This exam consists of 4 problems, worth 25 points each. Please write your answers clearly and legibly. Partial credit can be awarded, but only if you clearly show your thinking. Single-word or single-number answers, if wrong, will receive no partial credit. This is a closed book, closed note exam. No calculators are required or allowed for this exam.

<table>
<thead>
<tr>
<th>Name: ___________________</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem 1 (25pts)</td>
</tr>
<tr>
<td>Problem 2 (25pts)</td>
</tr>
<tr>
<td>Problem 3 (25pts)</td>
</tr>
<tr>
<td>Problem 4 (25pts)</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
Problem 1 (25pts)

The drawing below shows a lens with focal length $f=25\text{mm}$. Monochromatic light is incident upon the lens from the left, coming through two apertures with diameters much larger than the wavelength of the incident light.

a) (10pts) Draw the ray diagram showing the beam path of the light from $x=0$ to $x=100\text{mm}$. Draw as many rays as you think necessary to accurately represent the light’s behavior in this system (at least 3!).

![Diagram of lens with rays](image)

b) (5pts) Label the portions of the system where the beam is collimated (CL), converging (CV) and diverging (DV).

c) (10pts) Below, draw the region from $x=50\text{mm}$ to $x=100\text{mm}$ showing what the beam path would look like if the beam is NOT monochromatic and the lens displays chromatic aberration. (maybe pick three colors, such as red, green, and blue and trace their paths).
Problem 2 (25pts)

The expression below describes the electric field in (V/m) of a light wave traveling through space

\[ \vec{E}(x, t) = 2 \cos \left( 2\pi t + \frac{\pi}{2} x \right) \]

Give the

a) (2pts) Amplitude of the wave: ____________

b) (3pts) The direction of wave propagation: ______________________

c) (2pts) The frequency (\(\omega\)) of the wave: ____________

d) (3pts) The period (T) of the wave: ______________

e) (4pts) The wavevector and wavelength of the wave: \(k=___________, \lambda=___________\)

f) (2pts) The direction of polarization of the wave: ______________________

g) (3pts) The speed of the wave: ______________________

h) (6pts) Plot the wave below at t=0 and at t=T/2

![Wave plot](image-url)
**Problem 3 (25pts)**

a) (10pts) Explain where Ray Optics, as a theory of light, falls short. In what situations do we need to move from Ray Optics to Wave Optics? Feel free to supplement your answer with a figure.

b) (10 pts) Treating light as a simple wave works for many situations, but scientists struggled to understand how a wave (like light) could propagate from a star (like the sun) to Earth through the vacuum of outer space. What was initially proposed to explain this? What experiment proved this wrong? And what modification to wave optics was made to explain light propagation?

c) (5pts) As best you can, give below a pictorial representation of the double-slit interference experiment with very low (1 photon at a time) light levels.
Problem 4 (25pts)

a) (5pts) Light is incident, with an incidence angle \( \theta_i = 10^\circ \), from a medium 1 with refractive index \( n = 3 \) onto a medium 2 with \( n = 2 \). In medium 2, the light travels at an angle from the normal \( \theta_t \), where

i) \( \theta_t = \theta_i \)  
ii) \( \theta_t < \theta_i \)  
iii) \( \theta_t > \theta_i \)  
iv) \( \theta_t = 0 \)

b) (6pts) The plot below shows a standing wave at time \( t = 0 \). On the same axes, plot the standing wave at \( t = T/4 \) and \( t = T/2 \).

![Standing wave plot](image)

c) (4 pts) Light travels 3 paths: the first is a distance of 300m a material with refractive index \( n_1 = 2.5 \) (path 1), the second is 150 meters in a material with refractive index \( n_2 = 1.5 \) (path 2) and the third is 600 meters in a material with refractive index \( n_3 = 1 \) (path 3). Order the optical path lengths of the three paths from shortest to longest.

__________________ < __________________ < __________________

d) (6pts) Give an example of

i) A longitudinal wave: ______________  
ii) A transverse wave: ______________

e) (4pts) Explain what the Brewster Angle is and when and how it is observed.