The exam is closed book, but one page of notes is allowed, as are calculators. Make sure you understand what is asked: read the entire question before starting.

You must show your work and write (and draw!) legibly to get full credit.

And, as we all know, the solid angle enclosed by cone of half-angle $\theta$ is $2\pi[1-\cos(\theta)]$.

Name ______________________________________________

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Question 1 (20 pts): Waveguides

A long waveguide is made from a 2mm diameter cylindrical core of \( n = 1.5 \) glass, coated with a thin cladding of index 1.4142. The waveguide is used to collect light emitted uniformly in all directions by an atom floating in air, centered 1mm from the front face of the waveguide.

1a) What is the **numerical aperture** of the waveguide?

1b) What is the maximum internal angle of light **anywhere** in the core of the waveguide?

1c) What is the maximum emitted angle of light, \( \theta_{\text{emitted}} \), of light guided by the waveguide core?

1d) What fraction of light emitted from the source is guided by the waveguide core to the far end (neglecting surface reflections)?
2a) The input face of fiber waveguides is sometimes curved to improve light collection. Assuming the axial distance to the point source is still 1 mm, use the **paraxial lens law** (the lensmaker’s formula) to find the radius of curvature $R$ to make $\theta_{\text{emitted}} = 0$.

2b) This answer is NOT physically practical. Explain why not, and suggest some way the tip of the waveguide could be modified, or other optics added, to collect more light from the point source. Make a sketch to illustrate your proposed solution.
Question 3 (20pts): The magnifying glass

A biologist first inspects an insect 5mm in height by holding it 10" (25.4cm) away from his eye, then uses as a magnifying glass a thin plano-convex lens with focal length $f = 50\text{mm}$ to get a better look, with the lens exact 49.9mm away from the insect.

(1) What is the location the insect's image relative to the lens, and what is the height of the image? Is the image inverted?

(2) How much larger (in angular extent) does the insect appear than when it was 10" away from the biologist's eye?
Question 4 (20pts): Thin paraxial lens optics

(1) A thin lens with -45mm focal length is placed close (a negligibly small space) from a thin lens with 100 mm focal length, which is separated by 10 mm from a third lens of focal length 100mm. What is the paraxial focal length of the three-lens combo?

Sketch (qualitatively) the path of a ray entering the system parallel to the optical axis, showing the net direction of deflection.
(2) The thin negative lens is moved midway between the two positive lenses, as shown. What separation $D$ will make the paraxial focal length of the three-lens combo infinite? Sketch (qualitatively) the path of a ray entering the system parallel to the axis.
Question 5: Optical Design (20 points)

In the single lens imager at right, a spherical singlet lens 7 cm in diameter is positioned on the axis between an object and image plane separated by 20 cm, and used to image an object 1 cm high. The lens is made of a glass, and there is air between the object and image planes.

(1) If this problem were put into an optical design optimization program like Zemax, there are **5 parameters** which can be adjusted to optimize performance of the lens system. Label them on the drawing at right.

(2) There are many possible functions used in a merit function; give **two specific examples**.

(3) If you were unsatisfied with the result after optimizing the lens system as described above, you could change one or more design parameter to make your system perform very close to the paraxial model of performance. Name **two ways** to do that.