The study of light

Name: _________________________

Class: S3________

Class no.: ______

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Introduction

As you are about to make your decision of what elective subjects to study in the next three years, the physics teacher is going to provide you a solid experience of what physics lessons will be in our school.

Our physics lessons adopt FLIPPED CLASSROOM teaching strategy. In other subjects, you learn in lessons and do homework at home. For physics, you have to learn at home through watching videos prepared by your physics teacher. While in physics lessons, you have to finish assignments with your classmates. In this way, teacher may have more time to do demonstration, to clarify difficult concepts and you may also have more chance to do experiments, and ask for help from teachers and classmates more easily when doing assignment.

The S3 physics test and exam will follow the settings of Paper 1 in DSE, with MCQs and SQ, and the weightings are approximately 35% and 65% respectively. You should note that the quality of your assignment and your class performance are also important parts of your assessment. The following table may give you a clear summary:

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<th>Coursework Assessment (C.A.)</th>
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<tr>
<td>Tests</td>
<td>20%</td>
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<tr>
<td>Quizzes, Assignments and Class Performance</td>
<td>10%</td>
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<tr>
<td>Examination</td>
<td>70% of Term Mark</td>
</tr>
<tr>
<td>Multiple Choice Questions</td>
<td>24.5% ( (= 0.35 \times 70% ) )</td>
</tr>
<tr>
<td>Short Questions</td>
<td>45.5% ( (= 0.65 \times 70% ) )</td>
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So, how to get high marks?

Easy! Watch videos and finish all the questions in this book. Bring your Exercise book. Finish all assignments with quality answers; show your steps clearly and neatly. When your exercise book is returned, read the feedbacks from the teachers carefully. Do not leave questions unanswered; always ask for help from your physics teachers as soon as possible! Test and examination questions are very similar to those questions in your notes!
# S3 Physics – 2016/2017 (First Term)

## LIGHT – An introduction

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WHAT IF I AM ABSENT?

If you are absent from a physics lesson, you should watch the pre-lesson video and finish the assignment questions. You should ask your classmates which questions you should do and hand in your work as soon as possible before the next lesson.

If there is an experimental worksheet, you will do the experiment in the next lesson. If you have any difficulties, you are always welcome to ask your physics teacher for help.

WHAT IF I HAVE LOST MY BOOK?

Download and print it!

If you have lost your book, or somehow you find your book has some pages missed, just visit the school website and download a copy. Print your copy and bring it to the class.

http://www.slcss.edu.hk/s3physics.htm
1.1 Light travels in straight line

Light is a kind of *electromagnetic wave* (*em wave* for short). It *propagates* in the form of varying magnetic and electric field. In fact, *visible light* is a small part of the *electromagnetic spectrum*.

As a wave, different colours of light has different *wavelength*. The wavelength of visible light ranges from 400 nm to 700 nm, for violet and red light respectively. (*nm* for nano-meter, which is $10^{-9}$ m)
Question 1.
What is the shortest wavelength of visible light in nm? Which colour is it?

400 nm, which is violet.

Note: violet and purple are not the same. Violet is a colour of light, while purple is not. Google "violet purple difference" to find the explanation.

Note the difference between wavelength of red (left-most) and violet (right-most) light.
The following experiment is usually used to show that light travels in straight lines. A ray of light from the candle may passes through all the holes on the three cards if they are *collinear* (lie on the same straight line).


**Question 2.**
Describe the procedure of the experiment:

**Question 3.**
What is the function of cards A and C?

**Question 4.**
What is the function of card B?
1.2 Reflection and Refraction – a brief and qualitative introduction

Light may perform reflection, refraction and other phenomenon. Many commercial buildings in HK have a glass walls. Their window panes, like mirrors, form clear image of the city.

1.2.1 Reflection by curved surface
Curved mirrors are common. Surveillance mirror (left) and a spoon (right) are good examples.

Curved mirrors may produce images of various different natures. Images can be erect or inverted. Images can be magnified or diminished, or of the size as the object.
Make sure you can identify the nature of different images. Try also Question 57 in Chapter 5.

However, it becomes problematic when a building has a reflective curved surface.

**HOW A SKYSCRAPER CAN TURN THE SUN INTO A “DEATH RAY”**

1. Sunlight hits reflective glass side of the building.
2. Concave shape of the building causes the light reflecting off the glass to focus into a small point on the ground.
3. When light is focused into a small area it will generate more heat than diffused light. As the sun moves across the sky the hot spot also moves.

**Video:** http://www.youtube.com/watch?v=ousmnx1B-gU

**What happens?**
1.2.2 Refraction

Refraction is due to change of speed of light in different media. The change in speed of light in different media results in change in direction of propagation of light.

http://global.britannica.com/science/refraction
https://myweb.rollins.edu/jsiry/radicalEnergy.html
http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/ritter_example.html

Refraction of light by lenses produces images of different natures.

The image in this picture is

http://www.ekshiksha.org.in/eContent-Show.do?documentId=56
1.3 How fast is the speed of light?

The speed of light in vacuum was found to be 299,792 458 ms$^{-1}$, approximately $3 \times 10^8$ ms$^{-1}$. And the speed of light in vacuum does not change even when we measure it on a fast moving object such as a rocket. Based on this fact, Einstein developed the theory of relativity.

Watch the following video to see how we may measure the speed of light AT HOME!!

https://www.youtube.com/watch?v=Hbxy1W9O_Wk

1.3.1 What is light year?

A light year is the distance travelled by light in one year, so light year is a unit of distance.

Question 5.

Take speed of light = $3 \times 10^8$ ms$^{-1}$. Express 1 light year in kilometer (km).

The distance 1 light year

= distance travelled by light in one year time

= speed of light x duration of 1 year (measured in second)

= 

= (Hint: 1 km = 1000 m)
Compare with the radius of the earth which is 6370 km only, we can see that a light year is a huge distance, so light year is a unit for measuring huge distance between celestial objects only.

Similarly, light minute and light second are also units for distance between celestial objects (天體).

**Question 6.**
Using the figures in the above diagram, calculate the radius of the Earth’s orbit in kilometer (km).

Orbital radius of the Earth = Distance of the Earth from the Sun
= 8 light minutes

\[
\text{Distance} = 3 \times 10^8 \text{ m} \times 8 \\
= 2.4 \times 10^9 \text{ m} \\
= 2.4 \times 10^6 \text{ km}
\]

**Question 7.**
Light takes 4.3 years to travel from the Earth to Proxima Centauri (比鄰星). How far away is the Earth from Proxima Centauri? Express your answer in kilometer (km).

Distance between the Earth from Proxima Centauri
= 4.3 light years

\[
\text{Distance} = 3 \times 10^8 \text{ m} \times (4.3 \times 365.25 \times 24 \times 60 \times 60) \\
= 4.07 \times 10^{13} \text{ m} \\
= 4.07 \times 10^{10} \text{ km}
\]

*Proxima Centauri is the nearest star from our solar system!*
(1) SIGNIFICANT FIGURES
Values or numbers with long digits are often expressed in limited number of significant figures. The following are examples:

<table>
<thead>
<tr>
<th></th>
<th>Original values</th>
<th>no. of sig. fig.</th>
<th>Expressed as</th>
<th>Interpreted Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>299 792 458</td>
<td>4 sig. fig.</td>
<td>299 800 000</td>
<td>299750000 &lt; x &lt;= 299850000</td>
</tr>
<tr>
<td>2</td>
<td>31245.689</td>
<td>3 sig. fig.</td>
<td>3120</td>
<td>3115 &lt; x &lt;= 3125</td>
</tr>
<tr>
<td>4</td>
<td>12.34567</td>
<td>4 sig. fig</td>
<td>12.35</td>
<td>12.345 &lt; x &lt;= 12.355</td>
</tr>
<tr>
<td>5</td>
<td>45.6789</td>
<td>3 sig. fig</td>
<td>45.7</td>
<td>45.65 &lt; x &lt;= 45.75</td>
</tr>
<tr>
<td>6</td>
<td>57.996</td>
<td>1 sig. fig</td>
<td>60</td>
<td>55 &lt; x &lt;= 65</td>
</tr>
<tr>
<td>7</td>
<td>57.996</td>
<td>2 sig. fig</td>
<td>58</td>
<td>57.5 &lt; x &lt;= 58.5</td>
</tr>
<tr>
<td>8</td>
<td>57.996</td>
<td>3 sig. fig</td>
<td>58.0</td>
<td>57.95 &lt; x &lt;= 58.05</td>
</tr>
<tr>
<td>9</td>
<td>57.996</td>
<td>4 sig. fig</td>
<td>58.00</td>
<td>57.995 &lt; x &lt;= 58.005</td>
</tr>
</tbody>
</table>

(2) SCIENTIFIC NOTATION
Large values or numbers are often expressed in scientific notation. For example, the speed of light is 299 792 458 ms⁻¹. It is expressed as 299 800 000 ms⁻¹ in 4 sig. fig.. And in scientific notation, it is expressed as 2.998 x 10⁸ ms⁻¹ (4 significant figures) or simply 3.00 x 10⁸ ms⁻¹ (3 significant figures)

TRY the online quiz by Khan Academy to see if you understand:

https://www.khanacademy.org/math/pre-algebra/decimals-pre-alg/sig-figs-pre-alg/e/significant_figures_1
https://www.khanacademy.org/math/pre-algebra/exponents-radicals/scientific-notation/e/scientific_notation

(3) USING CALCULATOR TO HANDLE SCIENTIFIC NOTATION
To key in 3.00 x 10⁸, you should press 3 EXP 8 .

On the other hand, your calculator gives answers in scientific notation directly. Like this:
Question 8.
Just now in July 2015, the scientist suggested that a similar Earth named Kelper 452b can be found in 1400 light years away from the Earth. So, how far is Kepler 462b from us in km?
Convert 1400 light years into km
= 
= 

Question 9.
Using today technology, engineers can build a spacecraft travelling at 58,536 km$^{-1}$ (by New Horizons which just encountered Pluto in July 2015). How long does it take (i.e. Find the time taken) to go to Kepler 462b? Express your answer in years.
Time taken = distance / velocity
= 
= 

MATHEMATICAL SKILLS (2)

(4) CHANGING SUBJECTS

Given Distance $d = \text{Speed } v \times \text{Time taken } t$
therefore $d = vt$
then $v = d/t$ or $t = d/v$

Try the followings:
Question 10.
Given $d = 150 \text{ m}$, $t = 10\text{s}$, find $v$.
Ans: $v = 15 \text{ ms}^{-1}$

Question 11.
Given $v = 20 \text{ ms}^{-1}$, $t = 5\text{s}$, find $d$.
Ans: $d = 100 \text{ m}$

Question 12.
Given $v = 50 \text{ ms}^{-1}$, $d = 100 \text{ m}$, find $t$.
Ans: $t = 2 \text{ s}$
1.4 Colours and Laser

1.4.1 Colors
There are different colours of light. Adding two of them may produce a third one.

Red, blue and green are called primary colours because our human eyes have colour-sensitive sensory cells called cones to detect these colours. Mixing the primary colours may produce different colours of light.
1.4.2 Laser

Laser beam is a strong beam of light. A laser source produces a fine ray of light of single colour (monochromatic) which is very strong (coherent) and highly focussed (collimated). Nevertheless, red, green and blue lasers are nowadays very common and available at affordable price.


How is laser light different from the ordinary light in daily life?

Laser is much more powerful than ordinary light such as light from a light bulb. So, you should be extremely careful when working with laser. Never look into a laser or direct it to a human eye. Strong laser can cause loss of sight if it strikes on someone’s eye.
**Corner-cube reflectors** was placed on the moon for space exploration. It was like 3 mutually perpendicular mirrors. What do you think its function is?

<table>
<thead>
<tr>
<th>Corner-Cube Reflector</th>
<th>3 mutually perpendicular mirrors</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="http://www.alibaba.com/product-detail/Corner-Cube-Prism-Corner-Cube-Retroreflectors_265442242.html" alt="Corner-Cube Reflector" /></td>
<td><img src="https://sharepoint.umich.edu/lsa/physics/demolab/SitePages/6A10.30-%20Corner%20Cube%20Retroreflection.aspx" alt="3 mutually perpendicular mirrors" /></td>
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**Chapter 2 REFLECTION**

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<tr>
<td></td>
<td>Nature of image formed by plane mirror – Extended Object</td>
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**2.1 Reflection – regular and diffuse reflection**

| ![Reflection – regular and diffuse reflection](http://www.raven-family.com/Holidays/Hong%20Kong%202003/Hong%20Kong.htm) |
| ![Reflection – regular and diffuse reflection](http://mendowong.lofter.com/post/dfb7_abed2c) |

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**Question 13.**

There are two pictures of the HK Island, there is a **clear image of the landscape formed by the water on the left one** but not the right one. Explain why briefly.
Clear Images are formed by plane surface only. Wavy water surface and most solid surfaces cannot form clear image. Light are reflected by these surfaces by diffuse reflection as shown below.

On the other hand, light are reflected by mirror surface by regular reflection.

Nevertheless, diffuse reflection is important. We see an object when light from it enter our eyes.

Luminous objects such as the sun or a light bulb emit their own light. Most objects are non-luminous. Non-luminous objects such as a wooden desk, a piece of paper or my face reflect light to our eyes. When light are reflected by them, usually by diffuse reflection, we can see them.

Rose appears red because red light is reflected from the flowers. The other colours of light are absorbed by the flowers.

As our eye receives red light from the flowers and so we know the flowers are red.
Question 14.
Most leaves are green. What colours of light are absorbed by green leaves? What colour(s) is/are reflected?

Question 15.
The following shows the absorption spectrum of chlorophyll a and b. Using the graph, explain why green leaves appear green. (Hint: wavelength of green light is about 550nm.)

[Image of absorption spectrum]

http://www.visionlearning.com/en/library/Biology/2/Photosynthesis-I/192

Question 16.
The following shows the absorption spectrum of two T-shirts A and B. What are the colours of the T-shirts?

[Image of absorption spectrum]
2.2 Reflection by plane mirror – Laws of reflection (Group Experiment)

[ Experimental Worksheet will be provided ]

Procedure:
1. Place a plane mirror along the 90-90 line of the protractor below.
2. Direct a fine ray of light towards the center of the protractor at a certain angle of incidence.
3. Note that all angles should be measured from the NORMAL.
4. Measure the angle of reflection.
5. Repeat step 2 and 4 for several times with different angles of incidence.

Laws of reflection:
Set up the experiment as shown in the diagram.

http://boson.physics.sc.edu/~rjones/phys153/lab02.html

Before the experiment, make sure the mirror lies along the 90-90 line, so that the normal passes along the 0 degree direction.

During the experiment, make sure all light rays direct to the center of the half-protractor.

Question 17.
How would you mark the path of light ray?

Question 18.
How would you label the light rays so that you won’t mix them up?

There is a protractor for the experiment on the left page. Place the apparatus on its top. Mark the light rays and make measurements. Fill in the table and draw conclusion.

<table>
<thead>
<tr>
<th>Angle of incidence (∠i)</th>
<th>0°</th>
<th>15°</th>
<th>30°</th>
<th>45°</th>
<th>60°</th>
<th>75°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of reflection (∠r)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Conclusion from experimental result:
1. The incident ray, reflected ray and normal all lie in the same plane.
2. The angle of incidence (∠i) and angle of reflection (∠r) are found to be ________________.
Question 19.
Which, a larger or smaller protractor will probably give more accurate measurements of angles in this experiment? Explain your answer briefly.

*The laws of reflection states that*

1. The *incident ray*, *reflected ray* and *normal* all lie in the same plane.
2. The *angle of incidence* (\( \angle i \)) and *angle of reflection* (\( \angle r \)) are equal in size.
**Question 20.**
All reflections, including diffuse reflection, follow the laws of reflection. Draw the normals in the following figures to show that the angles of reflection and the respective angles of incident are always equal.

![Diagram](http://neilatkin.com/2014/04/10/10-cool-ideas-for-teaching-reflection-of-light/)

**Question 21.**
A light ray strikes onto a mirror and it is reflected as in Figure 21.a.

![Diagram](http://example.com)

When the mirror is turned an angle of $\theta$ anti-clockwise as in Figure 21.b, what is the angle turned by the reflected ray?
2.3 Image formation by plane mirror

When we look into a mirror, we see ourselves. Images formed by plane mirror are upright and left-side-right. In physics, we say the images are **erect** (i.e. upright) and **laterally inverted** (i.e. left-side-right).

http://www.ekshiksha.org.in/eContent-Show.do?documentId=56

**Question 22.**

Which hand is the girl in the picture using to draw her lips?

A. right hand  
B. left hand

http://thumbs.dreamstime.com/x/woman-front-mirror-18573974.jpg
Question 23.
Which hand is the girl in the picture using to apply make up?
A. right hand  B. left hand

http://www.gettyimages.co.uk/detail/photo/woman-applying-make-up-in-mirror-royalty-free-image/155291916

Question 24.
Some ambulances in HK appear like the one in the picture below. Explain the purpose of painting the laterally inverted characters on the front.

https://upload.wikimedia.org/wikipedia/commons/f/f4/HK_AMS_Ambulance2.JPG
2.4 Formation of point image

A point object produces a point image. Try the following experiment to locate the image $I$ of a point object $O$.

![Diagram](https://dcsks3science.wikispaces.com/file/view/Investigate_Reflection.jpg/289969887/Investigate_Reflection.jpg)

**Procedure**

1. Place the given worksheet on the bench.
2. Draw a line $MN$ in the middle that divides the paper into two equal halves.
3. Place the mirror along the divider $MN$.
4. Near one corner of the paper, mark a cross to represent the point object $O$.
5. Direct light from the ray box, passes through the point object $O$ and strikes the mirror at an angle.
6. Mark the *incident ray* and *reflected ray*.
7. Draw the observer eye at another corner to receive the reflected light.
8. Repeat step 6 and 7 at a different angle of incidence. Distinguish the two rays using different colours or different arrows.
9. *Produce the reflected rays backward using dotted line*. You will find them *intersect* at a point behind the mirror. The reflected light rays appear to come from this point. Mark it as image $I$.
10. Notify your teacher when have finished.
To draw ray diagrams of plane mirror ...

Some light from the point object strikes on the mirror and are reflected. To an observer, the reflected rays seen to come from a point behind the mirror, which is called **image**.

To locate the image, we must draw at least two light rays! Draw the reflected rays and produce them backward.

In fact, not all light rays are reflected to the observer’s eye, as shown below.

**Conclusion:**
1. The line joining the object \( O \) and image \( I \) is perpendicular to the mirror \( MN \), i.e. \( OI \perp MN \).
2. The **image distance** \( (v) \) equals **object distance** \( (u) \), i.e. \( u = v \).
Experiment - Method of “no parallax”
Your teacher should have shown you how to locate the image by using no parallax method.

http://physicsmax.com/to-locate-images-by-no-parallax-6756

Video: The following video shows “No Parallax method”:
https://www.youtube.com/watch?v=8_VRKY6fCA4

Question 25.
1. Mark the image of the object in each of the pictures below:
2. Draw incident ray from the object and reflected ray to the observer eye.
3. Produce the reflected ray backward and draw the virtual rays using dotted lines to the image.

(a) ![Image](image1.png)  (b) ![Image](image2.png)

SKILLS to draw ray diagrams of plane mirror – a smarter way!
The reflected light rays appear to come from the image. Hence, you may first draw the image (dotted, as the image is virtual) and then draw the virtual rays (again, dotted as these rays are virtual) from the image to the eye, and lastly draw the incident rays from the object.
**Question 26.**
Mary and John are in front of a mirror. John sees Mary in the mirror. The following shows a top-view of the situation.

(a) Draw the image of Mary, mark it as M’.
(b) Draw a light ray from Mary, and strikes the mirror, and then reflected to John finally.
(c) Does Mary see John? Explain your answer by drawing another ray diagram.
(d) John walks towards right at a speed of 2ms⁻¹. What speed is his image behind the mirror as seen by Mary? Is his image moving to the right? Or to the left?
2.5 Nature of image formed by plane mirror – Extended Object (i.e. Object that has a size)

For **extended object**, we should first locate the images of its **ends**, and then join them together to locate the **extended image**.

For example, in the following diagram, we may locate the images of the point A and B and label them as A’ and B’. Then join the images A’ and B’ together so that A’B’ is the extended image.

![Image of plane mirror and extended object](http://www.cliffsnotes.com/assets/10322.jpg)

Similarly for an extended object of “P”:

![Image of extended object P](http://askmichellephysics.blogspot.hk/2012/04/light-and-sound.html)

Extended images of plane mirror are always **erect** and **laterally inverted**. As the images cannot be projected onto a screen, the images are said to be **virtual**. Virtual rays and virtual image are drawn with dotted lines. So, don’t forget to use dotted line to draw the virtual image formed by plane mirror!

*So, a plane mirror always produces erect, laterally inverted and virtual image. The image is of the same size as the object.*
Question 27.
Complete the following ray diagrams. Draw light rays from the ends of the object, reflected by the mirror and then enter the observer eye. Lastly, draw the virtual rays and virtual images using dotted line.

Reference: https://www.tes.co.uk/teaching-resource/plane-mirror-ray-diagrams-11075436
**Question 28.**
Peter stands in front of a mirror. Draw the image of Peter behind the mirror. Then draw a light ray from his head to his eye, and also a light ray from his feet to his eye. *(Hint: Peter is just an extended object, draw his image first, then the reflected rays, and virtual rays from the head and feet of his image, and lastly the incident rays from his head and feet)*

![Peter](image)

**Question 29.**
The above ray diagram looks like Peter is looking through a window to see his twin brother (the virtual image) outside. Peter is 1.8 m tall. How long should the mirror be so that he may see his whole image? *(Hint: Consider a pair of similar triangles in the above figure)*

**Question 30.**
Does the minimum length of the mirror change if Peter walks further away from the mirror (so that his image is also further away)? Explain your answer briefly.
Question 31.
Calculate the minimum length of mirror FB for the lady to see herself in the mirror. (Drawing is not necessary)

![Diagram of mirror and lady](http://www4.uwsp.edu/physastr/kmenning/Phys250/Lect34.html)

Question 32.
(Optional) Sam and her Mother are both 3 m from a mirror. Mary is 1.5 m from the mirror. Draw the images of Mary and Sam in the following diagram. **Sam is 1.3 m tall and Mary is 1.2 m tall.**

![Diagram of Sam, Mary, and Mother](http://www4.uwsp.edu/physastr/kmenning/Phys250/Lect34.html)

(a) Draw rays in blue from the image of Sam to his Mother to show how she may see his image.
(b) Draw rays in green from the image of Mary to her mother to show how she may see Mary’s image.
(c) **Calculate** the minimum length of mirror for the mother to see the whole Sam in the mirror.
(d) Similarly, **calculate** the minimum length of mirror for the mother to see the whole Mary in the mirror.
Chapter 3 REFRACTION – Part 1 (Snell’s Law)

<table>
<thead>
<tr>
<th>Lesson 4</th>
<th>Refraction across an interface</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Refractive index – Snell’s law</td>
</tr>
<tr>
<td>Lesson 5</td>
<td>Image formation due to refraction - applications of refraction</td>
</tr>
<tr>
<td></td>
<td>Refraction and speed of light</td>
</tr>
<tr>
<td></td>
<td>Refraction by rectangular block and prism</td>
</tr>
</tbody>
</table>

3.1 Refraction across an interface

Light changes its direction when it enters glass. In fact, light changes its direction when it travels from one medium to another due to change of light speed.

**Snell’s law** is the relationship between the angle of incidence and angle of refraction, which states that the refractive index is

\[ \eta = \frac{\sin \theta_{\text{air}}}{\sin \theta_x} \]

where air and medium X forms an interface.
3.2 Refractive index – Snell’s law Experiment

Procedure:
1. Place the semi-circular block on the lower half of the protractor below.
2. Direct a fine ray of light towards the center of the semi-circular block at a certain angle of incidence.
3. Measure the angle of refraction.
4. Repeat step 2 and 3 for several times with different angles of incidence.

Laws of refraction

https://es.wikipedia.org/wiki/Ley_de_Snell
Laws of reflection:
In 1621, Willebrord Snellius (Snell) formulated the Snell’s Law which relates the angle of incidence and the angle of refraction. Let’s follow what he has done.

[ Experimental Worksheet will be provided ]

Set up the experiment as shown in the diagram.

https://es.wikipedia.org/wiki/Ley_de_Snell

There is a protractor for the experiment on the left page. Place the perspex semi-circular block on its lower half. Mark the light rays, label them and make measurement. Fill in the table and draw conclusion.

<table>
<thead>
<tr>
<th>Angle of incidence (( \angle i ))</th>
<th>0°</th>
<th>15°</th>
<th>30°</th>
<th>45°</th>
<th>60°</th>
<th>75°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of refraction (( \angle r ))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Observations during the experiment:
1. While light is refracted, it is also partially ____________________.
2. When light travels from air to glass, the angle of incidence is always __________ (larger/smaller) than the angle of refraction; we say that light ray bent towards normal.
3. When the angle of incidence increases, the angle of refraction also ________________.

Now, calculate the sine value of the angles and fill in the table.

Hint: Make sure your calculator is in degree measurement

<table>
<thead>
<tr>
<th>Angle of incidence (( \angle i ))</th>
<th>0°</th>
<th>15°</th>
<th>30°</th>
<th>45°</th>
<th>60°</th>
<th>75°</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sin \angle i )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle of refraction (( \angle r ))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \sin \angle r )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note that all sine values should be smaller than 1.
Then, plot a graph of \( \sin \angle i \) against \( \sin \angle r \)

1. Label the axes.
2. Mark the data points accurately.
3. Draw a best-fit straight line that passes through the origin.

A straight line graph that passes through the origin means the two quantities represented by the y-axis and x-axis are directly proportional (成正比).

Conclusion from experimental result:

1. From the graph above, which is a straight line graph passes through the origin, we conclude that ________________ and ________________ are directly proportional.

2. The ratio is called refractive index \( \eta \) (reads eta), therefore \( \eta = \frac{\sin \angle i}{\sin \angle r} \).
The slope of the above graph of \( \sin \angle i \text{ against } \sin \angle r \) is exactly the ratio \( \frac{\sin \theta_{\text{air}}}{\sin \theta_X} \), which is the refractive index of the medium X, perspex in this case.

From the graph, the slope is \( \frac{\sin \theta_{\text{air}}}{\sin \theta_X} \) = \( \frac{\text{refractive index}}{\text{refractive index}} \) which is the refractive index of the \( \eta_{\text{perspex}} = \) \( \frac{\sin \theta_{\text{air}}}{\sin \theta_X} \).

The refractive indexes of some common media are listed below:

<table>
<thead>
<tr>
<th>Medium</th>
<th>Refractive Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1</td>
</tr>
<tr>
<td>Air</td>
<td>1.003</td>
</tr>
<tr>
<td>Water</td>
<td>1.33</td>
</tr>
<tr>
<td>Glass</td>
<td>1.50 – 1.92</td>
</tr>
<tr>
<td>Diamond</td>
<td>2.42</td>
</tr>
</tbody>
</table>

Just take it as 1 !

Quite high !

A medium with a larger refractive index is said to be an **optically denser** medium.

The Snell’s Law states that the refractive index is \( \eta = \frac{\sin \theta_{\text{air}}}{\sin \theta_X} \).

**Question 33.**

A fine ray of light travels from air to medium X, fill in the table below:

<table>
<thead>
<tr>
<th>Angle of incidence</th>
<th>Angle of refraction (in X)</th>
<th>Refractive Index of X</th>
</tr>
</thead>
<tbody>
<tr>
<td>50°</td>
<td>30°</td>
<td>1.9</td>
</tr>
<tr>
<td>50°</td>
<td>30°</td>
<td>1.3</td>
</tr>
</tbody>
</table>

The refracted angles are always smaller than the incident angles when light travels from air to another medium, as light travels into an optically denser medium.

**Question 34.**

A fine ray of light travels from medium X to air, fill in the table below:

<table>
<thead>
<tr>
<th>Angle of incidence</th>
<th>Angle of refraction (in Air)</th>
<th>Refractive Index of X</th>
</tr>
</thead>
<tbody>
<tr>
<td>40°</td>
<td>60°</td>
<td>1.8</td>
</tr>
<tr>
<td>30°</td>
<td>60°</td>
<td>2.42</td>
</tr>
</tbody>
</table>

The refracted angles are always larger than the incident angles when light travels from a medium (not air) to air, as light travels from an optically denser medium to a less dense one.
From the last two questions, we can see that

1. **When light travels from lower to higher refractive index, it bends towards normal.** For example, from air ($\eta = 1.0$) to glass ($\eta \approx 1.5$)

2. **When light travels from higher to lower refractive index, it bends away from normal.** For example, from glass ($\eta \approx 1.5$) to air ($\eta = 1.0$).

Take the refractive index of air, water, glass and diamond be 1.00, 1.33, 1.5 and 2.42 respectively. Finish the following questions.

**Question 35.**
Light travels from air to glass as shown. Calculate all the missing angles. 
*Note: The light ray will later refract to air at the bottom.*

![Diagram of light ray in air to glass to air]

**Question 36.**
Light travels from water to air to glass. Calculate all the missing angles.

![Diagram of light ray in water to air to glass]

**Question 37.**
Repeat the last question. Imagine that the layer of air is very thin, extremely thin, or nothing at all. Does it affect the angle in glass?
Question 38.
Light travels from water to glass as shown. Find the refracted angle.

Question 39.
Light travels from glass to water as shown. Find the refracted angle.

Question 40.
Light travels from diamond to glass to water to air as shown. Calculate the refracted angle in the air layer.

Don’t miss these videos:

<table>
<thead>
<tr>
<th>SNELL’S LAW EXPERIMENT</th>
<th><a href="https://www.youtube.com/watch?v=yfawFJCRDSE">https://www.youtube.com/watch?v=yfawFJCRDSE</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>REFRACTION (Computer Simulation)</td>
<td><a href="https://www.youtube.com/watch?v=kc2o73FyN3I">https://www.youtube.com/watch?v=kc2o73FyN3I</a></td>
</tr>
</tbody>
</table>
3.3 Image formation due to refraction - applications of refraction:

There is refraction of light when it travels across different media. When light travels from air to glass (or water), it bends towards normal. On the other hand, when it travels from glass (or water) to air, it bends away from normal.

The refracted light ray will seem to come from a different point (instead of the object) and therefore an image is formed.

For example, this professor sits inside a transparent water tank. His body is inside water while his head is not. The light from his body travels from water to air, and bends away from normal at the water-air interface. The refracted light ray appears to come from another position - the image.

As his head does not align with his body, the picture looks pretty funny and strange.

Remember that we should always draw two light rays to locate the image. So, how should we correct the diagram?
Similar examples are found when people observe fish in water or a coin at the bottom of water. The fish appears to be at a point higher in position.

http://www.passmyexams.co.uk/GCSE/physics/reflection-and-refraction.html

A coin placed at the bottom of a cup may become visible when water is added. Take a look of the video to see how the trick is done: https://www.youtube.com/watch?v=JVxHbIFje4

http://faraday.physics.uiowa.edu/optics/6A42.40.htm
A stick *partially dipped* in water appears bent. The amount of bending depends on the observer position.

To locate the image, at least two light rays from one point of the object are drawn. Both light rays bend away from normal when they are refracted on the water surface. In the lower diagram, the virtual rays represented by dotted lines can locate the image $Y$ of the tip $X$ of pencil.

http://www.pxleys.com/photography-pictures/refraction/

Try it at home!

The two light rays from $X$ are refracted to the observer’s eye. The refracted rays appear to come from $Y$. So, $Y$ is the image of $X$.

https://en.wikipedia.org/wiki/Refraction
Question 41.
The picture shows that the head of a polar bear appears on the left of its body. Draw a ray diagram to explain the situation.

http://i.imgur.com/mMKup.jpg

Question 42.
A penny is invisible to the observer when the cup is empty. After water is added, the observer can see the penny. Draw light rays from the penny to the observer’s eye to show how the observer may see it when there is water.

Question 43.
A swimming pool appears to be shallower than what it should be. Draw two rays of light from the bottom of the pool to the boy’s eye, complete the ray diagram and find the image of the bottom of the pool.
1. Enjoy the fantastic world of mirrors. Mirror hallway, Mirror maze, Kaleidoscopes, Periscope, Semi-transparent mirror, Mirrors of invisibility and Funny mirrors. Take some photos there.

Photo(s)

2. Explain ONE of the following effects of reflection by mirrors with diagram:

☐ Your own profile
☐ Your back
☐ Total reverse
☐ Twins
☐ Sliding
☐ Reverse
☐ Vanishing body

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Tear this off and hand in to your teacher when completed.
S3 Science Museum Visit (2016-2017)

Go to the science museum in TST, find the experiments of visible light and complete the worksheet below.

1. **Total Internal Reflection**
   Find the tank with a ray of green laser. Use the set up to find the critical angle of the liquid in the tank.

   The critical angle of the liquid is _____, so the refractive index of the liquid is probably equal to _____.

2. **Real Image in Air**
   Find the ‘Spring Challenge’. You can see a spring. Feel it with your hand. Can you touch it? Explain in your own words how it happens. (You may draw a diagram to aid explanation)

   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________

3. **Telescope**
   Look through the lens of the telescope. Is the image seen larger or smaller than the object? What do you notice about the orientation of the image? Can you take a photo of the image?

   __________________________________________
   __________________________________________
   __________________________________________
   __________________________________________
4. Enjoy the fantastic world of mirrors. Mirror hallway, Mirror maze, Kaleidoscopes, Periscope, Semi-transparent mirror, Mirrors of invisibility and Funny mirrors. Take some photos there.

5. Explain ONE of the following effects of reflection by mirrors with diagram:
   - [ ] Your own profile
   - [ ] Your back
   - [ ] Total reverse
   - [ ] Twins
   - [ ] Sliding
   - [ ] Reverse
   - [ ] Vanishing body
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3. **Total Internal Reflection**
   Find the tank with a ray of green laser. Use the set up to find the critical angle of the liquid in the tank.

   The critical angle of the liquid is _____, so the refractive index of the liquid is probably equal to _____.

4. **Real Image in Air**
   Find the ‘Spring Challenge’. You can see a spring. Feel it with your hand. Can you touch it? Explain in your own words how it happens. (You may draw a diagram to aid explanation)

   ____________________________________________________________
   ____________________________________________________________
   ____________________________________________________________
   ____________________________________________________________

5. **Telescope**
   Look through the lens of the telescope. Is the image seen larger or smaller than the object? What do you notice about the orientation of the image? Can you take a photo of the image?

   ____________________________________________________________
   ____________________________________________________________
   ____________________________________________________________
   ____________________________________________________________

   Photo
Question 44.
When the boy sees the fish, it appears to be closer. Draw a ray diagram to explain.

Question 45.
Refer to the last diagram, when the fish sees the boy, he appears to be further away. Draw a ray diagram to explain.

Distorted vision due to refraction
An archer fish produces a water jet to hit bugs above water. Due to the refraction of light, the fish cannot see the exact position of its targeted bug. Small fish needs to learn from experience to adjust the water jet direction. On the other hand, the fish may target at bugs directly above where light does not change in direction, as shown in the right diagram.

http://www.physicsclassroom.com/class/refrn/Lesson-1/If-I-Were-an-Archer-Fish
The amount of refraction that takes place at a boundary depends upon the angle at which light is approaching the boundary.

When light strikes the interface along its normal, light does not change in direction. In fact, very little deviation occurs when light strikes an interface at angles close to the normal.

And so the trick of the Great Blue Heron (the bird in the picture) is to target its dinner by looking normally (i.e. perpendicularly) to the waters.

https://www.flickr.com/photos/physicsclassroom/galleries/72157625102649965/

3.4 Refraction and speed of light

Refraction is a result of change in speed of light. Light travels the fastest in a vacuum and becomes slower progressively in air, water, glass and diamond. Refractive index $\eta$ is in fact the ratio of speed of light in which

$$\eta = \text{speed of light in vacuum} / \text{speed of light in that medium}$$

Hence, the higher the refractive index, the slower the light travels in that medium.

**Question 46.**
Fill in the table below, give answers in 3 significant figures.

<table>
<thead>
<tr>
<th>Medium</th>
<th>Refractive index</th>
<th>Speed of light ($\times 10^8$ ms$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1</td>
<td>2.998 (usually taken as $3 \times 10^8$ for convenience, but not this time)</td>
</tr>
<tr>
<td>Air</td>
<td>1.003</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1.33</td>
<td></td>
</tr>
<tr>
<td>Glass (Crown glass)</td>
<td>1.52</td>
<td></td>
</tr>
<tr>
<td>Glass (Flint glass)</td>
<td>1.92</td>
<td></td>
</tr>
<tr>
<td>Diamond</td>
<td>2.42</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.50</td>
</tr>
</tbody>
</table>

Note that all refractive index is larger than 1!
3.5 Refraction by rectangular block and prism

There are two refractions when a light ray passes through a glass block or a prism. The following questions illustrate the idea.

3.5.1 Refraction by rectangular block

Refer to question 35, Light travels from air to glass and then emerge to air again.

The emergent light ray is parallel to the incident ray, but it is displaced laterally. We say the light ray suffers a lateral displacement. The size of lateral displacement depends on the angle of incidence, refractive index and the dimensions of the block.

http://www.learncbse.in/lakhmir-singh-physics-class-10-solutions-chapter-5-refraction-light/
3.5.2  Refraction by prism

Similarly, there are two refractions, both deflect the light ray towards the base of the prism.

![Diagram of light ray deflection through a prism](https://physicsfor10.files.wordpress.com/2013/05/prism-refraction-2-1.png)

There are two deflections, D1 and D2. The (total) angle of deflection is $D (\ = D_1 + D_2)$

**Question 47.**
Prove that the angle of deflection of the light ray in the following diagram is $49.18^\circ$

![Diagram with angles labeled](https://physicsfor10.files.wordpress.com/2013/05/prism-refraction-2-1.png)

**Question 48.**
Express the angle of deflection of the light ray in the following diagram.

![Diagram of light ray deflection through a prism](http://www.millersville.edu/physics/experiments/042/PRISM.GIF)
3.6 Dispersion of light:

While different colours of light travels at the same speed of $2.998 \times 10^8$ ms$^{-1}$ in vacuum (or air), different colours of light travels at different speeds in glass, hence they have different refractive indexes and so they are refracted differently. The process is called dispersion.

As different colours are refracted differently, a ray of white light (which consists of all the colours of light) is broken down into different colours when it enters a prism. We say that white light is dispersed into different colours. The colours are further separated when they emerge from the prism and refracted one more time.

Triangular prisms refracts white light into its spectrum, violet refracts the most as it has the shortest wavelength.

---

https://ehnishio2013.wordpress.com/

https://www.youtube.com/watch?v=uucYGK_Ymp0
Light bends towards the normal when it travels from air to glass. On the other hand, when light travels from glass to air, it bends away from normal.
When the incident angle in glass is large enough, the refracted angle in air becomes $90^\circ$. The *incident angle* at that time is called **critical angle of glass-air interface** or simply the critical angle of glass.

Nevertheless, the reflected ray becomes stronger as incident angle increases, and finally all the light is reflected, which we call **total internal reflection**.

So, when light travels from an optically denser medium to a less dense medium, the light ray will bend away from normal. Furthermore, when the incident angle is larger than critical angle, total internal reflection will occur.

Therefore, by Snell’s law,

\[
\eta = \frac{\sin \theta_{\text{air}}}{\sin \theta_x} = \frac{\sin 90^\circ}{\sin C} = \frac{1}{\sin C}, \text{ hence } \eta = \frac{1}{\sin C}
\]
Determine Critical Angle of glass-air interface

[ Experimental Worksheet will be provided ]

https://www.youtube.com/watch?v=NAaHRPsvJk

You are given a semi-circular block. Place the block on the lower half of the protractor below.
Procedure:
1. Direct a fine ray of light to the center of a semi-circular glass block through its curved face as shown.
2. Start with a small angle of incidence.
3. Slowly increase the angle of incidence. You should find that the reflected ray becomes ____________ (stronger/weaker) as you increase the angle of incidence.
4. The angle of refraction is always larger than the angle of incidence.
5. When the angle of refraction is 90°, stop rotating the incident ray.
6. Measure the angle of incidence at that time. This is the critical angle of the air-glass interface.

The critical angle of the air-glass interface is found to be ____________.

Hence we may find the refractive index of the semi-circular block \( \eta \) where \( \eta = \frac{1}{\sin C} \) = _______ 

Question 49.
Refer to the above experiment, describe the change in intensity (i.e. dimmer/weaker, brighter/stronger) of reflected and refracted ray as incident angle increases when light travels from glass to air.

Question 50.
Given the refractive index of the media, find the critical angle of the following interfaces:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Refractive index</th>
<th>Critical Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-Water</td>
<td>1.33 (Water)</td>
<td></td>
</tr>
<tr>
<td>Air-Glass</td>
<td>1.5 (Glass)</td>
<td></td>
</tr>
<tr>
<td>Air-Diamond</td>
<td>2.42 (Diamond)</td>
<td></td>
</tr>
</tbody>
</table>

Do you notice that ... ...
For a large refractive index, the critical angle will be smaller, and then total internal reflection would occur more easily.
Question 51.
Given the refractive index of the media, find the critical angle of the following interfaces:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Refractive index</th>
<th>Critical Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Water-Glass</td>
<td>1.33 (Water) and 1.5 (Glass)</td>
<td>62.5°</td>
</tr>
<tr>
<td>(b) Water-Diamond</td>
<td>1.33 (Water) and 2.42 (Diamond)</td>
<td>33.3°</td>
</tr>
<tr>
<td>(c) Glass-Diamond</td>
<td>1.5 (Glass) and 2.42 (Diamond)</td>
<td>38.3°</td>
</tr>
</tbody>
</table>

Question 52.
For the last question, draw the ray diagrams when the light rays strike the interfaces at respective critical angles.

Do you notice that ... ...
When light ray strikes an interface and the refracted ray travels along the interface, the light ray must come from the medium with larger refractive index.

For example, for air-water interface, light ray from the air side can never be refracted along the interface. Only light ray from the water side may be refracted along the interface.
4.2 Applications of Total Internal Reflection

(1) Light guide

Light may travel through a light guide by successive total internal reflection. Light transferred may be used for illumination or for data transmission. Optical fibre is an application of data transmission by total internal reflection of light.

Compared with copper wire for electrical signal data transmission, optical fibre is cheaper and lighter (less weight). Also, different colours of light may pass through a single optical fibre at the same time. Hence, an optical fibre can often transmit more data than a much thicker cable.

Compared to copper wire used in telephony, fiber could carry thousands of times more phone conversations and hundreds of times further, making the cost of a phone connection over fiber only a few percent as much as transmitting over copper.

Charles K. Kao, Father of Fibre Optics
(2) **Periscope and Other optical instrument**

A *periscope* has two reflecting surfaces inside to change the direction of light. Light falls onto a mirror may be reflected by different surfaces, and forms multiple images, which affects the quality of image formed. On the other hand, light reflected by total internal reflection has all the light energy reflected on a single surface and produces high quality image, which is sharp and bright.

(3) **Mirage and Looming (海市蜃樓)**

Mirage and looming are result of formation of *virtual image* when there is refraction of light due to *high temperature gradient of atmosphere*.

Light travels a little bit faster in warm air, and so warm air has a lower refractive index than cold air. When light travels from cool air to warm air, the light ray bends away from normal and hence the angle of refraction increases. Eventually, the light ray is reflected by total internal reflection and the reflected light ray forms an inverted image.

In desert, the air near the ground is warmer, and mirage is formed (left). In places near the poles, the air near the ground (sea) is cooler and a looming image is formed (right).

**MIRAGE VIDEO:** https://www.youtube.com/watch?v=HzIBmuLHMSE
Rainbow

The formation of rainbow is due to \textit{dispersion and total internal reflection of light}. The dispersions of light of the two refractions occur on the surface of water droplet separate different colours of light.

Rainbow usually occurs in early morning or about evening when the sun is close to the horizontal. When sunlight comes from behind the observer and strike on rain droplets, the droplets disperse light and totally reflect the different colours of light. The colour reflected to the observer eye depends on the direction of droplet from the observer. As in the following picture, the man sees rainbow red at the top and blue at the bottom.

And why rainbows are curved and usually form semi-circle? Because it is the direction of droplet (or their relative direction) that will determine the colour of light reflect to the observer eye.
Demonstration – total internal reflection

You may try the following experiment at home using an easily available laser pointer. It shows that light may travel along a water stream. *(Beware not to direct the laser pointer to anyone’s eye)*

http://www.pugetsound.edu/faculty-pages/worland/physics-pedagogy/

http://v017o.popscreen.com/aEJROGZoX0ZwMDQx_o_bending-the-light---physics-experiment.jpg

Video: Experiments on refraction, reflection and total internal reflection

http://www.youtube.com/watch?v=gDA_nDXM-ck
Question 53.
Draw the structure of a periscope using right angle prisms. Give one advantage and one disadvantage of using prism over plane mirror to make periscope.

Question 54.
The following video shows you a trick, with an invisible coin under a beaker of water. The coin re-appears when the gap between the coin and the beaker is filled with water.

https://www.youtube.com/watch?v=JVN4E8cnejQ

Draw a ray diagram and explain briefly why the coin was invisible at the beginning. Draw a second ray diagram and explain briefly why the coin re-appears when water is filled.
The wine glass in the picture below forms two images of different natures. The upper is erect and virtual, while the lower one is inverted and real. Both images are diminished.


<table>
<thead>
<tr>
<th>Chapter 5 REFRACTION – Part 3 (Lenses)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lesson 7</strong></td>
</tr>
<tr>
<td>Image formation – an introduction (hands-on)</td>
</tr>
<tr>
<td><strong>Lesson 8</strong></td>
</tr>
<tr>
<td>Lens Basic</td>
</tr>
<tr>
<td>Image formation of lenses - Construction rules</td>
</tr>
<tr>
<td><strong>Lesson 9</strong></td>
</tr>
<tr>
<td>Nature of image formed by convex and concave lens</td>
</tr>
<tr>
<td>Determine the focal length of a convex lens</td>
</tr>
<tr>
<td>Nature of image of concave lens</td>
</tr>
<tr>
<td><strong>Lesson 10</strong></td>
</tr>
<tr>
<td>Lens formula</td>
</tr>
</tbody>
</table>
5.1 Image formation – an introduction (hands-on)

Lenses (singular: lens) refract light and form images of various natures. The image can be **erect and virtual**, or it can be **inverted and real**. The image can be **magnified** or **diminished**.

The following experiment will let you experience how images of different natures are formed.

Also watch …

https://www.youtube.com/watch?v=FFWNvcEJDQ
5.2 Lens Basics

Lenses are classified as converging lens and diverging lens.

**Convex lens** is a *converging lens* which converges light. Parallel light rays strike the lens symmetrically will be converged to the principal focus of the lens. The separation between the focus and the lens is focal length.


**Concave lens** is a *diverging lens* which diverges light. Parallel light rays strike the lens symmetrically will be diverged from its principal focus.

http://www.a-levelphysicstutor.com/optics-concv-lnss.php#top
A lens, whether concave or convex, can be considered as a combination of blocks as shown below:

At different distances, convex lens may form very different images.

For concave lens, the image is always erect, virtual and diminished.
5.3 Image formation of lenses - Construction rules
To find the image of a lens, we may make use of its construction rules. For either convex lens or concave lens, there are three construction rules.

The following summarize the two sets of construction rules for different lenses.

Note:
The rays pass through the center of ALL lenses go straight, for both convex and concave lenses.
Question 55. - Construction rules and use of construction rules (*i.e.* intersection at focal plane)
You must be very familiar with the construction rules in order to use them to draw ray diagrams to locate the image.
To locate the image, we should draw two rays from a point object and strike the lens. The image is located at the point where the emerged rays seem to come from.

Two of the three rules may locate the image, and then you may even draw the whole image and tell its nature (inverted and real / erect and virtual) and magnification (magnified / diminished).

Try the following to familiarize the formation of image.
https://phet.colorado.edu/en/simulation/geometric-optics

Let’s use the following example to illustrate the idea:

<table>
<thead>
<tr>
<th>Ray Diagram Construction</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="https://voer.edu.vn/c/image-formation-by-lenses/0e60bf6/58c78b90" alt="Ray Diagram Construction" /></td>
<td>We should draw light rays from the tip of the object.</td>
</tr>
<tr>
<td><img src="https://voer.edu.vn/c/image-formation-by-lenses/0e60bf6/58c78b90" alt="Ray Diagram Construction" /></td>
<td>We may choose any two of the three light rays mentioned in construction rules.</td>
</tr>
<tr>
<td><img src="https://voer.edu.vn/c/image-formation-by-lenses/0e60bf6/58c78b90" alt="Ray Diagram Construction" /></td>
<td>In the first diagram, ray 1 is drawn.</td>
</tr>
<tr>
<td><img src="https://voer.edu.vn/c/image-formation-by-lenses/0e60bf6/58c78b90" alt="Ray Diagram Construction" /></td>
<td>In the second diagram, ray 2 is drawn.</td>
</tr>
<tr>
<td><img src="https://voer.edu.vn/c/image-formation-by-lenses/0e60bf6/58c78b90" alt="Ray Diagram Construction" /></td>
<td>In the third diagram, the refracted light rays will appear to come from a single point behind the lens. This point is the image of the tip of the object.</td>
</tr>
<tr>
<td><img src="https://voer.edu.vn/c/image-formation-by-lenses/0e60bf6/58c78b90" alt="Ray Diagram Construction" /></td>
<td>So, produce the two refracted rays backward to find where they appear to come from. This is the image of the tip of the object.</td>
</tr>
<tr>
<td><img src="https://voer.edu.vn/c/image-formation-by-lenses/0e60bf6/58c78b90" alt="Ray Diagram Construction" /></td>
<td>Lastly, the whole image can be drawn.</td>
</tr>
</tbody>
</table>
Image formation and Nature of image

Hints:

To draw ray diagram for convex lens or concave lens, we have to use at least two construction rules. As the light rays start from the tip of object, the refracted rays will seem to come from the tip of image.

http://www.kshitij-iitjee.com/ray-diagrams-for-thin-lenses

Question 56. – Using construction rules to locate image

Complete the following ray diagrams and locate the image.
Question 57. Complete the following ray diagrams.

(a) **Convex lens** – The nature of image depends on the object distance.

Take \( f = 5 \text{ cm} \), \( u = 15 \text{ cm} \), object height = 5 cm

(b) **Concave lens** – The image is always erect, virtual and diminished.

Take \( f = 5 \text{ cm} \), \( u = 15 \text{ cm} \), object height = 5 cm
5.4 Nature of image formed by convex lens and concave lens

This is a summary of image nature of convex lens

<table>
<thead>
<tr>
<th>Object distance (u)</th>
<th>Ray diagram</th>
<th>Type of image</th>
<th>Image distance (v)</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>( u = -\infty )</td>
<td><img src="image" alt="Ray diagram" /></td>
<td>inverted - reel - diminished</td>
<td>( v = f ) - opposite side of the lens</td>
<td>object lens of a telescope</td>
</tr>
<tr>
<td>( u &gt; 2f )</td>
<td><img src="image" alt="Ray diagram" /></td>
<td>inverted - real - diminished</td>
<td>( f &lt; v &lt; 2f ) - opposite side of the lens</td>
<td>camera - eye</td>
</tr>
<tr>
<td>( u = 2f )</td>
<td><img src="image" alt="Ray diagram" /></td>
<td>inverted - real - same size</td>
<td>( v = 2f ) - opposite side of the lens</td>
<td>photocopier making same-sized copy</td>
</tr>
<tr>
<td>( f &lt; u &lt; 2f )</td>
<td><img src="image" alt="Ray diagram" /></td>
<td>inverted - real - magnified</td>
<td>( v &gt; 2f ) - opposite side of the lens</td>
<td>projector - photograph enlarger</td>
</tr>
<tr>
<td>( u = f )</td>
<td><img src="image" alt="Ray diagram" /></td>
<td>upright - virtual - magnified</td>
<td>( - ) image at infinity - same side of the lens</td>
<td>to produce a parallel beam of light, e.g. a spotlight</td>
</tr>
<tr>
<td>( u &lt; f )</td>
<td><img src="image" alt="Ray diagram" /></td>
<td>upright - virtual - magnified</td>
<td>( - ) image is behind the object - same side of the lens</td>
<td>magnifying glass</td>
</tr>
</tbody>
</table>

http://www.miniphysics.com/ss-ray-diagrams-for-converging-lens.html
The following shows the ray diagram of a concave lens.

http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/raydiag.html

From all the above ray diagrams, we see that
- Inverted image must be real
- Erect image must be virtual
- For convex lens, the nature of image depends on object distance.
- For concave lens, the image is always diminished, erect and virtual.

**Question 58.**
Identify the nature and magnification of image of the picture below, state the type of lens used and for convex lens cases, match a ray diagram (labelled 1 to 6 on the last page) to represent the situation.

(a)

http://www.ekshiksha.org.in/eContent-Show.do?documentId=56
Inverted and Real

Diminished image

Convex lens, Case 2

Erect and Virtual

Diminished image

Concave lens (b)

Erect and Virtual

Diminished image

Concave lens (d)
Try the following to familiarize the formation of image.
Follow the instruction on P.63 and P.64, finish the following questions (Q55-63).

Question 59.
The object and image formed by a convex lens are 10 cm and 20 cm respectively. The image is erect. Draw a ray diagram to represent the situation. Find the focal length of the lens from the diagram.

Hint: Which case, 1-6?

Question 60.
The object and image formed by a convex lens are 10 cm and 20 cm respectively. The image is inverted. Draw a ray diagram to represent the situation. Find the focal length of the lens from the diagram.

Hint: Which case, 1-6?

Question 61.
The object and image formed by a concave lens are 30 cm and 20 cm respectively. Draw a ray diagram to represent the situation. Find the focal length of the lens from the diagram.

Hint: Concave lens! \( f > 50 \text{ cm} \)

Question 62.
The magnification of a hand lens (i.e. magnifying glass) is 3 when the object distance is 5 cm. Find the focal length of the lens.

Hint: Convex lens!

Question 63.
The object and image formed by a convex lens are 10 cm and 20 cm from the lens respectively. The image is inverted. Draw a ray diagram to represent the situation.

Hint: Which case, 1-6?
**Question 64.**
The object and real image formed by a convex lens are separated by 50 cm. The object is twice as high as the image. Draw a ray diagram to represent the situation.

*Hint: Real image! Which case, 1-6?*

**Question 65.**
A candle of height 10 cm is placed 45 cm from a convex lens of focal length 20 cm.
(a) Draw a ray diagram to locate the image accurately.
(b) Find the image distance.
(c) Find the image height.
(d) Find the magnification \( m \) of image by using the equation:
\[
m = \frac{\text{image size}}{\text{object size}}
\]
*Hint: Which case, 1-6?*

**Question 66.**
A candle of height 10 cm is placed 36 cm from a convex lens of focal length 20 cm.
(e) Draw a ray diagram to locate the image accurately.
(f) Find the image distance.
(g) Find the image height.
(h) Find the magnification \( m \) of image by using the equation:
\[
m = \frac{\text{image size}}{\text{object size}}
\]
*Hint: Which case, 1-6?*

**Question 67.**
Compare the results of the last two questions. What do you notice? Also compare the magnification of image in the two cases.
More difficult questions:

**Question 68.**
Complete the following ray diagram. State the nature and magnification of the image.

![Ray Diagram](image1)

**Question 69.**
Complete the following ray diagram. State the nature and magnification of the image.

![Ray Diagram](image2)
Question 70.
Complete the following ray diagram

Question 71. More uses of construction rules (i.e. intersection at focal plane)
Note that parallel rays that are not parallel to the principal axis will not come together at the focus, but at one of the other points on the focal plane. Complete the following ray diagrams:

Lastly, you must not miss the following online simulation:
https://phet.colourado.edu/en/simulation/geometric-optics
5.5 Fresnel lens

The deflection of light is due to the refractions that take place at the two faces of the lens. So, if we remove the rectangular volume (in red in the above diagram), the refraction of light should be similar to a conventional lens.

Fresnel lens is so made to save materials and volume so that lighter lens is produced. Nevertheless, the image quality of a Fresnel lens is lower than that of a conventional lens.

**Question 72.**
Follow the same idea, construct a CONCAVE Fresnel lens using the diagram below:

---

Conventional lens

Marked into rings, red area removed


Fresnel lens
5.6 Determine the focal length of a convex lens

Question 73. - Method 1 Optics Bench
Procedure:

![Image of convex lens setup](http://pcwallart.com/images/concave-lens-wallpaper-2.jpg)

Question 74. - Method 2 Same size image
Procedure:

![Diagram of convex lens setup with plane mirror](http://www.schoolphysics.co.uk/age16-19/Optics/Refraction/text/Lenses_focal_length_measurement/index.html)

Question 75. - Question
In method 2, explain briefly if the separation between the lens and the mirror affect the result?
Question 76. - Method 3 Image of distant object
Procedure:

Question 77. - Method 4 Plot a $1/u$ against $1/v$ graph
Procedure:
5.7 Lens Formula
The **lens formula** relates the object distance \(u\) and image distance \(v\):

\[
\frac{1}{u} + \frac{1}{v} = \frac{1}{f}
\]

The formula suggests that the graph \(1/u\) against \(1/v\) is a straight line graph of slope \(-1\) with both intercepts equal \(1/f\).

When using this equation a sign convention must be obeyed:

- **All real images are inverted, all virtual images are erect.**
- **Concave lens forms virtual, erect image only.**
- **When using the lens formula, adopt the REAL-IS-POSITIVE convention. So, virtual image has negative object distance.**
- **Convex lens has positive focal length, concave lens has negative focal length.**

**Instruction:**

*Use the lens formula\((1/u + 1/v = 1/f)\) to solve the following questions. After calculation for each question, draw the respective ray diagram to illustrate the situation.*

**Question 78.**

An object is 15 cm from a converging lens which has a focal length of 10 cm, where is the image?

**Question 79.**

An object is 8 cm from a converging lens which has a focal length of 10 cm, where is the image?
Question 80.

An object is 15 cm from a diverging lens which has a focal length of 10 cm, where is the image?

Question 81.

A 4.00-cm tall light bulb is placed a distance of 45.7 cm from a convex lens having a focal length of 15.2 cm. Determine the image distance and the image size.

Question 82.

A 4.00-cm tall light bulb is placed a distance of 8.30 cm from a convex lens having a focal length of 15.2 cm. Determine the image distance and the image size.

Question 83.

A 4.00-cm tall light bulb is placed a distance of 35.5 cm from a diverging lens having a focal length of 12.2 cm. Determine the image distance and the image size.

Question 84.

Determine the image distance and image height for a 5-cm tall object placed 45.0 cm from a convex lens having a focal length of 15.0 cm.
Question 85.

Determine the image distance and image height for a 5-cm tall object placed 30.0 cm from a convex lens having a focal length of 15.0 cm.

Question 86.

Determine the image distance and image height for a 5-cm tall object placed 20.0 cm from a convex lens having a focal length of 15.0 cm.

Question 87.

Determine the image distance and image height for a 5-cm tall object placed 10.0 cm from a convex lens having a focal length of 15.0 cm.

Question 88.

A magnified, inverted image is located a distance of 32.0 cm from a double convex lens with a focal length of 12.0 cm. Determine the object distance and tell whether the image is real or virtual.

Question 89.

An inverted image is magnified by 2 when the object is placed 22 cm in front of a lens. Determine the image distance and the focal length of the lens.
Question 90.

A concave lens has a focal length of 10.8 cm. An object is placed 32.7 cm from the lens's surface. Determine the image distance.

Question 91.

Determine the focal length of a concave lens that produces an image that is 16.0 cm behind the lens when the object is 28.5 cm from the lens.

Question 92.

A 2.8-cm diameter coin is placed a distance of 25.0 cm from a concave lens that has a focal length of 12.0 cm. Determine the image distance and the diameter of the image.

Question 93.

The focus is located 20.0 cm from a concave lens. An object is placed 12 cm from the lens. Determine the image distance.
Answers to questions:

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>400 nm, violet</td>
</tr>
<tr>
<td>2.</td>
<td>Hint: refer to pre-lesson video</td>
</tr>
<tr>
<td>3.</td>
<td>Hint: direction of light ray</td>
</tr>
<tr>
<td>4.</td>
<td>Hint: What happen when it is moved?</td>
</tr>
<tr>
<td>5.</td>
<td>$9.46 \times 10^{12}$ km</td>
</tr>
<tr>
<td>6.</td>
<td>$1.44 \times 10^8$ km</td>
</tr>
<tr>
<td>7.</td>
<td>$4.07 \times 10^{11}$ km</td>
</tr>
<tr>
<td>8.</td>
<td>$1.325 \times 10^{16}$ km</td>
</tr>
<tr>
<td>9.</td>
<td>25.8 million yrs</td>
</tr>
<tr>
<td>10.</td>
<td>15 ms$^{-1}$</td>
</tr>
<tr>
<td>11.</td>
<td>100 m</td>
</tr>
<tr>
<td>12.</td>
<td>$t = 2$ s</td>
</tr>
<tr>
<td>13.</td>
<td>Hint: calm water versus stormy water</td>
</tr>
<tr>
<td>14.</td>
<td>Hint: refer to previous page</td>
</tr>
<tr>
<td>15.</td>
<td>Hint: What color is not absorbed?</td>
</tr>
<tr>
<td>16.</td>
<td>Hint: Similar to the previous question</td>
</tr>
<tr>
<td>17.</td>
<td>Hint: Refer to pre-lesson video</td>
</tr>
<tr>
<td>18.</td>
<td>Hint: Be creative!</td>
</tr>
<tr>
<td>19.</td>
<td>Hint: about reading the scale (刻度)</td>
</tr>
<tr>
<td>20.</td>
<td>Hint: normal is always perpendicular to the surface</td>
</tr>
<tr>
<td>21.</td>
<td>Hint: Ask for a mirror and try!</td>
</tr>
<tr>
<td>22.</td>
<td>A</td>
</tr>
<tr>
<td>23.</td>
<td>B</td>
</tr>
<tr>
<td>24.</td>
<td>Hint: For drivers in front! (But how?)</td>
</tr>
<tr>
<td>25.</td>
<td>Hint: Refer to last paragraph on P.26!</td>
</tr>
<tr>
<td>26.</td>
<td>Hint: If light ray from John reaches Mary, she can see him.</td>
</tr>
<tr>
<td>27.</td>
<td>Hint: Draw the virtual images first!</td>
</tr>
<tr>
<td>28.</td>
<td>Hint: Draw the image of Peter first!</td>
</tr>
<tr>
<td>29.</td>
<td>Hint: Similar triangles with Peter eye as common vertices.</td>
</tr>
<tr>
<td>30.</td>
<td>No. Hint: Similar triangle</td>
</tr>
<tr>
<td>31.</td>
<td>0.8m (You must show calculation)</td>
</tr>
<tr>
<td>32.</td>
<td>(c) 0.65m (d) 0.8m</td>
</tr>
<tr>
<td>33.</td>
<td>1.532, 23.78$^\circ$, 40.5$^\circ$</td>
</tr>
<tr>
<td>34.</td>
<td>1.35, 64.16$^\circ$, 20.97$^\circ$</td>
</tr>
<tr>
<td>35.</td>
<td>35.26$^\circ$, 35.26$^\circ$, 60$^\circ$</td>
</tr>
<tr>
<td>36.</td>
<td>54.97$^\circ$, 54.97$^\circ$, 33.09$^\circ$</td>
</tr>
<tr>
<td>37.</td>
<td>Hint: Refer to your calculation in Q36</td>
</tr>
<tr>
<td>38.</td>
<td>36.39$^\circ$</td>
</tr>
<tr>
<td>39.</td>
<td>34.33$^\circ$</td>
</tr>
<tr>
<td>40.</td>
<td>60.14$^\circ$</td>
</tr>
<tr>
<td>41.</td>
<td>Hint: Refer to page 39 PHYSICS IS PHUN</td>
</tr>
<tr>
<td>42.</td>
<td>Hint: Draw refracted light ray from the coin to the eye when there is water.</td>
</tr>
<tr>
<td>43.</td>
<td>Hint: Locate the image of the bottom first!</td>
</tr>
<tr>
<td>44.</td>
<td>Hint: Draw two light rays from the mouth of the fish to the boy to locate the image of the fish.</td>
</tr>
<tr>
<td>45.</td>
<td>Hint: Draw light rays from the boy to the fish</td>
</tr>
<tr>
<td>46.</td>
<td>2.99, 2.25, 1.97, 1.56, 1.24, 1.43, 2.00</td>
</tr>
<tr>
<td>47.</td>
<td>- (proof)</td>
</tr>
<tr>
<td>48.</td>
<td>$\theta + \phi - \gamma - \beta$ (but why?)</td>
</tr>
<tr>
<td>49.</td>
<td>Hint: Refer to pre-lesson video</td>
</tr>
<tr>
<td>50.</td>
<td>48.8$^\circ$, 41.8$^\circ$, 24.4$^\circ$</td>
</tr>
<tr>
<td>51.</td>
<td>62.5$^\circ$, 33.3$^\circ$, 38.3$^\circ$</td>
</tr>
<tr>
<td>52.</td>
<td>Hint: Read “Do you notice that ...” below</td>
</tr>
<tr>
<td>53.</td>
<td>Hint: You can find it in your book</td>
</tr>
<tr>
<td>54.</td>
<td>Hint: When there is water, there is total internal reflection and the light ray from the coin cannot reach the observer’s eye</td>
</tr>
<tr>
<td>55.</td>
<td>Hint: Remember the 6 construction rules, 3 for convex lens and 3 for concave lens</td>
</tr>
<tr>
<td>56.</td>
<td>Hint: Draw two rays from the tip of object, then locate and draw the image.</td>
</tr>
<tr>
<td>57.</td>
<td>Hint: Choose a scale, mark the positions of the foci on the two sides first. Then draw the object.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
| 58. | (a) Erect and Virtual, Magnified image, Convex lens, Case 6  
      (b) Inverted and Real, Diminished image, Convex lens, Case 2  
      (c) Erect and virtual, Diminished image, Concave lens  
      (d) Erect and virtual, Diminished image, Concave lens  
      (e) Erect and Virtual, Magnified image, Convex lens, Case 6  
      (f) Erect and virtual, Diminished image, Concave lens  
      (g) Inverted and Real, Diminished image, Convex lens, Case 2 |
| 59. | Case 6, $f = 20$ cm (show why!)  
| 60. | Case 4, $f = 20$ cm (show why!)  
| 61. | $f = 60$ cm (show why!)  
| 62. | Case 6, $f = 7.5$ cm (show why!)  
| 63. | Case 4, $f = 6.7$ cm (show why!)  
| 64. | Hint: Diminished image, case 2, draw the ray diagram |
| 65. | $v = 36$ cm (real image),  
      $h = 8$ cm, $m = 0.8$ (Show why!) |
| 66. | $v = 45$ cm (real image),  
      $h = 12.5$ cm, $m = 1.25$ (Show why!) |
| 67. | Hint: interchange ... |
| 68. | Real and Inverted, and diminished  
      Hint: Find the image of the tip first. |
| 69. | Hint: Similar to the last question, but it is a CONCAVE lens! |
| 70. | Hint: Find the images of the tip and the tail of the object.  
      Hint: Remember the ray passes through the center of a lens go straight?  
      And parallel rays ... the focus ... 😊 |
| 71. | Hint: Remove rectangular blocks inside  
      Direct some rays of light towards a convex lens parallel to its principal axis, mark the point of intersection of the refracted light rays.  
      This is the focus.  
      The focal length equals the distance of the focus from the lens. |
| 74. | Form a same size SHARP image of an object using the convex lens with a plane mirror parallel to it as shown below.  
      The object distance is the focal length of the lens. |
| 75. | No, because the light rays strike the mirror at right angle.  
      So, the incident angle is $0^\circ$. |
| 76. | Form a SHARP image of a DISTANT object (e.g. a building) using the convex lens.  
      The image distance is the focal length of the lens. |
| 77. | Measure the object distance ($u$) and image distance ($v$) of the sharp images formed by the lens at different object distances.  
      Plot a graph of $1/u$ against $1/v$, it should be a straight line and the slope of the graph should be $-1$.  
      The intercepts should both equal to $1/f$. |
| 78. | $v = 30$ cm, real image |
| 79. | $v = 40$ cm, virtual image |
| 80. | $v = 6$ cm, virtual image |
| 81. | $v = 22.8$ cm, real image, $h = 1.99$ cm |
| 82. | $v = 18.3$ cm, virtual image, $h = 8.81$ cm |
| 83. | $v = 9.08$ cm, virtual image, $h = 1.02$ cm |
| 84. | $v = 22.5$ cm, real, $h = 2.5$ cm |
| 85. | $v = 30.0$ cm, real, $h = 5.0$ cm |
| 86. | $v = 60.0$ cm, real, $h = 15.0$ cm |
| 87. | $v = 30.0$ cm, virtual, $h = 15.0$ cm |
| 88. | $v = 19.2$ cm, Real |
| 89. | $v = 44$ cm, real, $f = 14.7$ cm, convex lens |
| 90. | $v = 8.12$ cm, virtual |
| 91. | $f = 36.5$ cm |
| 92. | $v = 8.11$ cm, virtual, diameter of image = 0.908 cm |
| 93. | $v = 7.5$ cm, virtual |
Notes:
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http://www.slcss.edu.hk/s3physics.htm