Lenses

4.6.2.5 · Waves · revision notes

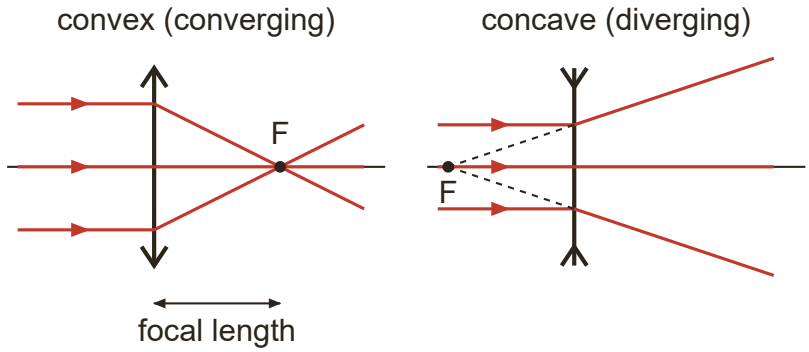
How convex and concave lenses form images by refraction, how to draw ray diagrams for them, and how to calculate magnification. GCSE Physics only, not in Combined Science. Expect ray diagrams to complete, image descriptions and magnification calculations (the magnification equation is on the Physics equation sheet).

Key facts

- Convex (converging): thicker in the middle; symbol has outward arrowheads
- Principal focus: where parallel rays meet (convex) or appear to come from (concave)
- A ray through the centre of a lens goes straight on
- Convex lens: real or virtual image; concave lens: always virtual
- Magnifying glass: object closer to a convex lens than the principal focus
- Concave (diverging): thinner in the middle; symbol has inward arrowheads
- Focal length = distance from the centre of the lens to the principal focus
- Real image: rays actually meet, can be shown on a screen. Virtual image: rays only appear to come from it
- magnification = image height ÷ object height (no units; on the equation sheet)

Lenses and focal length

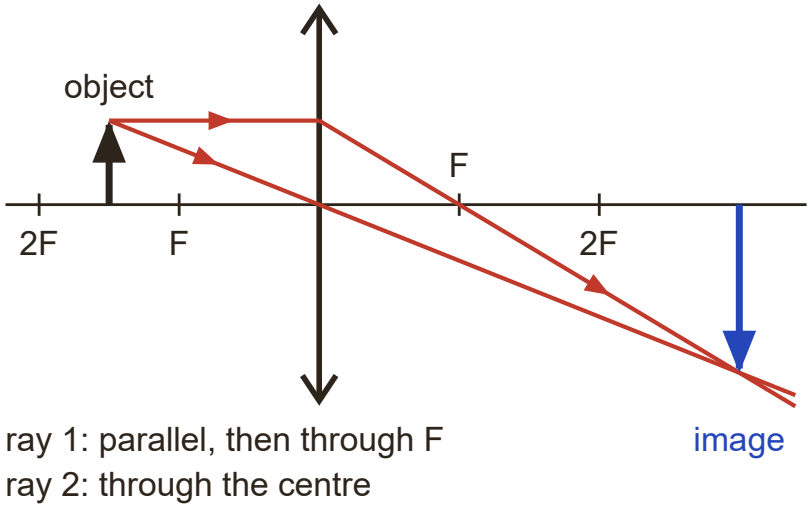
- A lens forms an image by **refracting** light.
- A **convex** (converging) lens is thicker in the middle. It brings rays parallel to the principal axis together at the **principal focus** (F) on the other side.
- A **concave** (diverging) lens is thinner in the middle. It spreads parallel rays out so that they appear to come from the principal focus on the same side as the object.
- The **focal length** is the distance from the centre of the lens to the principal focus. A lens has a principal focus on each side.
- In ray diagrams, a convex lens is drawn as a vertical line with **outward**-pointing arrowheads, and a concave lens as a line with **inward**-pointing arrowheads.



Convex: parallel rays meet at F. Concave: parallel rays spread out as if from F (dashed).

Drawing ray diagrams

- Draw two rays from the top of the object, using a ruler.
- Ray 1, **parallel** to the principal axis: after a convex lens it passes **through F** on the far side. After a concave lens it spreads out as if it came **from F** on the object's side; show this with a dashed line drawn back to F.
- Ray 2, through the **centre** of the lens: it carries on in a straight line.
- The top of the image is where the rays cross, or appear to cross.



Object between F and 2F: the image is real, inverted and magnified.

- A **real** image forms where rays actually meet, so it can be shown on a screen. A **virtual** image is where rays only appear to come from, so it cannot be shown on a screen.

What image you get

- Convex lens, object further from the lens than F: the image is **real** and **inverted**, on the other side of the lens. It is diminished if the object is more than two focal lengths (2F) away, and magnified if it is between F and 2F.
- Convex lens, object closer than F (a magnifying glass): the image is **virtual**, upright and magnified, on the same side as the object.
- Concave lens: the image is **always virtual**, upright and diminished, on the same side as the object.

Magnification

- **magnification = image height ÷ object height**
- Magnification is a ratio, so it has **no units**. Measure both heights in the same unit (both mm or both cm).
- A magnification greater than 1 means the image is bigger than the object; less than 1 means it is smaller.
- To investigate: move a screen until a convex lens gives a sharp image of a lit object, measure both heights with a ruler, then repeat with lenses of different focal lengths.

How to answer each type of question

Calculate magnification or image height

2 to 3 marks | **Grade 5**

1. Write down magnification = image height ÷ object height.
2. Put both heights in the same unit.
3. Substitute, or rearrange to image height = magnification × object height.
4. Do not give magnification a unit.

Example. A convex lens forms an image of an insect that is 12 mm tall. The image is 4.2 cm tall. Calculate the magnification.

Model answer.

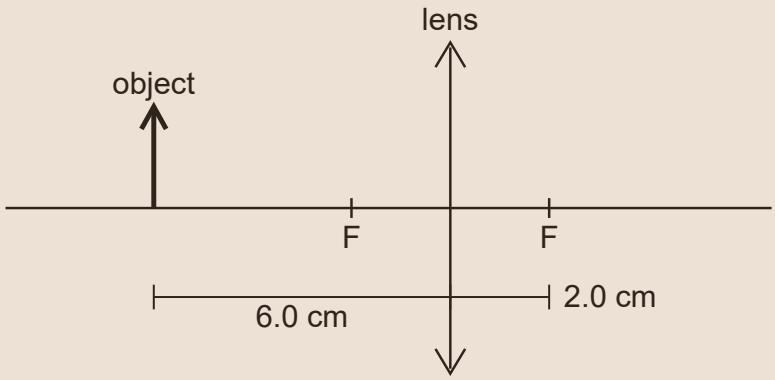
4.2 cm = 42 mm	(1)
magnification = 42 ÷ 12	(1)
magnification = 3.5	(1)

Complete a ray diagram for a convex lens

3 to 4 marks | Grade 5

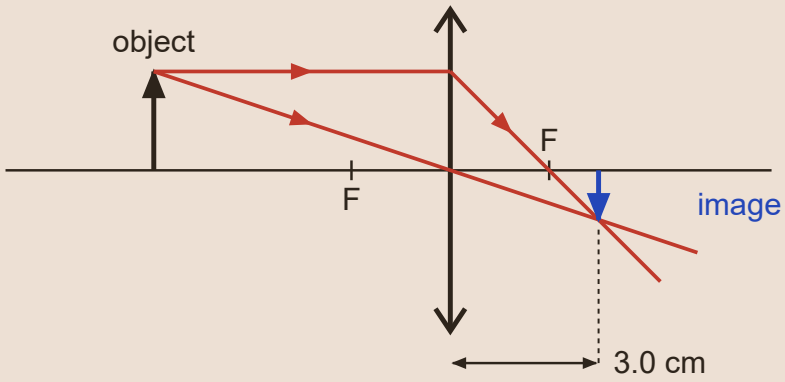
1. From the top of the object, draw a ray parallel to the axis, then through F on the far side.
2. From the top of the object, draw a ray straight through the centre of the lens.
3. Draw the image as an arrow from the axis to where the rays cross.
4. Describe the image: real or virtual, upright or inverted, magnified or diminished.

Example. An object 2.0 cm tall stands on the principal axis, 6.0 cm from a convex lens of focal length 2.0 cm. The diagram is drawn to scale.



Describe how you would complete the ray diagram to find where the image forms, and describe the image.

Model answer.



The rays cross 3.0 cm beyond the lens and 1.0 cm below the axis.

A ray from the top of the object travels parallel to the axis and is refracted through F on the far side (1). A ray from the top of the object passes straight through the centre of the lens (1). The rays cross 3.0 cm from the lens on the other side, 1.0 cm below the axis (1). The image is real, inverted and diminished (1).

Explain why an image is real or virtual

2 to 3 marks | Grade 7

1. Say whether the rays actually meet or only appear to come from the image.
2. Link this to whether the image can be shown on a screen.

Example. A concave lens forms an image of a candle flame.
Explain why this image cannot be shown on a screen.

Model answer. The image is virtual (1). The refracted rays spread out and never actually meet; they only appear to come from the image (1). So no light actually arrives at the image position to form a picture on a screen (1).

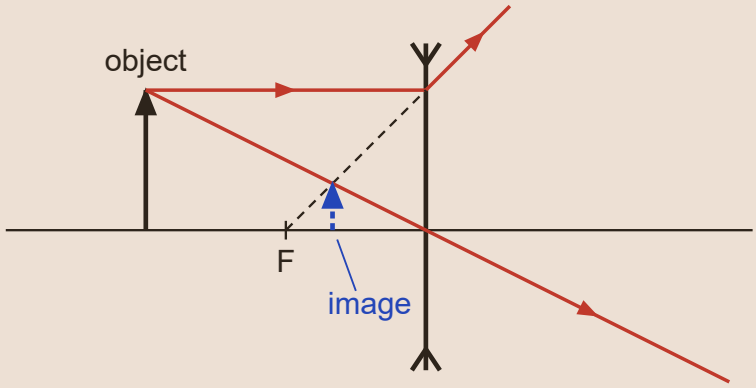
Describe a ray diagram for a concave lens

3 marks | Grade 5

1. Parallel ray: refracted outwards, then drawn back (dashed) to F on the object's side.
2. Second ray: straight through the centre.
3. The image is where the dashed line meets the second ray: virtual, upright, diminished.

Example. Describe how a ray diagram is drawn to find the image formed by a concave lens, and describe the image.

Model answer.



The image (dashed) is where the rays appear to come from: virtual, upright and diminished.

A ray from the top of the object parallel to the axis is refracted outwards (it diverges) (1). It is extended backwards as a dashed line through the principal focus on the same side as the object (1). A second ray goes straight through the centre of the lens; where it meets the dashed line is the top of the image, which is virtual, upright and diminished (1).

Don't lose marks

- Giving magnification a unit, such as cm.
- Dividing the object height by the image height instead of the other way round.

- Using different units for the image height and the object height.
- For a concave lens, bending the parallel ray through F on the far side. It must spread out as if it came from F on the object's side.
- Not using a ruler, or not extending the rays far enough to cross.

More tips

Memory tricks

- Convex bulges out, like the outward arrowheads on its symbol; concave 'caves in', like its inward arrowheads.
- With a single lens, real images are always inverted and virtual images are always upright.
- Magnification check: if the image is smaller than the object, your answer must be less than 1.
- Two rays are enough: 'parallel, then through F' and 'straight through the centre'.

Exam technique

- Describe an image with three words: real or virtual, upright or inverted, magnified or diminished (or the same size).
- Draw virtual rays and virtual images with dashed lines, and put arrows on real rays.
- The magnification equation is on the Physics equation sheet, but you must be able to rearrange it.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **Recognise the convex and concave lens symbols**
Convex: a line with outward-pointing arrowheads. Concave: a line with inward-pointing arrowheads.

Grade 4 — **Define principal focus and focal length**
A convex lens brings parallel rays to a focus at the principal focus; the focal length is its distance from the lens.

Grade 5 — **Calculate magnification**
magnification = image height ÷ object height, with both heights in the same unit; it has no units.

Grade 5 — **Describe an image in three words**
Say whether it is real or virtual, upright or inverted, and magnified or diminished.

Grade 5 — **Draw a ray diagram for a convex lens**
Use a ray parallel to the axis that refracts through F, and a ray through the centre that goes straight on.

Grade 5 — **Draw a ray diagram for a concave lens**
The parallel ray spreads out as if it came from F on the object's side; the image is always virtual.

Grade 7 — **Explain real and virtual images**
A real image forms where rays actually meet and can be shown on a screen; a virtual image is where rays only appear to come from.

Grade 8 — **Predict the image for any object position**
E.g. an object closer to a convex lens than F gives a virtual, upright, magnified image.

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