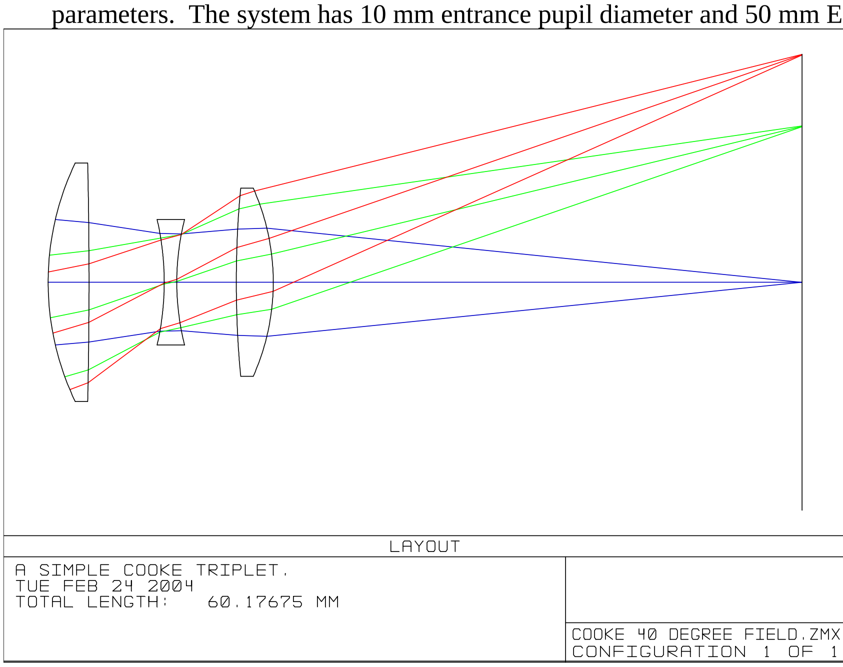
Optical Engineering 421/521 – Fall 2007
Sample Questions for Midterm 1

<u>Short answer</u>

1.) Sketch a pechan prism. Name a possible application of this prism., write the mirror matrix for this prism (or any other common prism)

2.) Define “diffraction limited depth of focus” and give an expression for it.

3.) For the following system, create an error budget for the three lens elements. Consider only the stability of the element positions. Define a set of tolerances that limits image motion to 1 μm. You will need to estimate some parameters. The system has 10 mm entrance pupil diameter and 50 mm EFL.



L1: 34 mm focal length
L2: -17 mm focal length
L3: 24 mm focal length

4.) Consider the same system above. The lens surfaces are specified to have surface irregularity less than 1 fringe over the full diameter as measured by a test plate. Estimate the degradation of image quality, defined as rms spot radius, due to each of the surfaces on **L1**.

5.) Consider the same system above. The lenses are specified to have surface irregularity less the 2 fringes as measured by a test plate. Assuming this is the only error in the system, estimate the image blur as an rms.

6.) Tilt in a wavefront is usually interpreted as image shift. It can also be interpreted as wavefront error. For the case of $\lambda/4$ wavefront tilt ($W(\rho,\theta) = \lambda/8 * \rho \cos \theta$), calculate the Strehl ratio. Does this make sense?

7.) Consider a camera lens with 5 mm aperture and 50 mm EFL used at light with 500 nm wavelength. Assume that the object is 1 km away. Calculate:

a) Calculate the diffraction limited resolution of the image (at the film)
b) calculate the smallest feature on the object 1 km away that can be resolved
c) calculate the diffraction limited depth of focus at the film plane
d) calculate how close can the object move to the camera, yet remain within this diffraction limited focus.

8.) In class, we developed a relationship that gives image position due to effect of a component using the beam footprint on the optics and the numerical aperture or focal ratio. Derive a similar relationship for an afocal system.

9.) Estimate the retardance that you would expect from a pentaprism with 50 mm aperture made from precision annealed glass (6 nm/cm). Use 500 nm light.

10.) Name an application that would require a tight specification for bubbles and inclusions.

11.) A pitch polished aspheric mirror will typically have surface roughness of 20 angstroms rms. This causes wide angle scatter. Calculate the total amount of scatter from one of these mirrors at 400 nm light.

12.) Draw a layout for a Gregorian type telescope. Graphically show the location of the nodal point for this system.

13.) What is the "magic" of the rhomboid, pentaprism, corner cube?

14.) Name 3 possible good merit functions for image quality of an average quality 35-mm camera lens.

15.) Define modulation transfer function. Why is this useful?

16.) Spherical aberration has the form $4r^4 - 4r^2 + 0.667$ where r is the normalized radial pupil coordinate (= 1 at the edge). For 1 µm of P-V spherical aberration, calculate the rms variation.

17.) Calculate the Strehl ratio for a system with $\lambda/4$ P-V spherical aberration.

18.) Consider an f/20 system with 500 nm light. Calculate the P-V wavefront error for 1 mm defocus.

19.) Calculate the rms wavefront error due to the 1 mm defocus above.

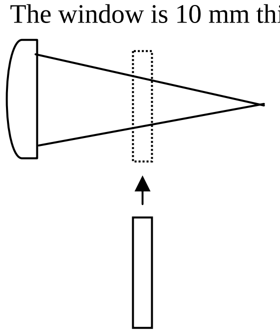
20.) Calculate the Strehl ratio for a perfect system that has $\lambda/4$ P-V focus error. Describe what this means.

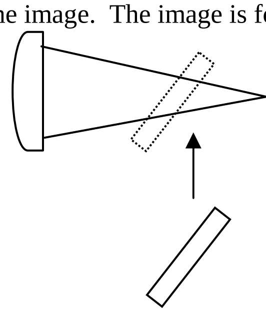
21.) Give a typical scratch/dig specification.

22.) Make a sketch that defines the mechanical and the optical axes of a lens

23.) A 25 mm diameter lens has a requirements of R = 100 +/= 0.1 mm. Calculate the tolerance in terms of the sag of the surface. Is this tight?

24.) For the two cases below, give the approximate shift in image position if the window is inserted into the converging beam as shown. Consider both axial and lateral effects.
The window is 10 mm thick, n = 1.5, 50 mm from the image. The image is formed at f/10.

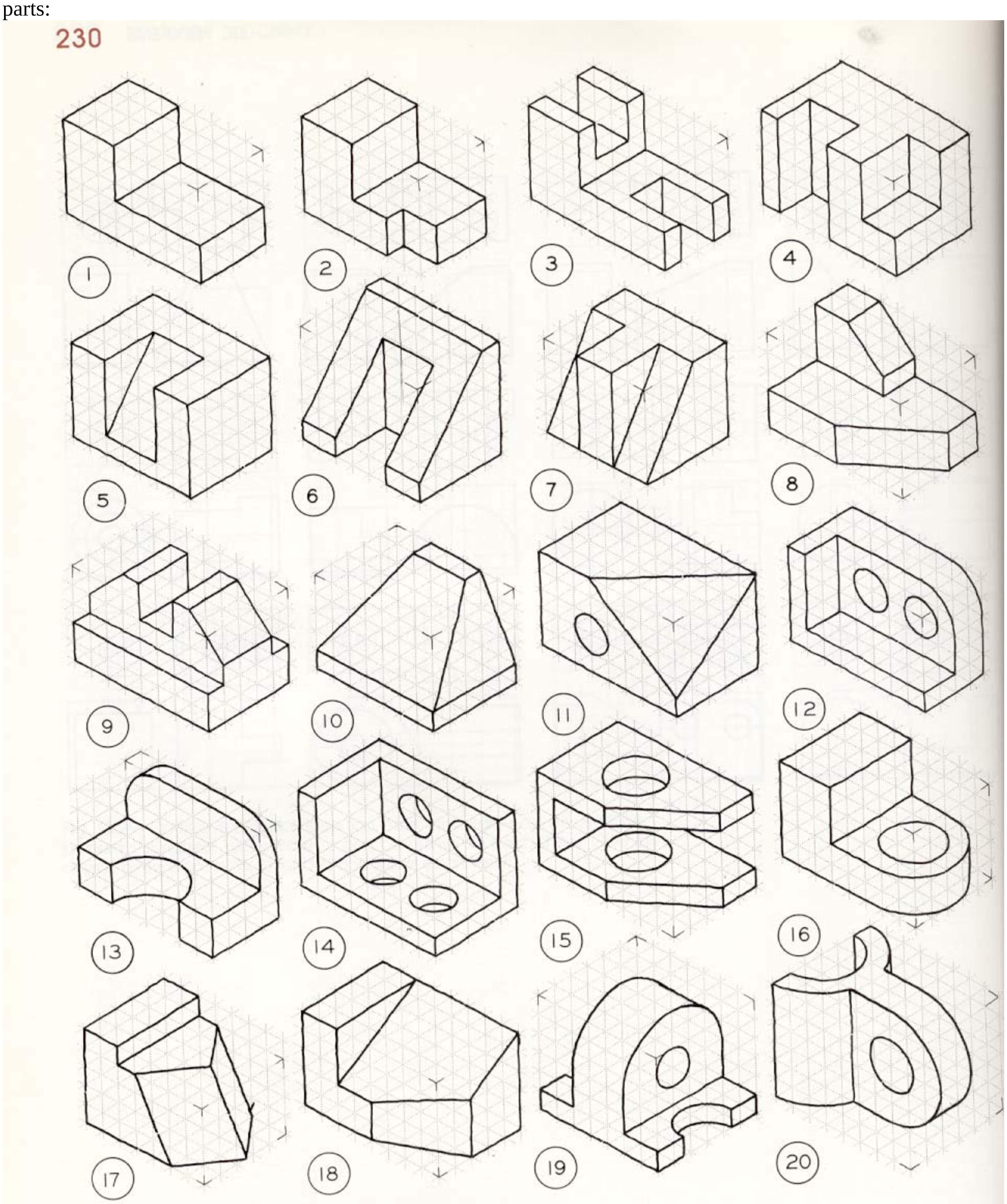




Tilted at 45°

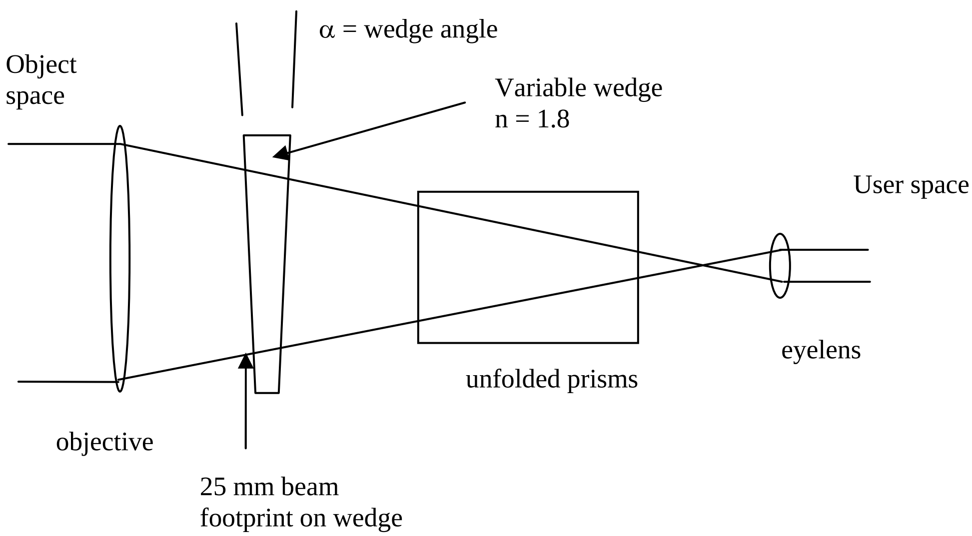
Name the aberrations that would be caused by the plate for each case.

25.) Sketch a 3-view orthographic projection. Some possible parts:



26.) Canon sells binoculars that actively stabilize the image using a variable wedge. The angular accelerations are measured with sensors and a correction is applied by changing the wedge of a fluid filled cavity. For the case of 10 x 35 binoculars, calculate the wedge required to fully the effect of tilting the binoculars by 1 mrad.

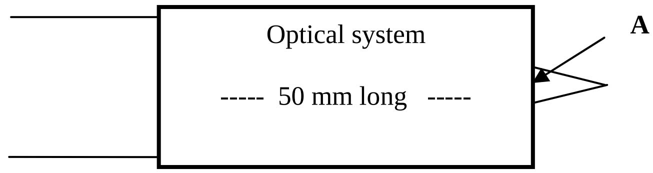
a) Give the diameters of the entrance pupil and the exit pupil
b) Give the value of the magnifying power
c) If the binoculars are tilted by 1 mrad, how much motion does the user observe (hint: draw a sketch of this or you will probably get it wrong)
d) Give the relationship between angular deviation at an element and system LOS for an afocal system
e) Show the relationship between the wedge angle α and the deviation it causes in user space.
f) Calculate the required wedge to correct for the 1 mrad tilt of the binoculars



27.) Draw a tunnel diagram for a dove prism. Give the mirror matrix. Draw ray paths for blue and red and use this to show why the dove prism does not suffer chromatic aberrations when used in collimated light

28.) For the following system, determine the position of the nodal point and show it on the drawing. Show the position of the nodal point relative to point A:

20 mm aperture
0.1 NA
10 mm BFD
5° FOV



29.) Estimate the **rms** wavefront error that you would expect from a Porro prism with 50 mm aperture made from H4 glass (dn = +/- 1E-6). Assume light with 500 nm wavelength. (use a rule of thumb to get rms).

30.) Calculate the Strehl ratio for an imaging system that uses the Porro prism from 3). Explain what this means.

31.) A pitch polished spherical mirror will typically have surface roughness of 10 angstroms rms. This causes wide angle scatter. Calculate the total amount of scatter from one of these mirrors at 400 nm light. Is this important?

32.) Sketch a pentaprism. Give the mirror matrix. What is the “magic” of the penta prism?

33.) Sketch a rhomboid prism. Give the mirror matrix. What is the “magic” of this prism?

34.) Sketch a plot of a modulation transfer function. Label the axes. Name an optical application for which MTF would be an appropriate metric.

35.) Give an expression for the diffraction limited depth of focus. What does it mean for a a system to be diffraction limited?

36.) Show the relationship between ETD and line of sight deviation for specifying wedge in a lens.

37.) A 25 mm diameter lens has a requirements of R = 500 +/= 1 mm. Calculate the tolerance in terms of the sag of the surface. Is this tight?

38.) Sketch a dove prism. Define three axes and write the mirror matrix for this prism. Draw its tunnel diagram.

39.) For the dove prism above, describe what happens if the prism is rotated by a small angle about each of the three axes.

40.) A wavefront with 1 µm P-V spherical aberration has a shape error described by the equation:

$S(\rho) = (1\mu m)\left(4\rho^4 - 4\rho^2 + 2/3\right)$ where ρ is the normalized pupil radial coordinate (ρ = 1 at the edge)

Show how to calculate the rms wavefront deviation for this case. You do not need to evaluate the integrals.

41) Show how outside micrometers avoid the Abbe offset error that is present for calipers.