Candidate 7 evidence

Introduction

Aim –

In my investigation I aim to measure the focal length of different lenses and mirrors, and I will look at some of the properties of these lenses.

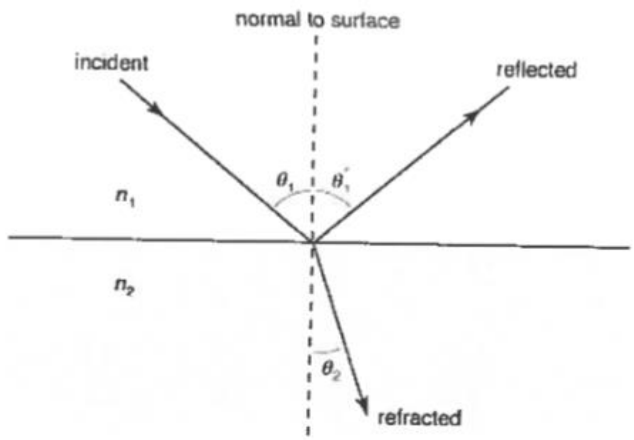
1. In experiment 1 I intend to find the focal length of a convex lens.
2. In experiment 2 I intend to determine the focal length of a convex lens by examining the object distance and image distance produced by the lens.
3. In experiment 3 I aim to calculate the magnification of a convex lens at both its conjugate points.
4. In experiment 4 I aim to determine the focal length of a concave lens.
5. In experiment 5 I aim to determine the focal length of a concave mirror,
6. In experiment 6 I aim to find the focal length of a convex mirror.

Summary –

Experiment	**Result**
1. Focal length of a convex lens	Focal length = 9.72 cm ± 0.04cm
2. Observing the link between the focal length of a convex lens with the object distance and image distance.	Focal length = 9.98 cm
3. Observing conjugate points and the magnification of the convex lens	Size of light source =2.91 cm ± 0.04 cm <u>Method 1</u> Magnification at conjugate point 1 = 3.48 ± 0.1 Magnification at conjugate point 2 = 0.29 ±0.01 <u>Method 2</u> Magnification at conjugate point 1 = -2.81±0.07 Magnification at conjugate point 2 = -0.24±0.01
4. Focal length of a concave lens	Focal length = -11.57 cm ± 0.3 cm
5. Focal length of a concave mirror	focal length = 10.32 cm ± 0.06 cm
6. Focal length of a convex mirror	focal length = -23.27 cm ± 0.12 cm

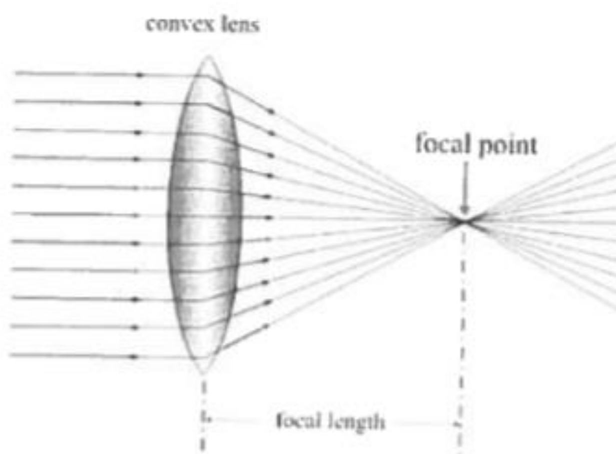
Underlying physics –

When light is travelling through a medium and the medium changes there may also be a change in refractive index, For example when light travels from air to glass the refractive index changes from a lower refractive index to a higher refractive index. If light were to enter a flat piece of glass from air at an angle θ_1 some of the light would be reflected whilst the remainder would be refracted at angle θ_2.

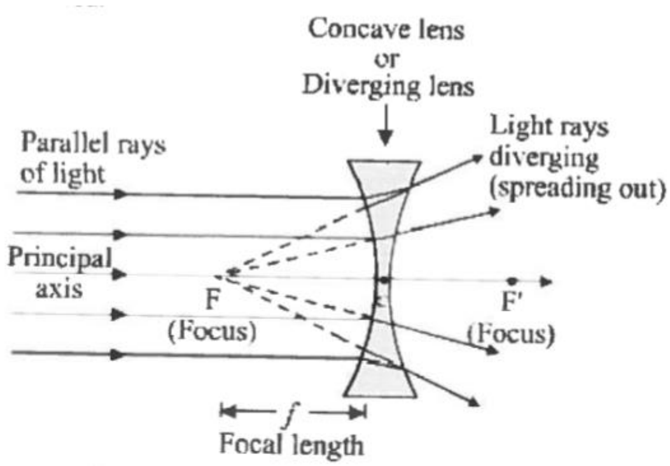


[1]

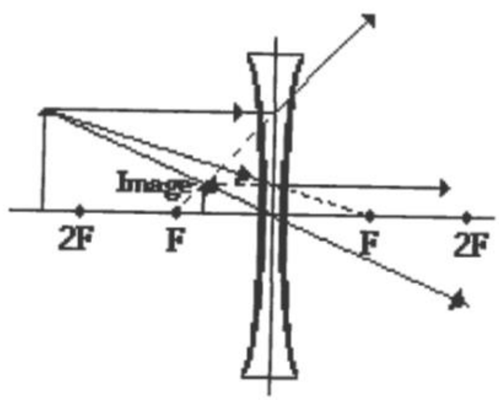
If light were to enter a curved material of a higher refractive index, the magnitude of the refraction will depend on the curve of the surface. When parallel rays of light are incident on a convex lens they refract so that the light converges towards one point, the focal point. The distance between the lens and the focal point will be the focal length of the lens.



A concave lens will produce a virtual image of a real object, unless focused on a virtual object then a real image will be formed.



The ray diagram below [2] shows ow the light emitted from an object onto a concave lens is made into an image:



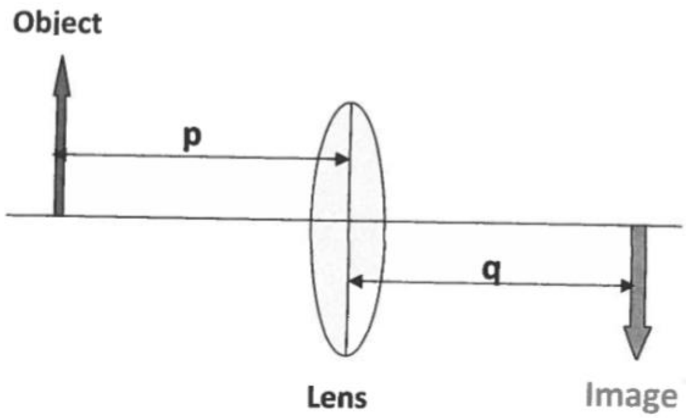
The light rays from the object hit the lens and refract outwards, the diagram shows that when the refracted rays are extended backwards the point at which they all intercept is the point at where the image is produced.

Lenses are designed to create an image of an item. Lenses can produce two types of image, real images and virtual images. A real image is made where beams of light from one source enters a lens from one side, then refracts to focus the light out of the other end of the lens creating an image. However a virtual image is created when light from a source is shone through a lens and the light is refracted so that the light diverges like with light going through a concave lens, so a virtual image can only be seen when looking into the optical lens. [3]

The focal length of a concave lens and convex lens can be calculated using the formula:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

f in the above equation corresponds to the focal length, p is equal to the physical objects distance from the lens and q is equal to the distance between image produced and the lens [4]. The units for the focal length depend on the units for p and q if their values are measured in centimetres the focal length will be in centimetres.



The diagram above shows how the distances p and q in the focal length formula relate to image and object distance.
There is a sign convention that comes with this focal length formula when carrying out calculations. For any convex lens (converging lens) the focal length is always positive, the focal length of a concave (diverging lens) is always negative. For any lens the object distance is always a positive value. However if the image produced is on the same side of the lens as the object then the image distance value is negative, the image distance value is positive when the image produced is on the opposite side of the lens than the actual object.

The linear magnification of a lens can be found using the formula:

$$M = \frac{\text{image size}}{\text{object size}} \text{ or } M = -\frac{q}{p}$$

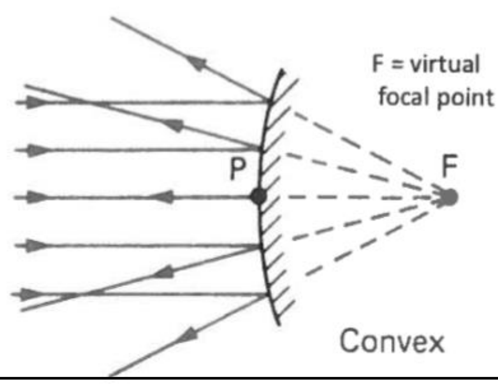
The magnification of a lens is the ratio of image size to object size. q and p relate back to the values in the focal length equation as object distance and image distance respectively and the magnification factor has no units. If the magnification ratio of the lens is positive the image created by the lens will be projected the same way up as the object. Conversely if the magnification ratio is negative the image will be inverted.

If an object is positioned over 4 focal lengths away from its image produced by a lens then it can have conjugate points. This means that the lens can be put in 2 distinct positions and still focus the image in the exact same place. The positions of these two points are the conjugate points. The size of the object can be measured using the sizes of the images produced when the lens is at its conjugate points.

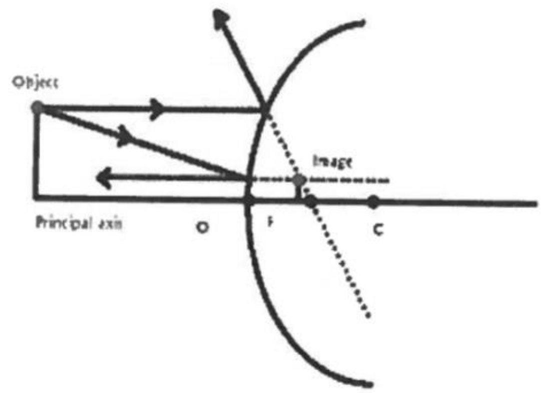
$$h_o = \sqrt{(h_1 h_2)}$$

The formula above shows how an objects size, h_o can be found when the values h_1 and h_2 (the size of the images produced of that object by the lens at each of the conjugate points) are known.

To increase the reflection of light that hits the surface of glass, glass can undergo silvering. silvering is the process of coating glass with a metallic substance [5]. Convex mirrors curve outwards towards the incident light rays. Convex mirrors diverge reflected light, this means that convex mirrors have a negative focal length that lays behind the mirror.



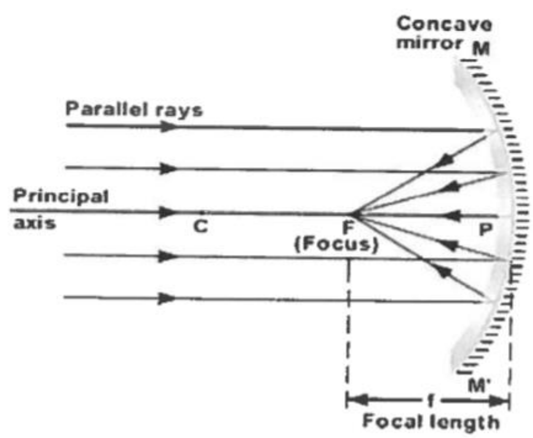
This means that convex mirrors can only create virtual images so the images formed by the mirror can't be projected onto a screen. This ray diagram [6] conveys how a virtual image where the virtual image of a convex lens is produced.



The diagram shows how the light rays emitted by the object hit the mirror and reflect outwards at an angle, then when the reflected beams are traced backwards the location of the created image is discovered.

Convex mirrors are used for many things for example they are used in car wing mirrors as they give a wide view of the surroundings, however they have a distorted perception of image depth as objects can be very close to the mirror but appear to be far away on the image produced by the mirror.

Concave mirrors are mirrors that curve inwards, this type of mirror converges light that is incident on it and focuses it into one point.

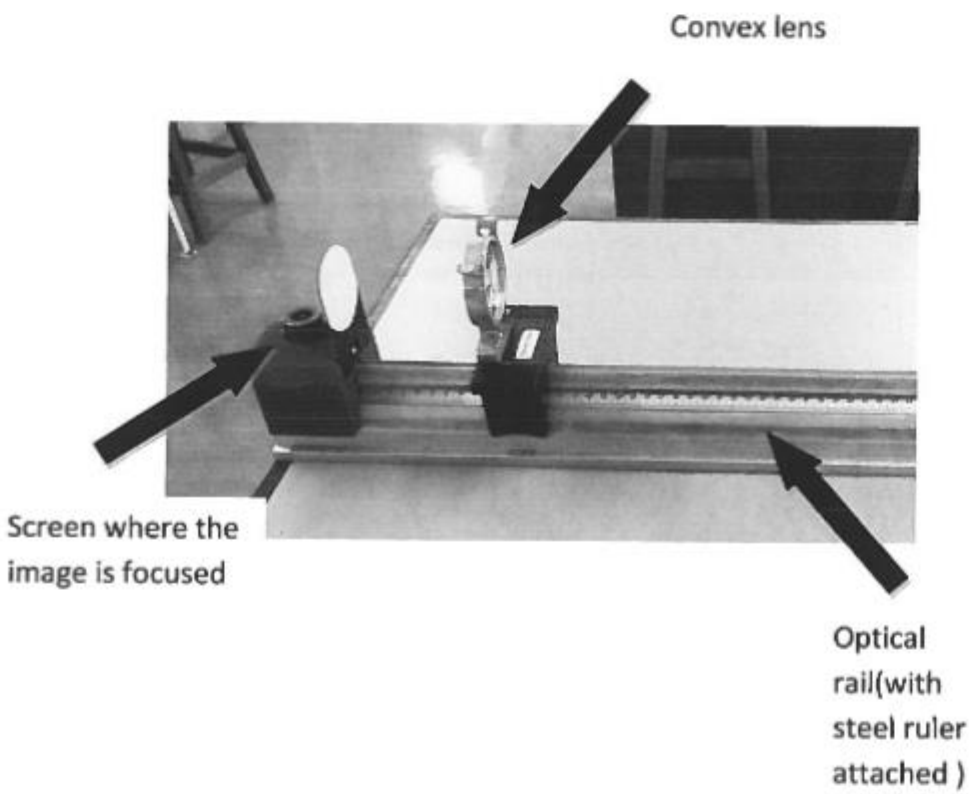


Concave mirrors can create virtual and real images depending on the objects position relative to the mirror. Unlike the convex mirror the concave mirror can project an image onto a screen. Concave mirrors have many uses such as reflecting telescopes and in concentrating energy for solar power.

Experiment 1 – Determining the focal length of a thin convex lens

<u>method –</u>

An optical rail was placed facing towards a window and then a screen was placed on the end of the optical rail, at the furthest point from the window. A convex lens was put on any point of the rail, and then the lens was moved to focus a sharp image of the furthest object possible on the screen. The distance between the screen and the centre of the lens was recorded using the steel ruler on the side of the optical rail. Next the lens was placed out of focus and refocused and the distance between the lens was recorded again, this was repeated until there was five sets of results.



Results –

Measurement	Focal length (distance of lens from screen) (cm)
1	9.8
2	9.7
3	9.7
4	9.6
5	9.8

Average distance = 9.72 cm

Analysis

Average focal length = 9.72 cm ± 0.04 cm

Conclusion

For my first experiment I successfully measured the focal length of the convex lens to be 9.72 cm ± 0.04 cm.

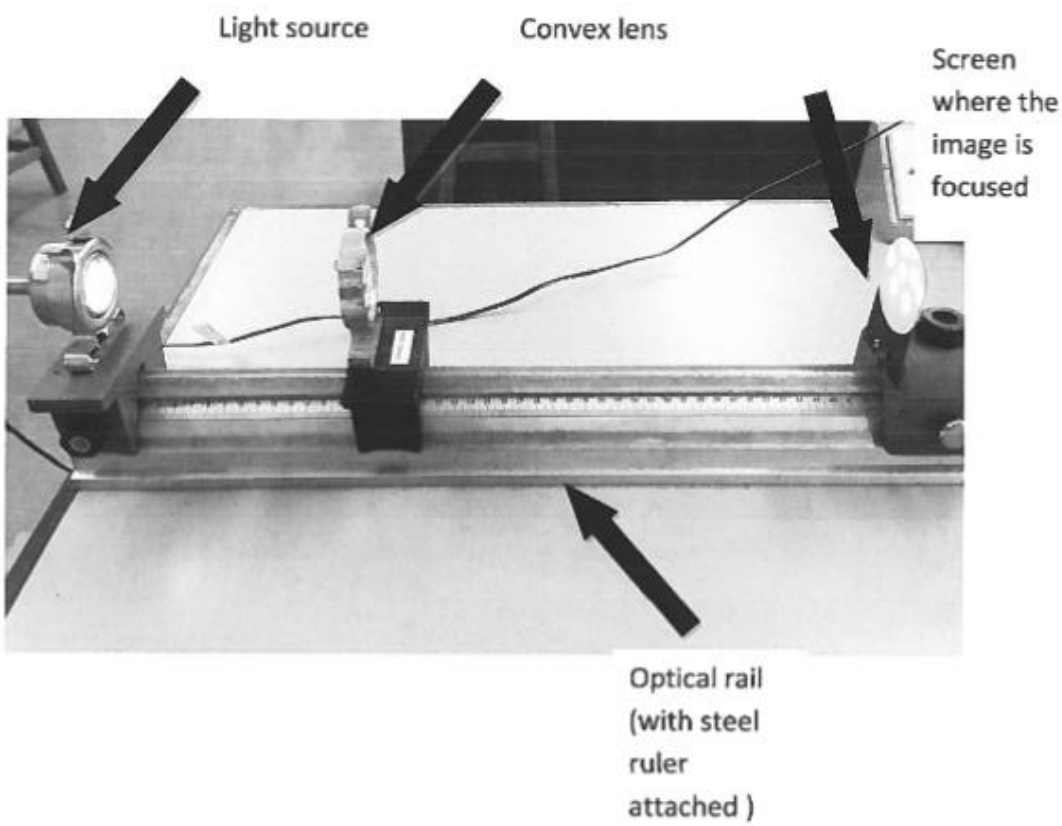
Evaluation

For my first experiment there was a very small absolute uncertainty of ± 0.41% this shows that there was little deviation in my results and that my measurements were all fairly accurate. I believe that this is mostly due to the simplicity of the experiment, it only constituted of moving a lens in and out of focus and that all five measurements taken were all roughly the same giving a low absolute error and an accurate result.

Experiment 2 – The relationship between object distance and image distance with the focal length of a convex lens

Method –

A light source was positioned at the end of the optical rail and a screen was put on the other end of the rail. Subsequently a convex lens was put on the rail at its focal length plus 5 cm from the light source (I recorded this distance as p). Next the screen was moved towards the lens until a focused picture of the light source was seen on the screen (the distance between the lens and the screen was recorded as distance q, it was measured using the ruler attached to the rail). After that the distance, p (the distance between the light and the lens) was increased by 5 cm each time from 15.3 cm to 60.3cm. For every value f p the new value of q was found by refocusing the light source on the screen. This was repeated until 5 sets of results were obtained. Then a graph of pq against p+q was plotted.



Results –

table of results

p(cm)	q1(cm)	q2(cm)	q3(cm)	q4(cm)	q5 (cm)
15.3	31	31.1	31	31.5	30.9
20.3	24	24.3	24.2	24.1	24.1
25.3	18.5	18.6	18.4	18.5	18.5
30.3	16.4	16.5	16.5	16.4	16.6
35.3	14.9	14.9	15	14.6	14.9
40.3	14.2	13.9	14.1	14.1	14
45.3	13.7	13.6	13.6	13.7	13.7
50.3	13.1	13.3	13.3	13.4	13.4
55.3	12.9	12.8	12.8	12.9	12.8
60.3	12.7	12.5	12.3	12.6	12.6

Average results table

p (cm)	Average q(cm)
15.3	31.1
20.3	24.14
25.3	18.5
30.3	16.48
35.3	14.86
40.3	14.06
45.3	13.66
50.3	13.3
55.3	12.84
60.3	12.54

Analysis –

The formula for the focal length of a lens is:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

This can be rearranged to:

$$f = \frac{pq}{p+q}$$

Therefore if a graph pf pq against p+q was to be plotted the gradient of the graph would equal the focal length of the lens.

Table of pq and p+q

pq (cm)	p+q(cm)
475.83	46.4
490.042	44.44
468.05	43.8
499.344	46.78
524.558	50.16
566.618	54.36
618.798	58.96
668.99	63.6
710.052	68.14
756.162	72.84

Conclusion –

To conclude from my second experiment where I investigated object distance and image distances link to the focal length of a convex lens, I determined the focal length of the lens to be 9.98 cm.

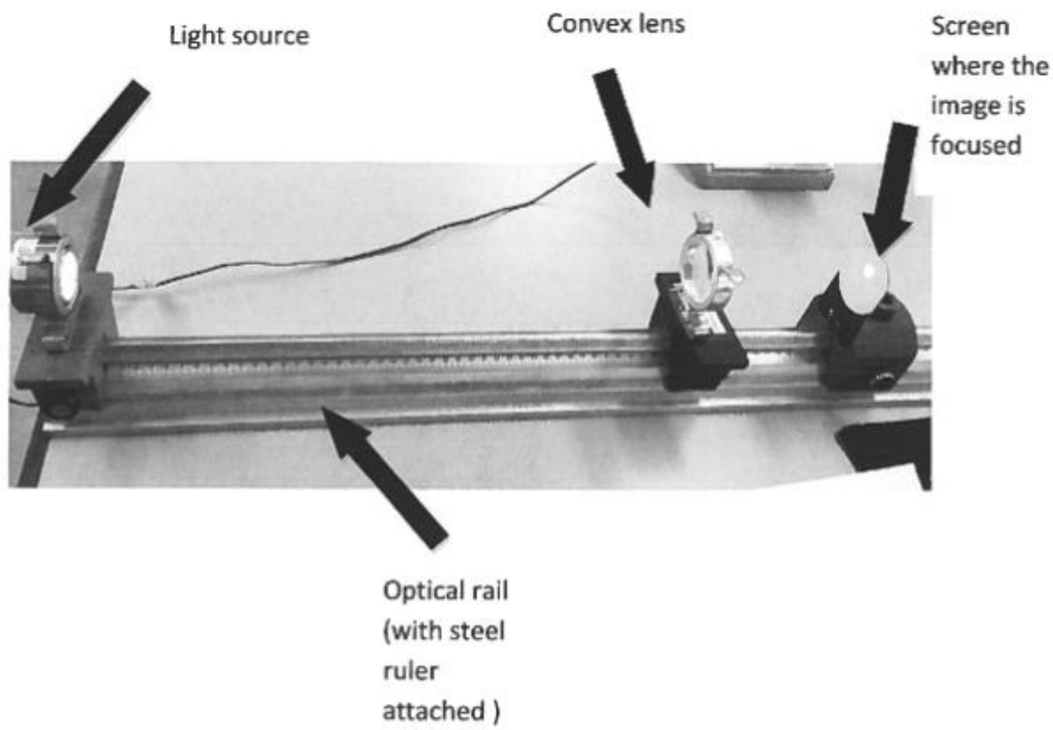
Evaluation –

For experiment 2 the focal length of the same convex lens that was used in experiment 1 was calculated again using a different method. In the first experiment the value of the focal length as calculated as 9.72 cm ±0.04 cm compared to the value given by the gradient of the graph made in experiment 2 which was 9.98 cm. There is a small difference in these two values and I feel this is because of the amount of measurements taken to plot the graph, if I had taken more sets of results the errors would decrease and my results would be closer together.

Experiment 3 – finding the conjugate points and the magnification of the convex lens

Method –

A light source was put at the end of the optical rail and then a screen was inserted roughly 6 focal lengths away from the light source (focal lengths of the convex lens being used in the experiment). Afterwards a convex was inserted approximately halfway between the light source and the screen. Then the lens was moved in the direction of the light source until a clear image is seen on the screen. A record of the distance between the light source and the lens was then taken using the ruler on the side of the optical rail (this distance was recorded as p_1). And a record of the height of the image was taken (this distance was recorded as h_1). The lens was subsequently moved towards the screen until a focused image of the light source is seen on the screen. Then a measurement of the separation between the light source and the lens was taken (this is the value for p_2) and the height of the image produced was recorded (this value is h_2). This experiment was repeated until 5 sets of results were collected.



Results

P_1 (cm)	H_1 (cm)
15.5	10.2
15.4	10.2
15.1	9.8
15.3	10.1
15.6	10.3

P_2(cm)	H_2(cm)
46.8	0.9
46.9	0.9
47.2	0.8
47.2	0.8
47.2	0.8

Averages

P_1= 15.32 cm p_2 = 47.02 cm

H_1= 10.12 cm h_2= 0.84 cm

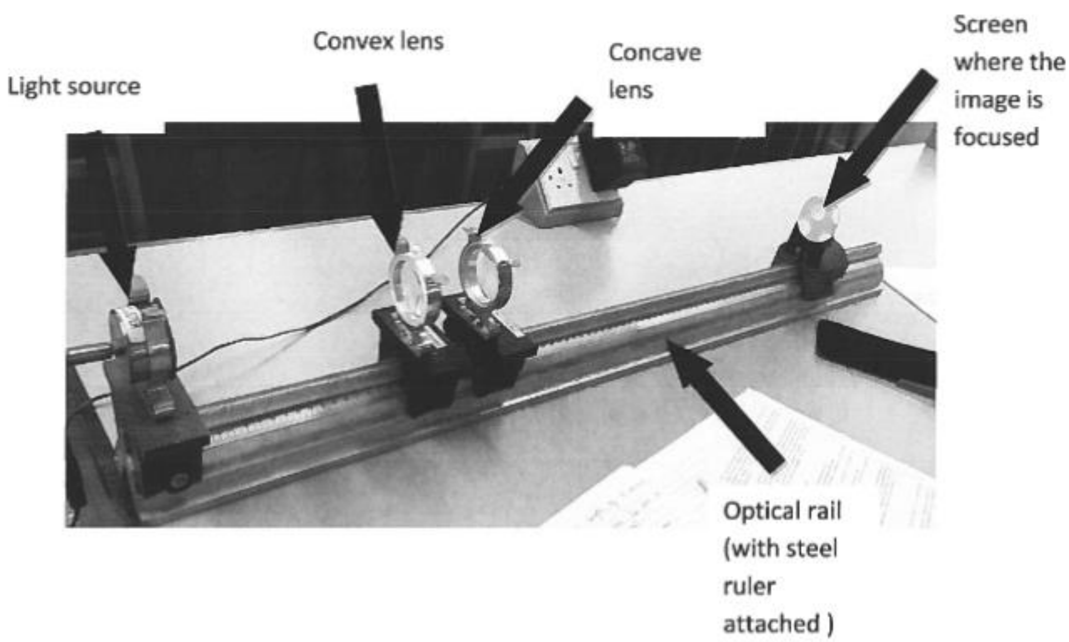
Conclusion –

To conclude for my third experiment I calculated the magnification of a convex lens at its two conjugate points. There were two different calculated values for both magnifications at each conjugate point. For my first method of calculation my results for the magnification for conjugate points 1 and 2 were 3.48 ± 0.1 and 0.29 ±0.01 respectively. My second method of calculation gave the magnification as -2.81 ±0.07 and -0.24 ±0.01 at the first and second conjugate points respectively.

Experiment 4 – Finding the focal length of a concave lens

Method

A light source was positioned on the end of an optical bench, then a convex lens was placed 2 focal lengths away from the light source. Next a screen was put on the optical bench behind the lens and it was moved until the screen until an image of the light source was focused on the screen. A concave lens was then placed 7.5 cm away from the convex lens (in between the convex lens and the screen). The distance between the screen and the concave lens was recorded as the value for p, and it was measure using the steel ruler on the side of the optical bench. Next the screen was moved along the optical bench until the light source was focused on it again. The new distance between the concave lens and the screen was recorded as the value for q. This experiment was repeated until there were 5 sets of results.



Results

P (cm)	Q(cm)
15.5	51.5
15.7	53.5
14.5	52.4
14.1	49.8
14.6	52.4

Averages

Average p = 14.88 cm

Average q= 51.92 cm

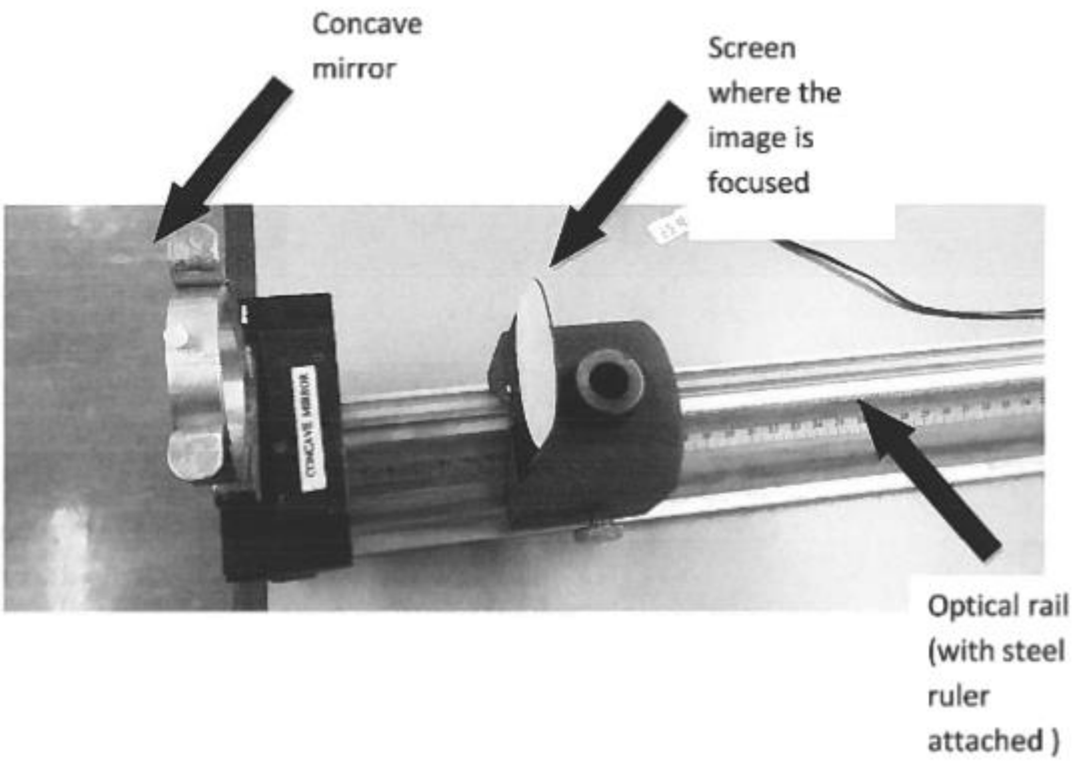
Conclusion –

To conclude in experiment 4 I effectively found the focal length of a concave lens as 11.57 cm ± 0.3 cm.

Experiment 5 – Finding the focal length of a concave mirror.

Method

An optical rail was set up by putting a convex mirror at the end of the rail and placing a screen in the middle of the rail. Then the most distant image possible was focussed on the screen by moving the screen towards the lens. The distance between the mirror and the screen was measured using the steel ruler attached to the optical rail and the value corresponding to the focal length of the mirror. This was repeated this until there were five sets of results.



Results

focal length (cm)
10.3
10.5
10.3
10.2
10.3

Average focal length = 10.32 cm

Conclusion –

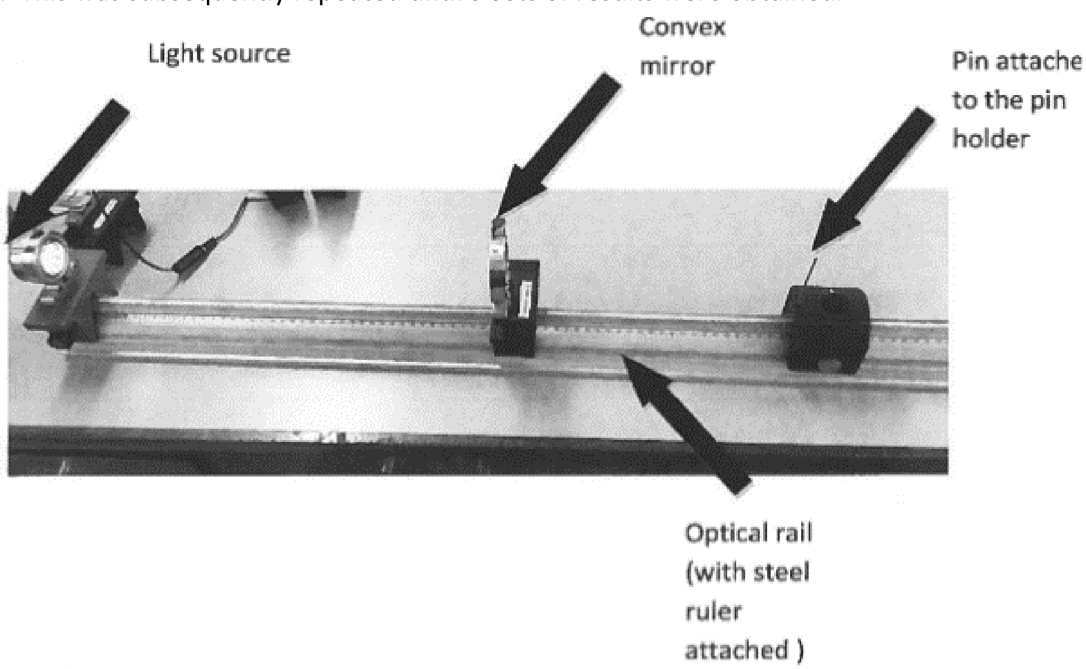
To conclude in experiment five I successfully found the focal length of a concave mirror to be

10.32 cm ± 0.06 cm.

Experiment 6 – Finding the focal length of a convex mirror

Method

A convex mirror was placed on an optical bench 40 cm away from a light source, this distance was recorded as, p and then a pin was positioned behind the mirror. Next whilst looking into the mirror the light source was located along with the pin. Next whilst swaying side to side and looking into the mirror it could be seen that the light source was moving with respect to the pin. The pin was moved further away from the mirror until the image off the light source in the mirror no longer moved with respect to the pin (this is called the point of no parallax), the distance between the mirror and the pin was recorded as distance q. This was subsequently repeated until 5 sets of results were obtained.



Results -

Point of no parallax (cm)
55.6
54.9
56.3
56.2
55.2

Average point of no parallax = 55.64 cm

Conclusion –

To conclude from my final experiment I found the focal length of a convex mirror to be -23.27 cm ± 0.12cm.

Overall Conclusion

To conclude, my investigation aim was to determine the focal lengths of convex and concave lenses and mirrors and to explore some of their properties such as magnification and conjugate points. I feel I have found the focal lengths of the lenses and mirrors considerably accurately due to pretty low absolute errors in my results, although I do not have a reference of their exact focal lengths to compare my values with.

I feel my most successful experiment was my first, finding the focal length of a convex lens. The experiment is easily repeatable and gave the result of 9.72 cm ± 0.04 cm. The inaccuracies in the measurement were very low as there were no problems with the equipment provided and the very small absolute error found was ± 0.41%.

I feel my least successful experiment was finding the magnification of the convex lens at its conjugate points. There was problems with the equipment and the measuring of certain values which would have increased the errors in my calculations. The absolute error for this experiment was ± 2.66% which is a pretty small error, however compared to the success of some of my other results is quite large.

Overall I feel investigation was a success and I believe my results convey this. None of my experiments were failures or had extremely high errors, and all of my experiments could easily be repeated to duplicate similar accurate results.

Bibliography

[1] http://steadyrun.com/differences-and-comparison/difference-comparison-reflection-refraction-light/ , accessed on February 26th 2018

[2] http://www.physicsclassroom.com/class/refrn/Lesson-5/Diverging-Lenses-Ray-Diagrams , accessed on March 27th 2018

[3]https://physics.stackexchange.com/questions/2658/virtual-vs-real-image , accessed on February 26th 2018

[4]http://www.physicsclassroom.com/class/refrn/Lesson-5/The-Mathematics-of-Lenses , accessed on February 26th 2018

[5] https://en.wikipedia.org/wiki/Silvering , accessed on February 26th 2018

[6] http://classnotes.org.in/class-10/light-reflection-and-refraction/images-formed-by-convex-mirror-using-ray-diagram/ , accessed on March 27th 2018