UNIVERSITY OF TORONTO
Department of Electrical & Computer Engineering
ECE 426F - Introduction to Optical Engineering
Test 1

Examiner: P.R. Herman **October 3, 2000.**

Aids: **one side, hand-written 8.5" x 11" sheet.** **Duration:** **50 minutes**

Answer all questions in spaces provided; use reverse side if necessary.

Marker: Winnie Ye Winnie.ye@utoronto.ca **GB 253**

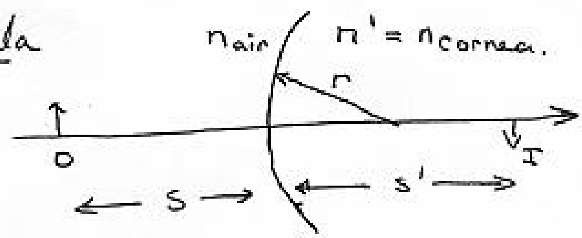
NAME	____________________
GRADE	/35 (2 BONUS)

1. The cornea is the first refractive surface of the eye at the air interface. The cornea has a refractive index of 1.376 and a radius of curvature of 1 cm. Find the primary and secondary focal lengths.

8 marks

Gaussian Formula

$$\frac{n_a}{s} + \frac{n_c}{s'} = \frac{n_c - n_a}{r}$$



$n_a = 1.0$
$n_c = 1.376$
$r = +1$ cm

SECONDARY FOCUS: $s = \infty$, $s' = f'$

$$\frac{1}{\infty} + \frac{n_c}{s'} = \frac{n_c - n_a}{r}$$

$$\therefore \boxed{f' = s' = \frac{n_c r}{n_c - n_a} = \frac{(1.376)(1)}{1.376 - 1.0} = 3.659\text{ cm}}$$

PRIMARY FOCUS: $s' = \infty$, $s = f$

$$\frac{1}{s} + \frac{n_c}{\infty} = \frac{n_c - n_a}{r}$$

$$\boxed{f = s = \frac{r}{n_c - n_a} = 2.6595\text{ cm}}$$

2. A 10-cm radius glass sphere ($n_g = 1.5$) is used to magnify an object in air. Find the magnification if the object is 8 cm from the first surface of the sphere. Carefully sketch a ray-tracing diagram showing the object, the intermediate image, the final image, and ray refraction at each surface.

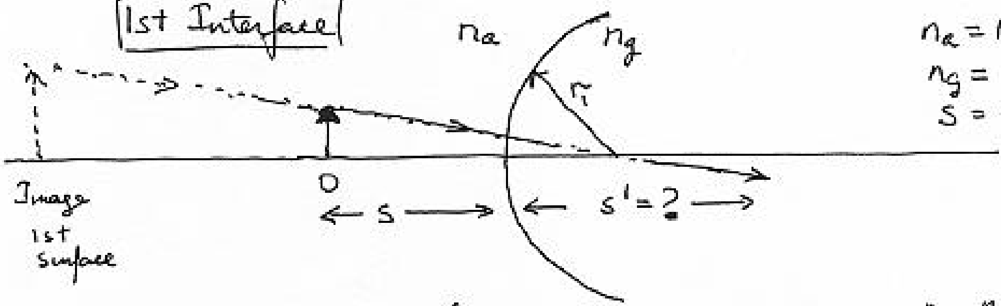
12 marks

1st Interface

$n_a = 1.0$ $r_1 = 10$ cm

$n_g = 1.5$

$s = +8$ cm



Gaussian Formula $\rightarrow$

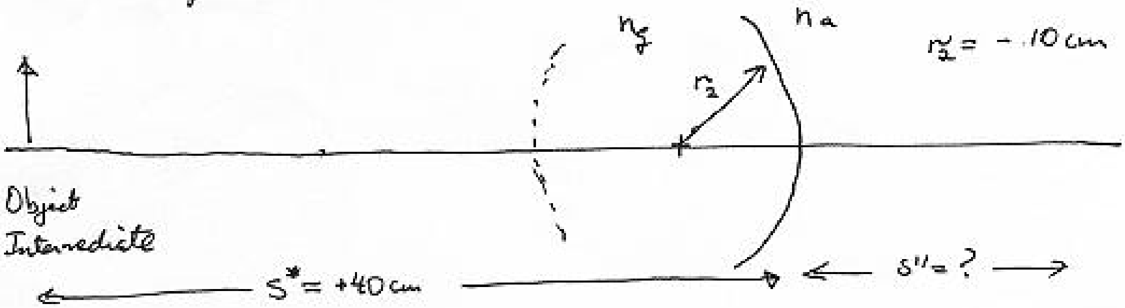
$$\frac{n_a}{s} + \frac{n_g}{s'} = \frac{n_g - n_a}{r_1}$$

$$\frac{1}{8} + \frac{1.5}{s'} = \frac{1.5 - 1.0}{10} \Rightarrow \boxed{s' = -20 \text{ cm}}$$

virtual image erect.

2nd Interface: object distance $= -(s' - 2r) = +40$ cm.

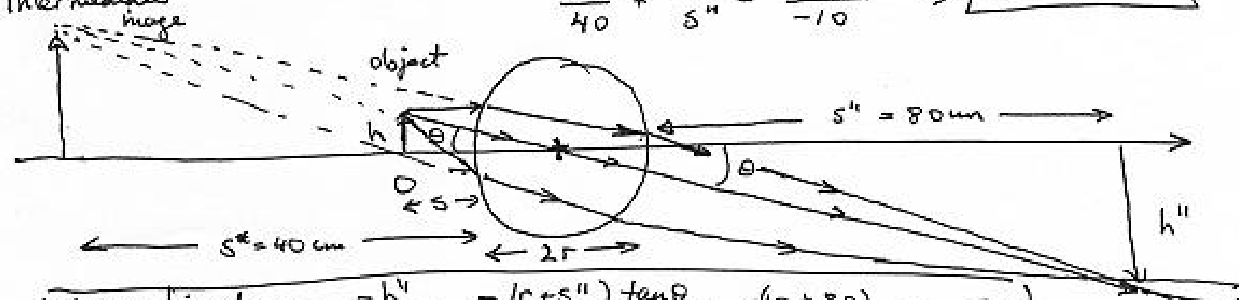
$r_2 = -10$ cm



Gaussian Formula

$$\frac{n_g}{s^*} + \frac{n_a}{s''} = \frac{n_a - n_g}{r_2}$$

$$\frac{1.5}{40} + \frac{1}{s''} = \frac{1 - 1.5}{-10} \Rightarrow \boxed{s'' = 80 \text{ cm}}$$



$$\boxed{\text{Magnification} = \frac{-h''}{h} = \frac{-(r + s'')\tan\theta}{(r + s)\tan\theta} = \frac{-(10 + 80)}{(10 + 8)} = -5\times}$$

$(n_L = 1.5)$

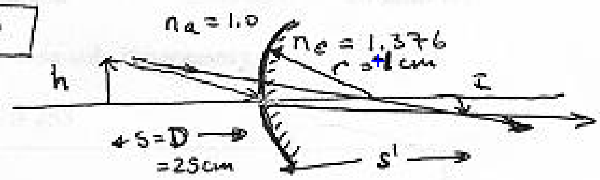
3. You are to specify the focal length (air reference) of a thin lens that would permit a 'normal' eye to image an object under water ($n_w = 1.33$). The lens is to be placed very close to but not touching the cornea of the eye such that all surfaces are surrounded by water. Assume the cornea has a refractive index of 1.376 and a radius of 1 cm. The object is positioned underwater, 25 cm from the cornea-lens combination. The eye is to be accommodated for vision at the near point (25 cm) in air. Sketches are required for a complete solution! **15 marks**

2 Mark Bonus: Determine how much bigger (or smaller) the object appears underwater with the lens than when viewed in air with the unaided eye at the near point.

Eye at Near Point in AIR (Reference)

(1) $$\frac{n_a}{s} + \frac{n_c}{s'} = \frac{n_c - n_a}{r}$$

$D = 25\text{cm}$



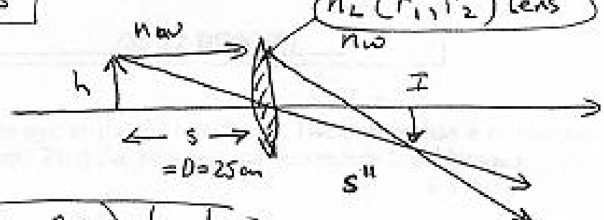
UNDERWATER – MUST BE IMAGED TO SAME s'

(A) Lens Underwater

$$\frac{n_w}{s} + \frac{n_w}{s''} = (n_L - n_w)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$s = D = 25\text{cm}$ object location

$$\frac{1}{f_{air}} \equiv (n_L - n_{air})\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

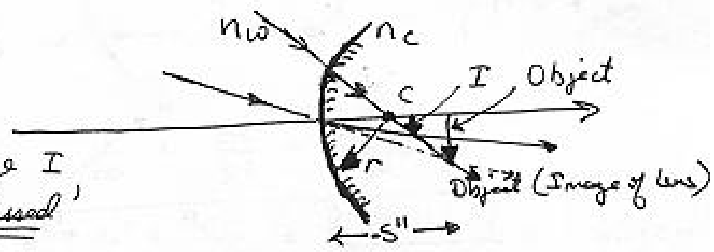


Substitution yields

(2) $$\frac{n_w}{D} + \frac{n_w}{s''} = \left(\frac{n_L - n_w}{n_L - n_{air}}\right)\frac{1}{f_{air}}$$

(B) eye underwater:

final image I on right figure must match up with top-figure image I in order for the object to be 'focussed' sharply.



(3) $$\frac{n_w}{(-s'')} + \frac{n_c}{s'} = \frac{n_c - n_w}{r}$$

Notes s'' is same in equations (2) + (3)
s' is same in equations (1) + (3)

ADD (2) + (3) ⇒ $$\frac{n_w}{D} + \frac{n_c}{s'} = \frac{n_c - n_w}{r} + \left(\frac{n_L - n_w}{n_L - n_a}\right)\frac{1}{f}$$

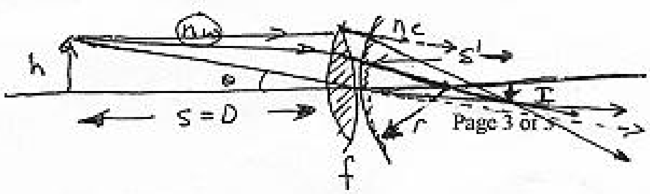
Subtract (1) ⇒ $$\frac{n_w}{D} - \frac{n_a}{s_R} = \left(\frac{n_L - n_w}{n_L - n_a}\right)\frac{1}{f} + \frac{n_a - n_w}{r}$$ ($s = D$)

$$\frac{1.33 - 1}{D = 25} = \frac{1.5 - 1.33}{1.5 - 1}\frac{1}{f} + \frac{1 - 1.33}{-1}$$

f = +0.9906cm

[redacted] cm

Bonus



lens + cornea in water images object h at distance D is same as h at distance D in air!

Magnification = 1