LF

i **Department of Physics**
Examination paper for TFY4195 Optics (Optikk)
Examination date: 2022-05-28
Examination time (from-to): 09.00 – 13.00
Permitted examination support material: All support material is allowed
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Technical support during examination: Orakel support services
Phone: 73 59 16 00

If you experience technical problems during the exam, contact Orakel support services as soon as possible before the examination time expires. If you don't get through immediately, hold the line until your call is answered.

OTHER INFORMATION

Do not open Inspera in multiple tabs, or log in on multiple devices, simultaneously. This may lead to errors in saving/submitting your answer.

Get an overview of the question set before you start answering the questions.

Read the questions carefully, make your own assumptions and specify them in your answer. If a question is unclear/vague – make your own assumptions and specify in your answer the premises you have made. **If you suspect that there are errors or insufficiencies in any of the questions, pls state and describe the details with text in the answer to question 1 (the long answer question).**

Cheating/Plagiarism: The exam is an individual, independent work. Examination aids are permitted, but make sure you follow any instructions regarding citations. During the exam it is not permitted to communicate with others about the exam questions or distribute drafts for solutions. Such communication is regarded as cheating. All submitted answers will be subject to plagiarism control. *Read more about cheating and plagiarism here.*

Specific for Optics exam: Note that most of the multiple choice questionsand answers are automatically scrambled so the question sets will be different to each student. Also the majority of the questions are selected from duplicates with different numerical values giving different answers (although difficulty level is the same).

Notifications: If there is a need to send a message to the candidates during the exam (e.g. if there is an error in the question set), this will be done by sending a notification in Inspera. A dialogue box will appear. You can re-read the notification by clicking the bell icon in the top right-hand corner of the screen. All candidates will also receive an SMS to ensure that nobody misses out on important information. Please keep your phone available during the exam.

Weighting and points: How the questions exactly are weighted should be shown on the at each question automatically in Inspera. Typically, the multiple choice/pairing questions gives 2 - 7p for each correct answer. There are no negative points for one question (but if multiple answers are needed, a wrong answer may induce a negative value. So only tick as many answers as asked for). The total number of points will be normalized to 100 (%) and graded with the scale for A, B, C, etc as outlined by NTNU recommendations.

ABOUT SUBMISSION

Answering in Inspera: If the question set contains questions that are not upload assignment, you must answer them directly in Inspera. In Inspera, your answers are saved automatically every 15 seconds.

Automatic submission: Your answer will be submitted automatically when the examination time expires and the test closes, if you have answered at least one question. This will happen even if you do not click “Submit and return to dashboard” on the last page of the question set. You can reopen and edit your answer as long as the test is open. If no questions are answered by the time the examination time expires, your answer will not be submitted. This is considered as “did not attend the exam”.

Withdrawing from the exam: If you become ill, or wish to submit a blank test/withdraw from the exam for another reason, go to the menu in the top right-hand corner and click “Submit blank”. This cannot be undone, even if the test is still open.

Accessing your answer post-submission: You will find your answer in Archive when the examination time has expired.

1 **For 10 free points, write something here:**

With a few sentences please indicate what you thought about this years version of the course, specifically around these issues:

a) What was the best part of the pensum/lectures?

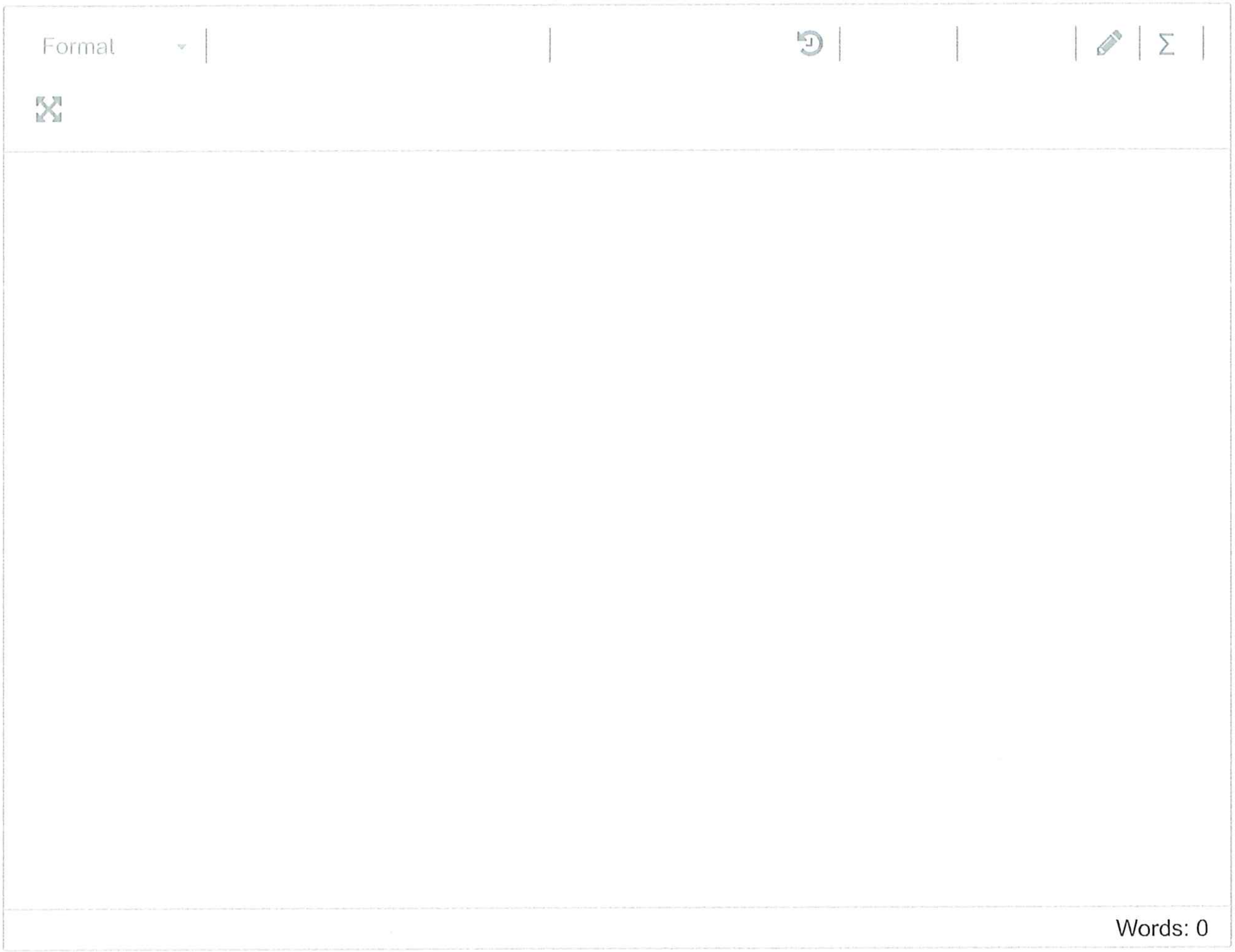
b) What parts can be improved?

c) Total workload. Do you feel the content was appropriate for a basic course in optics? Anything missing, in that case what?

c) How did the problem solving/assignments/labs balance in terms of workload? Pls indicate approximately how many hours /week you had to devote to the course on average throughout the semester.

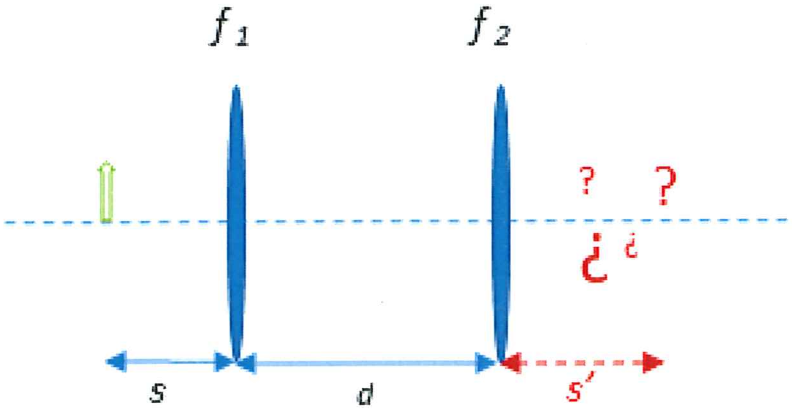
Errata: If you encounter or suspect there are errors or insufficiencies in your question set you may state those here (and it will be followed up after the exam).

Fill in your answer here



Maximum marks: 10

2 Two lenses are used to make an image of an object placed at a distance **s** from lens 1 as shown in the cartoon below. Where do you expect to to find the image (s') and what will the magnification (M_T) be? (recall the sign conventions that apply, and all length units are in cm.) Specifically, ***s = 6; d = 10;*** $f_1 = 15$; $f_2 = 10$.



USE THIN LENS LAW

$$\frac{1}{6} + \frac{1}{s_{i1}} = \frac{1}{15} \Rightarrow \frac{1}{s_{i1}} = \frac{1}{15} - \frac{1}{6} \Rightarrow s_{i1} = -10$$

SO, S_{o2} FOR $f_2 = d + 10 = 20$

$$\frac{1}{20} + \frac{1}{s_{i2}} = \frac{1}{10} \Rightarrow \frac{1}{s_{i2}} = \frac{1}{10} - \frac{1}{20} = \frac{1}{20} \Rightarrow \underline{s_{i2} = 20}$$

$$M_T = M_1 \cdot M_2 = -\left(\frac{s_{i1}}{6}\right)\left(-\frac{s_{i2}}{s_{o2}}\right) = \frac{10}{6} \cdot \left(-\frac{20}{20}\right) = \underline{-\frac{5}{3}}$$

Select two alternatives:

☑ $M_T = -5/3$

☐ $M_T = -2/3$

☐ $M_T = -3/5$

☐ s' = 6

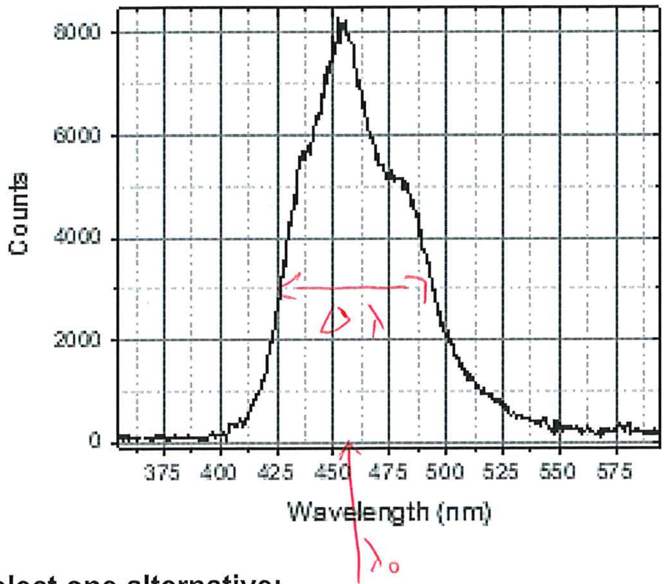
☐ s' = 2

☑ s' = 20

☐ $M_T = -3/2$

Maximum marks: 8

3 The plot shows the spectrum of a light source to be used in a Michelson interferometer experiment. What is the approximate coherence length of the source?



Select one alternative:

[✓ $3.4\mu m$]

○ $22\mu m$

○ $0.23mm$

○ $0.061mm$

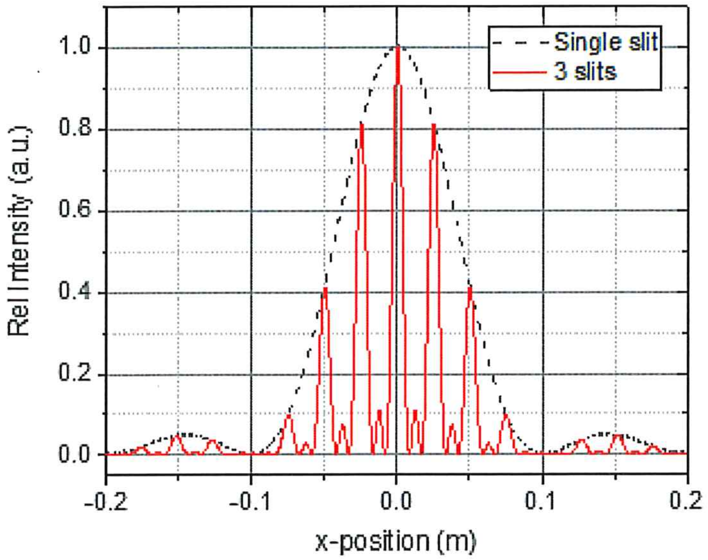
COHERENCE LENGTH IS CALCULATED USING $l_c = \frac{\lambda_0^2}{\Delta\lambda} \sim \frac{452^2}{60} \sim 3.4\cdot10^3$ nm

→ 3.4 μm

Maximum marks: 5

4 Marit is making multiple slit diffraction experiments with thin slits arranged vertically. On a screen some distance away (3 m) she records the diffraction patterns of a single slit and 3 slits, respectively, each being 13 μm thin. Based on the recorded diffraction patterns shown below for a single slit and the 3 slit arrangement:

1) What was the wavelength used? 2) What was the separation *a*, between the 3 slits?



THE DASHED ENVELOPE GIVES THE SMALLEST SLIT WIDTH

1st ZERO @ 0.1 m = y_m

FROM PEDROTTI Ch 11.1 & 11.6

distance

$$y_m = m \cdot \frac{\lambda \cdot f}{b}$$

m=1

width

$$\Rightarrow \lambda = \frac{y_m \cdot b}{f} \approx \frac{0.1 \cdot 13 \cdot 10^{-6}}{3}$$

~ 433 nm

Select two alternatives:

☑ $a = 52\mu m$

☐ $\lambda = 632nm$

☐ $a = 114\mu m$

☑ $\lambda = 439nm$

☐ $\lambda = 770nm$

☐ $a = 87\mu m$

THE SLIT SEPARATION WE GET FROM THE FINE STRUCTURE. 4TH MAXIMUM COINCIDES WITH $y_m \approx 0.1$

$$\rightarrow \frac{4\lambda}{a} = \sin\theta \simeq \tan\theta \simeq \frac{y_m}{f}$$

SMALL ANGLE APPROX

Maximum marks: 8

$$\Rightarrow a = \frac{4\lambda \cdot f}{y_m} = \frac{4 \cdot 433 \cdot 3 \cdot 10^{-9}}{0.1} \simeq 51.96 \mu m$$

~ 52 µm

5 Hildegunn is in the diffraction lab and just set up a Loyd double slit experiment using two thin slits ($10\mu m$) separated 0.20 mm. There is an eye safe laser available ($\lambda = 600nm$) with small divergence and an exit aperture which is unknown. By directing the laser beam towards a wall far away she notices the spot is circular. She wants to check the diameter of the laser aperture using the spatial coherence phenomenon.

Keeping the laser quite far away (some 1-2 meters) on a rail, and directing the beam onto the double slits, she observes clearly (by closing the room lights) the diffraction pattern as simulated on the preparation assignment. Bringing the laser closer to the double slit the diffraction pattern eventually fades away at approx. 24 cm from the double slit.

What was the diameter of the laser aperture?

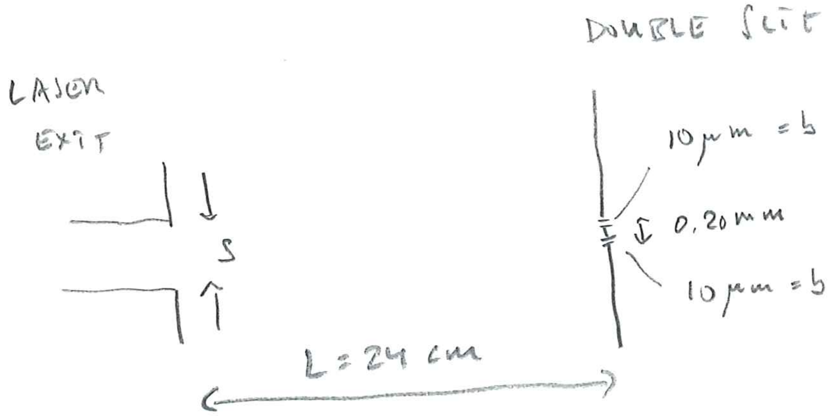
Select one alternative:

○ 0.25 mm

✓ 0.88 mm

○ 0.73 mm

○ 1.0 mm



Maximum marks: 5

SEE PEDROTTI CH 9-6.

USE $l_s \simeq \frac{L\cdot\lambda}{s}\cdot 1.22$ $\Rightarrow s = \frac{L\cdot\lambda\cdot 1.22}{l_s} = \frac{0.24\cdot 600\cdot 10^{-9}\cdot 1.22}{0.20\cdot 10^{-3}}$

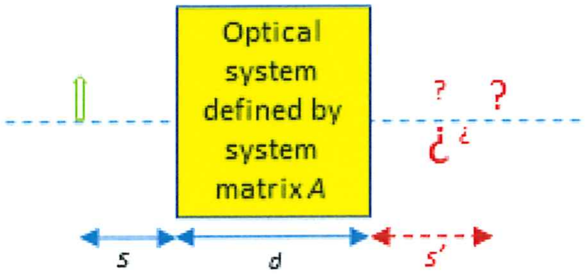
$\uparrow$ CIRCULAR APERTURE

$= 878\ \mu m$

~ 0.88 mm

6 An optical system is used to make an image of an object placed at a distance ***s*** = 6 from its entrance plane as shown in the cartoon below. Where do you expect to to find the image (s') and what will the magnification (M_T) be? The corresponding system matrix A (defined as in the Pedrotti book) is shown as an inset. (Recall the usual sign conventions that apply, and that all length units are in cm.)

$$A = \begin{pmatrix} -1/2 & 6 \\ -1/12 & -1 \end{pmatrix}$$



SET UP MATRICES

$$\begin{pmatrix} 1 & S_i \\ 0 & 1 \end{pmatrix}\begin{pmatrix} -\frac{1}{2} & 6 \\ -\frac{1}{12} & -1 \end{pmatrix}\begin{pmatrix} 1 & \overset{S_o}{6} \\ 0 & 1 \end{pmatrix}$$

$$\Downarrow$$

$$\begin{pmatrix} -\frac{1}{2} - \frac{S_i}{12} & 3 - \frac{3}{2}S_i \\ -\frac{1}{12} & -\frac{18}{12} \end{pmatrix}$$

gives M_T

$= 0 \rightarrow$ imaging

Select two alternatives:

☐ s' = 6

☐ M_T = -3/2

☐ M_T = -5/3

☑ s' = 2

☐ s' = 20

☑ M_T = -2/3

☐ M_T = -3/5

IMAGING CONDITION $3 - \frac{3}{2}S_i = 0 \Rightarrow S_i = 2$

Maximum marks: 8

$$M_T = -\frac{1}{2} - \frac{S_i}{12}\Bigg|_{S_i=2} = -\frac{2}{3}$$

7 An electromagnetic wave propagating in the vacuum is given by the expression:

$$\bar{E}(x,t) = \hat{y} \cdot E_0 \cos\left[4\pi \cdot 10^{14}\left(\frac{x}{c} + t\right)\right]$$

$$= \hat{y} \cdot E_0 \cos(k \cdot x \mp \omega t)$$

n.b. positive x-propagation

negative x-propagation

c is the speed of light and E_0 its electric field amplitude [V/m]. What is the wavelength and direction/strength of the magnetic field vector in relation to the electric field amplitude?

Select two alternatives:

IDENTIFY

$$\frac{4\pi \cdot 10^{14}}{c} = |k| = \frac{2\pi}{\lambda}$$

$$\Rightarrow \lambda = \frac{2\pi \cdot c}{4\pi \cdot 10^{14}} \simeq 1.5\mu m$$

☐ $\lambda = 1250nm$

☐ $\lambda = 1.0\mu m$

☑ $\lambda = 1.5\mu m$

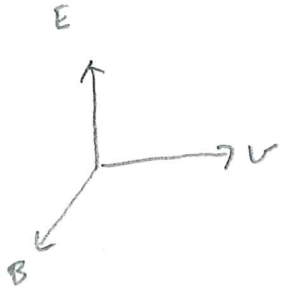
☐ $B\ field\ amplitude : \hat{y}(E_0/c)$

☐ $B\ field\ amplitude : \hat{z}(E_0/c)$

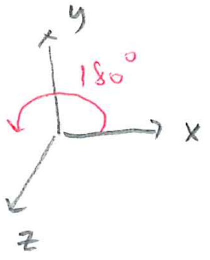
☐ $\lambda = 500nm$

☑ $B\ field\ amplitude : -\hat{z}(E_0/c)$

☐ $B\ field\ amplitude : -\hat{y}(E_0/c)$



RIGHT HAND-RULE



WAVE IS TRAVELLING IN NEG. DIRECTION, E_0 ALONG $\hat{y}$

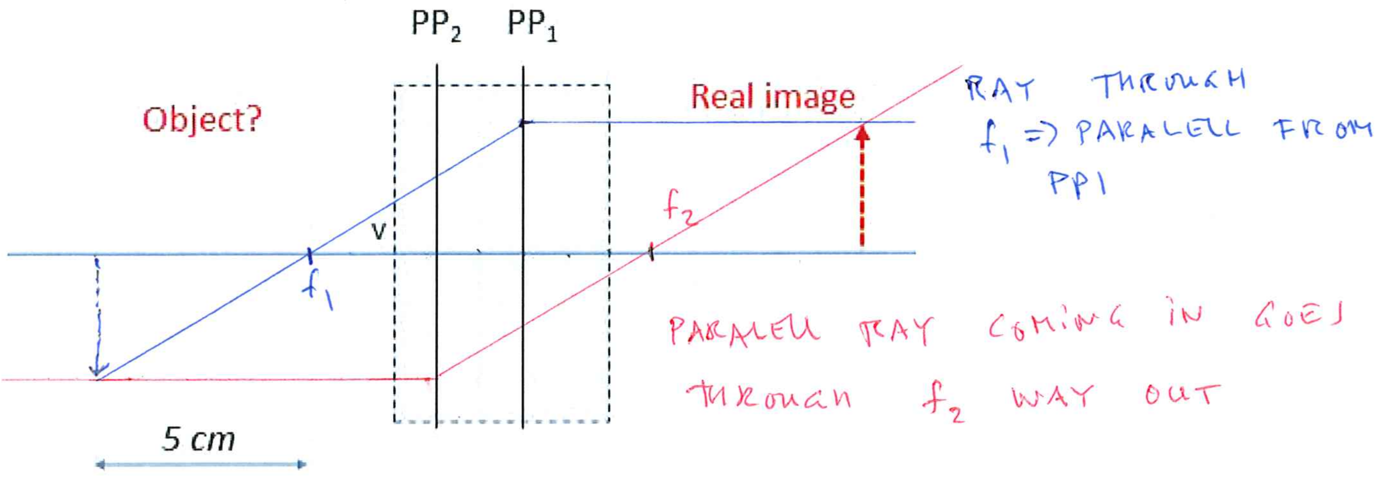
$\Rightarrow$ ROTATE 180° ABOUT $\hat{y}$

AND B WILL BE ALONG NEGATIVE $\hat{z}$.

Maximum marks: 6

8 The principal planes of an optical system (dashed rectangle) are indicated in the cartoon below. It is also known that the front and back focal lengths are 5 cm. Where should an object (real) be placed (**s_o**: distance to the input plane at 'V') in order to form a real image as shown in the picture? What is the transversal magnification, **M** ?

(The 5 cm arrow indicates the length scale.)



RAY THROUGH f_1 => PARALELL FROM PP1

PARALELL RAY COMING IN GOES THROUGH f_2 WAY OUT

GRAPHICALLY WE SEE $s_o = 7$ cm

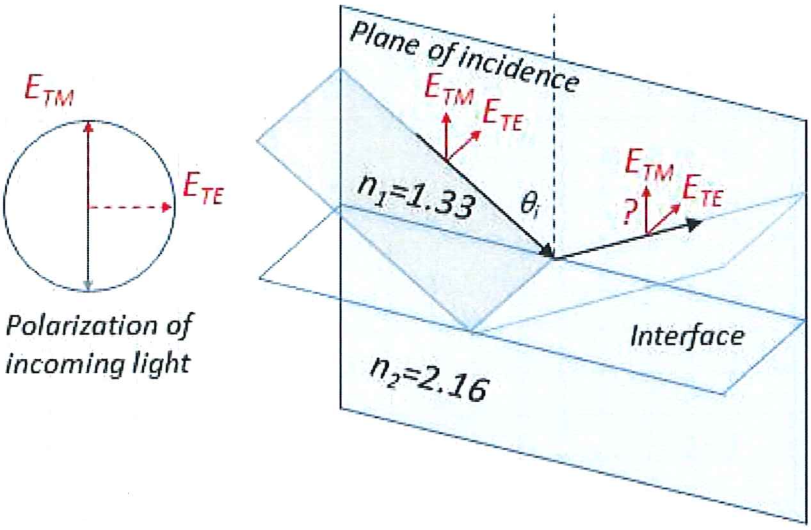
$M = -1$

Select two alternatives:

- ☑ **s_o** = 7 cm
- ☐ **s_o** = 3 cm
- ☐ M = +1
- ☐ M = +3/2
- ☐ **s_o** = 5 cm
- ☑ M = -1
- ☐ M = -3/2

Maximum marks: 8

9 An p-polarized laserbeam (TM-mode) is impinging onto a water - ZrO_2 (cubic phase) interface from the water side (see picture with essential refractive indices inserted). The angle of incidence $\boldsymbol{\theta_i}$ is 58.4°. What can you say about the fate of the laser light?



Select one alternative:

○ Essentially all light is reflected.

○ All transmitted light is circularly polarized.

○ All reflected light is circularly polarized.

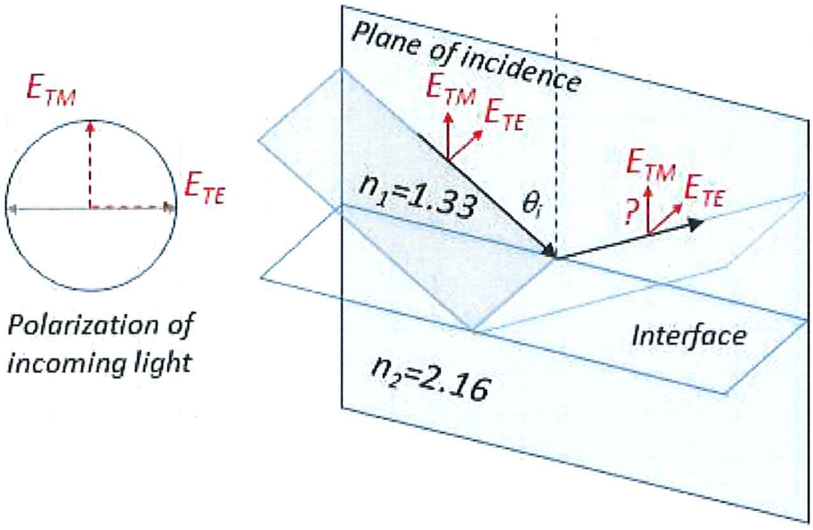
✓ Essentially no light is reflected.

FOR THE REFLECTION THERE IS THE BREWSTER ANGLE (POLARIZATION ANGLE). HENCE, NO P-POL (TM) IS REFLECTED.

$$\theta_B = \tan^{-1}\left(\frac{n_2}{n_1}\right) \simeq 58.4$$

Maximum marks: 4

10 An s-polarized laserbeam (TE-mode) is impinging onto water - ZrO_2 (cubic phase) interface from the water side (see picture with essential refractive indices inserted). The angle of incidence θ_i is 58.4°. What can you say about the fate of the laser light?



Select one alternative:

✓ Approx. 20% of the light is reflected.

○ All reflected light is circularly polarized.

○ All transmitted light is circularly polarized.

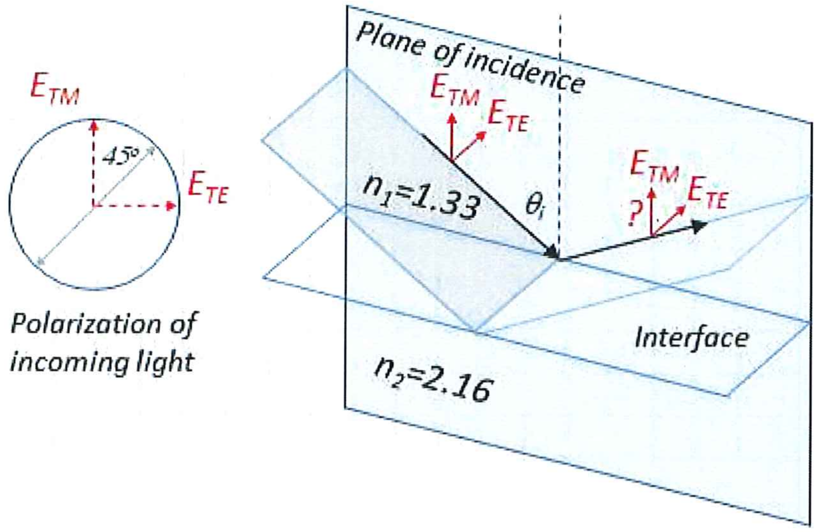
○ Essentially no light is reflected.

FOR s-polarized LIGHT THERE ARE NO RESTRICTION.

r_{TE} can be calculated from e.g. EQ 27-27 in PP GIVING $r_{TE}^2 \sim 0.20$

Maximum marks: 4

11 An 45°-polarized laserbeam is impinging onto a water - ZrO_2 (cubic phase) interface from the water side (see scheme with essential refractive indices inserted). The angle of incidence θ_i is 38.0°. What can you say about the fate of the laser light?



Select one alternative:

USE EXCLUSION PRINCIPLE

☑ All reflected light is linearly polarized.

○ Essentially all light is reflected. ← NO, NO TOTAL REFL. OR S-WAVE (TE)

○ Essentially no light is reflected. ← NO, BREWSTER LAW ONLY FOR P-WAVE (TM)

○ All transmitted light is circularly polarized. ← NO, NO PHASE-SHIFT IF NOT TOTAL INTERNAL REFLECTION

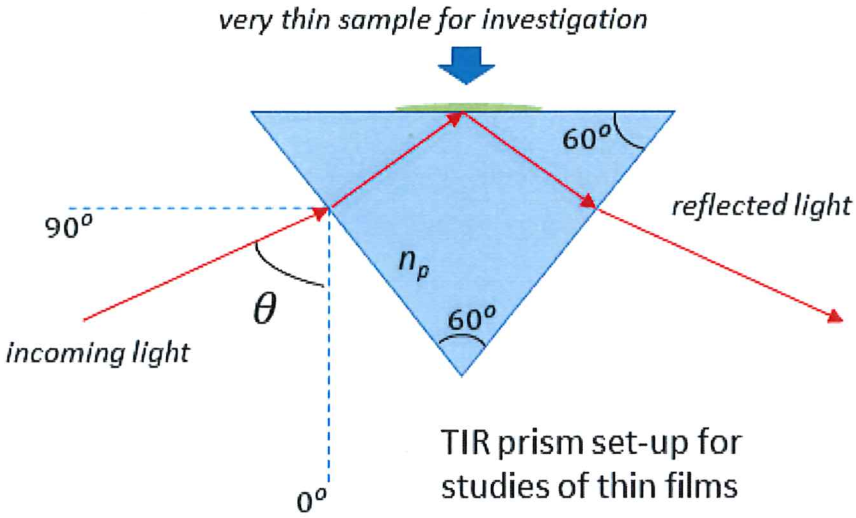
Maximum marks: 4

23-27 GIVE RELATION

23-28 $\frac{r_{TE}}{r_{TM}}$ BUT LIGHT STILL LINEARLY POLARIZED

12 Victoria is designing a total internal reflection (TIR) set-up using a prism for investigation of very thin films (thickness < 50 nm) as shown in the picture. Upon total internal reflection of unpolarized laser light ($\lambda = 633nm$) the evanescent field at the top surface of the prism can sense a thin layer of sample. She wants to design a rotation arrangement but need to know exactly at what incident angles (defined as θ in the figure below) the impinging light will experience total internal reflection inside the prism at the sample. Specifically, what will be the useful TIR angles θ in the range 0 - 90° ?

The refractive index of the prism, n_p = 1.50. The surroundings can be considered to be air, n = 1.00 (as the sample is very thin).



TIR prism set-up for studies of thin films

Select one alternative:

○ 0° - 41.81°

○ 41.81° - 60°

○ 28.29° - 90°

✓ 32.08° - 90°

○ 24.43° - 90°

Maximum marks: 7

IF THE ANGLE θ IS SMALLER THAN SOME ANGLE θ_c THERE IS NO TIR IN THE PRISM.

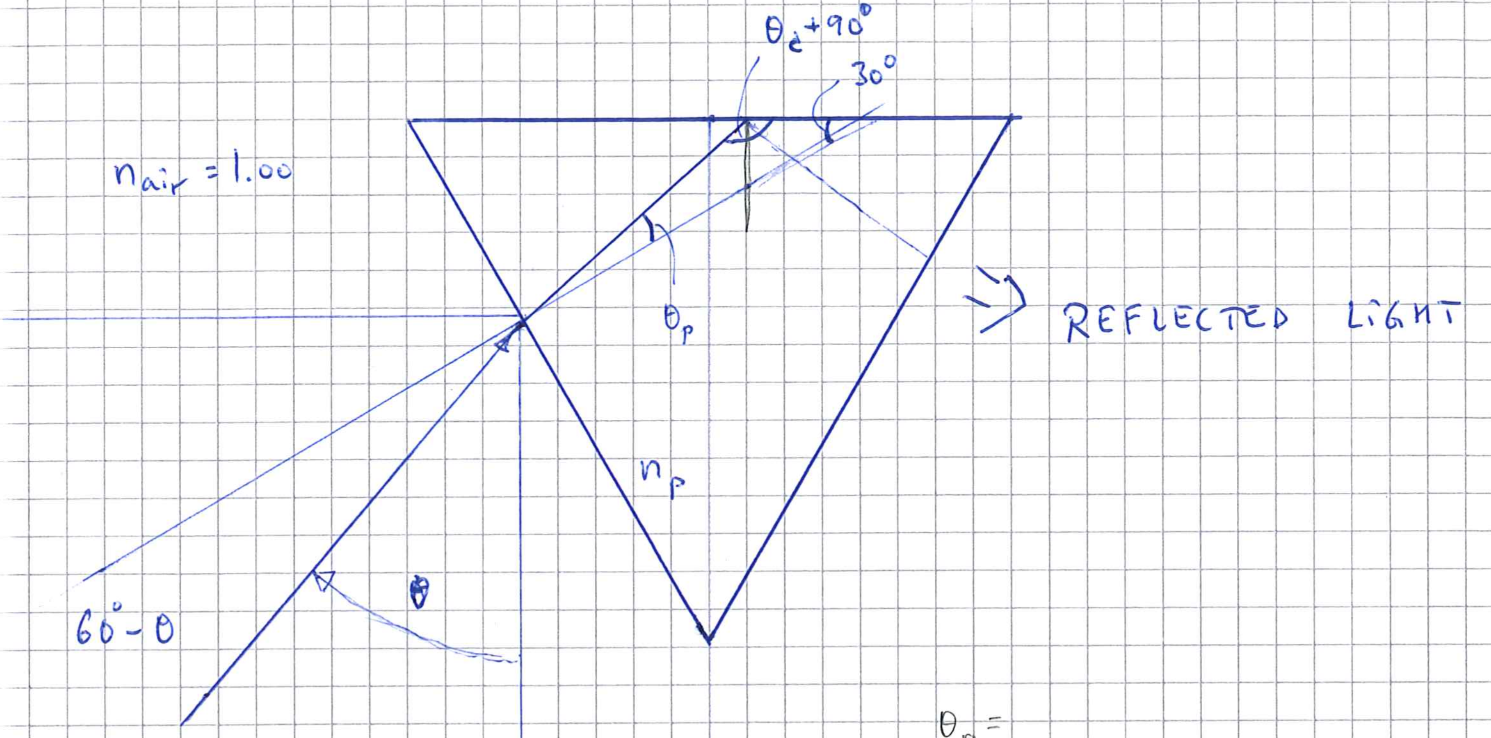
HENCE, INTERVAL WILL BE $\theta_c \rightarrow 90°$

$n_p = 1.50 \Rightarrow \theta_c = 32.08° \rightarrow 90°$

$\left(\begin{array}{l} n_p = 1.55 \Rightarrow \theta_c = 28.29° \\ n_p = 1.60 \Rightarrow \theta_c = 24.432° \end{array} \right)$ OTHER VARIANTS

SEE FULL SOLUTION ⇒

12 CONT.



$\theta_p =$

$1 \cdot \sin(60° - \theta) = n_p \cdot \sin\theta_p$

$\theta_p + \theta_c + 90° + 30° = 180° \Rightarrow \theta_p + \theta_c = 60° \Rightarrow \theta_p = 60° - \theta_c$

$\theta_c = \sin^{-1}\left(\frac{1}{n_p}\right)$ DEFINING CRITICAL ANGLE FOR TIR INSIDE PRISM

$\therefore \sin(60° - \theta) = n_p \cdot \sin(60° - \theta_c) = n_p \cdot \sin\left(60° - \sin^{-1}\left(\frac{1}{n_p}\right)\right)$

$60° - \sin^{-1}\left(n_p \cdot \sin\left(60° - \sin^{-1}\left(\frac{1}{n_p}\right)\right)\right) = \theta$

CRITICAL ANGLE DEFINED AS Θ

1.5 $\underbrace{\underbrace{\underbrace{}_{41.81°}}_{18.19°}}_{0.468254}$ $\underline{\underline{32.08° = \Theta_c}}$

(1.6 $\underbrace{}_{38.682°}$ 21.3178 $24.432 = \Theta_c$)

$\underbrace{}_{40.18°}$ 19.8222

(1.55 $28.29 = \Theta_c$)

12. CONT

$$n_p \sin 60^\circ = n_\ell \Rightarrow n_p = \sin^{-1} 60^\circ = 1.1547$$

	INTERN	
n_p	θ_c	θ
1.5	41.81	32.079
1.55	40.18	28.29
1.60	38.68	24.43
1.1547	60°	60°

CHECK →

$$\theta = 60^\circ - \sin^{-1}\left\{n_p \cdot \sin\left(60^\circ - \sin^{-1}\left(\frac{1}{n_p}\right)\right)\right\}$$

FOR MATLAB ,

$$\theta = 180\left(\frac{\pi}{3} - \sin^{-1}\left\{n_p \cdot \sin\left(\frac{\pi}{3} - \sin^{-1}\left(\frac{1}{n_p}\right)\right)\right\}\right)/\pi \quad [\text{DEG}]$$

13 Please match the scientists with the description of their best known achievement.

2p for each correct answer. -1p for each wrongly checked answer.

	 Carl Freidrich Gauss 1777 - 1855	 James Clerk Maxwell 1831 - 1879
Postulated the time-varying 'displacement current', to complete the magnetic curl equation and ultimately resulting in a unifying theory of electromagnetism.	○	✓
Pioneer in the understanding of induction, describing the relation between time-varying magnetic and electric fields.	○	○
Made the first contemporary book on optics including phenomena of imaging, reflexions, refractions, diffraction and Colors..	○	○
One of the first distinguished mathematicians that also rediscovered and become famous for the law of refraction for light at interfaces.	○	○
Made important development in the description of lenses and imaging, but most famous for his mathematical ground-work paving the way for electromagnetics.	✓	○

Maximum marks: 4

14 Please match the scientists with the description of their best known achievement.

2p for each correct answer. -1p for each wrongly checked answer.

	 Isaac Newton 1643 - 1727	 Willebrord Snellius 1580-1626
One of the first distinguished mathematicians that also rediscovered and become famous for the law of refraction for light at interfaces.	○	✓
Postulated the time-varying 'displacement current', to complete the magnetic curl equation and ultimately resulting in a unifying theory of electromagnetism.	○	○
Made important development in the description of lenses and imaging, but most famous for his mathematical ground-work paving the way for electromagnetics.	○	○
Explained the laws of refraction by the *principle of least time,* but perhaps mostly know as mathematician for his 'last theorem'	○	○
Made the first contemporary book on optics including phenomena of imaging, reflexions, refractions, diffraction and Colors..	✓	○

Maximum marks: 4

15 A photon emitted from a photochemical process has the energy 1.5 eV. What is the corresponding approximate wavelength in nanometers?

Select one alternative:

- ○ 622 nm
- ✓ 829 nm
- ○ 497 nm
- ○ 414 nm
- ○ 355 nm

1.5 eV => 829 nm

OTHER VARIANS → (2.5 eV => 497 nm)

→ (3.5 eV => 355 nm)

$$E = h\nu = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{hc}{e \cdot E}$$

JOULE

eV

Maximum marks: 5

16 An array of red LEDs (light emitting diodes) operating at 640 nm is used in a 'darkroom' for UV-sensitive cell cultures. The output power is 150 w. The array is arranged in a circular plane, covered by a plastic transparent (for red light) plastic shield, and can be considered to emit light in a homogeneous half-sphere, see figure. What is the resulting radiant intensity (I_e) for the illumination source?

$$I_e = \frac{P}{\Omega}$$

← POWER

SOLID ANGLE

FULL SPERE => $\Omega = 4\pi$

$\frac{1}{2}$ —"— => $\Omega = 2\pi$

$\therefore \frac{P}{2\pi}$

Select one alternative:

- ○ 31.8 W/Sr
- ✓ 23.9 W/Sr
- ○ 7.95 W/Sr
- ○ 15.9 W/Sr

OTHER VARIANTS

(100 W => 15.9 W/Sr)

(50 W => 7.95 W/Sr)

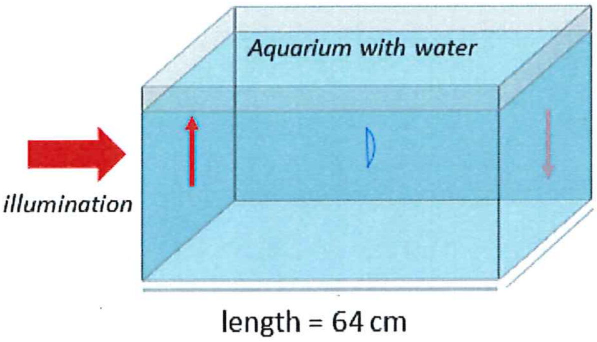
150 W => 23.9 W/Sr

(200 W => 31.8 W/Sr)

Maximum marks: 5

17 Miriam is doing some optical experiments with her old aquarium (see scheme below). She found a relatively thin plano-convex lens with the inscription 'n = 1.750', which we may assume is the refractive index of the glass material. Placing the lens in the middle of the aquarium she discovers that any object illuminated on either of the surfaces on the short sides of the aquarium, is forming a real image with the same size on the other side - but inverted.

If the refractive index of the water is taken to be 4/3, what is the radius of curvature of the non-flat side of the lens? (N.b. the lens is not drawn to scale.)



Select one alternative:

○ 2.5 cm

✓ 5 cm

○ 10 cm

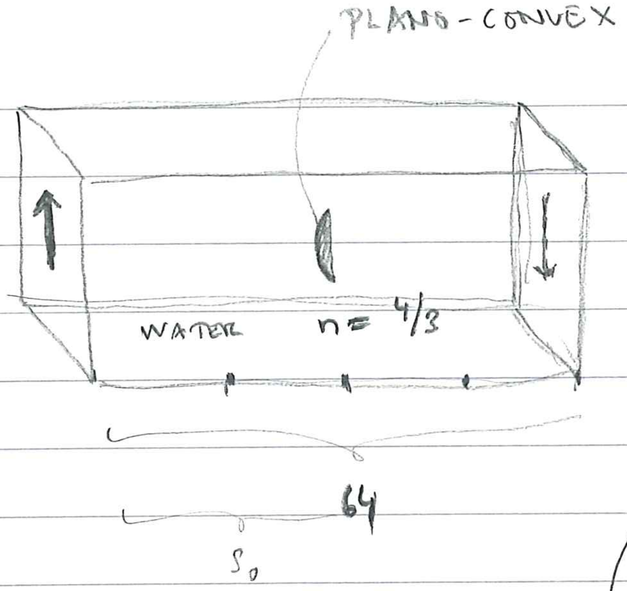
○ 16 cm

○ 8 cm

SEE DETAILS →

Maximum marks: 5

LF (19)



GIVING SAME SIZE
BUT INVERTED

FOR THE IMAGING CONDITION $S_o = 2f$ $\Rightarrow f = 16$ cm
GIVING INVERTED IMAGE AT $S_o = S_i$

LENS MAKER FORMULA (CHECK PP)

$$\frac{1}{f} = \frac{n_L - n_W}{n_W} \cdot \frac{1}{R}$$

$$\frac{1}{16} = \frac{7/4 - 4/3}{4/3} \cdot \frac{1}{R}$$

$$\frac{1}{16} = \frac{\frac{21}{12} - \frac{16}{12}}{\frac{4}{3}} \cdot \frac{1}{R}$$

$$\frac{1}{16} = \frac{\frac{5}{12}}{\frac{4}{3}} \cdot \frac{1}{R} \Rightarrow \frac{R}{16} = \frac{15}{4 \cdot 12} = \frac{5 \cdot 3}{4 \cdot 12}$$

$$R = \frac{5 \cdot 3 \cdot 16}{4 \cdot 12} = \frac{5 \cdot \cancel{3} \cdot \cancel{4} \cdot \cancel{4}}{\cancel{4} \cdot \cancel{4} \cdot \cancel{3}} = 5 \text{ cm}$$