Revision Notes

Light

Experiments

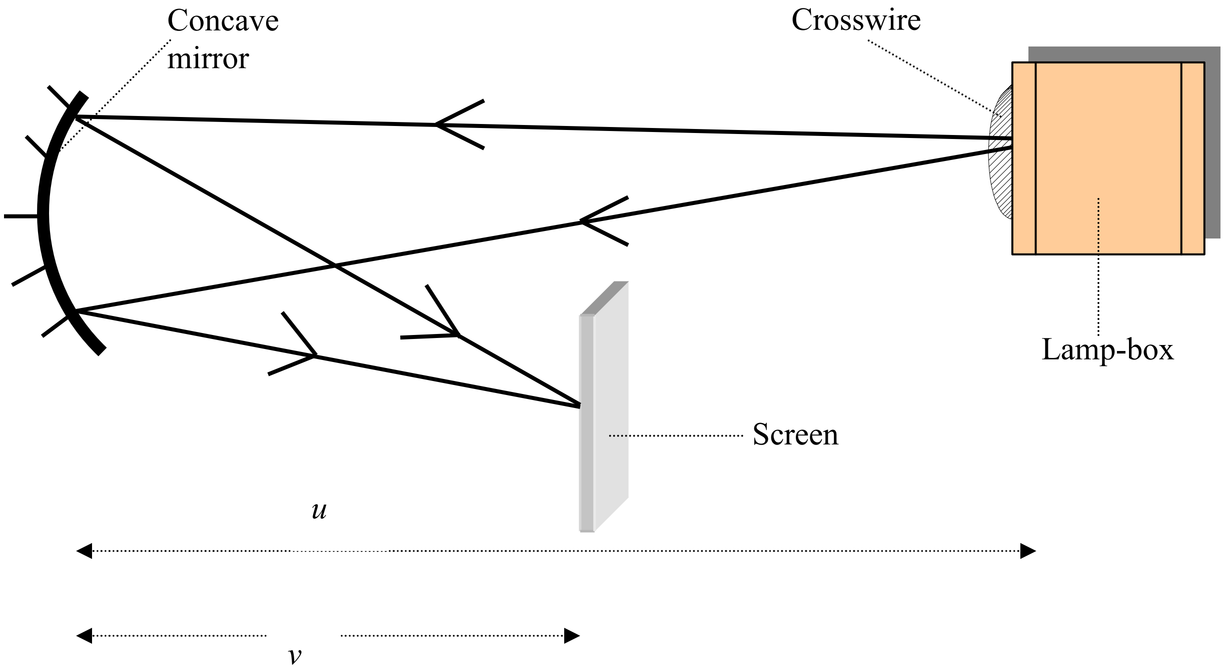
Formulae

Definitions

MEASUREMENT OF THE FOCAL LENGTH OF A CONCAVE MIRROR

Apparatus

Concave mirror, screen, lamp-box with crosswire.



Procedure

1. Place the lamp-box well outside the approximate focal length - see notes.
2. Move the screen until a clear inverted image of the crosswire is obtained.
3. Measure the distance *u* from the crosswire to the mirror, using the metre stick.
4. Measure the distance *v* from the screen to the mirror.
5. Calculate the focal length of the mirror using $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$.
6. Repeat this procedure for different values of *u.*
7. Calculate *f* each time and then find an average value.

Results

u/cm	$\frac{1}{u}$/cm^{-1}	v/cm	$\frac{1}{v}$/cm^{-1}	$\frac{1}{f}$/cm^{-1}	f/cm

Average f =

Notes

The approximate method for finding the focal length is recommended as a starting point for this experiment. The approximate method is described in the Appendix.

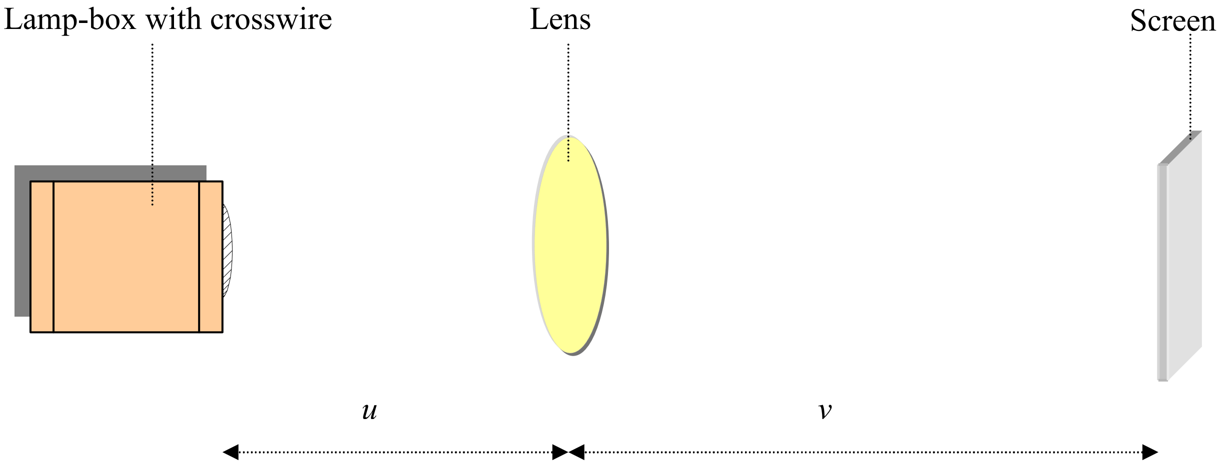
A microscope lamp makes a very suitable strong light source. Cover the glass of the lamp with a piece of tracing paper. Use ‘peel-and-stick’ letters to create an ‘object’ on the tracing paper.

NOTES:

MEASUREMENT OF THE FOCAL LENGTH OF A CONVERGING LENS

Apparatus

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



Procedure

1. Place the lamp-box well outside the approximate focal length – see notes.
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. Calculate the focal length of the lens using $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$.
6. Repeat this procedure for different values of u.
7. Calculate f each time and then find the average value.

Results

u/cm	$\frac{1}{u}$/cm^{-1}	v/cm	$\frac{1}{v}$/cm^{-1}	$\frac{1}{f}$/cm^{-1}	f/cm

Average f =

Notes

The approximate method for finding the focal length is recommended as a starting point for this experiment. The approximate method is described in the Appendix.

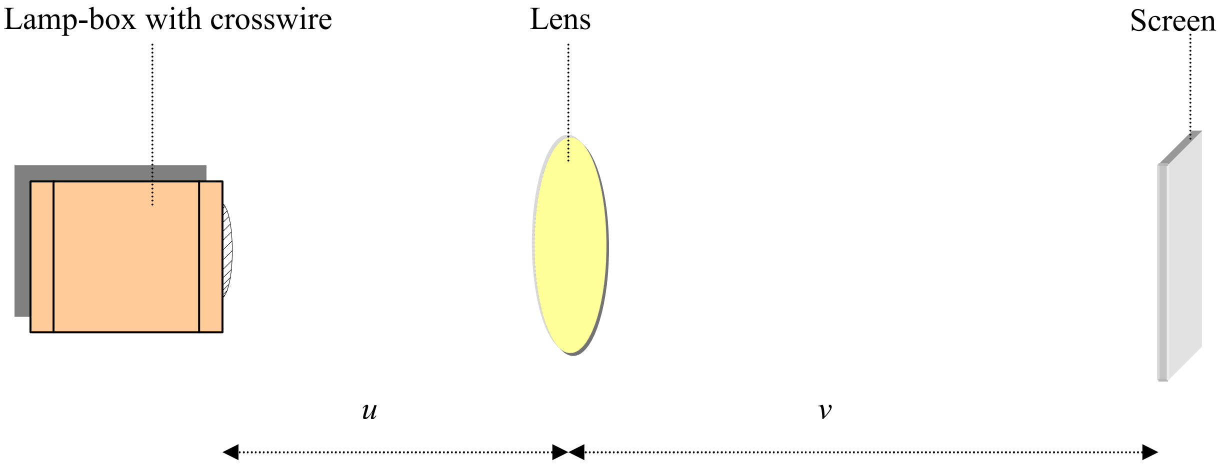
A microscope lamp makes a very suitable strong light source that can be used in daylight. Cover the glass of the lamp with a piece of tracing paper. The tracing paper can be attached with some bluetack. Use ‘peel-and-stick’ letters to create an ‘object’ on the tracing paper. If the ‘object’ is a simple three-letter word then the inversion of the image will be obvious.

NOTES:

MEASUREMENT OF THE FOCAL LENGTH OF A CONVERGING LENS

Apparatus

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



Procedure

4. Place the lamp-box well outside the approximate focal length – see notes.
5. Move the screen until a clear inverted image of the crosswire is obtained.
6. 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. Calculate the focal length of the lens using $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$.
6. Repeat this procedure for different values of *u*.
7. Calculate *f* each time and then find the average value.

Results

u/cm	$\frac{1}{u}$/cm^{-1}	v/cm	$\frac{1}{v}$/cm^{-1}	$\frac{1}{f}$/cm^{-1}	f/cm

Average f =

Notes

The approximate method for finding the focal length is recommended as a starting point for this experiment. The approximate method is described in the Appendix.

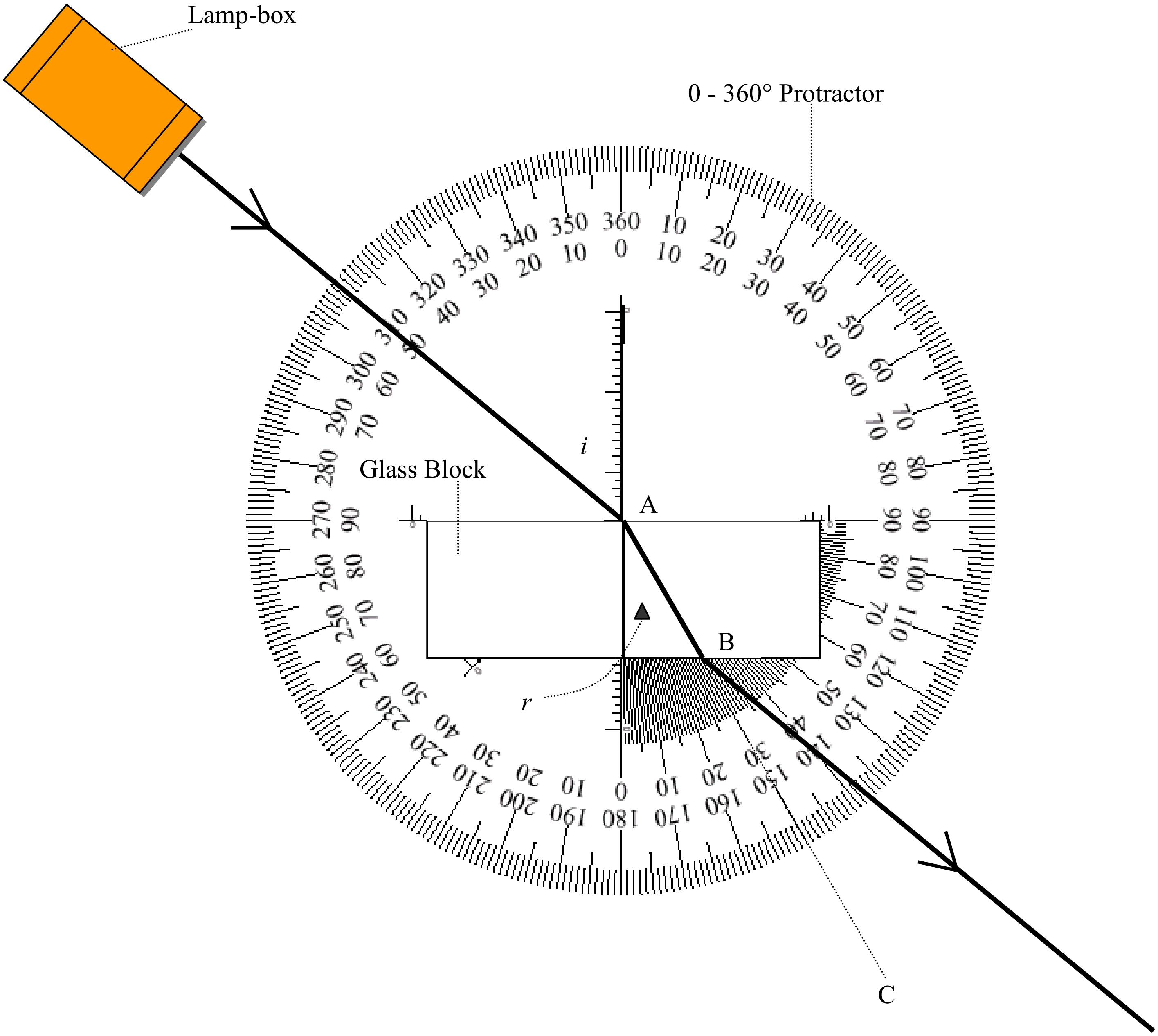
A microscope lamp makes a very suitable strong light source that can be used in daylight. Cover the glass of the lamp with a piece of tracing paper. The tracing paper can be attached with some bluetack. Use ‘peel-and-stick’ letters to create an ‘object’ on the tracing paper. If the ‘object’ is a simple three-letter word then the inversion of the image will be obvious.

NOTES:

VERIFICATION OF SNELL'S LAW OF REFRACTION

Apparatus

Glass block, lamp-box, 0-360^0 protractor, (photocopied from page 56 of Physics A Teacher's Handbook)



Procedure

1. Place a glass block on the 0-360^0 protractor in the position shown on the diagram and mark its outline.
2. Shine a ray of light from a lamp-box at a specified angle to the near side of the block and note the angle of incidence.
3. Observe the ray of light leaving the glass block and similarly mark the exact point B where it leaves the glass block.
4. Remove the glass block. Join BA and extend to C.
5. Note the angle of refraction *r*.
6. Repeat for different values of *i*.
7. Draw up a table as shown.
8. Plot a graph of sin *i* against sin *r*.

Results

i/°	*r*/°	sin *i*	sin *r*	$\frac{\sin i}{\sin r}$

Average value of $\frac{\sin i}{\sin r}$ =

A straight line through the origin verifies Snell's law of refraction i.e. $\sin i \propto \sin r$.

The slope of the line gives a value for the refractive index of glass.

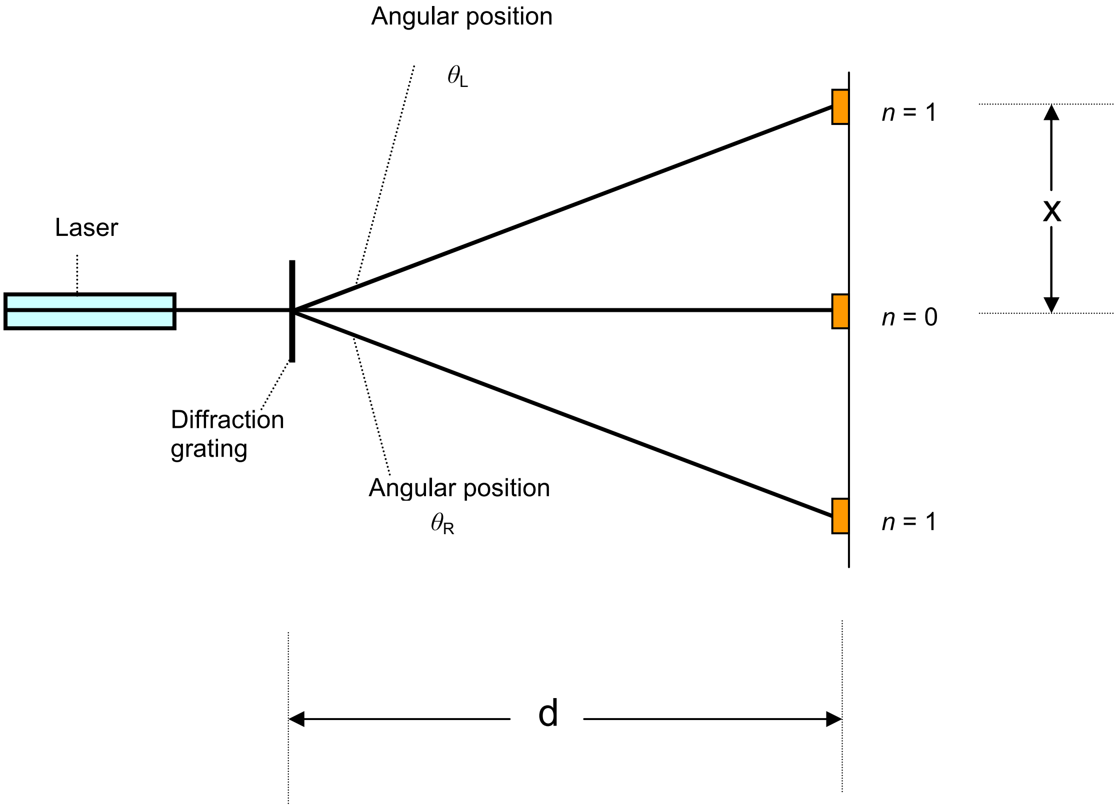
The refractive index of glass is equal to the average value of $\frac{\sin i}{\sin r}$.

Notes

MEASUREMENT OF THE WAVELENGTH OF MONOCHROMATIC LIGHT

Apparatus

Sodium lamp, spectrometer and diffraction grating (300 lines per mm).



Procedure

1. Set up apparatus as in diagram. (Let ***d*** be exactly 1 metre if possible to make calculations simpler later on.)
2. Measure the distance from the zero order image to the first order image to the right. This is $\boldsymbol{x}$.
3. θ_R is calculated from $\theta_R = \tan^{-1}\left(\frac{x}{d}\right)$.
9. Similarly calculate θ_L to the first order image on the left.
10. Calculate θ using $\theta = \frac{\theta_R + \theta_L}{2}$.
11. Calculate the distance s between the slits using $s = \frac{1}{N}$, where N is the number of lines per metre on the grating.

12. Calculate the wavelength λ using $n\lambda = s.\sin\theta$.
13. Repeat this for different orders (n) and get an average value for the wavelength.

Results

n	θ_R/ °	θ_L/ °	$\theta = \frac{\theta_R - \theta_L}{2}$ / °	λ/m

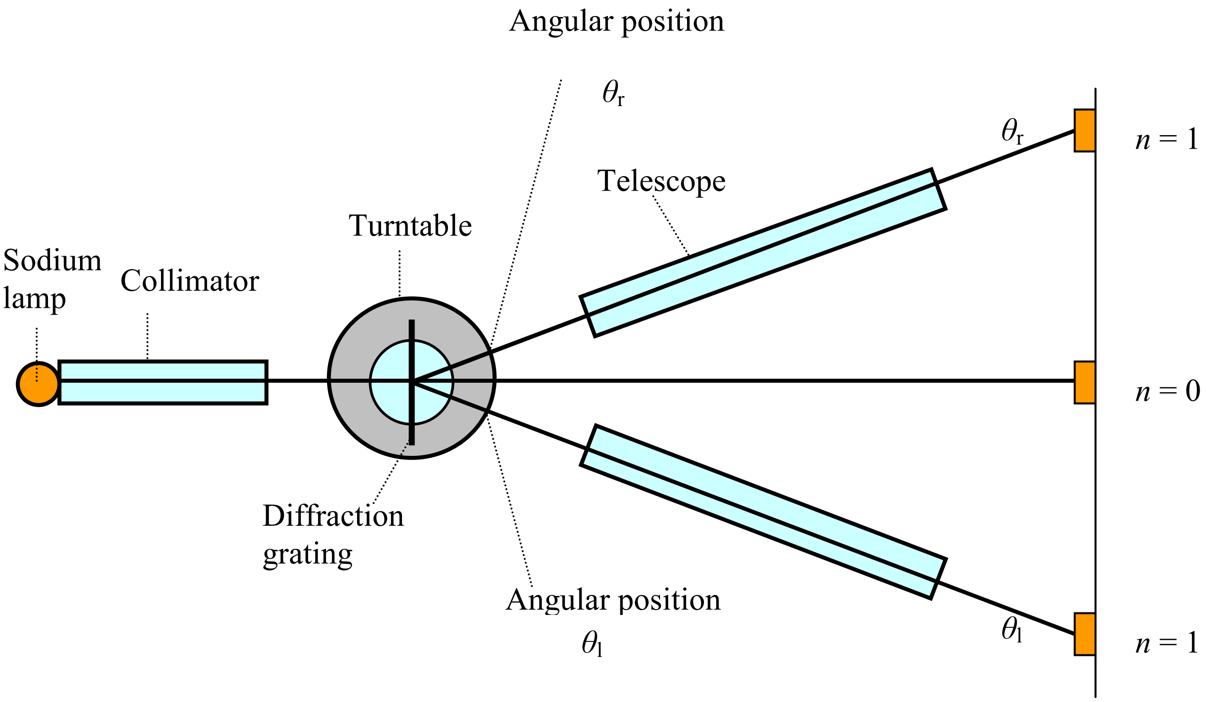
Average λ =

Notes:

MEASUREMENT OF THE WAVELENGTH OF MONOCHROMATIC LIGHT

Apparatus

Sodium lamp, spectrometer and diffraction grating (300 lines per mm).



Procedure

4. Adjust the eyepiece of the telescope so that the crosswires are sharply focused.
5. Focus the telescope for parallel light using a distant object. There should be no parallax between the image seen in the telescope and the crosswires seen through the eyepiece.
6. Place the sodium lamp in front of the collimator.
7. Level the turntable of the spectrometer if necessary.
8. Looking through the telescope, focus the collimator lens and adjust the width of the slit until a clear narrow image is seen.
9. Place the diffraction grating on the turntable at right angles to the beam.
10. Move the telescope to the right until the cross wires are centred on the first bright image. Take the reading θ_r from the scale on the turntable. (To see the scale more easily shine a lamp on it and use a magnifying lens).

11. Move the telescope back through the centre and then to the first bright image on the left.
9. Take the reading θ_l from the scale.
10. Calculate θ using $\theta = \frac{\theta_r - \theta_l}{2}$.
11. Calculate the distance d between the slits using $d = \frac{1}{N}$ where N is the number of lines per metre on the grating.
12. Calculate the wavelength λ using $n\lambda = d \sin\theta$.
13. Repeat this for different orders (n) and get an average value for the wavelength.

Results

n	θ_r/ °	θ_l/ °	$\theta = \frac{\theta_r - \theta_l}{2}$ / °	λ/m

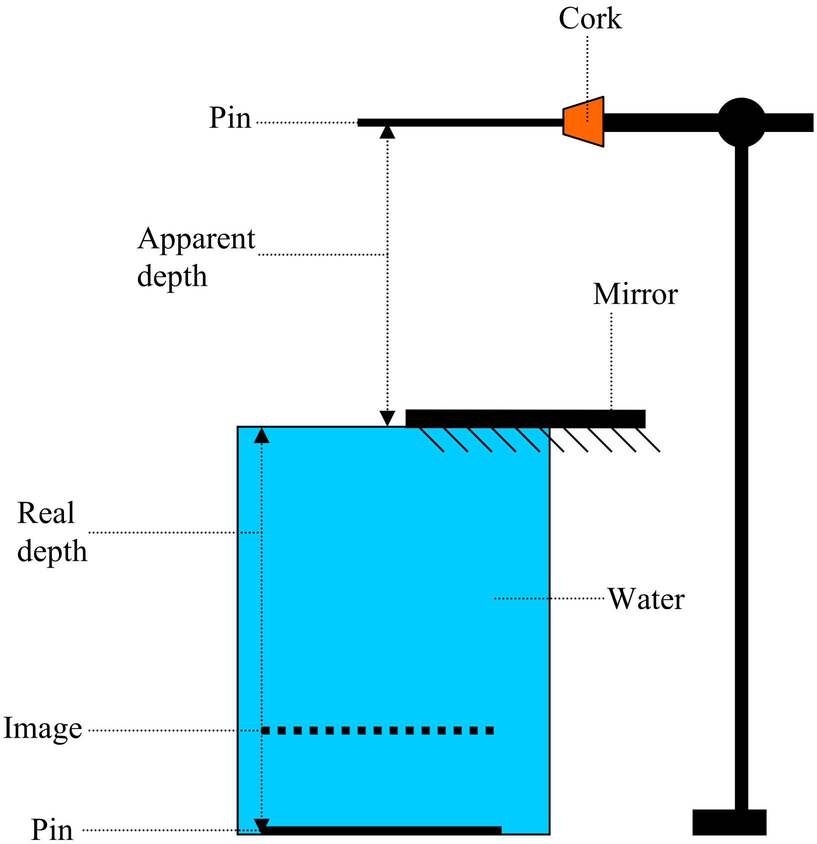
Average λ =

NOTES:

MEASUREMENT OF THE REFRACTIVE INDEX OF A LIQUID

Apparatus

Plane mirror, two pins, cork, retort stand, large containers.



Procedure

1. Fill a container to the top with water.
2. Place the plane mirror to one side on top of the container.
3. Put a pin on the bottom of the container.
4. Adjust the height of the pin in the cork above the mirror until there is no parallax between its image in the mirror and the image of the pin in the water.
5. Measure the distance from the pin in the cork to the back of the mirror – this is the apparent depth.
6. Measure the depth of the container – this is the real depth.

7. Calculate the refractive index, $n = \frac{\text{real depth}}{\text{apparent depth}}$.
8. Repeat using different size containers and get an average value for n.

Results

real depth/cm	apparent depth/cm	$n = \frac{\text{real depth}}{\text{apparent depth}}$

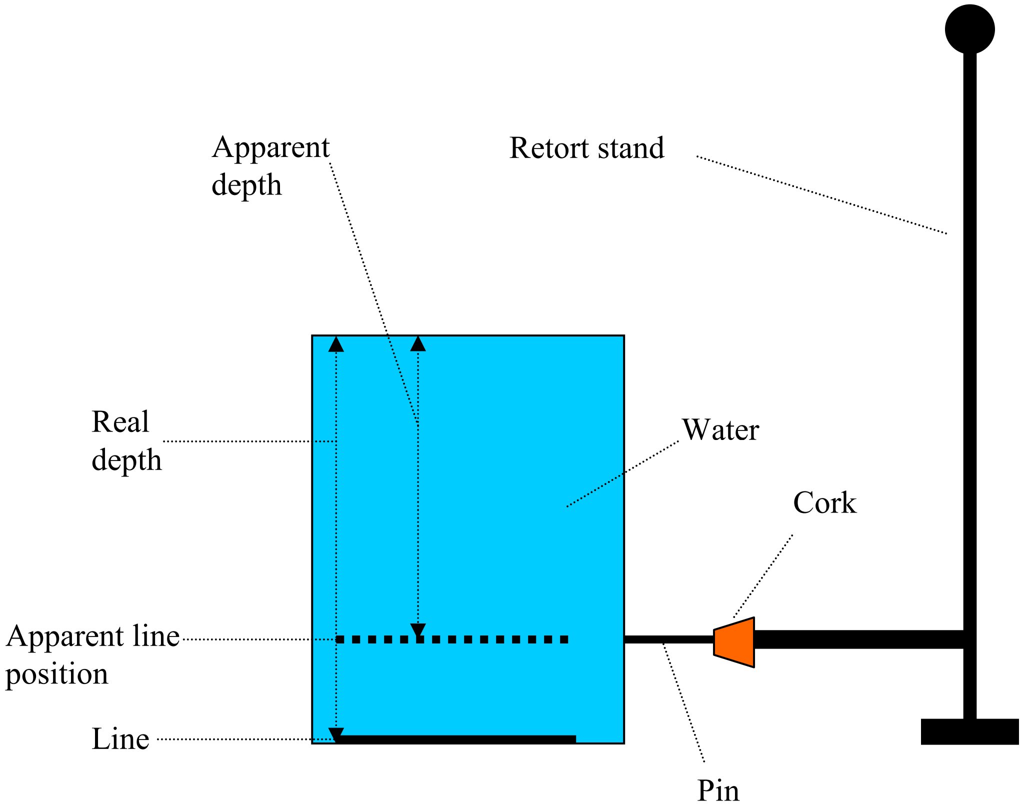
Average n =

NOTES:

MEASUREMENT OF THE REFRACTIVE INDEX OF A SOLID

Apparatus

Glass block, sheet of paper, pin, cork, retort stand, ruler.



Procedure

9. Set up equipment as in diagram.
10. View the line from above, through the block.
11. Adjust the position of the pin in the cork next to the block until there is no parallax between it and the image of the line seen through the block.
12. Measure the distance from the pin to the top of the glass block – this is the apparent depth.
13. Measure the height of the glass block – this is the real depth.
14. Calculate the refractive index, $n = \frac{\text{real depth}}{\text{apparent depth}}$.

15. Repeat using different size glass blocks (make sure they are the same type of glass!) and get an average value for n.

Results

real depth/cm	apparent depth/cm	$n = \dfrac{\text{real depth}}{\text{apparent depth}}$

Average n =

NOTES:

Light – The Laws of Reflection:

Reflection:

Reflection of light is the bouncing of light off an object.

The Laws of Reflection:

1. The incident ray, the normal and the reflected ray are all on the same plane.
2. The angle of incidence is equal to the angle of reflection.

The Laws of Refraction:

Refraction:

Refraction is the bending of light as it passes from one medium to another.

The Laws of Refraction:

1. The incident ray, the refracted ray and the normal are all on the same plane.
2. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for any two media. **This is Snell's Law.**

Refractive Index:

The refractive index of a medium is the ratio of the sine of the angle of incidence to the sine of the angle of refraction, when light enters the medium from a vacuum.

Total Internal Reflection:

Critical Angle (c):

The critical angle is the angle of incidence which corresponds to an angle of refraction of 90° for any given medium.

Total Internal Reflection:

When light is travelling from a dense to a rarer medium, and it strikes a boundary at an angle greater than the critical angle, all the light is reflected back into the denser medium, this is known as total internal reflection.

Diffraction and Interference of Light:

Diffraction:

Diffraction is the spreading out of waves as they pass through a gap or around an obstacle.

Polarisation of Light:

Polarisation of Light:

Polarised light is light which vibrates in one plane only.

Dispersion of Light:

Dispersion:

Dispersion is the splitting up of white light into its constituent colours; red, orange, yellow, green, blue, indigo, violet. (**Richard Of York Gave Battle In Vein**.)

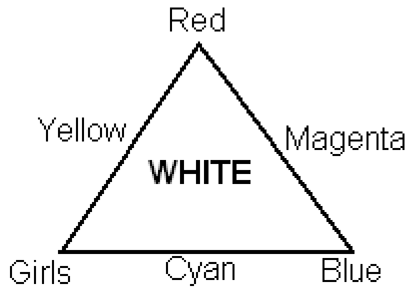
Colours:

Primary Colours:

The primary colours of light are red, blue and green. Any other colours can be made by combining these. If they are mixed equally they produce white light.

Secondary Colours:

The secondary colours are made by mixing two primary colours equally. The secondary colours are cyan (turquoise), magenta and yellow..



Richard **M**y **B**rother **C**alls **G**irls **Y**oung **W**omen.

Complimentary Colours:

Complimentary colours are a primary colour and a secondary colour which mix together to form white light.

Mathematical Problems

Introduction:

In this section of the booklet, we examine the formulas and the mathematical problems on the physics course. Each formula will be dealt with in turn. The formula will be shown, followed by what each part of the formula means, a worked example will follow that and finally a few mathematical problems some of which are from the Leaving Certificate past papers. You do not need to be a great mathematics student to solve these problems as you will be mainly multiplying and dividing. The ability to manipulate a formula will be of great help. The formulas are given to the students for ordinary level but you will still need to know how to use them.

UNIT 1 – Waves and Optics

Velocity of a wave: $c = f\lambda$

Where c *= the speed of the wave,* f *= the frequency and* λ *= the wavelength in m*

Example: *Water waves of frequency 0.5 Hz have a wavelength of 6 m. What is their speed?*

Solution: frequency = f = 0.5 Hz wavelength = λ = 6 m

$$c = f\lambda$$

$$c = (0.5)(6)$$

$$c = 3\ \text{ms}^{-1}$$

1. Sound waves have wavelength 2 m and have frequency of 170 Hz. What is the speed of sound?
2. Calculate the wavelength of a sound wave whose frequency is 512 Hz, if the wave travels as 340 m s^{-1}
3. 61 consecutive crests of water pass a point in ½ of a minute. What is the frequency of the wave?
4. The wavelength of sound emitted from a whistle is 3 m and the speed of sound in air is 340 m s^{-1}. Find the frequency of the sound waves.
5. The wavelength of visible light varies from 3.7×10^{-7} m to 7.0×10^{-7} m. Find the highest frequency an electromagnetic wave can have and still be 'visible'. Take the speed of light to be 3×10^{8} m s^{-1}.
6. A stationary wave is set up between a loud-speaker, which is emitting a note of 2000 Hz, and a wall. If the distance between the first and the eleventh nodes is 85 cm, calculate the velocity of the sound.

The Doppler Effect:

Approaching observer: $f' = \dfrac{fc}{c-u}$ *Moving away from observer:* $f' = \dfrac{fc}{c+u}$

Where c = the speed of the wave; f = the actual frequency; f' = the apparent frequency; u = the speed of the source

Example: *A police car travelling at 30 m s^{-1} passes a stationary observer. Its siren emits a note of frequency 1 kHz. If the velocity of sound is 336 m s^{-1}, what is the frequency heard by the observer when the car is (i) approaching the observer (ii) moving away from the observer?*

Solution: f = 1000 Hz u = 30 m s^{-1} c = 336 m s^{-1} *f'* = ?

(i) When car is approaching: $f' = \dfrac{fc}{c-u} = \dfrac{(1000)(336)}{336-30} = 1098\ \text{Hz}$

(ii) When car is moving away: $f' = \dfrac{fc}{c+u} = \dfrac{(1000)(336)}{336+30} = 918\ \text{Hz}$

1. A source of sound of frequency 4 kHz is approaching an observer at 30 m s^{-1}. If the velocity of sound is 340 m s^{-1}, what is the frequency detected by the observer?

2. A source of sound of frequency 2 kHz is moving away from an observer at 40 m s^{-1}. If the velocity of sound is 340 m s^{-1}, what is the frequency detected by the observer?

3. A whistle which is emitting a note of 1 kHz is whirled in a horizontal circle on the end of a string 1.2 m long at constant angular velocity of 50 rad s^{-1}. What are the highest and lowest frequencies heard by a person standing some distance away (speed of sound = 340 m s^{-1})?

4. A source of sound of constant pitch moves away from a stationary observer. The observed frequency is 10% lower than that from the source when it is not moving. If the speed of sound in air is 340 m s^{-1}, find the speed of the source.

5. Bats use high frequency waves to detect obstacles. A bat emits a wave of frequency 68 kHz and wavelength 5.0 mm towards the wall of a cave. It detects the reflected wave 20 ms later. Calculate the speed of the wave an the distance of the bat to the wall. If the frequency of the reflected wave is 70 kHz, what is the speed of the bat towards the wall?

6. The red line emitted by a hydrogen discharge tube in the laboratory has a wavelength of 656 nm. The same red line in the hydrogen spectrum of a moving star has a wavelength of 720 nm. Is the star approaching the earth? Justify your answer. Calculate (i) the frequency of the red line in the stars spectrum and (ii) the speed of the moving star.

The Fundamental Frequency of a Stretched String:

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

Where f = the frequency; l = the length of the string; T = the tension; and μ = the mass per unit length of the string

Example: *A wire of length 3 m and mass 0.6 kg is stretched between two points so that the tension of the wire is 200 N. calculate the fundamental frequency of the vibration*

Solution: f =? l = 3 m T = 200 N $\mu = \frac{\text{mass}}{\text{length}} = \frac{0.6}{3} = 0.2 \text{ kg m}^{-1}$

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}} = \frac{1}{(2)(3)}\sqrt{\frac{200}{0.2}} = 5.27 \text{ Hz}$$

1. A string of mass per unit length 0.04 kg m^{-1} and length 0.8 m is placed under a tension of 200 N. Calculate its fundamental frequency of vibration.

2. A string on a guitar is vibrating at its fundamental frequency of 500 Hz. Its length is 0.6 m and its mass per unit length is 0.02 kg m^{-1}. Calculate the tension in the string.

3. A wire of length 4 m and mass 0.04 kg is stretched between two points so that the tension in the wire is 400 N. Calculate its fundamental frequency of vibration.

4. A string on a guitar gives out a note of a certain frequency. By how much must the tension in the string be increased if it is to give out a note of twice the frequency, its length remaining the same?

5. When the tension in a stretched string is 40 N, its fundamental frequency is 260 Hz. Find its fundamental frequency if its tension is increased to (i) 160 N, (ii) 200 N.

For mirrors:
v is + for a real image
v is − for a virtual image
f is + for a concave mirror
f is − for a convex mirror

For lenses:
v is + for a real image
v is − for a virtual image
f is + for a convex lens
f is − for a concave lens

The Mirror and Lens Formula:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Where f = the focal length; u = the object distance;
v = the image distance

Magnification formula:

$$\text{Magnification} = \frac{\text{Image distance (or height)}}{\text{Object distance (or height)}} \quad \text{i.e.} \quad m = \frac{v}{u}$$

Lens Power Formula:

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

Two lenses in contact:

$$P = P_1 + P_2$$

Example: *An image which is four times the size of an object is formed in a convex lens of focal length 30 cm. where must an object be placed if:*

(i). the image is real,
(ii). the image is virtual?

Solution: Magnification $m = \frac{v}{u} = 4 \Rightarrow v = 4u$

Real Image

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{4u} \Rightarrow \frac{5}{4u} = \frac{1}{30} \Rightarrow u = 37.5\,\text{cm}$$

Virtual Image

$$\frac{1}{f} = \frac{1}{u} - \frac{1}{v} \Rightarrow \frac{1}{f} = \frac{1}{u} - \frac{1}{4u} \Rightarrow \frac{3}{4u} = \frac{1}{30} \Rightarrow u = 22.5\,\text{cm}$$

1. A dentist holds a concave mirror of focal length 25 mm at a distance of 20 mm from a cavity in a tooth. Find the position of the image of the cavity. What is the magnification of this image?

2. An object O is placed 30 cm in front of a concave mirror of focal length 10 cm. How far from the mirror is the image formed?

3. The 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.

4. The power of an eye when looking at an object should be 60 m^{-1}. A person with defective vision has a minimum power of 64 m^{-1}. Calculate the focal length of the lens required to correct this defect. What type of lens is used?

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

6. The power of a normal eye is +60 m^{-1}. A short sighted person's eye has a power of +65 m^{-1}. Calculate (i) the power, (ii) the focal length, of the contact lens required to correct the person's short-sightedness.

Refractive Index (n):

$$n = \frac{\sin i}{\sin r} \qquad n = \frac{\text{real depth}}{\text{apparant depth}}$$

$$n = \frac{1}{\sin C} \qquad n = \frac{c_1}{c_2}$$

n = refractive index; i = angle of incidence; r = angle of refraction; C = critical angle; c_1 = speed of light in medium 1; c_2 = speed of light in medium 2.

Example: *A block of glass of thickness 4 cm is placed on top of a mark on the bench. When the mark is viewed perpendicularly through the glass a virtual image of it appears 2.67 cm from the top of the block. Find the refractive index of the glass.*

Solution:

$$n = \frac{\text{Real depth}}{\text{Apparent depth}} = \frac{4}{2.67} = 1.5$$

1. An optical fibre has a refractive index of 1.5. Calculate the speed of light travelling through the optical fibre.
   (speed of light in air = 3.0 × 10^8 m s^{-1})

2. A ray of light enters glass from water. The angle of incidence is 60° and the angle of refraction is 52°. Calculate the refractive index between water and glass.

3. A ray of light enters glass from air. The refractive index of glass is 1.5 and the angle of incidence is 25°. Calculate the angle of refraction.

4. ${}_{\text{air}}n_{\text{water}} = 4/3$. The speed of light in air is 3×10^8 m s^{-1}. Calculate the speed of light in water.

5. The speed of light in water is 2.3×10^8 m s^{-1}. The speed of light in air is 3×10^8 m s^{-1}. Calculate the refractive index of water.

6. A point source is at the bottom of a pool of still water. Light from the source enters the air through a circle of radius 4 m at the surface of the pool. If the refractive index of water is 1.33, find the depth of the pool.

Diffraction Grating:

$$n\lambda = d\sin\theta$$

Where: n = the order of the image (1st, 2nd, etc…); λ = wavelength of light; d = the distance between the slits; θ = the angle where the bright fringe occurs.

Example: *A diffraction grating has 350 lines per mm ruled on it. Monochromatic light of wavelength 5.2×10^{-7} m is incident normally on it. What is the highest order diffraction image formed?*

Solution: $n\lambda = d\sin\theta$. Maximum value of n occurs when $Sin\theta$ is a maximum, i.e. when $\sin\theta = 1$

$$\Rightarrow \quad n_{\max} \;=\; \frac{d}{\lambda} \qquad\qquad d = \frac{1}{350}\,\text{mm} \;=\; 2.857\times10^{-6}\,m$$

$$\Rightarrow \quad n_{\max} \;=\; \frac{\left(2.857\times10^{-6}\right)}{\left(5.2\times10^{-7}\right)} \;=\; 5.49$$

The maximum value for *n* is 5 (must be whole number). The 5th order image is the highest.

1. A fine diffraction grating has 500 lines per mm ruled on it. Find the value of the grating constant.

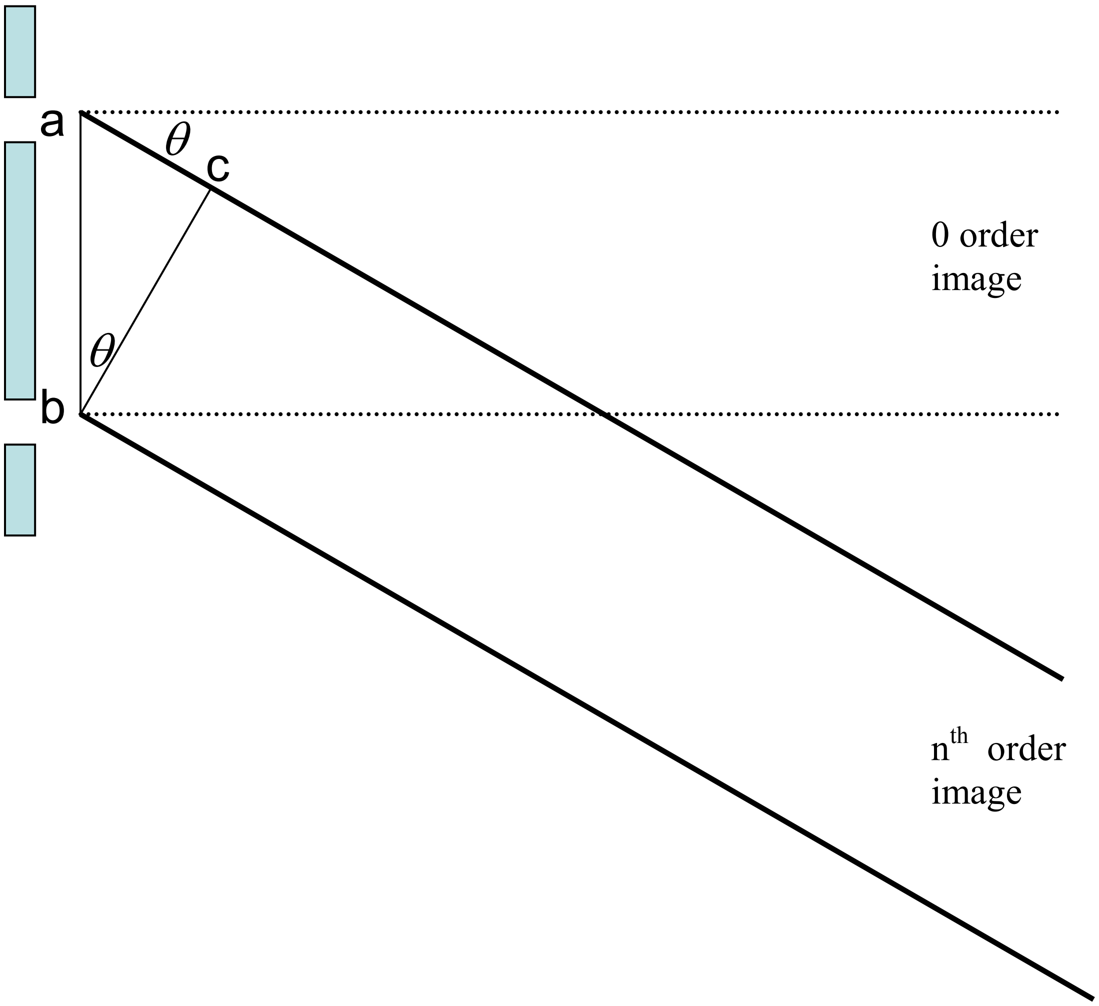
2. Monochromatic light falls normally (i.e. at right angles to) a diffraction grating. The grating has 800 lines per mm engraved on it and the first order image is at an angle of 30º from the straight through position. That is the wavelength of the light?

3. When a parallel grating beam of monochromatic light is incident normally on a diffraction grating having 400 lines per mm on it, the angle between the 2nd order image and the normal to the grating is 31º. What is the wavelength of the light?

4. A beam of monochromatic light of wavelength 5×10^{-7} m is incident normally on a diffraction grating that has 600 lines per mm ruled on it. A screen is placed 0.4 m from the grating. Find the distance of the second order image from the central image.

5. A diffraction grating has 400 lines per mm ruled on it. Monochromatic light of wavelength 6.2×10^{-7} m is incident normally on it. What is the highest order diffracted image formed?

The Grating Equation



$|ac|$ *is the path difference for waves from **a** to **b** diffracted at an angle* θ *to the central bright fringe (the zero order image.)*

If $|ac|$ *is a whole number of wavelengths, then constructive interference will result.*

$\Rightarrow |ac| = n\lambda$, where $n \in N_0$

but

$$\sin\theta = \frac{|ac|}{|ab|}$$

And $|ac| = |ab|\sin\theta$

However, $|ab| = d$, the distance between the slits

$\Rightarrow |ac| = n\lambda = d\sin\theta$

$$\boxed{\therefore n\lambda = d\sin\theta}$$

This is the condition necessary for image generation by constructive interference