Chapter 5: **Lenses**

***Please remember to photocopy 4 pages onto one sheet by going A3→A4 and using back to back on the photocopier***

Two types of spherical lens: ***convex*** (which is also called ‘converging’ because it causes rays which are arrive parallel to the principle axis to converge) and ***concave*** (caves in as you look at it – also called ‘diverging’).

**Convex (converging) lenses – ray diagrams**

You should be able to draw a ray diagram showing how an image is formed by a convex lens when the object is placed

1. outside the focus – resulting in a real image
2. inside the focus – resulting in a virtual image

**Two Rules**

1. From top of object to lens (parallel to principle axis), then through the focus on the other side.
2. From top of object to centre of lens and continues straight through.

For each of the following label the *focus*, the *object* and the *image*.
Put arrows on all rays, and state whether the image is real or virtual, upright or inverted, magnified or diminished

**Object outside f – real image**





**Object inside f – virtual image**





Notice that when the object is inside the focal point the light rays never intersect, but from the viewer’s perspective they *appear to do so* ***on the same side of the lens as the object*** (the viewer is to the right of the lens in the diagrams above).

**Note**

A real image is always on the other side of the lens (to the object) and is inverted.

A virtual image is always on the same side of the lens is upright.

**Concave (diverging) lenses – ray diagrams**

Here only one diagram is needed; the image is always diminished, upright and virtual.

**Two Rules**

1. From the top of the object to the lens, parallel to principle axis and up *as if coming from the focus*.
2. ****From the top of the object to centre of lens and continue straight through.



Notice that in this situation (similar to the convex lens when the object is inside the focus) the light rays never intersect, but from the viewer’s perspective they *appear to do so* **at the same side of the lens as the object**.

The image is therefore always ***virtual***, regardless of where the object is placed.

**Summary of ray diagrams (mirrors and lenses)**

**Maths Problems**

**Relationship between focal length (*f*), object distance (*u*) and image distance (*v*)**

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**Convention:**

For a *convex* lens *f* is positive

For a *concave* lens *f* is negative

If you are looking for *v* and it turns out to be *positive*, it means that the image is a *real* *image*.

If you are looking for *v* and it turns out to be *negative*, it means that the image is a *virtual* *image*.

This is referred to as the *real is positive* convention (Think ‘RIP’).

Remember that for a convex lens the image is only virtual if the object is inside the focus.

For a concave lens the image is always virtual.

**Magnification\***

*Magnification* refers to the ratio of the height of the image to the height of the object (if the image is 2 times higher than the object then the magnification is 2. It can be shown that this ratio is the same as the ratio of the image distance to the object distance *v*:*u*)

$$M=\frac{image height}{object height}= \frac{v}{u}$$

**Power of a Lens\***

Power of a Lens = 1/focal length

$$f= \frac{1}{P}$$

$$P= \frac{1}{f}$$

T**he unit of power is m-1.**

**Convention**

The power of a ***converging*** (convex) lens is taken as ***positive*** (+) {because f is positive}.

The power of a ***diverging*** (concave) lens is taken as ***negative*** (-) {because f is negative}.

**Two lenses in contact**

If two lenses of power P1 and P2 are placed in contact, the power P of the combination is given by

PTotal = P1 + P2

Remember to use the correct sign notation.

**This formula is used to determine the size and type of lens to use to correct for long- and short-sightness:**

Pcorrected eye = Pdefective eye + Pcorrective lens

See exam questions for examples

**The eye\***

****

**Cornea** – together with **the lens**, form part of the focusing system

**Optic Nerve** – carries the information in electrical form to the brain

**Iris** – acts like a shutter to control the amount of light entering the eye

**Retina** - light sensitive screen at the back of the eye

**Power of accommodation**

**The *power of accommodation*** of the eye is its ability to focus a real image of an object on the retina, whether the object is near to or far away from your eye. The eye does this by changing the shape of the lens.

**Defects of Vision; short and long-sightedness**

**Short Sight**

A Short-sighted person can see nearby objects clearly but cannot bring distant objects into focus.

Short-sightedness is corrected with a convex (diverging) lens.

**Long Sight**

A Long-Sighted person can see distant objects clearly but cannot bring nearby objects into focus.

Long-sightedness is corrected with a concave (converging) lens.



**Remember** PTotal = P1 + P2
Well here this means that:

**Pcorrected eye = Pdefective eye + Pcorrective lens**

**Leaving Cert Physics syllabus: Lenses**

|  |  |  |  |
| --- | --- | --- | --- |
| **Content** | **Depth of Treatment** | **Activities** | **STS** |
|  |  |  |  |
| Lenses | Images formed by single thin lenses.Knowledge that 1/f = 1/v + 1/u | Simple exercises on lenses by ray tracing *or* use of formula. | Use of lenses |
|  |  |  |  |
|  | m = v/u |  |  |
|  |  |  |  |
|  | Power of lens: P = 1/f |  |  |
|  |  |  |  |
|  | Two lenses in contact:P = P1 + P2 |  |  |
|  |  |  |  |
|  | The eye: Optical structure, short sight, long sight, and corrections. |  | Spectacles |
|  |  |  |  |

**MEASUREMENT OF THE FOCAL LENGTH OF A CONVEX LENS**

**APPARATUS**

Converging lens, screen, lamp-box with crosswire, metre stick, retort stand.

**DIAGRAM**

**PROCEDURE**

**First find an approximate value for the focal length.**

* Focus the image of a distant object onto a screen.
* Measure the distance between the lens and the screen.

This corresponds to an approximate value for the focal length of the lens.

1. Place the ray-box well outside the approximate focal length.
2. Move the screen until a clear inverted image of the crosswire is obtained.
3. Measure the distance u from the crosswire to the lens, using the metre stick.
4. Measure the distance v from the screen to the lens.
5. Repeat this procedure for different values of u.
6. Calculate the focal length of the lens each time using the formula **** and get an average.

**RESULTS**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Object distance *u*** |  |  |  |  |  |  |
| **Image distance *v*** |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| **Focal Length *f*** |  |  |  |  |  |  |

**SOURCES OF ERROR / PRECAUTIONS**

1. Determining when the image was in sharpest focus; repeat each time and get an average.
2. Parallax error associated with measuring u and v; ensure your line of sight is at right angles to the metre stick.
3. Take all measurements from the centre of the lens.

**Extra Credit**

**Stereo Vision**

Roll a piece of paper into a tube. Hold it with one hand, say, the left hand, and look at a distant object through it with your left eye, keeping your right eye closed. Now, bring your right palm in front of your right eye so as to touch the tube, and then, open your right eye as well. You will see the distant object clearly through a hole in your right palm! (Both hands should be about 15-20 centimetres from your eyes). It’s fantastic, isn’t it? How do you explain it?

Why?

**Answer**

Your brain receives two separate images from your eyes and combines them. Usually the images are similar so you don’t notice any discrepancies.

**Power of Accommodation**

Hold these notes out at arm’s length and notice that you can still read them clearly.

Now slowly bring the notes in until they are touching your nose. You can now no longer read them clearly.

Can you explain why?

**Answer**

For objects which are approximately 6 m or closer to your face, the lens in your eye has to change shape to allow the light rays to intersect on your retina…it accommodates to give a clear image.

The lens in your eye cannot curve sufficiently to enable the rays of light to intersect on your retina.

For objects greater than 6 m from your face the rays of light are travelling roughly parallel so the shape of the lens remains roughly constant.

**Optic Nerve / Blind Spot**

Close one eye and look at the cross with the open eye – can you still see the black dot “out of the corner of your eye”?

Now slowly move your head towards the cross. Notice that at one particular distance the black dot disappears out of the corner of your eye but then reappears as you move in closer still.
Why?

**Answer**

This is because at that one specific position light from the black dot was falling on the opening to your optic nerve and there is no retina there so no light receptors. For this reason it is known as your blind spot.

**‘Adjusting’ your eyes to the brightness**

We are annoyed when cars coming from the opposite direction have their headlights on, because the bright light dazzles our eyes. Conversely when we enter a dark room for a while we are unable to see anything but then slowly our eyes get ‘adjusted’ and we are able to discern faintly the objects around us. Why do our eyes react to light the way they do? Hint: try the following activity.

Look into the eyes of another student beside you while the room is suddenly darkened – what do you notice about their ‘eyeballs’? The effect is even more impressive (for obvious reasons) is you go from dark to brightness. Can you explain why?

**Answer**

Your iris acts like a pair of shutters which close together when too much light gets through and opens up when there is very little light in the background to enable more light to get through. If too much light gets through it seems to ‘drown’ the receptors and we interpret this as pain (our eyes are ‘dazzled’).

**Wearing goggle underwater helps you to see more clearly.**

Have you noticed that when swimming underwater, you can see much better if you wear goggles.

Why?

**Answer**

Light refracts when travelling from air through the cornea of your eye, but water and the cornea have the same refractive index (not surprising I suppose – the cornea seems to be mostly water) so light which travels from water to your cornea doesn’t refract much at all, so there is no focusing on the retina.

By wearing goggles however light which hits your eye is coming from air, so the usual focusing applies and objects appear normal. Unless you happen to be on a family holiday in Majorca and find yourself underwater staring at Granny’s cellulite arse, in which case ‘normal’ is not the word which first comes to mind.

By the way, this concept was asked in 2008, Question 8 (no reference to Granny unfortunately).

**Upside down glasses**

The lens in our eye inverts the image of the object we’re looking at so that the image which forms on the back of our eye (the retina) is actually inverted! So why doesn’t the world look upside down?

What would happen if we wore a pair of glasses which made the image on the retina the right way up?

**Answer**

The brain realises that the image on the retina is upside-down so takes this into account when ‘forming’ the final image.

The upside-down glasses were first investigated by George Stratton in the 1890’s. Since the image that the retina of our eye sees is inverted, he wanted to explore the effect of presenting to the retina an upright image. He reported several experiments with a lens system that inverted images both vertically and horizontally. He initially wore the glasses over both eyes but found it too stressful, so he decided to wear a special reversing telescope over one eye and keep the other one covered.

In his first experiment, he wore the reversing telescope for twenty-one hours. However his world only occasionally looked normal so he ran another experiment where he wore it for eight days in a row. On the fourth day, things seemed to be upright rather than inverted. On the fifth day, he was able to walk around his house fairly normally but he found that if he looked at objects very carefully, they again seemed to be inverted. On the whole, Stratton reported that his environment never really felt normal especially his body parts, although it was difficult to describe exactly how he felt. He also found that after removing the reversing lenses, it took several hours for his vision to return to normal.

**\*The Eye**

Did you know that a TV screen shows 24 pictures a second? Because a fly sees 200 images a second, it would see TV as still pictures with darkness in between.

**Confusion with Mirrors and Lenses**

Whereas a *concave mirror* *gives a real image* (unless the object was inside the focus) this time it’s a *convex* *lens* *which gives a real image* (unless the object is inside the focus) and *a concave lens always gives a virtual image*.

Secondly, whereas with mirrors a virtual image was always formed behind the mirror, with lenses it’s a real image which is formed at the other side of the lens, and a virtual image is always formed on the same side of the lens as the object.

After that however the chapter is remarkably similar to the chapter on spherical mirrors.

**Why are you advised not to water plants on a bright sunny day?**

The water forms droplets on the leaves. Thesedroplets act as converging lenses and focus thesun onto the leaves, burning them. As a result theleaves will have brown spots.

**\*Power of a lens**

The power of a lens is defined as the reciprocal of the focal length in metres. The unit of power is the m–1. Opticians use the dioptre as the name of the unit of power but this is not used in the SI system.

**Refractive Index of parts of the eye**

n cornea = 1.376

n lens = 1.42

n vitreous humour = 1.336

**Physics, Art and History**

Focus an image of a distant object on a screen (a white page) using lenses or mirrors. This is always impressive, particularly when you notice that the image is in colour, and upside down.

The lenses must be convex (converging), and the mirrors concave. Why?

Some historians of art now believe that from the early 15th century many Western artists including Van Eyck, Caravaggio and Vermeer used mirrors and lenses to create living projections.

Optics would have given artists a new tool with which to make images that were both immediate and powerful, enabling them to project colour images onto flat surfaces and then capture these projections in pencil and paint.

**The maths questions**

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$$Magnification= \frac{Height of image}{Height of object}$$

The following diagram (which you don’t need to know) illustrates that the ratio between image height and object height is also the ratio between the image distance (v) and the image distance (v).



This formula often causes confusion:

While v and u are *lengths* (from the image to the lens and from the lens to the object respectively), the above formula is actually telling us about the ration between *heights*.

So if v is 10 cm and u is 2 cm, it means that the image length is 5 times greater than the object length, but from the magnification formula it also means that the height of the image will be 5 times greater than the height of the object.

In other words, the magnification is 5.

**The maths questions: convention**

Note: none of the following has ever been required on any exam questions to date on this topic. However it is on the syllabus so is included here.

But for the record:

For a concave mirror f is positive

For a convex mirror f is negative

For a real image v is positive

For a virtual image v is negative

The last two lines are what is referred to as the ‘Real is Positive’ convention (RiP).

Remember that for a convex lens the image is only virtual if the object is inside the focus.

For a concave lens the image is always virtual.

u is always positive for both types of lens.

If you are told that v is virtual, or if it is obvious from the question (because the lens is concave or because the object is inside the focal length if the lens is convex) then you should make the value for v negative at the beginning of the question.

Another common mistake is to add 1/u to 1/v, but forgetting to invert the answer to get f.

I also suggest working the whole sum out in the calculator, rather than trying to find lowest common denominators etc. But this does require being proficient in the use of your calculator!

It is also advisable in this case to show your workings in your answer. This is so that if mess up the calculator work, at lease the examiner can see that you had the right idea.

**Exam questions**

1. [2006]

A converging lens is used as a magnifying glass.

Draw a ray diagram to show how an erect image is formed by a magnifying glass.

1. [2006]

A diverging lens cannot be used as a magnifying glass. Explain why.

1. [2006]

A converging lens has a focal length of 8 cm.

Determine the two positions that an object can be placed to produce an image that is four times the size of the object?

1. [2002 OL]

A lens has a power of +50 m-1. What type of lens is it and what is its focal length?

1. [2008 OL]

A concave lens has a power of 0.1 cm−1. What is the focal length of the lens?

1. [2004]

Two converging lenses, each with a focal length of 10 cm, are placed in contact. What is the power of the lens combination?

1. [2002]

The power of a normal eye is +60 m-1. A short-sighted person’s eye has a power of +65 m-1.

1. Calculate the power of the contact lens required to correct the person’s short-sightedness.
2. Calculate the focal length of the contact lens required to correct the person’s short-sightedness.
3. [2006]

The power of an eye when looking at a distant object should be 60 m–1. A person with defective vision has a minimum power of 64 m–1.

1. Calculate the focal length of the lens required to correct this defect.
2. What type of lens is used?
3. Name the defect.
4. [2002]

Draw a labelled diagram showing the optical structure of the eye.

1. [2002]

How does the eye bring objects at different distances into focus?

1. [2008]
2. An eye contains a lens system and a retina, which is 2.0 cm from the lens system.

The lens system consists of the cornea, which acts as a fixed lens of power 38 m–1, and a variable internal lens just behind the cornea.

The maximum power of the eye is 64 m–1.

Calculate how near an object can be placed in front of the eye and still be in focus.

1. Calculate the maximum power of the internal lens.
2. Light is refracted as it enters the cornea from air as shown in the diagram.

Calculate the refractive index of the cornea.

1. Draw a diagram to show the path of a ray of light as it passes from water of refractive index 1.33 into the cornea.
2. A swimmer cannot see properly when she opens her eyes underwater.

When underwater why does the cornea not act as a lens?

1. What is the maximum power of the eye when underwater?
2. Why do objects appear blurred when underwater?
3. Explain how wearing goggles allows objects to be seen clearly.

**Mandatory Experiment**

1. [2005 OL]

You carried out an experiment to measure the focal length of a converging lens.

1. Draw a labelled diagram of the apparatus that you used in the experiment.
2. Describe how you found the position of the image formed by the lens.
3. What measurements did you take?
4. How did you get a value for the focal length of the converging lens from your measurements?
5. Give one precaution that you took to get an accurate result.
6. [2009]

A student was asked to measure the focal length of a converging lens. The student measured the image distance *v* for each of three different object distances *u*. The student recorded the following data.

|  |  |  |  |
| --- | --- | --- | --- |
| *u*/cm | 20.0 | 30.0 | 40.0 |
| *v*/cm | 65.2 | 33.3 | 25.1 |

1. Describe how the image distance was measured.
2. Give two precautions that should be taken when measuring the image distance.
3. Use all of the data to calculate the focal length of the converging lens.
4. What difficulty would arise if the student placed the object 10 cm from the lens?

1. [2003]

The following is part of a student’s report of an experiment to measure the focal length of a converging lens.

“I found the approximate focal length of the lens to be 15 cm.

I then placed an object at different positions in front of the lens so that a real image was formed in each case.”

The table shows the measurements recorded by the student for the object distance *u* and the image distance *v*.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *u*/cm | 20.0 | 25.0 | 35.0 | 45.0 |
| *v*/cm | 66.4 | 40.6 | 27.6 | 23.2 |

1. How did the student find an approximate value for the focal length of the lens?
2. Describe, with the aid of a labelled diagram, how the student found the position of the image.
3. Using the data in the table, find an average value for the focal length of the lens.
4. Give two sources of error in measuring the image distance and state how one of these errors can be reduced.

**Exam solutions**

1. ****Object inside focal point

Two (appropriate) rays from object to lens

Two rays emerge correctly from lens

Rays produced back to form upright virtual image (on same side as object)

1. The image is always diminished.
2. 1/u + 1/v = 1/f

Magnification = v /u = 4  v = 4u

For real image: 1/u + 1/4u = 1/8  u = 10 cm

For virtual image: 1 /u - 1/4u = 1/8  u = 6 cm

1. P = 1/f ⇒ f = 1/P ⇒ f = .02 m. It is a converging (convex) lens.
2. P = 1/f  f = 1/P = 10 cm.
3. P1 = 1/f1 = 10 m−1 , P2 = 1/f2 = 10 m−1

P = P1 + P2 = 20 m-1

1. (i) PTotal = P1 + P2

60 = 65 + P2

Power = - 5 m

(ii)P = 1/f  f = - 0.2 m

1. (i) P = P1 + P2  60 = 64 + P2  P2 = -4 ( m-1)

****P = 1/f  f = 1/P  1/f = (-)4  f = (-)¼ m = (-)25 cm

(ii)Diverging / concave lens

(iii)Short sight / myopia

1. See diagram.
2. It can change the shape of the lens which in turn changes the focal length of the lens.
3. Pmax = 64 m-1 = 1/f

f = 0.0156 m = 1.56 cm

1/u = 1/v +1/f  1/u = 1/2 = 1/1.56  u = 7.14 cm

1. Pmax = P1 + P2  64 = 38 + P2  P2 = 26 m-1

  n = sin 37/sin 27  n = 1.33

1. Both media have the same refractive index so there is no bending of light.

Draw a straight line passing from one medium to the other without bending.

1. Because light does not refract at the cornea since there is no change in refractive index.
2. The maximum power of the eye is 64 m–1, but this includes the focusing power of the cornea (38 m-1) which doesn’t work underwater, so maximum power = 64 – 38 = 26 m–1.
3. Because the internal lens by itself is not powerful enough to focus light on retina.
4. Because light which hits the cornea is coming from air and so there will be refraction here (the cornea willnow act as a lens).

**Mandatory Experiment**

1. 
2. See diagram. Include a metre-stick.
3. We kept the ray-box and the lens fixed and moved the screen until there was a clear image formed on the screen.
4. We measured the distance from object (cross-wires) to the lens (u) and the distance from the lens to the screen (v).
5. By substituting the values for u and v into the formula **.**
6. Ensure that the crosshairs are in focus, repeat and find the average, avoid error of parallax.
7. ****Object, (converging) lens, screen /search pin

Sharp image (state/imply) // no parallax (between image and search pin)

Measure (distance) from image/screen to (centre of) lens

1. Measure from the centre of the lens (to the screen) / measure perpendicular distance /avoid parallax error
2. 1/u + 1/v = 1/f

Correct substitution

f = 15.3 cm, 15.8 cm, 15.4 cm

fave = (15.5 ± 0.4) cm

1. Object would be inside the focal point so an image cannot be formed on a screen

**Alternative (graphical method):**

|  |  |  |  |
| --- | --- | --- | --- |
| 1/u  | 0.050 | 0.033 | 0.025 |
| 1/v  | 0.0153 | 0.0300 | 0.0398 |

Inverse values for u and for v

Plot points

Read intercept(s)

f = (15.87 ± 0.40) cm

1. Focus the image of a distant object on a screen.

The distance from the lens to screen corresponds to the focal length.

1. Set up as shown.

Adjust the position of the screen until a sharp image is seen.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *u*/cm | 20.0 | 25.0 | 35.0 | 45.0 |
| *v*/cm | 66.4 | 40.6 | 27.6 | 23.2 |
| f/cm | 15.4 | 15.5 | 15.4 | 15.3 |

1.

1/u+ 1/v = 1/f

Average **=** 15.4 cm

1. Image not sharp / parallax error in reading distance / not measuring to centre of lens / zero error in metre stick.