LF

Department of Physics
Examination paper for TFY4195 Optics (Optikk)
Examination date: 2021-05-20
Examination time (from-to): 09.00 – 13.00
Permitted examination support material: All support material is allowed
Academic contact during examination: Prof. Mikael Lindgren
Phone: 41466510

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

If a question is unclear/vague – make your own assumptions and specify in your answer the premises you have made. Only contact academic contact in case of errors or insufficiencies in the question set.

Saving: Answers written in Inspera are automatically saved every 15 seconds. If you are working in another program remember to save your answer regularly.

Cheating/Plagiarism: The exam is an individual, independent work. Examination aids are permitted. All submitted answers will be subject to plagiarism control. *Note that the multiple choice questions 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 3 - 5p for each correct answer. There are no negative points. 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.

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 25 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:

How do you find the assignments using computer as a part of the pensum?

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

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.

Fill in your answer here

Format

WRITE ANYTHING

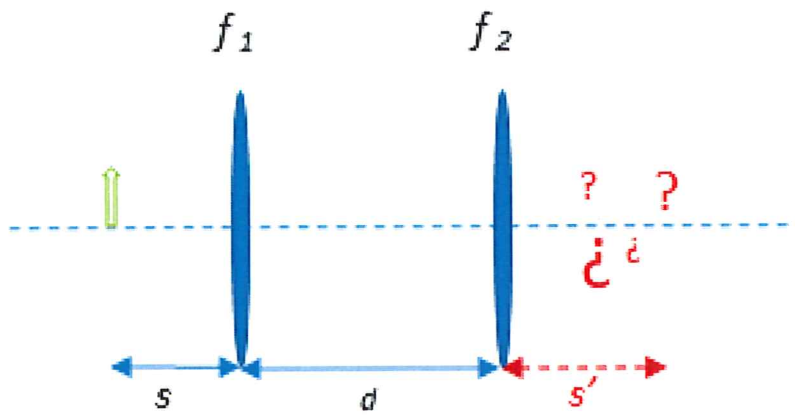
~~> GET POINTS

10 POINTS V2022

Words: 0

Maximum marks: 25

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* = 6; *f*$_1$ = 4; *f*$_2$ = 3.**



Select two alternatives:

- [ ] M_T = -5/3
- [x] M_T = -2/3
- [ ] M_T = -3/2
- [ ] M_T = -3/5
- [x] s' = 2
- [ ] s' = 20
- [ ] s' = 6

$$\frac{1}{6} + \frac{1}{s_{i1}} = \frac{1}{4} \Rightarrow \frac{1}{s_{i1}} = \frac{1}{4} - \frac{1}{6} = \frac{3-2}{12} = \frac{1}{12}$$

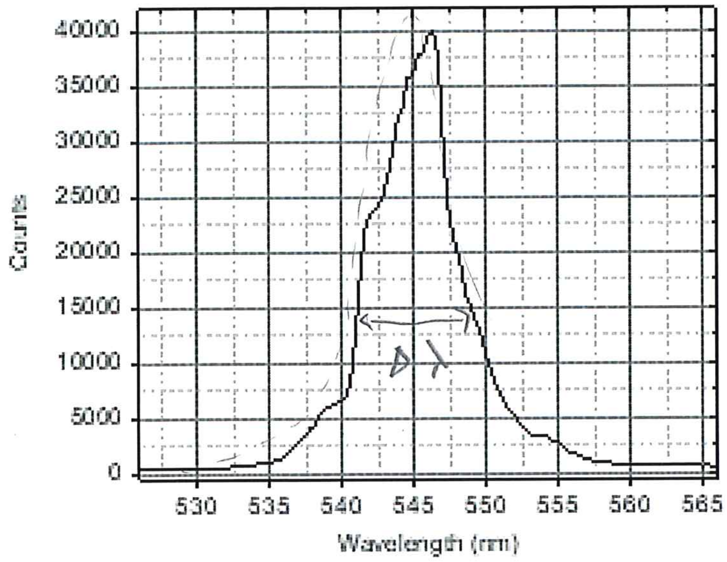
$$s_{i1} = 12 \quad \Rightarrow \quad s_{o2} = 6 - 12 = -6$$

$$-\frac{1}{6} + \frac{1}{s_{i2}} = \frac{1}{3} \Rightarrow \frac{1}{s_{i2}} = \frac{1}{3} + \frac{1}{6} = \frac{3}{6} \Rightarrow \underline{s_{i2} = 2}$$

$$M_T = \left(-\frac{s_{i1}}{s_{o1}}\right)\left(-\frac{s_{i2}}{s_{o2}}\right) = \left(-\frac{12}{6}\right)\left(-\left(\frac{2}{-6}\right)\right) = -\frac{24}{36} = -\frac{2}{3}$$

Maximum marks: 6

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?



↑ $\lambda_0 = 545$ $\Delta\lambda \approx 9.5$ $l_c = \frac{\lambda_0^2}{\Delta\lambda} = \frac{(545)^2}{9.5}$ nm

$\simeq 31 \cdot 10^5$ nm $= 0.031$ mm

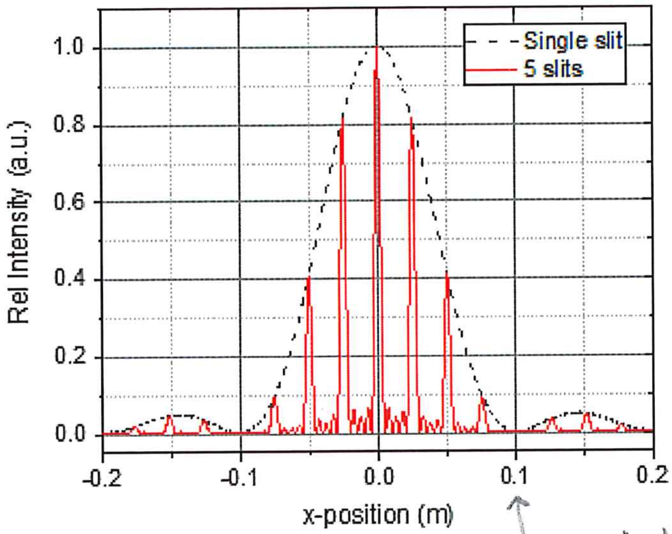
Select one alternative:

- ○ 3.4μm
- ○ 0.23mm
- ○ 22μm
- ✓ 0.031mm

Maximum marks: 4

4 Marit is making multiple slit diffraction experiments with thin slits arranged vertically. On a screen some distance away (3.5 m) she records the diffraction patterns of a single slit and 5 slits, respectively, each being 19 µm thin. Based on the recorded diffraction patterns shown below for a single slit and the 5 slit arrangement:

1) What was the wavelength used? 2) What was the separation *a*, between the 5 slits?



Multiple slit formula

$$I = I_0 \cdot \left(\frac{\sin\beta}{\beta}\right)^2 \left(\frac{\sin N\alpha}{\sin\alpha}\right)^2$$

↑ Diffraction ↑ INTERFERENCE

1st diffraction minima given by N=1 and here, m=1

SMALL ANGLE APPROX PERMIS ON

$m \cdot \lambda = b \cdot \sin\theta \sim b \tan\theta \sim b \cdot \frac{y_m}{f}$

$\Rightarrow \lambda = 19 \mu m \cdot \frac{0.1 \ m}{3.5 \ m} = 0.543 \mu m \sim 550 \ nm$

Select two alternatives:

- [ ] $\lambda = 439nm$
- [x] $\lambda = 550nm$
- [x] $a = 76\mu m$
- [ ] $a = 114\mu m$
- [ ] $a = 52\mu m$
- [ ] $\lambda = 770nm$

FOR THE FINE STRUCTURE, FORTH MINIMA ZERO @ 0.1

$(N-1)\lambda = (5-1)\lambda = 4\lambda = a \cdot \frac{y_m}{f} \Rightarrow a = \frac{4\lambda f}{y_m} = 76 \ \mu m$

Maximum marks: 6

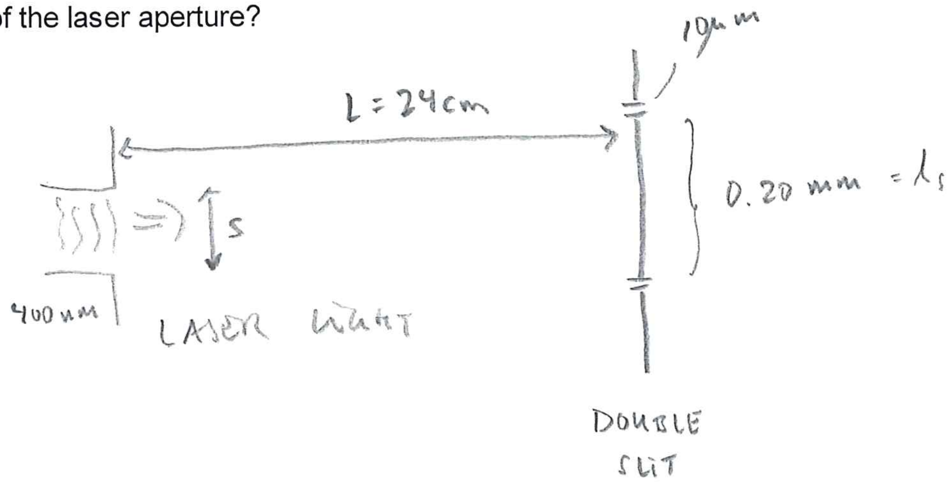
5 Hildegunn is in the diffraction lab and just set up a Loyd double slit experiment using two thin slits ($10\mu m$) separated 0.20 mm. There is an eye safe laser available ($\lambda = 400nm$) with small divergence and an exit aperture which is unknown. By directing the laser beam towards a wall far 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:

- ○ 1.0 mm
- ○ 0.88 mm
- ○ 0.73 mm
- ✓ 0.59 mm



Maximum marks: 4

FOR SPATIAL COHERENCE LIMIT

$$l_s = \frac{L \cdot \lambda}{s} \cdot 1.22 = 0.20 \text{ mm}$$

↑ circular aperture

$$s = \frac{L \cdot \lambda \cdot 1.22}{0.20 \text{mm}} = \frac{0.24 \cdot 400 \cdot 10^{-9} \cdot 1.22}{0.2 \cdot 10^{-3}} = 5.86 \cdot 10^{-4} \text{ m}$$

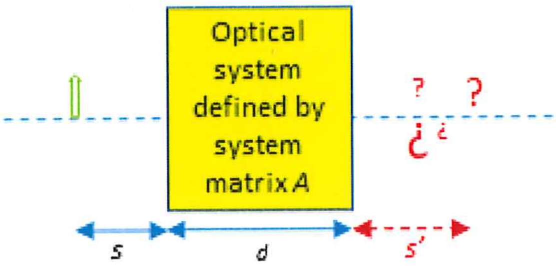
~ 0.59 mm

↑ Make all meter [m]

$s = 2$

6 An optical system is used to make an image of an object placed at a distance ***s*** 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.)

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



Select two alternatives:

- [ ] s' = 2
- [ ] M_T = -3/5
- [x] M_T = -3/2
- [ ] s' = 20
- [ ] M_T = -5/3
- [x] s' = 6
- [ ] M_T = -2/3

$$\begin{pmatrix} 1 & s_i \\ 0 & 1 \end{pmatrix}\begin{pmatrix} -1 & 6 \\ -\frac{1}{12} & -\frac{1}{2} \end{pmatrix}\begin{pmatrix} 1 & 2 \\ 0 & 1 \end{pmatrix} =$$

$$\begin{pmatrix} 1 & s_i \\ 0 & 1 \end{pmatrix}\begin{pmatrix} -1 & 4 \\ -\frac{1}{12} & -\frac{2}{3} \end{pmatrix} =$$

$$\begin{pmatrix} -1-\frac{s_i}{12} & 4-\frac{2s_i}{3} \\ -\frac{1}{12} & -\frac{2}{3} \end{pmatrix}$$

Maximum marks: 6

$=0$ GIVES s_i $\quad 4 = \frac{2s_i}{3} \Rightarrow s_i = \frac{12}{2} = 6$

Gives M_T $\quad -1-\frac{6}{12} = -\frac{3}{2}$

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

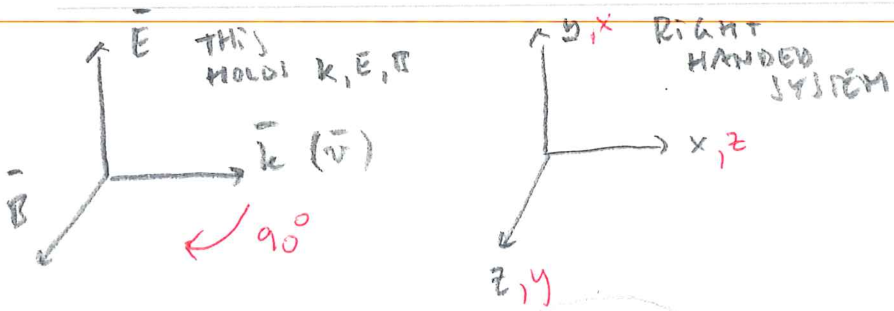
$$\bar{E}(y,t) = \hat{x} \cdot E_0 \cos\left[8\pi \cdot 10^{14}\left(\frac{y}{c} - t\right)\right]$$

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:

- ☐ $\lambda = 500\text{nm}$
- ☐ $\lambda = 1.0\mu\text{m}$
- ☐ B field amplitude : $\hat{z}(E_0/c)$
- ☐ B field amplitude : $-\hat{y}(E_0/c)$
- ☑ B field amplitude : $-\hat{z}(E_0/c)$
- ☐ B field amplitude : $\hat{y}(E_0/c)$
- ☐ $\lambda = 1.5\mu\text{m}$
- ☑ $\lambda = 750\text{nm}$

Maximum marks: 4



TO GET $\bar{B}$ ROTATE 90° SO $\bar{k}$ IS ALONG y, THEN $\bar{B}$ WILL BE IN NEG $-\hat{z}$

$\bar{E}(y,t) = \hat{x} \cdot E_0 \cos\left[8\pi \cdot 10^{14}\left(\frac{y}{c} - t\right)\right]$

$\frac{\omega}{c}$ — propagates along $\hat{y}$

IDENTIFY

$\frac{\omega}{c} = k = \frac{2\pi}{\lambda} = \frac{8\pi \cdot 10^{14}}{3 \cdot 10^8} \Rightarrow \lambda = \frac{3}{4} \cdot 10^{-6} = 750\text{ nm}$

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

$$\bar{E}(x,t) = -\hat{z} \cdot E_0 \cos\left[6\pi \cdot 10^{14}\left(\frac{x}{c} - t\right)\right]$$

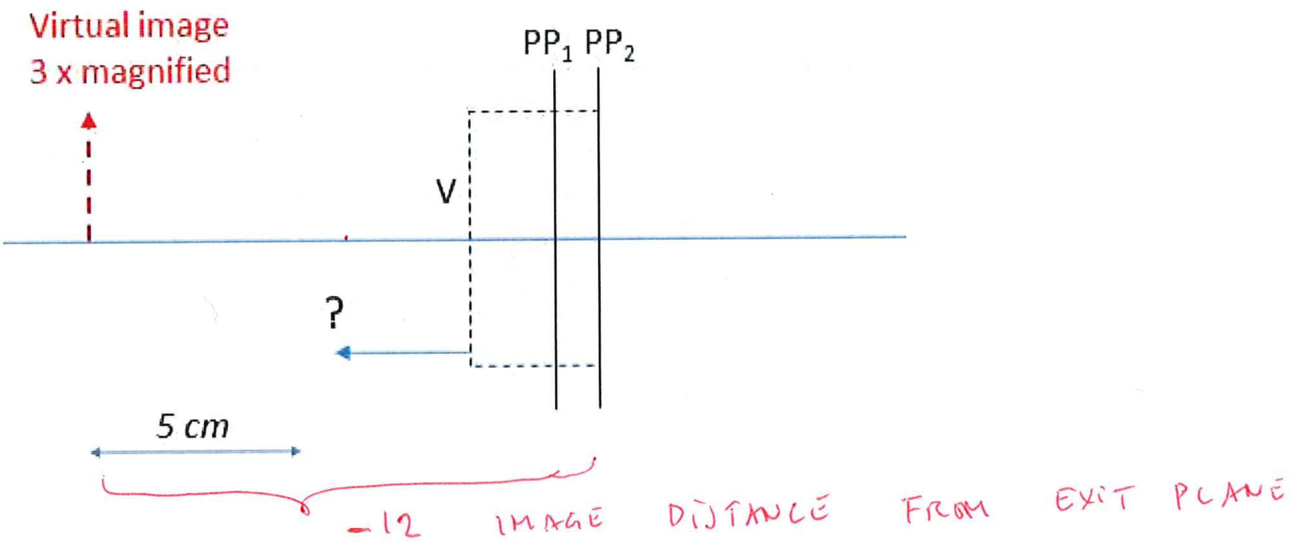
c is the speed of light and E_0 its electric field amplitude [V/m]. What is the wavelength and direction/strength of the magnetic field vector in relation to the electric field amplitude?

Select two alternatives:

- [ ] $\lambda = 500\text{nm}$ SOLVE AS PROBLEM 7.
- [ ] $\lambda = 750\text{nm}$
- [x] $\lambda = 1.0\mu\text{m}$
- [ ] $\lambda = 1.5\mu\text{m}$
- [ ] B field amplitude : $-\hat{y}(E_0/c)$
- [ ] B field amplitude : $-\hat{z}(E_0/c)$
- [ ] B field amplitude : $\hat{z}(E_0/c)$
- [x] B field amplitude : $\hat{y}(E_0/c)$

Maximum marks: 4

9 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 6 cm. Where should an object be placed (with reference to the input plane at 'V') in order to form a virtual image 3 times magnified, as shown in the picture. (The 5 cm arrow indicates the length scale.)



Select one alternative:

- ○ 5 cm
- ○ 4 cm
- ○ 1 cm
- ○ 3 cm
- ✔ 2 cm

USE RAY TRACE BY "TRIAL AND ERROR"

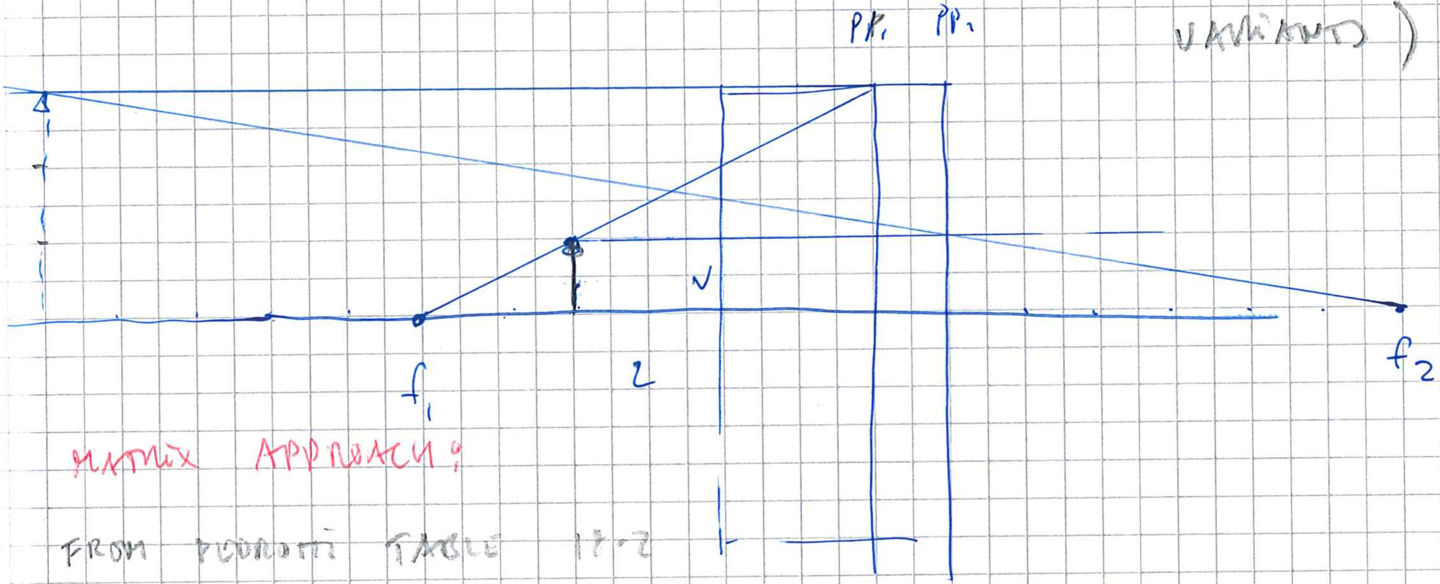
OR USE MATRIX APPROACH WITH $s_i = -12$

Maximum marks: 8

SEE NEXT → PAGE

LF 9.

RAY-TRACING SOLUTION (JUST TRY THE REASONABLE VARIANTS)



MATRIX APPROACH:

FROM PEDROTTI TABLE 18-2

$$2 = \frac{D-1}{C} \; ; \quad 0 = \frac{1-A}{C} \; ; \quad -4 = \frac{D}{C} \; ; \quad 6 = -\frac{A}{C}$$

$$\Rightarrow C = -\frac{1}{6} \; ; \quad D = \frac{2}{3} \; ; \quad A = 1$$

ALSO USE eq 18.25 $\quad f_1 = -6 = \frac{AD}{C} - B \Rightarrow B = 2$

IMAGE DISTANCE

$$\begin{pmatrix} 1 & -12 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 2 \\ -\frac{1}{6} & \frac{2}{3} \end{pmatrix} \begin{pmatrix} 1 & s_0 \\ 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 3 & -6 \\ -\frac{1}{6} & \frac{2}{3} \end{pmatrix} \begin{pmatrix} 1 & s_0 \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} 3 & 3s_0 - 6 \\ -\frac{1}{6} & -\frac{s_0}{6} + \frac{2}{3} \end{pmatrix}$$

$\rightarrow s_0 = 2$

$M_T = 3$

OK

10 An unpolarized laserbeam is impinging onto a glass-air interface from the glass side. The refractive index of the glass is 1.735 and the angle of incidence is 30° (with reference to the surface normal). What can you say about the fate of the laser light?

Select one alternative:

- ○ All light is transmitted.
- ✓ All reflected light is polarized.
- ○ All light is reflected.
- ○ All transmitted light is polarized.

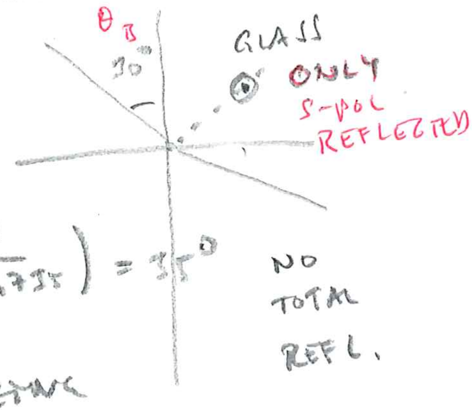
$n_{in} = 1.735$

$n_{ut} = 1.0$

$\theta_{crit} = \sin^{-1}\left(\frac{1}{1.735}\right) = 35^\circ$

$\theta_B = 30^\circ$ POLARIZING ANGLE

=>



NO TOTAL REFL.

Maximum marks: 4

11 An unpolarized laserbeam is impinging onto a glass-air interface from the glass side. The refractive index of the glass is 1.735 and the angle of incidence is 40° (with reference to the surface normal). What can you say about the fate of the laser light?

Select one alternative:

- ○ All light is transmitted.
- ○ All transmitted light is polarized.
- ○ All reflected light is polarized.
- ✓ All light is reflected.

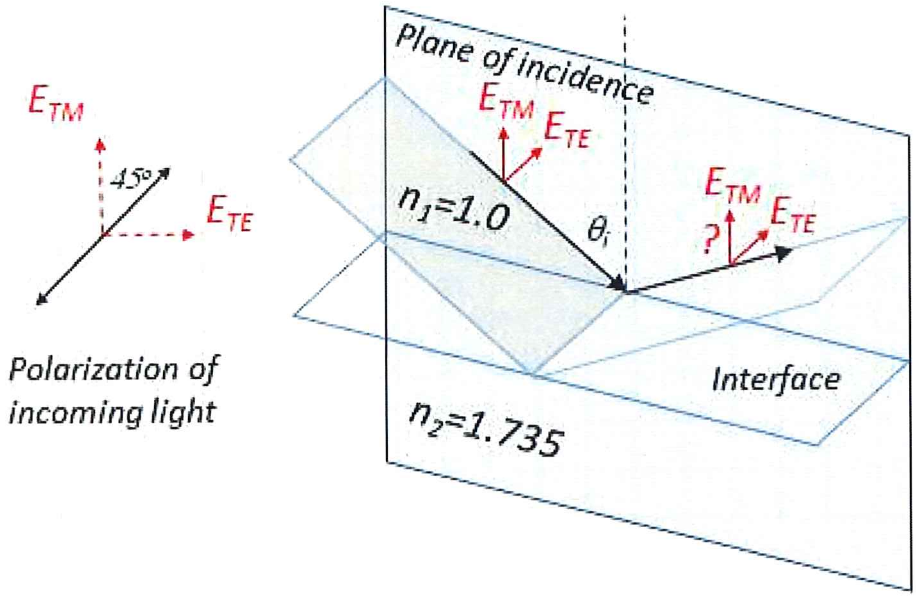
SINCE $\theta > \theta_c$

TOTAL INTERNAL REFLECTION

Maximum marks: 4

12 Light is reflected on an interface between air and a glass material, at an angle of incidence $\theta_i = 45^o$, as shown in the picture. The incoming light is linearly polarized 45^o, meaning the amplitude components of the transverse electric field (TE mode) and the electric field component in the plane of incidence (TM mode), have equal amplitudes.

What can you say about the polarization state of the reflected light?

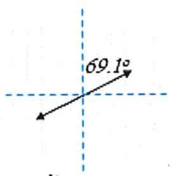


The refractive index parameters are given in the cartoon.

Select one alternative:

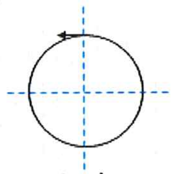
USE EQN PP 23.27 23.28

NOT POSSIBLE SINCE $|r_{TE}|>|r_{TM}|$

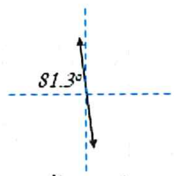


linear

✓


circular

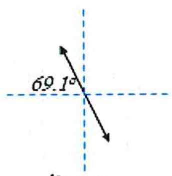
○



linear

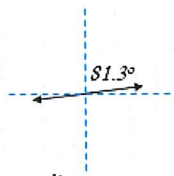
○

BOTH REQUIRE PHASE-SHIFT FROM TOTAL INTERNAL REFLECTION



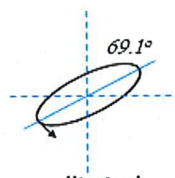
linear

○



linear

○



elliptical

○

MATLAB CODE ⇒ FOR DETAILED CALCULATION

12 cont

```
% Plot Fresnel external reflection;
% Mikael Lindgren Mayy 11th, 2021
clear all; close all;
%
ni = 1.0; %  incoming index
nt = 1.735; % outgoing index
n = nt/ni;
tetaBext = atan(n)*180/pi   % polarizing angle for external reflection
```

```
tetaBext = 60.0422
```

```
tetaBint = atan(1/n)*180/pi  % dito internal reflection
```

```
tetaBint = 29.9578
```

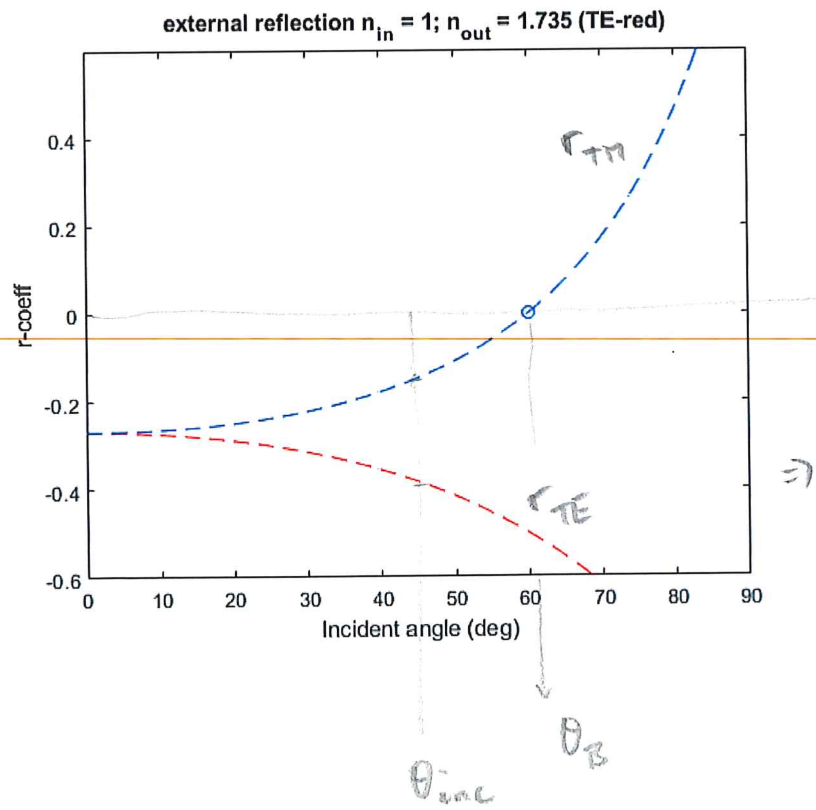
```
% angluar range
teta = linspace(0,89.9,101)';  % 101 points in degrees
tetar = pi*teta/180; % Matlab uses radians
% refl coeffs for certain incident angle  eqs. 23-27 and 23.28 in PP
phi = pi/4; phi_inc = phi*180/pi  % incident angle 45 deg in radians and degrees
```

```
phi_inc = 45
```

```
rTE_phi = (cos(phi)-sqrt(n^2-sin(phi).*sin(phi)))./((cos(phi)+sqrt(n^2-sin(phi).*sin(phi))));
rTM_phi = (-n^2*cos(phi)+sqrt(n^2-sin(phi).*sin(phi)))./((n^2*cos(phi)+sqrt(n^2-sin(phi).*sin(phi))));
r_pol = atan(rTE_phi/rTM_phi)*180/pi    % ratio rTE/rTM in terms of angle
```

```
r_pol = 69.0513
```

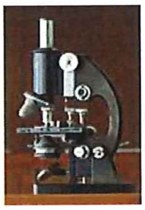
```
% reflection coefficients external, all angles
rTE = (cos(tetar)-sqrt(n^2-sin(tetar).*sin(tetar)))./((cos(tetar)+sqrt(n^2-sin(tetar).*sin(tetar))));
rTM = (-n^2*cos(tetar)+sqrt(n^2-sin(tetar).*sin(tetar)))./((n^2*cos(tetar)+sqrt(n^2-sin(tetar).*sin(tetar))));
% plot
plot(teta,rTE,'r--',teta,rTM,'b--',tetaBext,0,'ob'); axis([0 90 -0.6 0.6]);   % circle at Brewster angle
xlabel('Incident angle (deg)'); ylabel('r-coeff'); title('external reflection n_i_n = 1; n_o_u_t = 1.735 (TE-red)')
```



$\Rightarrow |r_{TE}| > |r_{TM}|$

Maximum marks: 5

13 Match the basic optical system with the most representative ray-transfer system matrix. N.b., the length unit is cm where appropriate.

	$\begin{bmatrix} 1.000 & 0.000 \\ -0.200 & 1.000 \end{bmatrix}$	$\begin{bmatrix} 0.000 & 3.500 \\ -0.286 & 1.000 \end{bmatrix}$	$\begin{bmatrix} -3.10 & 16.4 \\ 0.370 & -2.28 \end{bmatrix}$	$\begin{bmatrix} -0.167 & 21.0 \\ 0 & -6.00 \end{bmatrix}$
	○	○	○	✓
	○	○	✓	○
	○	✓	○	○
	✓	○	○	○

Maximum marks: 8

$$\begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & 0 \\ -\frac{1}{f} & 1 \end{pmatrix}$$

PUT IN SOME TYPICAL PARAMETERS f & L

CAMERA

$$\begin{pmatrix} 0 & 3.5 \\ -\frac{1}{3.5} & 1 \end{pmatrix} = \begin{pmatrix} 1 & 3.5 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ -\frac{1}{3.5} & 1 \end{pmatrix}$$

LUPP MAGNF. GLASS (TYPICAL)

$$\begin{pmatrix} 1 & 0 \\ -\frac{1}{5} & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -0.2 & 1 \end{pmatrix}$$

TELESCOPE

$$\begin{pmatrix} -\frac{1}{6} & 21 \\ 0 & -6 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -\frac{1}{3} & 1 \end{pmatrix}\begin{pmatrix} 1 & 18+3 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ -\frac{1}{18} & 1 \end{pmatrix}$$

TYPICAL TELESCOPE

STANDARDS DISTANCE

MICROSCOPE

$$\begin{pmatrix} -3.1 & 16.4 \\ 0.37 & -2.28 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -\frac{1}{5} & 1 \end{pmatrix}\begin{pmatrix} 1 & 16.4 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ -\frac{1}{4} & 1 \end{pmatrix}$$

okular TERM objective

14 Match the scientist with their most known achievement(s) in optics and electromagnetics.

	 Max Karl Planck 1858-1947	 Christiaan Huygens 1629-1695	 Pierre de Fermat 1607-1665
Discovered the radiation law that ultimately explained light as photons giving the photon energy as the E = hv.	✓	○	○
Explained the laws of refraction by the *principle of least time,* but perhaps mostly know as mathematician for his 'last theorem'	○	○	✓
One of the founders of mathematical physics, in optics known for the *spherical wave principle* proving the reflection, refraction and diffraction of light.	○	✓	○

Maximum marks: 6

15 Match the scientist with their most known achievement(s) in optics and electromagnetics.

	 Michael Faraday 1791 - 1867	 André-Marie Ampère 1775 - 1836	 James Clerk Maxwell 1831 - 1879
Pioneer in the understanding of induction, describing the relation between time-varying magnetic and electric fields.	✓	○	○
Known for his mathematical foundations for describing magnetic fields and how they relate to currents.	○	✓	○
Postulated the time-varying 'displacement current', to complete the magnetic curl equation and ultimately resulting in a unifying theory of electromagnetism.	○	○	✓

Maximum marks: 6