Midterm Exam 2

Print your full LAST name: ________________________________

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#1 total: _________
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Exam total: _________ / 200
1. **(50 points total)** You have two identical 5x magnifiers. Your eye has a Near Point of 20.0 cm and a standard Far Point. You are trying to view a sand grain that is a 1-mm cube.

   a. **(_______ / 25 points)** What is the approximate viewing angle ($\theta_{\text{aided}}$, in radians) that you achieve when you use just one of the magnifiers to view the sand grain in the conventional way—in standard, “comfort” configuration?

   b. **(_______ / 25 points)** Now calculate the angular magnification ($M$) you will achieve by using the two lenses together in this configuration (with your eye right next to lens 2).

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**a.** The power rating:  
\[ 5 = \frac{25}{f} \]  
Therefore:  
\[ f = 5 \text{ cm for each lens} \]  
The $M$ you achieve:  
\[ M_{\text{standard mag}} \approx \frac{NP}{f} \]  
\[ = \frac{20}{5} = 4.00 \]  
That is:  
\[ \frac{\theta_{\text{aided}}}{\theta_{\text{best unaided}}} \approx 4.00 \]  
Or:  
\[ \theta_{\text{aided}} \approx 4.00(\theta_{\text{best unaided}}) \]  
where  
\[ \theta_{\text{best unaided}} \approx \frac{h_0}{NP} \approx \frac{.1}{20} \approx 0.005 \text{ rad} \]  
Substituting:  
\[ \theta_{\text{aided}} \approx 4.00(h_0/\text{NP}) \approx (4.00)(0.1/20) \]  
\[ \approx 0.0200 \text{ rad} \]  
3 pts.total: value = 2; units = 1/2; sig. figs. = 1/2

**b.** Again:  
\[ f = 5 \text{ cm for each lens} \]  
And:  
\[ M = \frac{\theta_{\text{aided}}}{\theta_{\text{best unaided}}} \]  
where  
\[ \theta_{\text{best unaided}} \approx \frac{h_0}{\text{NP}} \approx \frac{.1}{20} \approx 0.005 \text{ rad} \]  
Now compute the image and viewing distance (and thus $\theta_{\text{aided}}$) offered by the lens combo:

**What lens 1 does:**  
\[ \frac{1}{5} = \frac{1}{2.06} + \frac{1}{d_{i,1}} \]  
Solving for $d_{i,1}$:  
\[ d_{i,1} = -3.5034 \text{ cm} \]  
Therefore:  
\[ h_{o,2} = h_{i,1} \]  
\[ = m_{i} h_{o,1} \]  
\[ = -(d_{i,1}/d_{o,1})h_{o,1} \]  
\[ = -(-3.5034/2.06)(0.1 \text{ cm}) = 0.17007 \text{ cm} \]  
And:  
\[ d_{o,2} = 3.5034 + 0.500 = 4.0034 \text{ cm} \]  
2 pt.

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What lens 2 does:

\[ \frac{1}{5} = \frac{1}{4.0034} + \frac{1}{d_{i2}} \]

Solving for \( d_{i2} \):

\[ d_{i2} = -20.0853 \text{ cm} \]

Therefore:

\[ h_{i2} = m_2 h_{o2} \]

\[ = -\left( \frac{d_{i2}}{d_{o2}} \right) h_{o2} \]

\[ = -\left( \frac{-20.0853}{4.0034} \right) (0.17007 \text{ cm}) = 0.85325 \text{ cm} \]

Calculate \( \theta_{\text{aided}} \):

\[ \theta_{\text{aided}} = \frac{h_{i2}}{d_{\text{view}}} \]

\[ = \frac{0.85325}{20.0853} \approx 0.042481 \text{ rad} \]

Thus:

\[ M \approx \frac{0.042481}{0.005} \]

\[ = 8.50 \]

3 pts. total: value = 2; units = 1/2; sig. figs. = 1/2
2. (50 points total) A certain person with identical eyes wears contact lenses (−3.70 D) all the time. When reading or doing other close work, he uses reading glasses (+1.60 D), too—while still wearing his contact lenses.

   a. (_______ / 30 points) Find the focal range (NP and FP) of his eye.

   b. (_______ / 10 points) What is the shortest distance from his eye that he can focus clearly on an object while wearing just his contact lenses?

   c. (_______ / 10 points) What is the greatest distance from his eye that he can focus clearly on an object while wearing his contact lenses and his reading glasses?

Diagrams help a lot!

   a. First, find his Far Point—what his contacts (worn by themselves) are designed to correct:

   Like this:
   
   \[ \frac{1}{f_{\text{contact}}} = \frac{1}{\infty} + \frac{1}{-(FP)} \]

   Or:
   
   \[ FP = -f_{\text{contact}} \]

   where
   
   \[ f_{\text{contact,cm}} = \frac{100}{RP_{\text{contact}}} = \frac{100}{-3.70} = -27.027 \text{ cm} \]

   So:
   
   \[ FP = 27.0 \text{ cm} \]

   And his Near Point is where the combination of the two lenses places the image of a book that he is holding at the standard acceptable distance (25 cm).

   A complete diagram of that multi-lens situation looks like this:

   - A diagram is not required (full credit for a correct solution can be earned without it), but up to 5 points will be awarded for correctly stating this.

   - This summary is not required (full credit for a correct solution can be earned without it), but up to 5 points will be awarded for correctly stating this.

   Take this step-by-step—one lens at a time, in order....

   What lens 1 does:
   
   \[ \frac{1}{f_1} = \frac{1}{d_{o,1}} + \frac{1}{d_{i,1}} \]

   where
   
   \[ f_1 = \frac{100}{RP_{\text{glassas}}} = \frac{100}{1.60} = 62.5 \text{ cm} \]

   and
   
   \[ d_{o,1} = 25 - 2 = 23 \text{ cm} \]

   Solving for \( d_{i,1} \):
   
   \[ d_{i,1} = -36.392 \text{ cm} \]

   Therefore:
   
   \[ d_{o,2} = 36.392 + 2 = 38.392 \text{ cm} \]
What lens 2 does: 
\[ 1/f_2 = 1/d_{o,2} + 1/d_{i,2} \]
where 
\[ f_2 = f_{\text{contact}} = -27.027 \text{ cm} \]
and 
\[ d_{o,2} = 38.392 \text{ cm} \]
Solving for \( d_{i,2} \):
\[ d_{i,2} = -15.861 \text{ cm} \]
Therefore: 
\[ NP = 15.9 \text{ cm} \]

b. The question: For what object distance will his contact lens place an image at his Near Point?
Find out: 
\[ 1/f_{\text{contact}} = 1/d_{o,\text{min}} + 1/(-NP) \]
That is: 
\[ 1/(-27.027) = 1/d_{o,\text{min}} + 1/(-15.861) \]
Solve for \( d_{o,\text{min}} \):
\[ d_{o,\text{min}} = 38.4 \text{ cm} \]
To read without his reading glasses, he must hold the book about 38.4 cm from his eyes.
(If he holds it any closer, the resulting image will land nearer to his eye than his near point.)

c. Consider: If he places any object outside the focal length of his reading glass lens, it will produce a real image (upside down, behind his head somewhere)—useless.
But if he places an object “right at” (OK, a micron inside) the focal length of the reading glass lens, it will send the resulting image out to the horizon—where his contact lenses have equipped him to view a distant object anyway.
So the farthest viewably point is the focal point of his reading glasses.
That’s 62.5 cm from those lenses, which is 64.5 cm from his eye.
3. (50 points total) A laser beam is sent toward a converging lens, as shown below, along a path that is parallel to the lens' optical axis. The enlarged view at right shows the detail of the ray's path (the solid line) through the lens and then out again into the surrounding air.

Show all work/calculations for each of the following.

a. (_______ / 25 points) Calculate the index of refraction of this lens' material.

b. (_______ / 25 points) If \( d = 1.743 \) cm, estimate the focal length of this lens. You may assume that the lens surfaces are approximately flat (i.e. straight edges) in the tiny region enlarged here.

a. Looking at the first incidence (from air to lens material), we see that the ray veers from the horizontal by an amount \( 100° - 95.7° = 4.3° \). That is, its new direction (compared to horizontal) is \( \angle -4.3° \).

Snell's Law:
\[
\frac{n_{\text{air}} \sin 10°}{\sin 5.7°} = n_{\text{lens}}
\]
Solve for \( n_{\text{lens}} \):
\[
\frac{n_{\text{air}} \sin 10°}{\sin 5.7°} = 1.75
\]

b. Now looking at the second incidence (from lens material to air):

Snell's Law:
\[
\frac{n_{\text{lens}} \sin 14.3°}{\sin \theta} = n_{\text{air}}
\]
Solve for \( \theta \):
\[
\theta = \sin^{-1}(n_{\text{lens}} \sin 14.3°/n_{\text{air}}) = 25.585°
\]
And therefore:
\[
\theta_f = \theta - 10° = 15.585°
\]
Now find the focal length:

\[ \frac{d}{f} = \tan \theta_f \]

Solve for \( f \):

\[ f = \frac{d}{\tan \theta_f} \]

\[ = 1.743/\tan(15.585^\circ) \]

\[ = 6.25 \text{ cm} \]

3 pts. total: value = 2; sig. figs. = 1
4. **(50 points total)** The diagram, a side view (not to scale) shows the initial situation: A large tub is resting on a scale. The tub is partially filled with oil, and the reading on the scale is 1500 N. Then the irregularly-shaped object, whose density is 500 kg/m$^3$, is lowered via the thin, massless wire so that the object is at rest, partially immersed in the oil (with its flat, horizontal underside not touching the bottom of the tub). The tension in the wire is then 870 N; the scale then reads 1830 N. The object is then lifted completely out of the oil, and the valve in the overhead supply pipe is opened for 6.20 s, which is just long enough to supply additional oil (in a steady flow) to the tub so that the scale again reads 1830 N. The first oil from the pipe hits the oil in the tub at a speed of 6.44 m/s. All sections of the pipe are cylindrical, and the pipe at the valve has a radius of 3.00 cm. All other dimensions are as shown, given in meters. Ignore any fluid loss onto the object when it is removed from the oil—it all drips back into the tub. Ignore air drag.

a. **(______/35 points)** If the object had been lowered until the tension in the wire went to zero, what volume of oil would the object then be displacing? (You may assume that there is sufficient oil so that the object could become fully immersed without touching the bottom, if necessary.)

b. **(______/15 points)** Calculate the pressure of the oil at point A (the midpoint of that section of the pipe) while the valve was open.

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For problem 4, to be answered on this page... Show full math work and/or to support your solution and answer. If you need more space, use the next page, ---->
And the weight of the oil that was added is equal to the buoyant force that existed previously.

In other words: \( m_{\text{oil added}} g = 330 \text{ N} \)

So: \( m_{\text{oil added}} = 330/9.80 = 33.6735 \text{ kg} \)

Now, what was \( V_{\text{oil added}} \)? We get that from a flow-rate calculation at the supply pipe outlet (call that point B):

We know this: \( V_{\text{oil added}} = Q_B (\Delta t) = (A_B v_B)(\Delta t) \)

Kinematics to get \( v_B \):

Here that means this: \( v_{\text{impact }, \text{oil}}^2 = v_B^2 + 2g\Delta y \)

Solve for \( v_B \):

Substitute:

Find \( \rho_{\text{oil}} \):

So \( \rho_{\text{object}} < \rho_{\text{oil}} \), so the object would float if released into the tub.

And we know this: \( V_{\text{object, immersed}} / V_{\text{object}} = \rho_{\text{object}} / \rho_{\text{oil}} \)

Solve for \( V_{\text{object, immersed}} \):

Voil.displaced = \( V_{\text{object, immersed}} = (0.2449)(500/672.66) = 0.182 \text{ m}^3 \)

b. To find the pressure at point A, compare points A and B via Bernoulli’s equation.

Like this:

where \( h_B = 0 \):

and \( P_B = P_{\text{atm}} \):

and \( v_A = (A_P v_B) / A_A \):

Solve for \( P_A \):

\[ P_A = P_{\text{atm}} + (1/2)\rho_{\text{oil}} v_A^2 [1 - (A_A/A_P)^2] - \rho_{\text{oil}} g h_A \]

where \( A_A = .03 \):

\[ = (1.01 \times 10^5) + (1/2)(672.66)(2.8555)^2 [1 - (.03^2/.3^2)] - (672.66)(9.80)(1.20) \]

\[ = 9.58 \times 10^4 \text{ Pa} \]
GENERAL DIRECTIONS

Fill out the cover sheet completely, as indicated. Then follow the general guidelines below and the specific directions on each page for each item.

For ALL items (unless directed otherwise):
- In all expressions and symbolic solutions, reduce them to simplest form.
- In all final numerical answers, use standard SI units and three significant digits.

No item will be given full credit if it does not include valid reasoning/work to justify the solution/answer. Correct answers alone are generally worth about 10% of the points.

For T/F/N items: Evaluate each statement as being either…
- demonstrably True (T),
- demonstrably False (F), or
- with Not enough information (N) to declare it either True or False.

You must fully explain your reasoning. Little credit will be given for a correct T/F/N answer without a valid explanation to accompany it.

For items asking for numeric answers:
You may use any valid method and physics, provided that you show your work/reasoning and math steps (and it’s generally best to stick with symbolic solutions as far as you can, anyway). Little credit will be given for a correct answer without a valid explanation to accompany it.

For items asking for symbolic solutions or any/all parts of the ODAVEST protocol:
These items will state which symbols may be considered “known values” (and which therefore may appear in your final answer).

Physical constants and other possibly useful information:

\[
\begin{align*}
n_{\text{air}} &= 1.00 & V_{\text{cylinder}} &= \pi r^2 h \\

v_{yf}^2 &= v_{yi}^2 + 2a_y \Delta y & g_{\text{earth, surface}} &= 9.80 \text{ m/s}^2 \\

P_{\text{atm, earth, surface}} &= 1.01 \times 10^5 \text{ Pa}
\end{align*}
\]