope can only be brought to focus at the centre of the eyepiece. (The greater the frequency, the more a particular colour of light is bent. For this reason, objects displaying light of various colours are not seen at the same point of focus across the electro-magnetic spectrum.) Several of these problems were solved by improving the eye-piece and including multiple lenses in it. Today, telescopes are corrected for image brightness, colour, image quality and contrast as well as portability of the device.