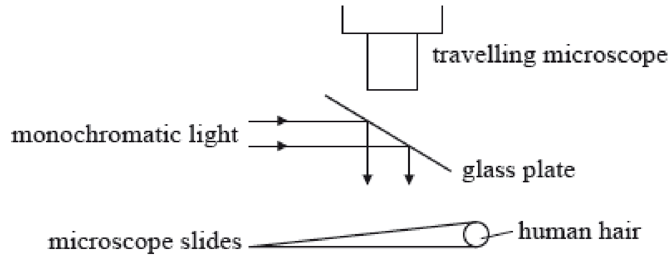
HL Paper 3

This question is about thin-film interference.

The diagram (not to scale) represents an experimental set-up designed to measure the diameter of a human hair.



A hair is used to separate two microscope slides. A monochromatic beam of light is reflected onto the two slides by the glass plate. The light is then reflected from the two slides and transmitted through the glass plate and is viewed by the travelling microscope.

a. State why the light reflected from the two microscope slides produces a system of interference fringes. [1]

b. The condition that a bright fringe is observed in the field of view of the travelling microscope is given by the relationship [1]

$$2t = \left(m + \frac{1}{2}\right)\lambda$$

where t is the thickness of the air film formed by the wedge at the point where the bright fringe is observed, m is an integer and λ is the wavelength of the incident light.

State the reason for the factor $\frac{1}{2}$ in the relationship.

c. In the diagram, the length of the slides is 5.00 cm. The wavelength of the monochromatic light is 5.92×10^{-7} m. Using the travelling microscope it is observed that 50 fringes occupy a length of 0.940 cm. Show that the diameter of the hair used to separate the slides is about $80\ \mu\text{m}$. [3]

Markscheme

a. light reflected from the top slide interferes with light reflected from the bottom slide;

b. the light reflected from the bottom slide undergoes a π change in phase;

c. in moving from one (bright) fringe to the next the thickness of the air film changes by $\frac{\lambda}{2}$;

in 5.0 cm number of fringes $= \frac{5}{0.940} \times 50 = 266$;

therefore diameter of hair $= 133 \times 5.92 \times 10^{-7} = 7.87 \times 10^{-5}$ m;

$80\ \mu\text{m}$

Examiners report

a. A significant number of candidates did not attempt this question or made very poor attempts at answering.

b. A significant number of candidates did not attempt this question or made very poor attempts at answering.

c. A significant number of candidates did not attempt this question or made very poor attempts at answering. Candidates who gave good answers often used, correctly, a similar triangles approach to determining the diameter of the hair in part (c).

This question is about thin-film interference.

A thin film of oil lies on a puddle of water. White light from above shines on the film at normal incidence.

a. Outline the process by which coloured fringes are formed. [3]

b. The following data are available: [2]

Refractive index of oil = 1.4
Refractive index of water = 1.3
Thickness of the oil film = 250 nm

Calculate the maximum wavelength of the incident light for which **destructive** interference occurs.

Markscheme

a. light reflects from the top surface of the oil and the top surface of the water;

mention of interference/superposition;

path difference exists between both reflected rays;

different wavelengths interfere constructively for different positions/angles (hence colours appear/shift);

b. $\lambda \left(= t\frac{2n}{m}\right) = 250 \times 10^{-9}\,\frac{2\times 1.4}{1}$;

$\lambda = 700\,(\mathrm{nm})$;

Examiners report

a. [N/A]
b. [N/A]

This question is about thin-film interference.

A thin film of oil of constant thickness floats on the surface of water. The refractive indices n of each material is shown on the diagram.

a. Explain why the film of oil appears to show coloured fringes. [2]

b. When white light is normally incident on the surface of the oil, the film appears green to an observer. The wavelength of green light in air is 520 nm. Calculate the thickness of the film of oil. [2]

Markscheme

a. the light reflects at the air:oil and the oil:water boundary; *(can be shown on diagram)*

light reflecting from the oil:water boundary interferes with the light reflecting from the air:oil boundary;

depending on the thickness of the oil, different frequencies show constructive/destructive interference (hence coloured fringes);

b. *for constructive interference*:

$\left(2nt = \left[m + \frac{1}{2}\right]\lambda\right)$

$t = \left[m + \frac{1}{2}\right]\frac{\lambda}{2n}$ ***or*** $\left[0 + \frac{1}{2}\right]\frac{520\times10^{-9}}{2\times1.40}$;

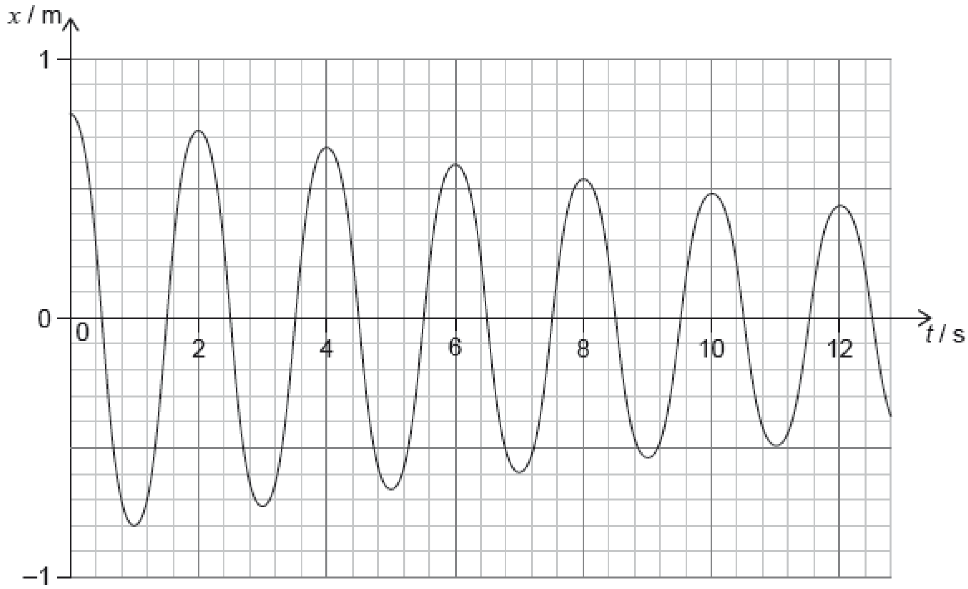
$t = 93\text{ nm}$;

Examiners report

a. A large number of candidates did not explain two reflected rays, and that interference was dependent on the thickness of the oil film.

b. A large number of candidates did not explain two reflected rays, and that interference was dependent on the thickness of the oil film.

The graph below represents the variation with time *t* of the horizontal displacement *x* of a mass attached to a vertical spring.



The total mass for the oscillating system is 30 kg. For this system

a. Describe the motion of the spring-mass system. [1]

b.i. determine the initial energy. [1]

b.ii. calculate the Q at the start of the motion. [2]

Markscheme

a. damped oscillation / *OWTTE*

[1 mark]

b.i. E «$= \frac{1}{2} \times 30 \times \pi^2 \times 0.8^2$» $= 95$ «J»

Allow initial amplitude between 0.77 to 0.80, giving range between: 88 to 95 J.

[1 mark]

b.ii $\Delta E = 95 - \frac{1}{2} \times 30 \times \pi^2 \times 0.72^2 = 18$ «J»

$Q =$ « $2\pi \frac{95}{18}$ =» 33

Accept values between 0.70 and 0.73, giving a range of ΔE between 22 and 9, giving Q between 27 and 61.

Watch for ECF from (b)(i).

[2 marks]

Examiners report

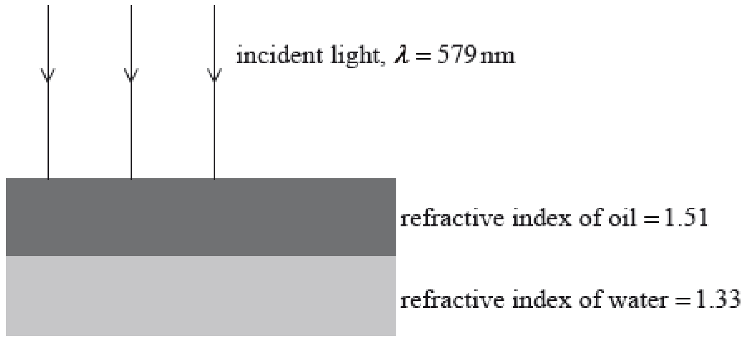
a. [N/A]

b.i. [N/A]

b.ii. [N/A]

This question is about thin-film interference.

A thin layer of oil of refractive index 1.51 floats on water of refractive index 1.33. Light of wavelength 579 nm is incident normally to the surface.



a. Determine the minimum thickness of the oil layer that gives rise to the least amount of light being reflected. [3]

b. Describe the change in the intensity of the reflected light as the thickness of the oil layer in (a) is gradually increased. [2]

Markscheme

a. use of $m = 1$;

$2 \times 1.51 \times t = 1 \times 579 \times 10^{-9}$;

$t = 1.92 \times 10^{-7}$ (m);

*Award **[3]** for a bald correct answer.*

*Award **[2 max]** for use of $m = \frac{1}{2}$ giving 9.6 $\times$ 10^{-8} (m).*

*Award **[2 max]** for answer of $\frac{\lambda}{2}$ for air (2.9 $\times$ 10^{-7} (m)).*

b. intensity increases;

intensity then decreases and increases repeatedly;

when thickness becomes very large the intensity becomes constant;

Examiners report

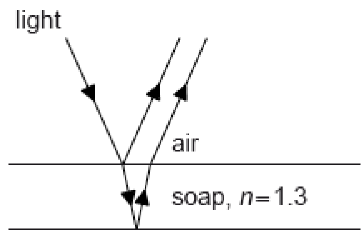
a. In (a) the correct thin film formula from the data booklet was sometimes chosen, but many candidates were able to answer the question using first principles. A common mistake was was to give the half wavelength value in air rather than oil or to forget the phase change on the hard reflection.

b. Few could give a well reasoned answer to (b) and were often lucky to score one mark.

This question is about thin-film interference.

Monochromatic light with wavelength 572 nm is incident from air on a thin soap film.

The soap solution has a refractive index of 1.3.



a. Calculate the wavelength of the light within the soap solution. [1]

b. Calculate the minimum thickness of the soap film that results in constructive interference for the reflected light. [1]

c. Without a calculation, explain why a soap film that is twice as thick as that calculated in (b) results in destructive interference. [2]

Markscheme

a. $\lambda' = \frac{\lambda}{1.33} = \frac{572}{1.3} = 440 \text{ nm};$

b. 110 nm;

c. there would be a full wavelength within the film;

but the phase change at the first surface means that there is always destructive interference;

Examiners report

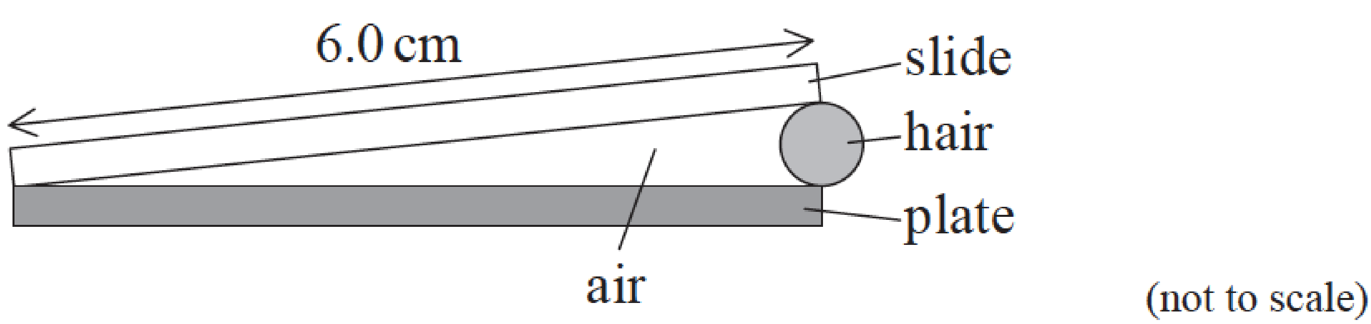
a. Vast majority of candidates calculated the values well and also explained destructive interference properly.

b. Vast majority of candidates calculated the values well and also explained destructive interference properly.

c. Vast majority of candidates calculated the values well and also explained destructive interference properly.

This question is about wedge fringes.

A glass microscope slide of length 6.0cm is placed on a glass plate and illuminated using a monochromatic source of light of wavelength 590nm. A hair is trapped at one end of the slide forming an air wedge between the glass plate and the slide.



An observer viewing the microscope slide at near-normal incidence measures the fringe spacing to be 0.29 mm. Calculate the thickness of the hair.

Markscheme

there are $\frac{60}{0.29}$ fringes=207;

2×1×t=207×5.9×10^{-7};

t=61(μm);

or

$(\tan\theta =)\ \frac{1}{6.0(\mathrm{cm})} = \frac{0.5\lambda}{\Delta x}$;

$t = \frac{[0.06(\mathrm{m})\times 0.5\times 5.9\times 10^{-7}(\mathrm{m})]}{0.00029(\mathrm{m})}$;

t=61(μm);

A phase change of $\frac{1}{2}\lambda$, if seen in working, can be ignored and does not affect the answer.

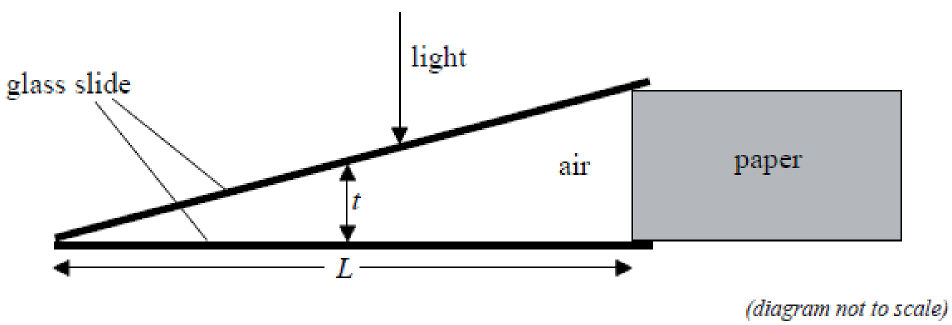
*Award **[3]** for a bald correct answer.*

Examiners report

[N/A]

This question is about wedge film interference.

One flat, glass slide is placed at an angle on top of a second identical slide. The slides are in contact along one short edge and are separated at the other edge by a thin piece of paper, as shown below.



A thin wedge of air of variable thickness, t , is trapped between the two slides. The arrangement is viewed normally from above, using light of wavelength 590 nm. The glass plates are coated, so that reflection only takes place at the bottom surface of the top plate and the top surface of the bottom plate.

A series of straight bright and dark fringes, equally separated and parallel to the short edge of the slides, is seen.

a. Deduce that the thickness of the air wedge t that gives rise to a bright fringe, is given by $2t = (m + \frac{1}{2})\lambda$. [2]

b. The length of the air wedge, L, is 8.2 cm. The bright fringes are each separated by a distance of 1.2 mm. Calculate the thickness of the paper. [3]

Markscheme

a. phase change of π occurs on reflection at one slide but not the other;

constructive interference occurs when path difference between two reflected rays is $\frac{\lambda}{2}$, $\frac{3\lambda}{2}$, $\frac{5\lambda}{2}$ etc;

the extra distance travelled is twice the thickness of the air (wedge) hence 2t = [m+½] λ;

b. number of fringes = $\frac{82}{1.2} = 68$;

fringe separation corresponds to a change in thickness of $\frac{\lambda}{2}$;

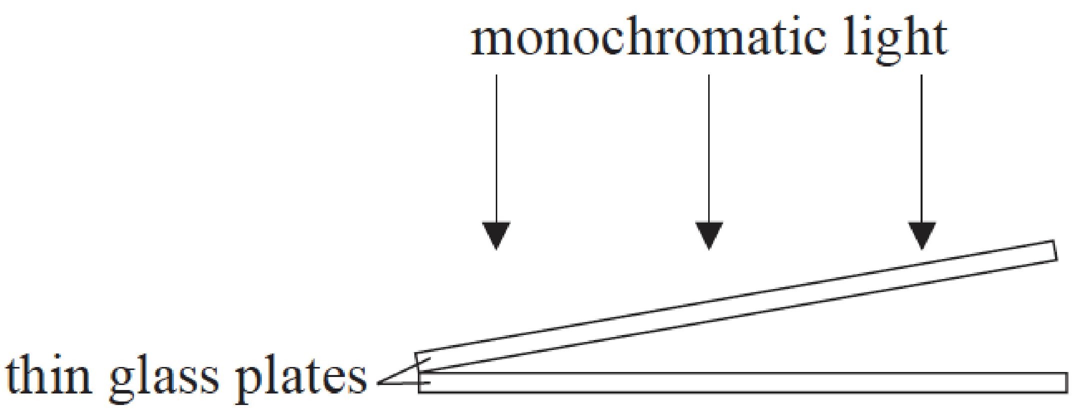
thickness of paper$= 68 \times \frac{590\times10^{-9}}{2} = 2.0 \times 10^{-5}\mathrm{m}$;

Examiners report

a. [N/A]
b. [N/A]

This question is about wedge films.

The diagram shows two thin glass plates used to form a thin air wedge.



A beam of monochromatic light is incident on the air wedge. The reflected light is observed through a microscope and a pattern of equally spaced parallel fringes is observed.

a. Outline how the fringes are formed. [3]

b. State and explain how the fringe separation changes if the angle of the wedge is increased slightly. [2]

Markscheme

a. fringes arise as a result of interference between light reflected from top and bottom plates;

there is a phase difference of π at bottom reflection;

hence constructive interference when $2d=(n+½)\lambda$ and destructive when $2d=n\lambda$;

b. the fringe separation would decrease;

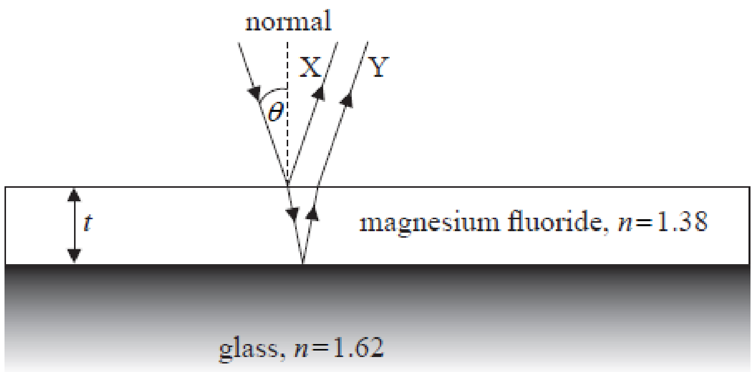
the distance between the points/places/positions where the light is in phase or antiphase would be shorter;

Examiners report

a. [N/A]
b. [N/A]

This question is about thin-film interference.

A piece of glass of refractive index 1.62 is covered with a thin film of magnesium fluoride of thickness *t* and refractive index 1.38. The diagram shows a ray of monochromatic light incident on the film at an angle θ to the normal.



X is a ray reflected from the surface of the film and Y is reflected from the surface of the glass.

a. Show that when $\theta=0$ the condition for destructive interference between rays X and Y is [2]

$$2t=(m+½)\lambda$$

where *m* is an integer and λ is the wavelength of light in the magnesium fluoride film.

b. Light of wavelength 640 nm in air is incident normally on the glass surface. [3]

(i) Show that the wavelength of light in the magnesium fluoride film is 464 nm.

(ii) Calculate the minimum thickness of the film for which no light will be reflected back into the air.

Markscheme

a. the path difference (at normal incidence) is 2*t*;

since there is phase change of π at both surfaces there is destructive interference if the path difference is half integral multiple of the wavelength;

and so $2t=(m+½)\lambda$

b. (i) $\lambda=\frac{\lambda_{\text{air}}}{n}=\frac{640}{1.38}$;

=464nm

(ii) $m=0 \Rightarrow t=\frac{\lambda}{4}$;
$t=\left(\frac{464}{4}=\right)116\text{nm}\approx 120\text{nm};$

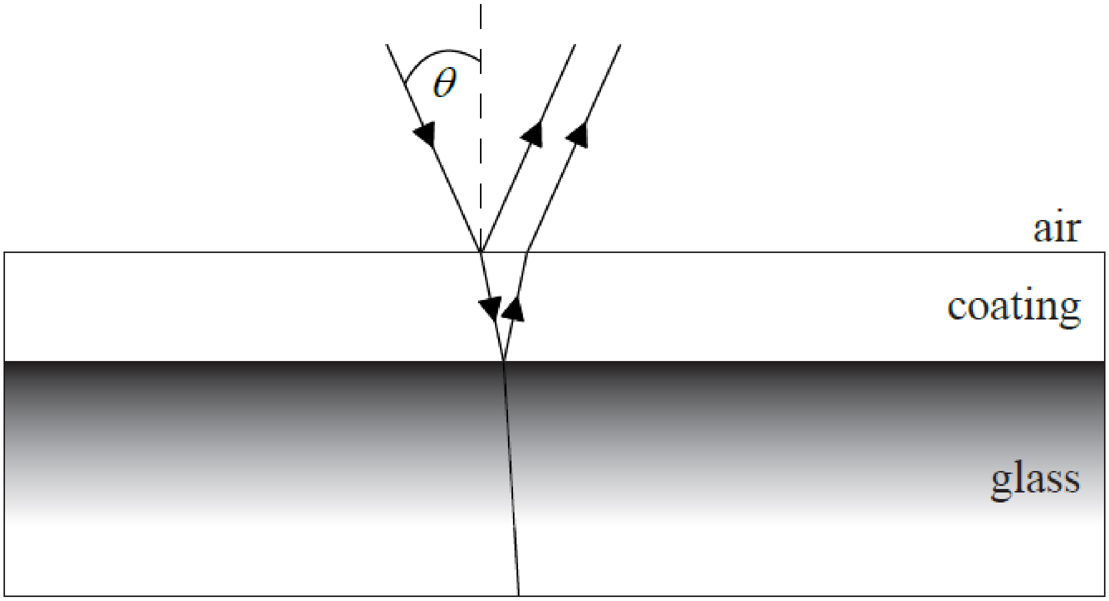
Examiners report

a.

b.

This question is about thin-film interference.

The anti-reflective coating of a lens consists of a thin layer of a suitable material placed between the air and the glass of the lens.



The following data are available.

Refractive index of air = 1.0
Refractive index of coating = 1.2
Refractive index of glass = 1.5

a. State what phase change occurs on reflection at the air-coating boundary and at the coating-glass boundary. [1]

b. The thickness *d* of the coating layer is 110 nm. [3]

Determine the wavelength for which there is no resultant reflection from the surface of the lens for light at normal incidence *(θ = 0°*).

Markscheme

a. 180° / *π;*

b. path difference must be $\frac{\lambda}{2}$;

physical thickness must be $\frac{\lambda}{2n}$;

so, maximum wavelength $\left(\text{is}\left[2nt=\left[m+\frac{1}{2}\right]\lambda\right]\to\lambda=4n_cd\right)=528\,(\text{nm})$;

Allow any valid alternative method.

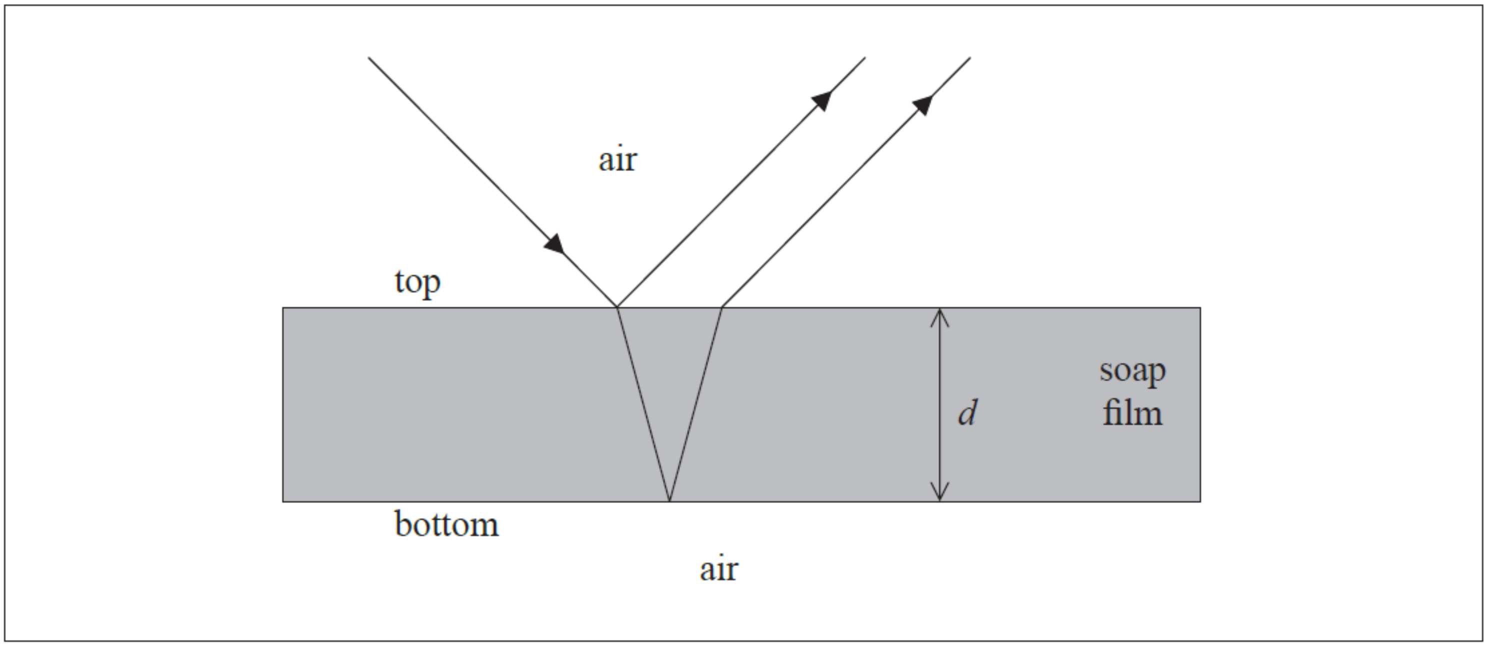
Examiners report

a. was well done in general

b. Was poorly understood. There were some good answers but many candidates omitted *n* or put *n* = 1 as in a diffraction grating.

This question is about thin-film interference.

a. A ray of monochromatic light is incident on a thin film of soap water that is suspended in air. The diagram shows the reflection of this ray from the top and bottom surfaces of the film. [1]



On the diagram, label, with the letter P, the point at which a phase difference of π occurs.

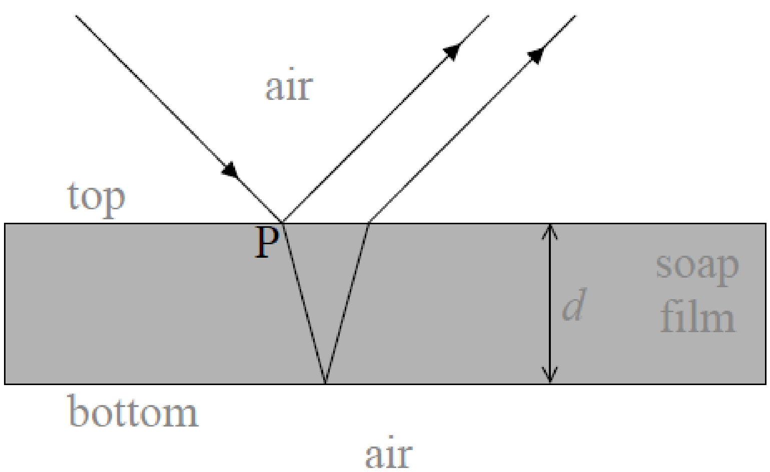
b. White light is incident normally on the soap film. The thickness d of the soap film is 225 nm and its refractive index is 1.34. [4]

(i) Show that the longest wavelength of light λ in air for which the reflected rays destructively interfere is 603 nm.

(ii) Explain why the soap film will appear coloured.

Markscheme

a.



P as shown;

b. (i) for destructive interference, use of $2\mu d = n\lambda$ to give $\lambda = 2\mu d$ (*ie* $n=1$);

$\lambda = 2 \times 1.34 \times 225$;

(603nm)

Answer given, look for correct working.

(ii) the reflected light is white minus the wavelengths that suffer destructive interference;
some colours are determined by the missing wavelengths;
some colours are enhanced due to constructive interference;

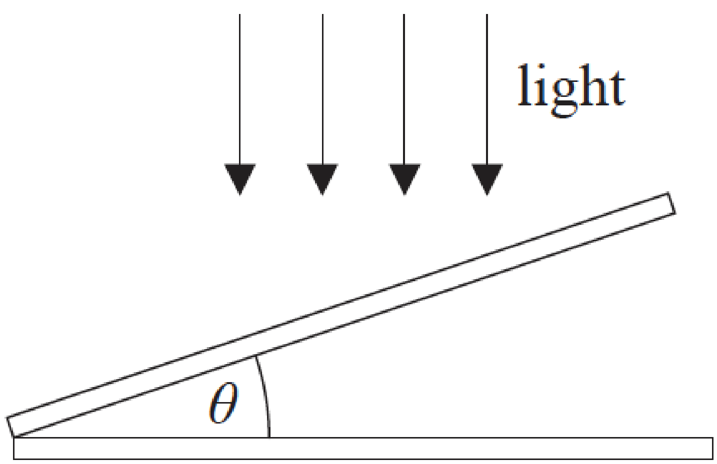
Examiners report

a. There is considerable uncertainty amongst candidates about the surface at which a phase change occurs on reflection.

b. (b)(i) was an easy two marks for most. However (b)(ii) was poorly answered. More often than not only refraction, diffraction or dispersion were mentioned - even though the G5 question was clearly indicated as being about thin film interference. It is very good practice for candidates to read the stem of the question carefully before starting, and to highlight key phrases or data.

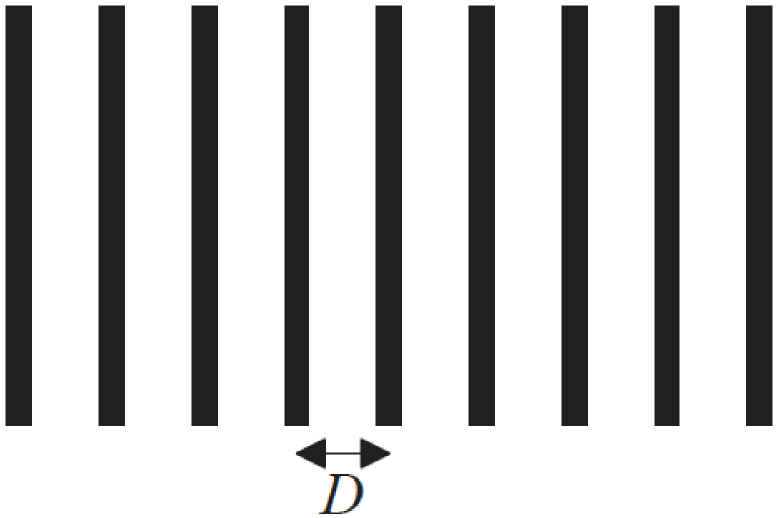
This question is about thin-film interference.

A thin air wedge consists of two flat glass plates that form an angle θ of 1.0×10^{-3}rad.



(not to scale)

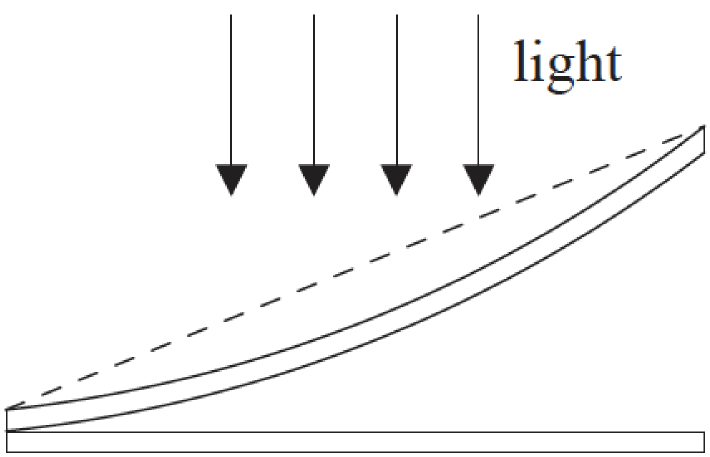
When illuminated with monochromatic light from above, the fringe pattern below is observed in the reflected light. The distance *D* between two consecutive fringes is 0.30mm.



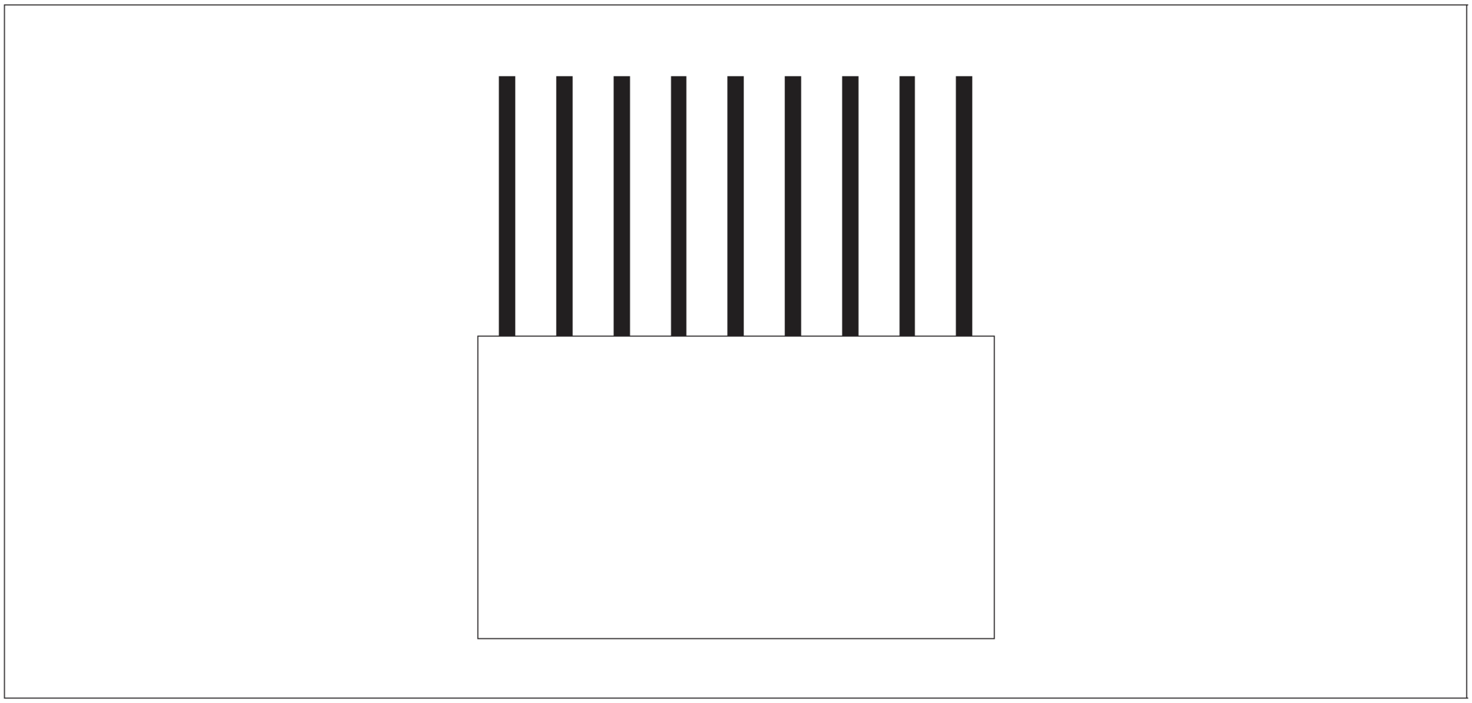
(not to scale)

a. Calculate the wavelength of the light. [2]

b. The upper glass plate is now replaced with a curved glass plate. The dotted line represents the upper glass plate used in (a). [2]



Sketch the new fringe pattern in the space below. The fringe pattern of (a) is given for comparison.



Markscheme

a. $\lambda = (2D\tan\theta =)\, 2 \times 0.30 \tan 10^{-3}$ ***or*** $2 \times 0.30 \sin 10^{-3}$;

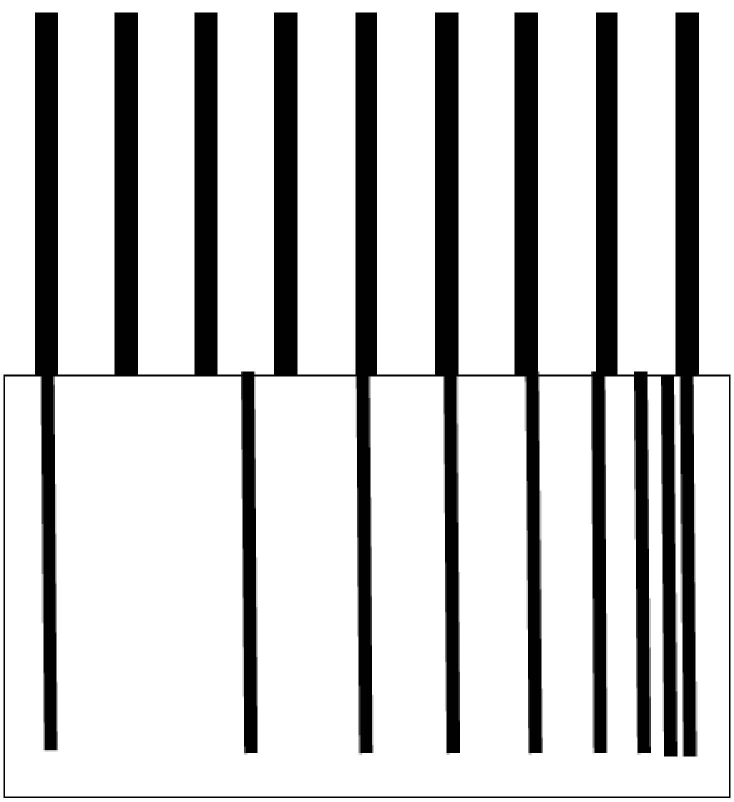
$\lambda = 6.0 \times 10^{-7}\,(\mathrm{m})$;

*Award **[1 max]** for use of degrees instead of radians giving* $\lambda = 1.0 \times 10^{-8}\,(\mathrm{m})$.

b. decreasing distance from left to right;

distance larger than original at left and shorter than original at right;

eg:



Examiners report

a. This part of syllabus does not appear to be well understood. Some candidates calculated the wavelength but many used the formula from the data booklet without explanation. Only a few analysed the situation well. Even the well prepared candidates had a problem with the radian angle unit. The majority of candidates found the change in shape of one of the plates very difficult. Only a few candidates realized that the number of fringes must not change.

b. This part of syllabus does not appear to be well understood. Some candidates calculated the wavelength but many used the formula from the data booklet without explanation. Only a few analysed the situation well. Even the well prepared candidates had a problem with the radian angle unit. The majority of candidates found the change in shape of one of the plates very difficult. Only a few candidates realized that the number of fringes must not change.