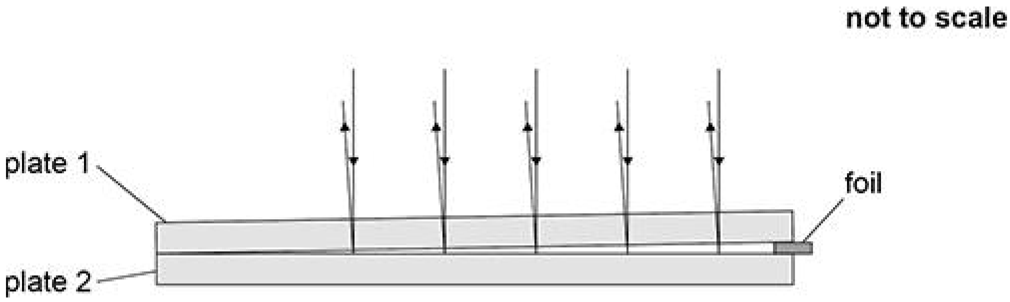
Q1.

Figure 1 shows an arrangement used to determine the thickness of metal foil using interference of light.

Figure 1



Two thin glass plates are separated by the foil at one end. Monochromatic light is incident on the glass plates from above. A series of bright fringes is observed when viewed from above, as shown in **Figure 2**.

Figure 2

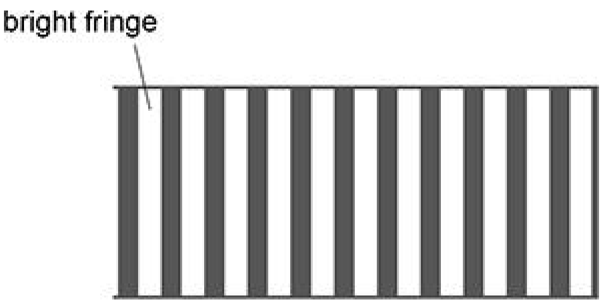
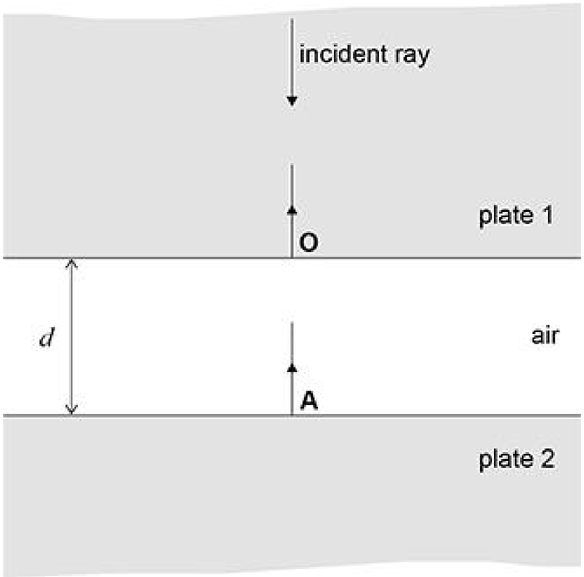


Figure 3 shows part of the arrangement where a bright fringe occurs.

The angle between the two plates caused by the foil in **Figure 1** is very small. This allows the following approximations to be made for **Figure 3**:

- the plates are parallel to each other
- the light rays travel perpendicular to both plates.

Figure 3



Some of the incident light is reflected at **O**. The remainder of the light is transmitted through the air gap and is reflected at **A**.

The reflected light from **A** combines at **O** with the reflected light from **O**.

At **O**, there is a phase difference between the reflected light from **A** and the reflected light from **O**.
This phase difference is caused by:

- the path difference due to the air gap
- the reflection at **A**.

At **A** the phase of the light that is reflected is changed by 180°.
At **O** there is no change to the phase of the light that is reflected or that is transmitted.

The thickness **OA** of the air gap is d.

(a) Deduce the relationship between d and the wavelength λ of light that produces a bright fringe.

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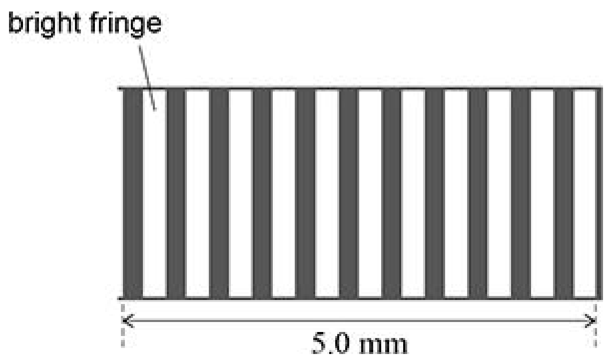
(3)

Figure 4 shows a small part of the fringe pattern as viewed from above.

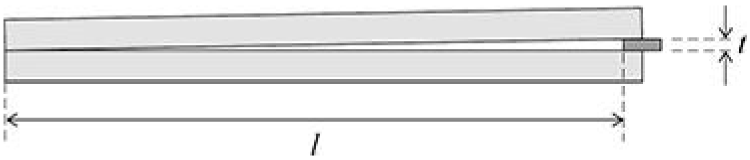
Figure 4



The distance between the centre of one bright fringe and the centre of the next bright fringe is s.

The thickness of the foil is t and the length of each glass plate up to the edge of the foil is l as shown in **Figure 5**.

Figure 5



It can be shown that

$$\frac{t}{l} = \frac{\lambda}{2s}$$

(b) Determine t using **Figure 4**.

$\lambda = 590$ nm
$l = 6.0$ cm

$t =$ ____________________ m

(2)

(c) The space between the plates is now filled with water. The same light source is used, and t and l remain the same as before.

Deduce how the distance s will change when water fills the space between the plates.

refractive index of water = 1.3

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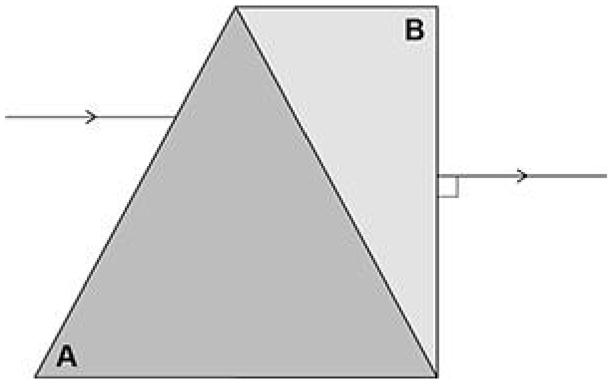
(3)

(Total 8 marks)

Q2.

Figure 1 shows two prisms **A** and **B** of different refractive indices joined to make a block.
A ray of monochromatic light is shown entering and then leaving the block.

Figure 1



(a) Complete, on **Figure 1**, the path of the ray of light inside the block.

(1)

(b) Deduce which prism, **A** or **B**, has the greater refractive index.

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(2)

The block is used with a telescope to investigate stars.
The block can be replaced with a diffraction grating.

(c) Describe **one** non-astronomical application of a diffraction grating.

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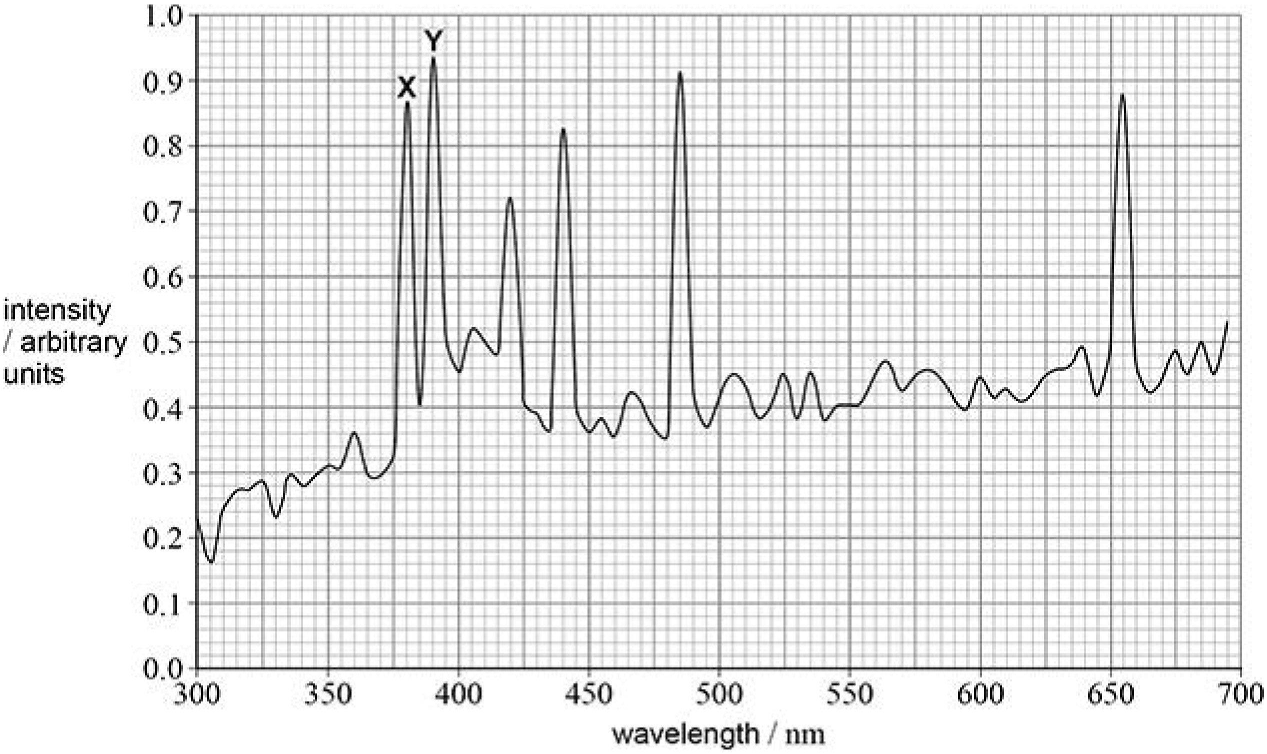
(1)

(d) **Figure 2** shows a spectrum of light. Two lines in the spectrum are labelled **X** and **Y**.

Figure 2



The light passes at normal incidence through a diffraction grating. The number of lines per metre for the grating is G.

The first-order diffraction angle of **X** is at 28.2° to the normal.

Calculate G.

G = ____________________ m^{-1}

(3)

(e) A scientist wants to obtain an accurate value for the difference in wavelength between line **X** and line **Y**.

She has two options:

- option 1: to analyse the second-order spectrum from the original grating
- option 2: to analyse the first-order spectrum from a grating with $2G$ lines per metre.

Discuss which option she should choose.

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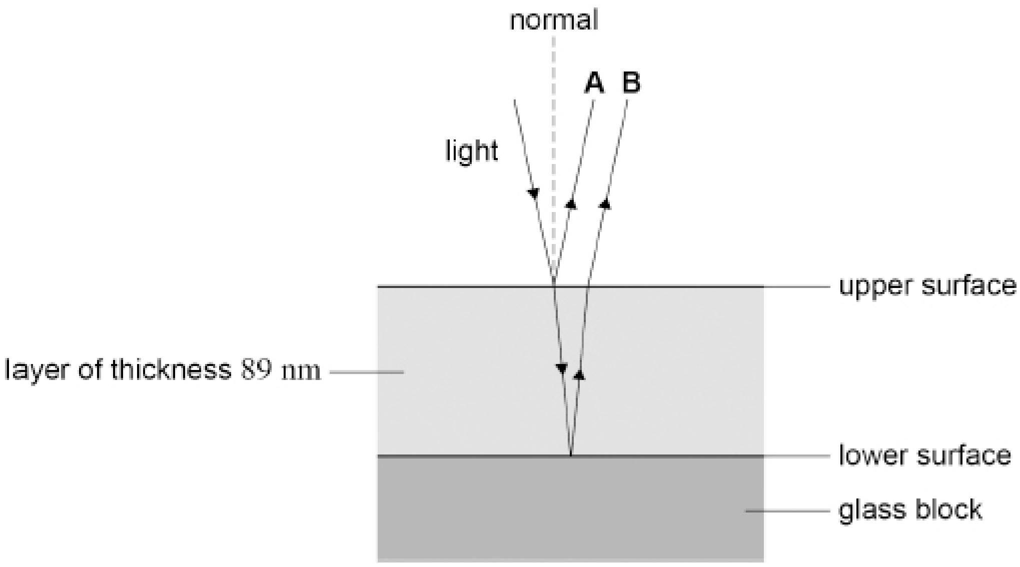
(3)

(Total 10 marks)

Q3.

A glass block is coated with a layer of transparent material.
Figure 1 shows the incident ray and the reflected rays when monochromatic light is shone onto the upper surface of the transparent layer.

Figure 1



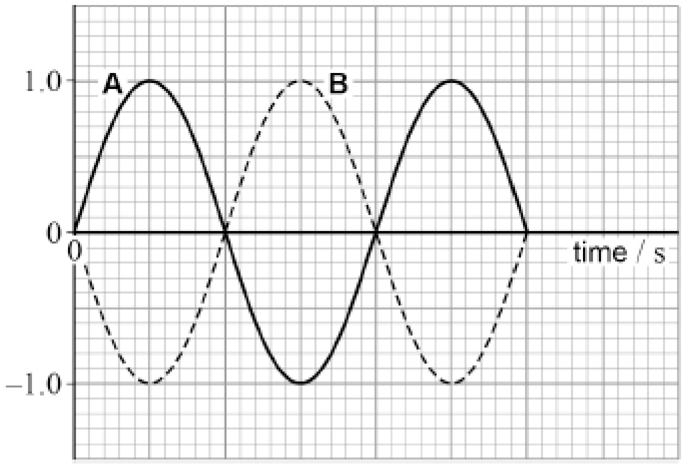
A is light reflecting from the upper surface of the layer.
B is light that leaves the layer after reflection from the lower surface.

When light reflects at the upper and lower surfaces, there is a change of phase. In this case, the change of phase is the same at each surface and so can be ignored.

When the monochromatic light is incident **normally** on the upper surface of the layer, **A** and **B** meet and interfere.
Assume that the light is incident **normally** on the upper surface throughout this question.

(a) **Figure 2** shows how **A** and **B** vary with time at the upper surface.

Figure 2



In the layer, the light has a wavelength of 356 nm.
The thickness of the layer is 89 nm.

Explain why destructive interference occurs at the upper surface for this thickness.

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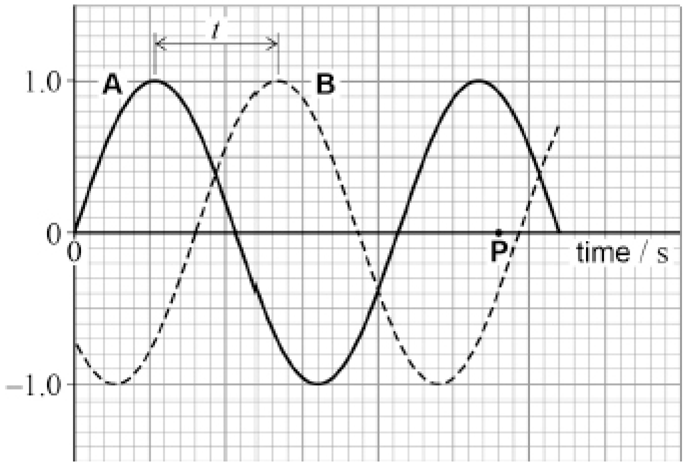
(3)

The frequency of the monochromatic light incident on the layer is changed.

Figure 3 shows how **A** and **B** vary with time at the upper surface for this light.

Figure 3



(b) Calculate the resultant of the waves at time **P** in **Figure 3**.

resultant = ____________________

(2)

The frequency of the light in **Figure 3** is 4.72×10^{14} Hz.

(c) The phase difference between **A** and **B** shown in **Figure 3** is 137°.

Show that the time interval labelled t in **Figure 3** is approximately 8×10^{-16} s.

(3)

(d) 89 nm is the minimum thickness that will produce a phase difference of 137° between **A** and **B**.

Calculate the refractive index of the material of the layer.

refractive index = ____________________

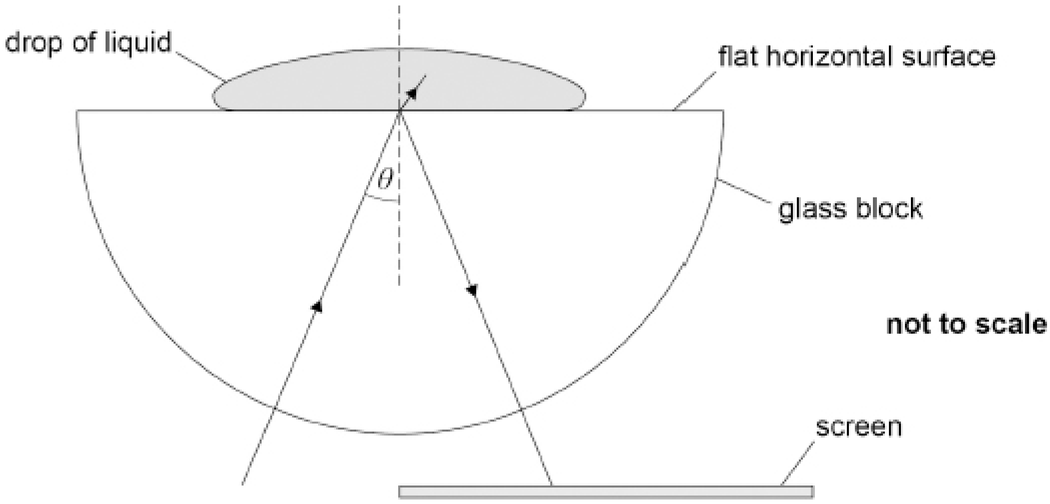
(4)

(Total 12 marks)

Q4.

Figure 1 shows a type of refractometer.
A semi-circular glass block is arranged so that its semi-circular faces are vertical.
A drop of liquid is placed at the centre of the flat horizontal surface of the block.

Figure 1



Light enters the block through the curved surface and is incident on the midpoint of the horizontal surface at angle of incidence θ.
Light that reflects at the glass–liquid boundary is detected on a screen that lies parallel to the horizontal surface.

(a) Explain why the light ray in **Figure 1** does not change direction as it enters the block.

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(1)

(b) The refractometer is calibrated using a drop of liquid.
When θ = 15°, light is partially refracted at the glass–liquid boundary.

Calculate the angle of refraction at this boundary.

refractive index of glass block = 1.84
refractive index of liquid = 1.33

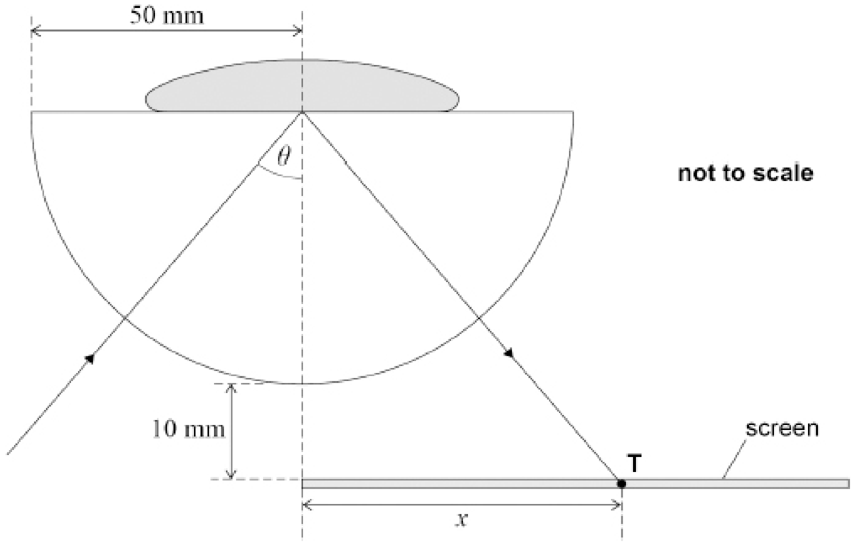
angle of refraction = ____________ °

(2)

The refractometer is used to determine the critical angle θ_c at the glass–liquid boundary.

Figure 2 shows dimensions of the arrangement.

Figure 2



The intensity of the light ray on the screen is observed as θ is increased from 15°. When $\theta = \theta_c$ the intensity of the light ray is seen to increase sharply at a point **T** on the screen.

The distance between the left-hand edge of the screen and **T** is x.

(c) Explain why the intensity of the light ray on the screen increases at **T**.

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(2)

(d) The liquid is replaced with a drop of sugar solution.
The refractive index of the sugar solution is greater than 1.33

Deduce how this change affects the position at which the sharp increase in intensity is observed on the screen.

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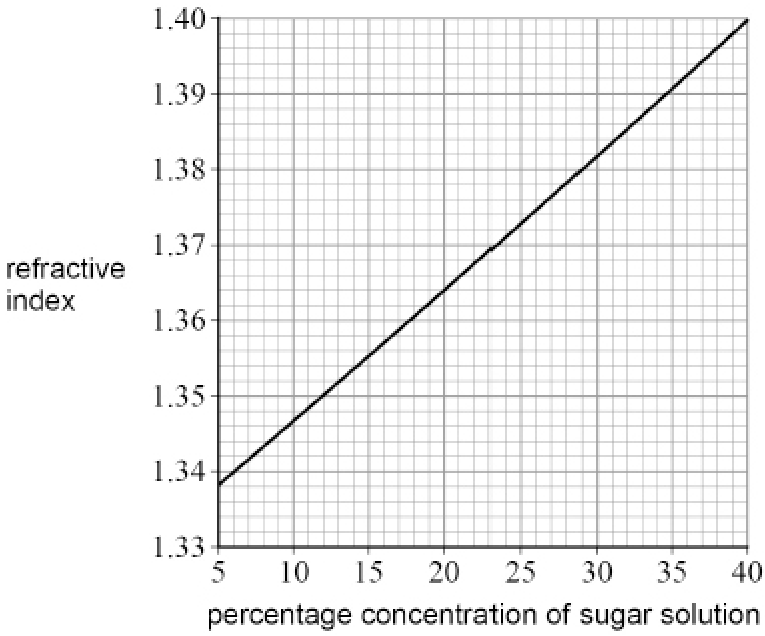
(2)

(e) The refractometer in **Figure 2** is used to determine the concentration of a sugar solution.

Figure 3 shows the variation of refractive index with concentration of sugar solution.

Figure 3



For a drop of a particular sugar solution, $x = 69$ mm.

Determine the percentage concentration of the sugar solution.

refractive index of glass block = 1.84

percentage concentration = ____________________

(3)

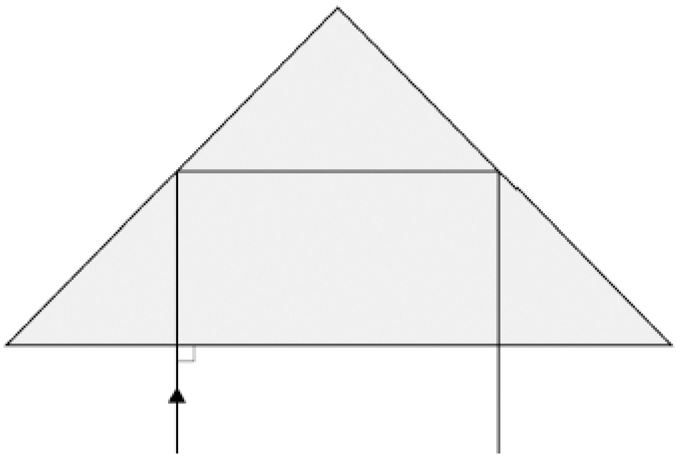
(Total 10 marks)

Q5.

Porro prisms are used in binoculars to reverse the path of the light. The prism is in the shape of a right-angled isosceles triangle.

Figure 1 shows a ray of light, at normal incidence on the longest side, passing through a glass Porro prism.

Figure 1



The critical angle for light in the prism is 41.5°.

(a) Show that the glass used to make the prism has a refractive index of about 1.5

(1)

(b) Explain why the ray emerges parallel to the incident ray.

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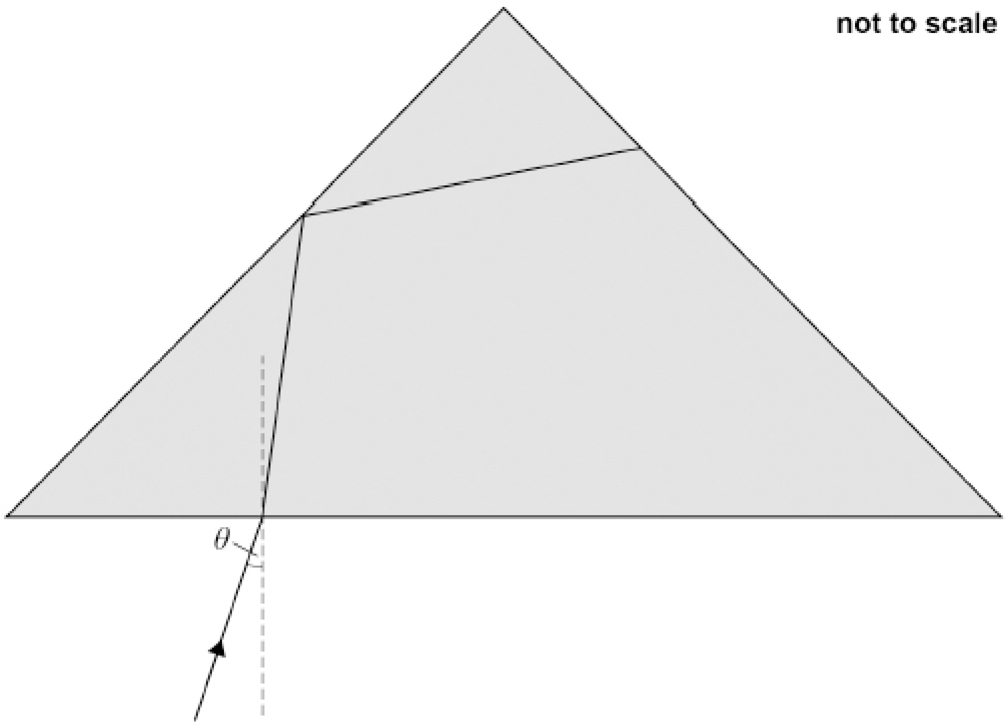
(2)

Figure 2 shows a ray of light entering the prism at an angle of incidence θ and reflecting off one of the shorter sides.

Figure 2



θ is the largest angle of incidence for which all of the light leaves through the longest side.

(c) Draw on **Figure 2** the path of the ray of light as it continues inside the prism and emerges from the longest side.

(3)

(d) When the angle of incidence is greater than θ, some of the light escapes the prism through one of the shorter sides.
Assume that the refractive index is 1.5 and the critical angle is 41.5°.

Show that θ is about 5°.
You can use **Figure 2** in your answer.

(4)

(e) A manufacturer wants to make a prism with a larger value of θ.

Two alternative changes to the original design of the prism are suggested:

1. use a prism of the original glass in the shape of an equilateral triangle, as shown in **Figure 3**

2. use a prism of the original shape made from glass with a smaller refractive index, as shown in **Figure 4**.

Figure 3

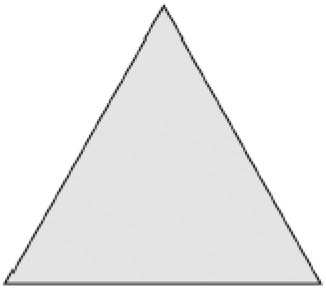
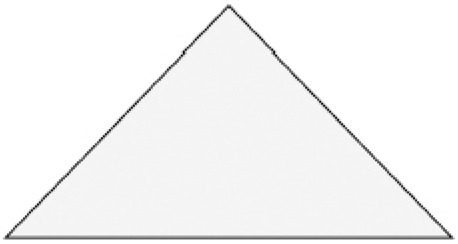


Figure 4



Discuss whether either of the two suggestions would work.

1 ____

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2 ____

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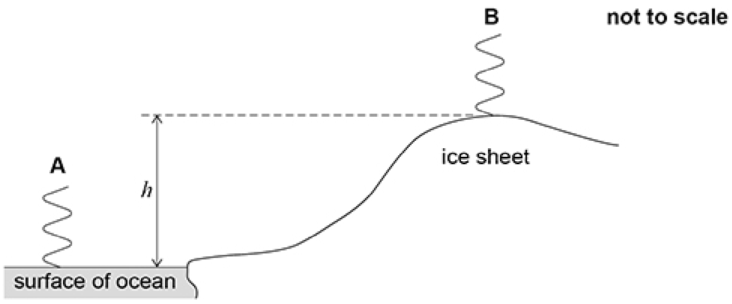
(4)

(Total 14 marks)

Q6.

A satellite system is used to measure the height h of the top of an ice sheet above the surface of the ocean.
The satellite emits two pulses **A** and **B** of infrared radiation. **A** is incident on the surface of the ocean and **B** is incident on the top of the ice sheet as shown in **Figure 1**.

Figure 1



(a) The frequency of the infrared radiation is 3.8×10^{14} Hz.
Each pulse has a duration of 6.0 ns.

Calculate the number of cycles in each pulse.

number of cycles = _______________

(2)

(b) **A** and **B** reflect and return to the satellite. The travel time is the time between the emission of a pulse and its return to the satellite.

The difference in the travel times of **A** and **B** is 10.7 μs.

Calculate h.

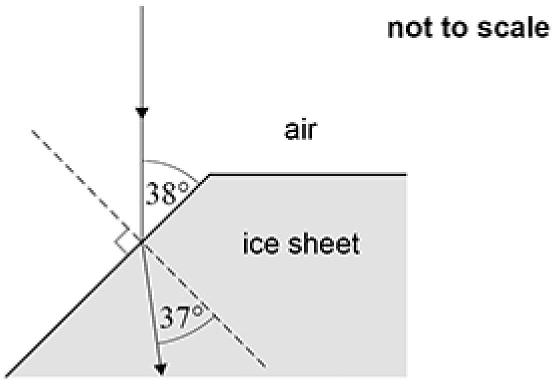
h = _______________ m

(2)

Some of the infrared radiation enters the ice sheet.

Figure 2 shows the path of infrared radiation that refracts at a sloping part of the ice sheet.

Figure 2



(c) Calculate the refractive index of the ice.

refractive index = _______________

(2)

(d) Calculate the wavelength of the infrared radiation when it is inside the ice sheet.

wavelength = _______________ m

(2)

(Total 8 marks)

Q7.

A student buys a portable loudspeaker that is powered by its own internal battery. The battery in the loudspeaker is initially uncharged.

(a) The battery is connected to a charger that maintains a constant potential difference of 5.0 V across the battery. It takes 2.6 hours for the battery to become fully charged. The average current in the battery during this time is 2.0 A.

The battery is disconnected from the charger.
The fully-charged battery operates the loudspeaker for 12 hours before it is completely discharged.

Calculate the average output power of the battery during these 12 hours.

average output power = ________________ W

(2)

(b) A mobile phone transmits data to the loudspeaker using microwaves. The data are processed at the loudspeaker to produce sound waves.

Microwaves and sound waves travel at different speeds.

Describe **two** other differences between microwaves and sound waves.

1 ____

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2 ____

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(2)

(c) A second loudspeaker receives the same data from the mobile phone. The two loudspeakers act as coherent sources of sound waves.

State the **two** conditions required for the sources to be coherent.

1 ____

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2 ____

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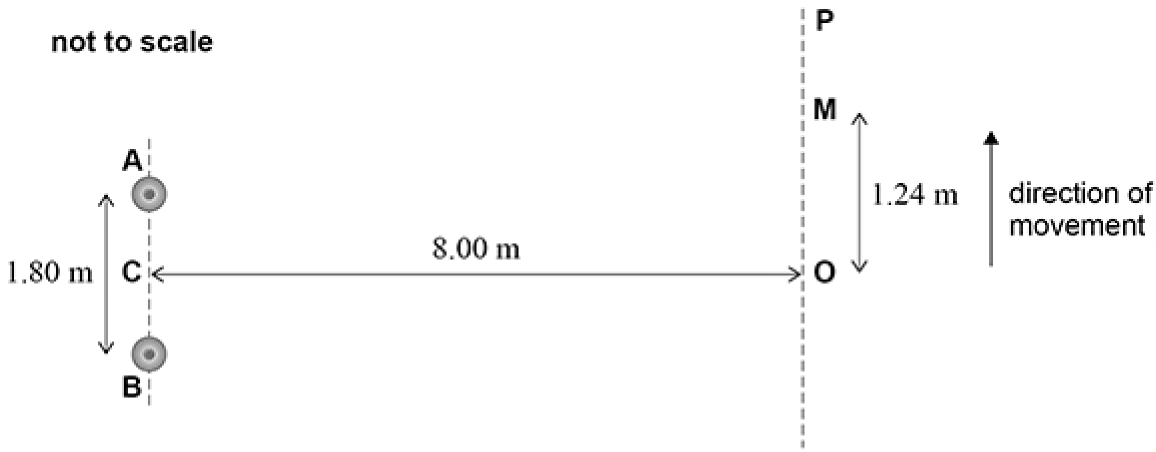
(2)

The figure below shows two loudspeakers **A** and **B** that act as coherent point sources of sound of a single frequency.



C is the midpoint between **A** and **B**.
Distances **OA** and **OB** are equal.
OP is perpendicular to **CO**.

The student uses a sound-level meter to measure the intensity of the sound. The meter detects a maximum intensity at **O**.
The student moves the meter along **OP**. The intensity decreases and reaches a first minimum at **M**. The intensity then increases as the meter moves towards **P**.

The student records the following distances:

AB = 1.80 m
CO = 8.00 m
OM = 1.24 m.

(d) Show that the difference between the path lengths **AM** and **BM** is approximately 0.3 m.

(2)

(e) The speed of sound is $340\ \mathrm{m\ s^{-1}}$.

Determine the frequency of the sound waves.

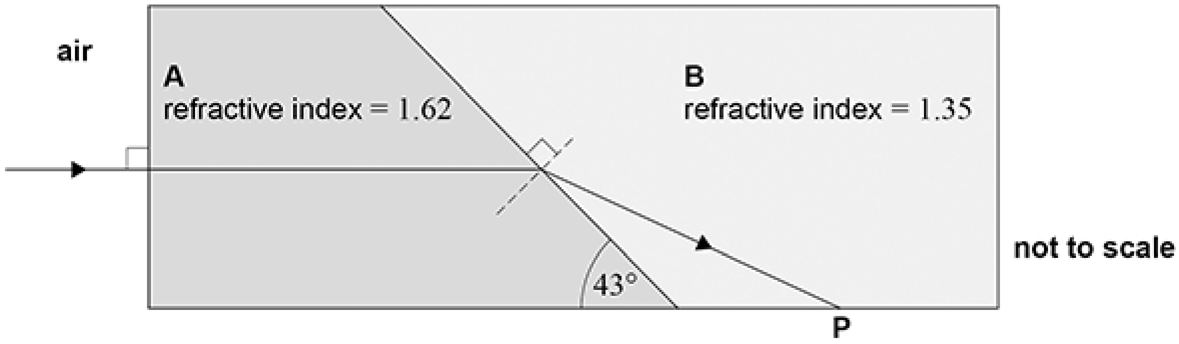
frequency = _______________ Hz

(2)

(Total 10 marks)

Q8.

Two transparent prisms **A** and **B** of different refractive indices are placed in contact to produce a rectangular block.
The figure below shows the path of a ray, incident normally on **A**, refracting as it crosses the boundary between the prisms.



(a) Explain how the path of the ray shows that the refractive index of **A** is greater than the refractive index of **B**.

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(1)

(b) Show that the angle of refraction of the ray in **B** is about 60°.

(2)

(c) Draw, on the figure above, the path of the ray immediately after it reaches **P**.
Justify your answer with calculations.

(3)
(Total 6 marks)