Name: _____ Class: _____ Date: _____

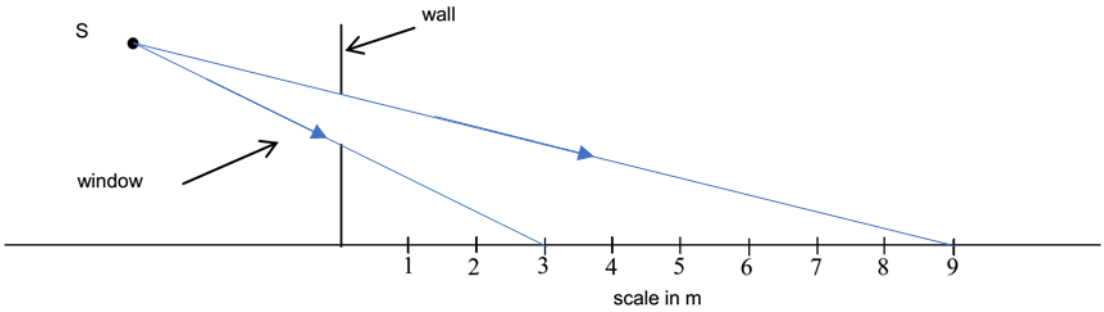
Sec 3 Physics

Worksheet 3: Reflection, refraction and lenses (answers)

Reflection

1 The diagram, drawn to scale, shows a very small bright light at S shining into a darkened room through a window set in a vertical wall. A scale is marked in metres on the floor as shown.

a **(i)** Draw **two** rays to show the limits of the bright patch on the scale, and measure the length of the scale that is illustrated. [1]

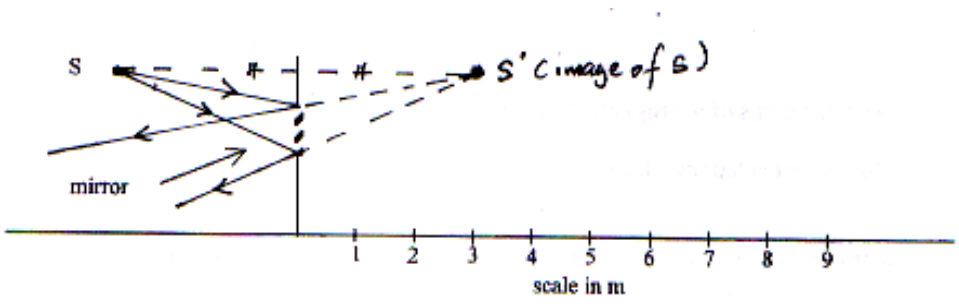


Length of bright patch = 6 m [1]

(ii) Which property of light rays does this example demonstrate?

Light rays travel in straight line. [1]

b The window is now covered with a plane mirror as shown below.



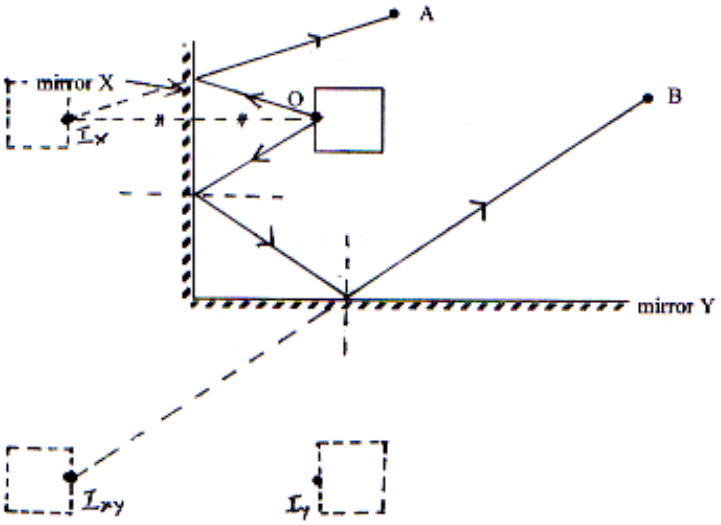
(i) Show how two rays from S are reflected by the mirror and use them to locate the image of S.

Mark clearly the position of the image of S. [2]

(ii) Write down **one** characteristic of this image.

Image is virtual / laterally inverted / same size as the object / upright. [1]

2 The diagram shows two mirrors X and Y, and a solid object with a coloured spot at O, the centre of its left hand face.

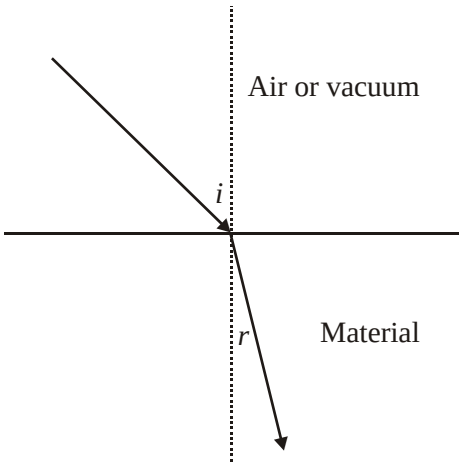


a An eye at A sees an image of O resulting from the reflection at the mirror X. Mark **I**, the position of this image, and draw a ray from O to the eye at A. [1]

b When the eye is moved to B, it sees an image of O resulting from reflections at *both mirrors*. Draw a ray of light from O which enables the eye at B to see this image. [2]

Refraction

3 **a** With the aid of a suitable diagram define the term refractive index as applied to an optical material.

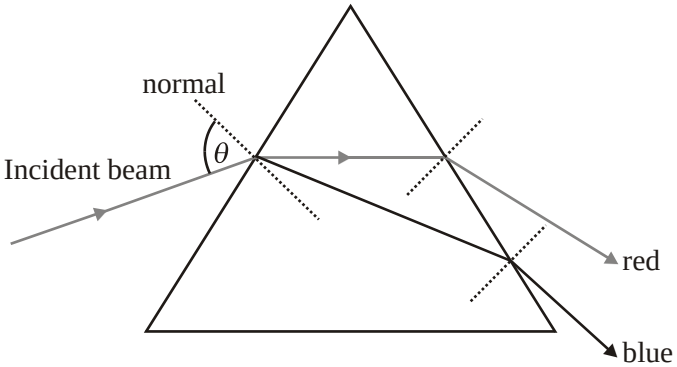


definition consistent with diagram $n = \frac{\sin i}{\sin r}$;

with i in air or vacuum;

[2]

The diagram below shows the path followed by a ray of red light that is incident on one face of a glass prism at an angle θ to the normal.



Marking points:
- refraction at first surface;
- refraction at emergent surface;
- deviation greater than red light;

If the refractions are correct but the angle of refraction is less than that for red light award **[2]**.

b **(i)** The red light is now replaced by blue light. On the diagram sketch the corresponding path followed by a ray of blue light incident at the same angle θ. [3]

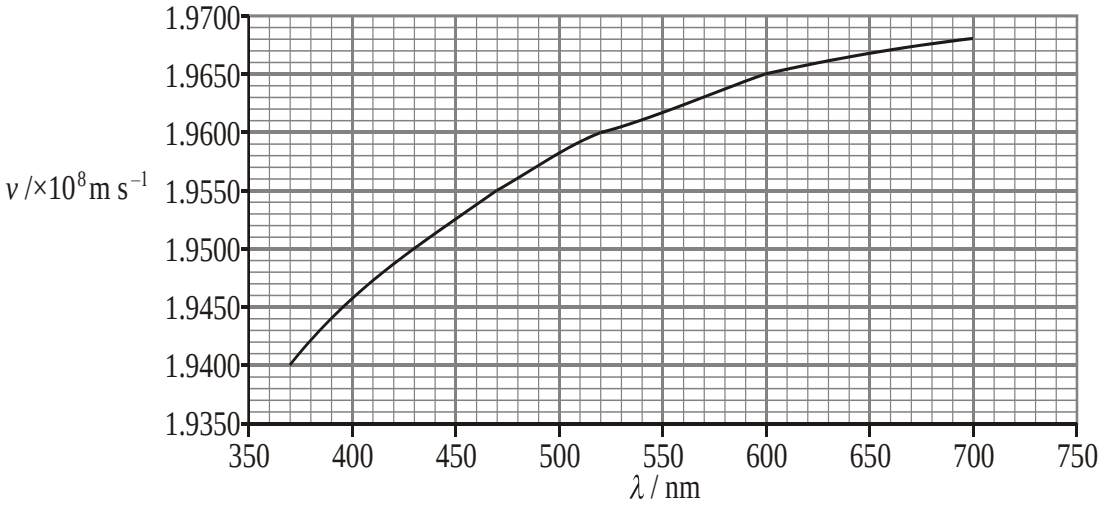
(ii) State and explain whether the refractive index for red light in the glass is greater than, equal to or less than the refractive index for blue light.

less — refraction angle is greater therefore sin i / sin r is smaller;

[1]

4 This question is about optical dispersion.

The graph below shows the variation with wavelength λ of the speed v of light in one type of glass.



a Use data from the graph to determine, to the correct number of significant digits, the refractive index for blue light of wavelength 400 nm in this type of glass.

(free space speed of light c = 2.9979 × 10^8 m s^{-1})

for blue, from the graph v =1.9455 (±0.0005) × 10^8 m s–1;

$$n = \frac{c}{v} = \frac{2.9979}{1.9455} = 1.5409\ (\pm 0.0005)$$

[2]

b The refractive index of red light of wavelength 650 nm in this type of glass is about 1.52. Use this fact and your answer in (a) to explain optical dispersion.

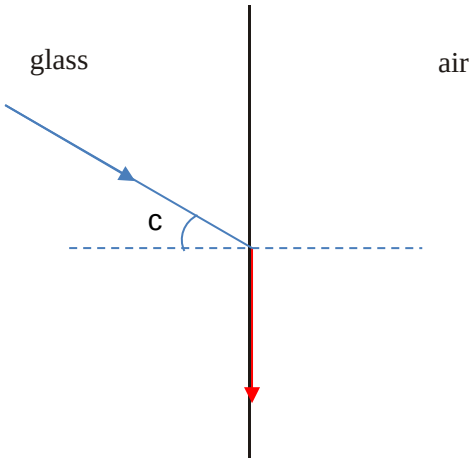
white light contains light of different wavelengths;
each wavelength is deviated by a different amount as it passes through the prism / the refractive index of the prism is dependent on the wavelength / *OWTTE*;

the refractive index is larger for blue light, therefore the refractive angle is smaller;
and so blue light is bent more towards the normal / *OWTTE*;

Alternatively, the response may use the aid of a diagram. [2]

5 This question is about refractive index and critical angle.

The diagram below shows the boundary between glass and air.

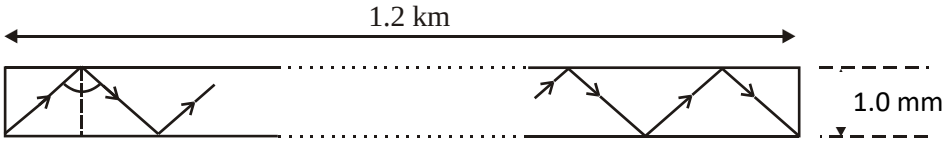


a On the diagram, draw a ray of light to illustrate what is meant by critical angle. Mark the critical angle with the letter "c". [3]

Marking points:

light incident from glass;
emergent ray along boundary;
c marked correctly;

A straight optic fibre has length 1.2 km and diameter 1.0 mm. Light is reflected along the fibre as shown below.



At each reflection, the angle of incidence is equal in value to the critical angle. The refractive index of the glass of the fibre is 1.5.

b Deduce that the length of the light path along the optic fibre is about 1.8 km.

$\sin c = \frac{1}{1.5}$;
for every 1.0 mm length, light travels 1.5 mm;
path length = 1.2 km × 1.5
= 1.8 km;

Award [4] for any correct calculation that leads to 1.8 km.

The speed of light in the fibre is 2.0×10^8 m s^{-1}.

c Calculate the time for a pulse of light to travel the length of the fibre when its path is

(i) along the axis of the fibre.

time = $\frac{1200}{2.0 \times 10^8}$ = 6.0 μs;

[1]

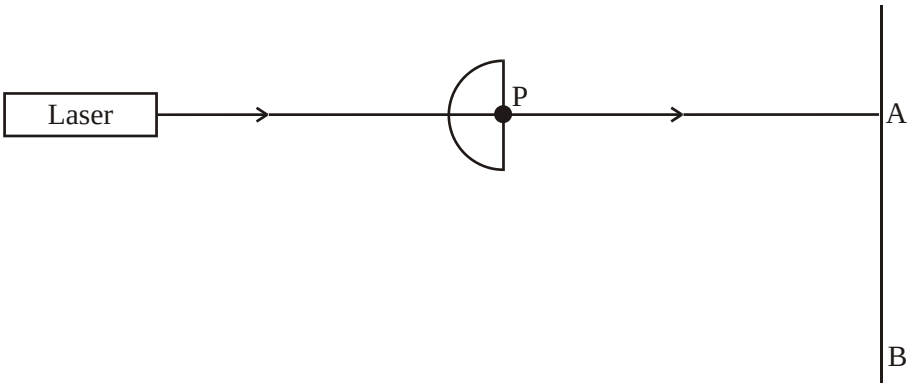
(ii) as calculated in (b).

time = 9.0 μs;

[1]

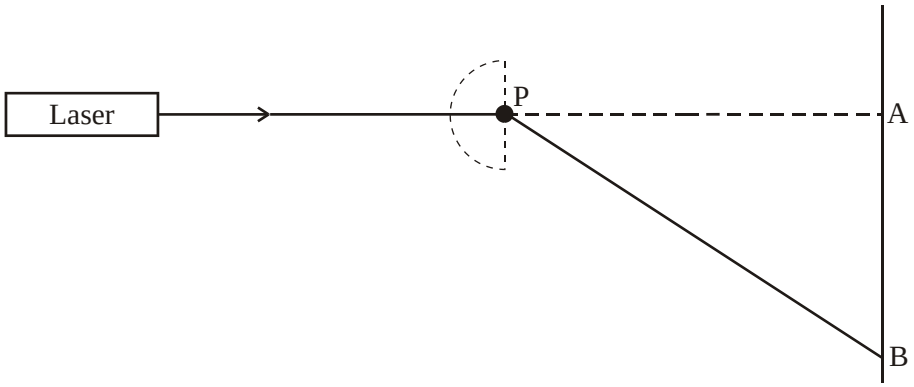
6 This question is about refractive index.

Light from a laser is directed at a semi-circular glass block. The light passes undeviated through the block and on to a screen, forming a spot at A as shown.



The semi-circular block is rotated about the point P. The spot of light on the screen is seen to move downwards. When the spot reaches point B, it disappears.

a Complete the diagram below to show the position of the semi-circular block when the spot is at point B. The original position of the block is shown as a dotted line.



Marking point: diagram showing ray emerging along flat face; [1]

In a particular experiment, the distance PA is 120 cm and distance AB is 138 cm.

b Calculate the refractive index of the glass of the block.

$\tan\theta = \frac{138}{120}$, θ = 49.0°;
critical angle = 41.0°;
$n = \frac{1}{\sin c} = 1.52$; (allow ecf if sensible) 3

Award [1 max] if the critical angle is = 49.0° or (answer $n = \frac{1}{\sin c} = 1.33$). [3]

The laser is changed for one emitting light of higher frequency. The experiment is then repeated.

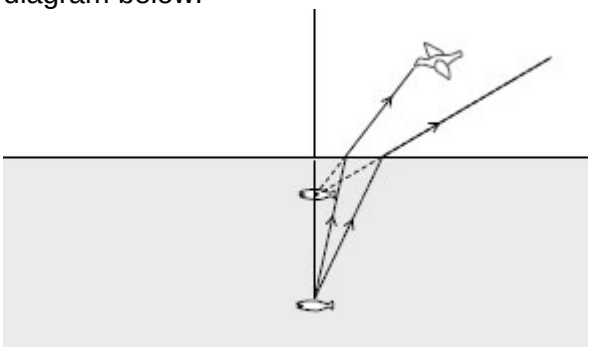
c State and explain whether the distance AB will be greater or less than 138 cm.

n is greater at higher frequency

so *C* is smaller;

hence AB is larger; [3]

7 A bird is hovering above a pond. A fish is in the pond at the position shown in the diagram below.



one ray from fish with correct refraction;

2nd ray from fish with correct refraction;

rays backward to give correct position of image;

since no numerical values are given. A quantitative solution is asked for in part (a)(iii).

a Draw rays on the diagram above to locate the position of the image of the fish as seen by the bird. [3]

b Explain whether the image of the fish is real or virtual.

virtual since extension of rays gives its position / appear to come from fish / *OWTTE*;

[1]

c The fish is 48 cm below the surface of the pond. The bird hovers vertically above the fish. Calculate the apparent depth of the fish. The refractive index of water is 1.3.

$n = \frac{\text{real depth}}{\text{apparent depth}}$;

$\text{apparent depth} = \frac{48}{1.3} = 37 \text{ cm}$; [2]

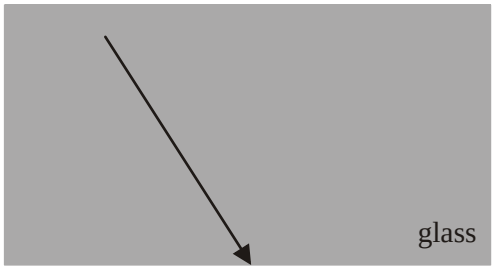
8 This question is about dispersion and refractive index.

a State and explain what is meant by the dispersion of white light.

splitting / separation (of white light) into its component colours;

because different frequencies have different refractive indices; [2]

b A narrow beam of light is incident from glass on a boundary between glass and air as shown below.



The beam consists of a mixture of red and blue light.

(i) On the diagram above, draw labelled rays to show the path of the red and blue light in air. [2]

Marking point:

both bending away from the normal;
blue greater deviation than red;

(ii) The refractive index of glass for the red light is 1.52. Calculate the maximum angle of incidence on the glass air boundary for the red light to pass into the air.

recognize maximum angle = critical angle, $\sin c = \frac{1}{n}$;

$c = \sin^{-1}\frac{1}{n} = 41.1^\circ$ [2]

(iii) Explain whether the blue light would pass into the air for the angle calculated in (ii).

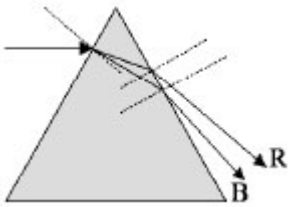
the blue light would not pass into the air;

the refractive index for blue light is greater implies critical angle is smaller;

*Award **[0]** for wrong explanation or no explanation* [2]

9 This question is about refraction and dispersion.

a A thin beam of white light is incident on one surface of a glass prism as shown below.



Marking points:

bends towards the normal at first surface;
away from normal at second;
blue is deviated to a greater degree than red at both interfaces;
Normals do not need to be drawn
*Award **[1 max]** if dispersion is shown at second face only.*

On the diagram above, draw lines to show the approximate paths of the red and of the blue light as it passes through the prism and back into the air. [3]

b State and explain, with reference to your diagram, whether the refractive index of glass for blue light is greater or less than that for red light.

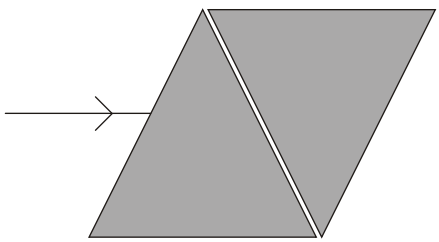
refraction angle for blue light is less than for red light (at the first boundary);

since $n = \frac{\sin i}{\sin r}$

n for blue is greater / *n* for red is less;

[3]

c A second similar prism is placed close to the first prism in (b) as shown below.



Suggest the appearance and the direction of the light that emerges from the second prism.

recombined / white light;

parallel to the incoming beam;

ignore displacement and / or rays within block

[2]

10 **a** Define refractive index.

$\frac{\sin i}{\sin r}$ ***or*** $\frac{c}{v}$ with terms for each expression defined; [1]

b In a certain medium, the speed of light of a particular frequency is 2.1×10^8 m s^{-1}. Calculate the refractive index of the medium for this frequency.

$n = \frac{3.0 \times 10^8}{2.1 \times 10^8}$;
$= 1.4$

[2]

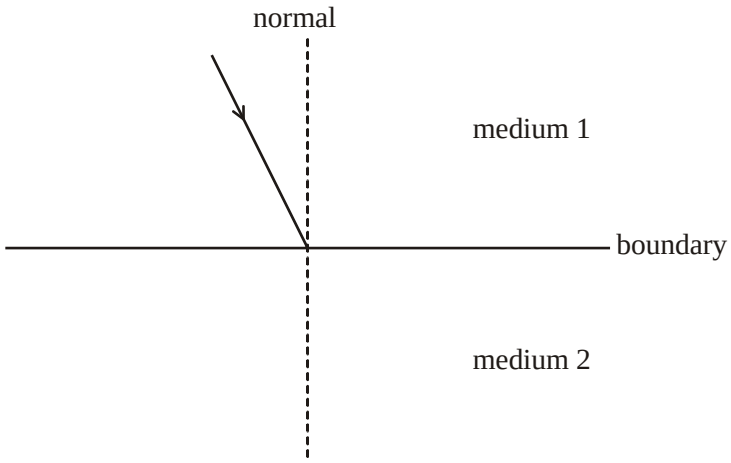
c With reference to your answer in (b), describe what is meant by optical dispersion.

speed of light in a medium depends on frequency;

the refractive index depends on frequency;

light of different frequencies refracted by different amounts / *OWTTE*; [3]

11 **a** The diagram below shows a ray of monochromatic light incident on the boundary between two media. The dotted line is the normal to the boundary.



The refractive index of medium 1 is n_1 and that of medium 2 is n_2 and $n_1 > n_2$. The ray is incident at an angle to the normal that is less than the critical angle.

(i) Explain what is meant by critical angle.

when the (transmitted) ray/light in medium 2 is along the boundary/refracted at 90°;
the angle of incidence in medium 1 is the critical angle;
or
when a ray/light is incident on the boundary at an angle greater than the critical angle;
the ray is not transmitted / no light is transmitted but is totally reflected at the boundary / is totally internally reflected; [2]

(ii) On the diagram above, draw lines to show the paths of the ray after it is incident on the boundary. [2]

Marking points:

reflected ray with angle of reflection = angle of incidence;
transmitted ray with angle of refraction greater than angle of incidence;
Judge both by eye.

b Derive a relationship between n_1, n_2 and the critical angle ϕ_c.

$n_1 \sin\theta_1 = n_2 \sin\theta_2$
$\theta_1 = \phi_c$ and $\theta_2 = 90^\circ$
$n_1 \sin\phi_c = n_2$

[2]

Lenses

12 This question is about the human eye.

The human eye produces images of objects that are placed between the near point and the far point of the eye.

a (*not in syllabus*) Explain what is meant by

(i) *near point*.

the position of the closest object that can be brought into focus by the unaided eye / *OWTTE*; [1]

(ii) *far point*.

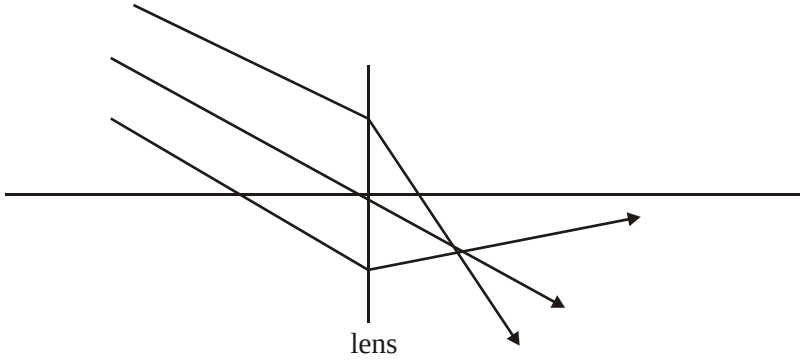
the position of the furthest object that can be brought into focus by the unaided eye / OWTTE; [1]

(iii) Deduce from the answers in part (a) (i) and (a) (ii), which point refers to the condition of myopia and presbyopia.

far point for myopia; near point for presbyopia. [1]

The optical working of the eye may be modelled as a single lens of variable focal length. In this model, when the eye is focused on a distant object which is not on the principal axis, the eye lens has a focal length of 1.7 cm.

b (i) Draw a labelled ray diagram to show how the eye lens forms an image of the distant object. (*Note: this is a sketch and does not need to be drawn to scale*.)



two (or more) parallel rays into lens;
which all converge after refraction at the lens;

Award [2 max] for a correct ray diagram showing rays diverging from an object at twice the focal length (or more) from the lens

[3]

(ii) State the distance from the lens to the image.

about 1.7 cm; (*clue is distant object*) [1]

To focus on an object 50 cm away from the eye, the eye lens in the model changes shape to change its focal length. This enables the image distance to remain the same for all object distances.

c (i) Determine the new focal length of the eye lens.

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ with $u = 50$ cm and $v = 1.7$ cm;

$f = 1.64 \approx 1.6$ cm;

Award [1 max] for a scale diagram since accuracy is inappropriate. [2]

(ii) Suggest what change takes place in the shape of the lens in this model. Explain your answer.

lens gets fatter / OWTTE;
since focal length decreases;

[2]

In the human eye most of the refraction actually takes place due to the change of medium from air to the cornea (the transparent structure at the front of the eye). The following refractive indices are known.

Material	Refractive index
air	1.00
cornea	1.34
water	1.33

d **(i)** Explain what is meant by *refractive index*.

ratio of speed of EM waves;
in vacuum to their speed in medium; *OR*

definition as ratio of sin (angle of incidence) to sin (angle of refraction);
explanation of how these angles are measured; [2]

(ii) Use the information to suggest why it is impossible for a person to see objects clearly when swimming underwater.

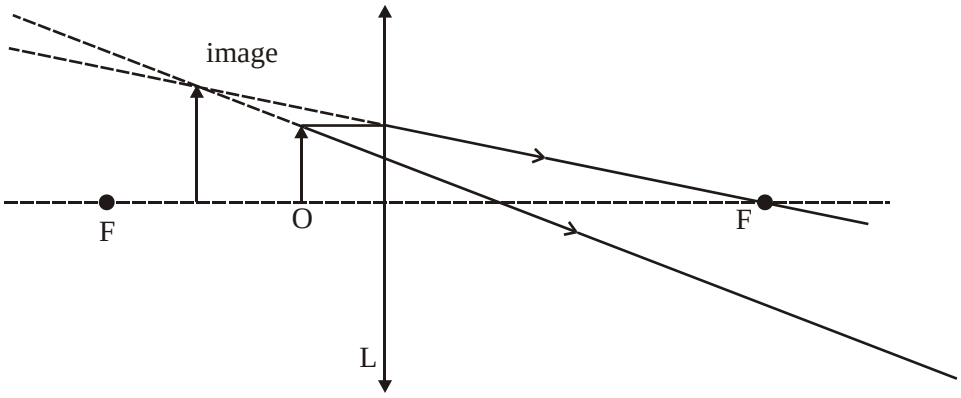
normally the refraction is from air to cornea and the difference in refractive index is large;
if under water refraction is from water to cornea and the difference in refractive index is negligible so no image is formed / OWTTE;

OR

rays crossing the water-eye boundary will undergo little refraction since the n's are nearly equal;
hence, rays cannot be brought to a focus (focussed); [2]

13 This question is about converging lenses.

a The diagram shows a small object O represented by an arrow placed in front of a *converging lens* L. The focal points of the lens are labelled F.



Award [2] for any two appropriate rays and [1] for correct positioning of the image (upright).

(i) Define the *focal point* of a converging lens.

it is the point on the principal axis;

through which a ray parallel to the principal axis passes after going through the lens; *Award [0] if focal point is defined as a distance*. [2]

(ii) On the diagram above, draw rays to locate the position of the image of the object formed by the lens. [3]

(iii) Explain whether the image is real or virtual.

it is virtual because no rays pass through the image / cannot be formed on a screen; [1]

b A convex lens of focal length 6.25 cm is used to view an ant of length 0.80 cm that is crawling on a table. The lens is held 5.0 cm above the table.

(i) Calculate the distance of the image from the lens.

$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \quad \Rightarrow \quad \frac{1}{v}=\frac{1}{6.25}-\frac{1}{5.0};$

$v=-25$ cm, so distance is 25 cm;

[2]

(ii) Calculate the length of the image of the ant.

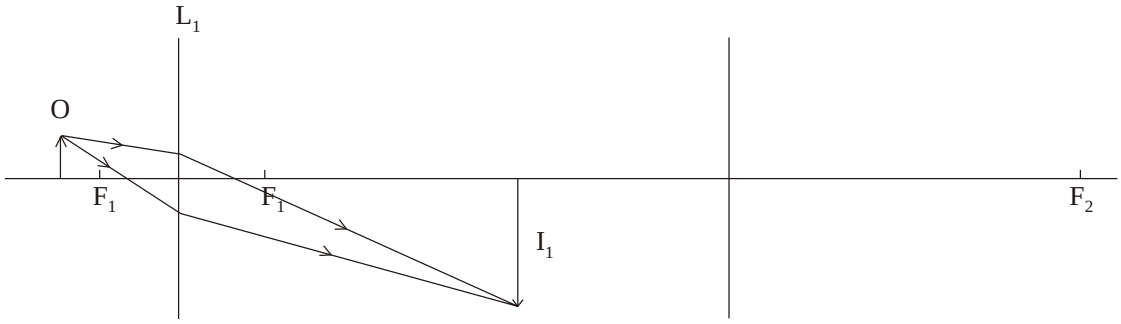
$M=\left|\frac{v}{u}\right|=\left|\frac{-25}{5}\right|=5;$

$L'=5\times 0.8=4.0$ cm;

[2]

14 *(Not in syllabus)* This question is about image formation by lenses

The diagram below shows the positions of two convex lenses L_1 and L_2 used in an optical instrument. F_1 and F_2 are the principal foci of L_1 and L_2 respectively. The object O is viewed through the two lenses.



The diagram also shows two rays from the object O to the position of the image I_1 produced in the lens L_1.

a **(i)** Mark the position of the other principal focus of lens L_2. Label this position F_2. [1]

same distance F_2 but on the other side of L_2.

(ii) The image I_1 acts as an object for the lens L_2. Draw two construction rays to locate the position of the image I_2 formed by lens L_2. Label this image I_2. [3]

ray parallel to principal axis through F_2;
ray undeviated through pole of lens;
correct extrapolation to marked image;

b State and explain whether the image I_2 is real or virtual.

virtual because rays only appear to come from it;

[1]

c State the name of this optical instrument.

(compound) microscope; [1]

d State

(i) the change, if any, in the <u>positions of the lenses</u> so that the final image in (a) (ii) is formed at infinity;

L1 unchanged;

L2 moved (to right) so that I1 is at F2; [2]

(ii) why the image, formed at infinity, is magnified.

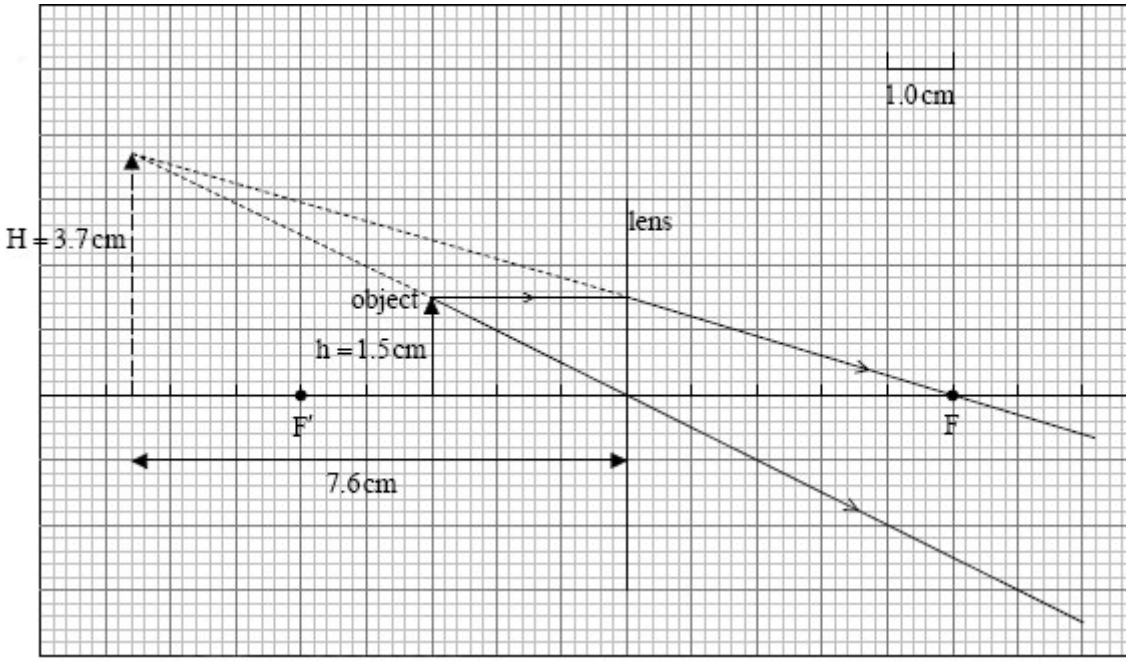
angle (subtended) at eye by image is larger than that (subtended) by object;

[1]

15 This question is about magnification.

An object is placed 3.0 cm from a converging (convex) lens of focal length 5.0 cm.

a On the diagram below, draw rays to locate the position of the image produced by the lens.



ray through centre (pole) of lens;
ray parallel to principal axis;
location of image between 6.9 cm and 8.1 cm;

b On the diagram above, mark with the letter E, the position from which the image should be viewed. [1]

eye to the right of lens;

c Use your ray diagram above to calculate the magnification of the image.

$M = \frac{h_i}{h_o} = \frac{3.7}{1.5};$ $= 2.5(\pm 0.2)$ or $M = \frac{v}{u} = \frac{7.6}{3.0};$ $= 2.5(\pm 0.2);$

[2]

d For high magnification, a compound microscope may be used. This microscope consists of an objective lens and an eyepiece lens.

(i) State the type of lens used as both the objective lens and the eyepiece lens.

converging (convex) lenses; [1]

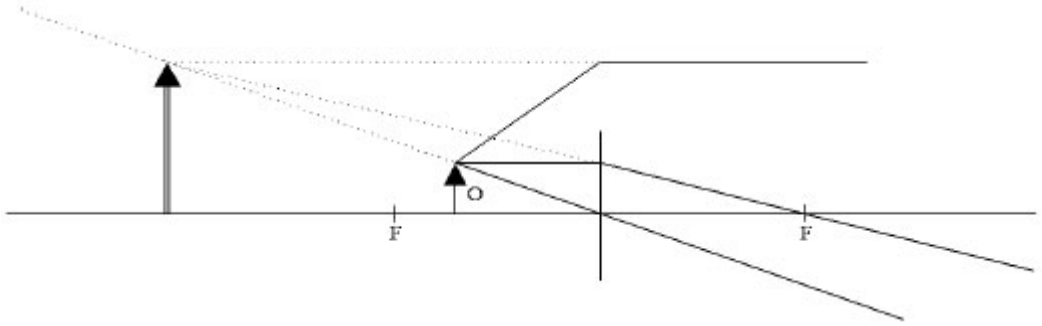
(ii) The magnification produced by the objective lens is 24. The image of the object produced by this lens is formed 3.4 cm from the eyepiece lens of focal length 4.0 cm. Determine the magnification of the final image produced by the microscope.

$\frac{1}{3.4}+\frac{1}{v}=\frac{1}{4.0}$;
$v=-22.7$ cm;
$M=\left|\frac{-22.7}{3.4}\right|=6.7$;
Total magnification $=6.7\times24=160$;

Allow two sig fig for answer ($\pm$)25 cm.
$\Rightarrow$ magnification = 7.4
$\Rightarrow$ total magnification = 180

[4]

16 The diagram below shows a thin converging lens and an object, O.



one ray through the optical centre of the lens;
one through a focal point;
back traced to locate image;
No need for arrows or dotted lines

The principal foci of the lens are at F.

a Construct rays to locate the position of the image of the object. [3]

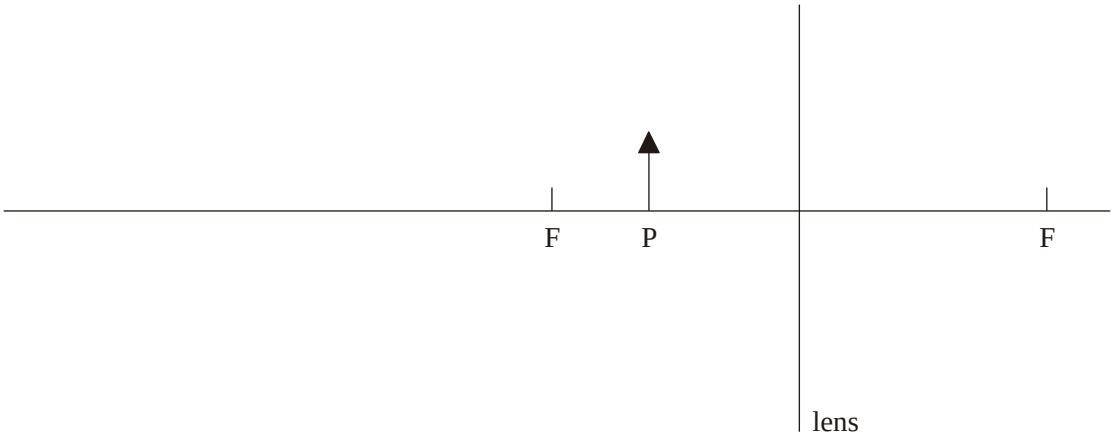
b Describe fully the nature of the image formed.

virtual, magnified, erect;

Award [2] for all three and [1] for any two. [2]

17 This question is about image formation by a converging lens.

An object P is placed close to a converging lens as shown in the diagram below. The principal foci F of the lens are marked.



a On the diagram above, draw rays to locate the position of the image formed by the lens. Label this image with the letter I. [3]

one correct ray;
second correct ray;
image construction lines clear and image drawn in, labelled I;

b The near point of an observer's eye is 25.0 cm from the eye. The lens in the diagram is positioned 4.0 cm from the lens in the observer's eye so as to form an image of the object P at the near point. The focal length of the lens is 8.0 cm.

(i) Determine the distance from the object to the lens.

image is formed at $v = -21$ cm from lens;

$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad \Rightarrow \quad \frac{1}{u} = \frac{1}{21} + \frac{1}{8}$;

$u = 5.8$ cm;

Award [2 max] if 25 cm used for v.

[3]

c **(i)** (*Not in syllabus*) Lenses are subject to chromatic aberration and spherical aberration.

Describe and explain chromatic aberration and spherical aberration.

Chromatic aberration: different amounts of refraction for different colours / wavelengths;

colour fringing of image; [2]

Spherical aberration: rays parallel to principal axis at edge of lens brought to different focus from those near centre of lens / *OWTTE*; image blurred / *OWTTE*; [2]

(ii) Suggest how the effects of spherical aberration can be reduced.

restrict aperture; [1]

18 This question is about image formation by a converging lens.

a Define the *principal focus* (*focal point*) of a converging lens.

the point on the principal axis of the lens; through which a ray parallel to the principal axis goes after refraction in the lens / OWTTE; [2]

b An object is placed 30 cm in front of a converging lens of focal length 15 cm. The object is moved 5.0 cm closer to the lens. Determine the displacement of the image.

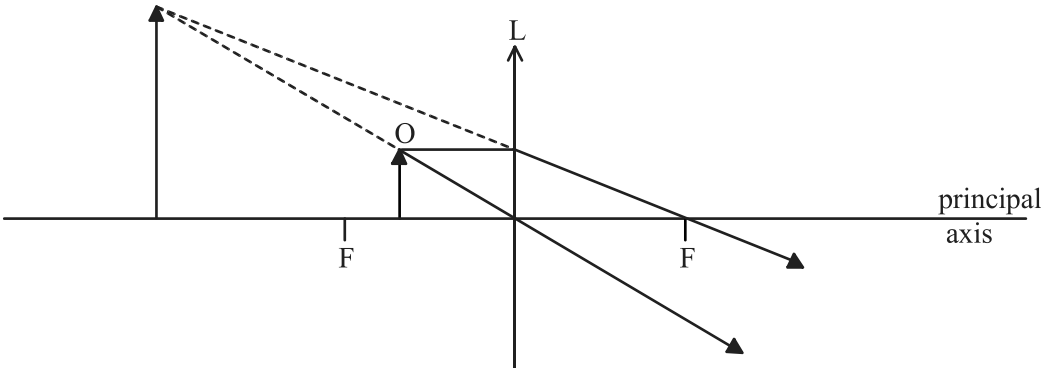
for u = 30 cm, v = 30 cm;
for u = 25 cm, v = 37.5 cm;
distance moved = 7.5 cm;
away from lens;

or
for those using a scaled diagram:
choice of suitable scale;
correct construction of both images;
measurement of separation between 6.0 and 9.0 cm;
correct statement of direction of displacement;

[4]

19 This question is about image formation.

a A converging lens L has principal foci at F. An object O is placed in front of the lens as shown below.



two rays as shown;
extrapolated back to locate image;
Do not penalize if rays do not have arrows.

(i) Define *principal axis* and *principal foci*.

Principal axis: a line at right angles to the plane of the lens and that passes through the (optical) centre of the lens / *OWTTE*; [1]

Principal foci: a point on the principal axis to which rays parallel to the principal axis pass after refraction (through the lens) [1]

(ii) On the diagram above, construct rays to locate the position of the image formed by the lens. [2]

(iii) Explain whether the image is real or virtual.

virtual as the rays diverge after passing through the lens;
cannot be focused onto a screen / appear to come from a point / OWTTE;
Award [1 max] for an explanation based on the image on the same side of the lens. [2]

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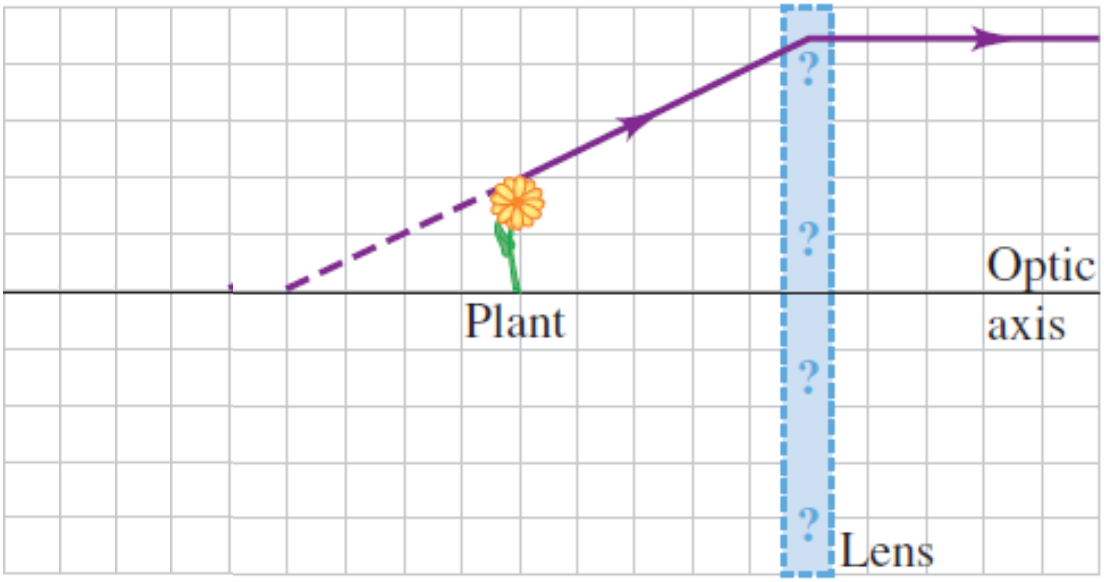
20 A small plant near a thin lens. The ray shown is one of the principal rays for the lens. Each square is 2.0 cm along the horizontal direction, but the vertical direction is not to the same scale. Use information from the diagram to answer the following questions:



a Using only the ray shown, decide what type of lens (converging or diverging) this is. [1]

convex

b What is the focal length of the lens?

18.0 cm

[1]

c Locate the image by drawing the other two principal rays. [3]

22.5 cm to the left of the lens

d Calculate where the image should be, and compare this result with the graphical solution in part (c).

22.5 cm to the left of the lens

[2]