SAMPLE RAY TRACING STUDIES

For these exercises you must have already downloaded (from the FTP SITE) the configuration data files "Equicnvx.ray", "Cooke.ray" and "Plcnvx.ray" .

I.) THE EQUICONVEX LENS

A.) Spherical aberrations of the focal point:

1.) In the CONFIGURATION screen click on LOAD CONFIGURATION FROM FILE; then open the file "Equicnvx.ray". This should automatically fill in the configuration cells with data which defines the system as an equiconvex lens (with specified input and output planes). Now click on "ADD RAYS".

2.) In the TRACE ONE TO TWENTY FIVE RAYS screen note that the defaults specify a single ray with a RAY HEIGHT of 1 and a RAY ANGLE of zero (a horizontal ray). Leave these entries as they are, and in the four remaining cells of the RAY HEIGHT AT SOURCE row add RAY HEIGHTS of 2, 3, 4, and 0. This will specify 5 rays, all horizontal, at ray heights of 0, 1, 2, 3, and 4. Now click on OK.

3.) The RAY PLOT screen should soon appear showing the lens and the five rays. Note the spherical aberration (the paraxial, thin lens approximations have all (horizontal incoming) rays intersecting the optical axis at a common focal point). Click "HIDE CONTROLS" for a better view. Then click anywhere to restore the controls. To add more rays to this plot, click "ADD RAYS":

4.) This brings up the TRACE ONE TO TWENTY FIVE RAYS screen again, still holding your previous ray specifications. Now add four more rays, all horizontal, with RAY HEIGHTS of -1, -2, -3, and -4 by simply adding a negative sign before each of your previous RAY HEIGHT entries (just leave the zero entry as is, or delete it, or make it -0, it doesn't matter). Click OK to view the results.

5.) We can magnify this RAY PLOT screen in ONLY the vertical direction so as to see more details: While still in this RAY PLOT screen, click on the ERASE PLOT command in the menu bar at the top of the screen - the plot of the lens and rays should disappear. Now click on the ADD RAYS control, bringing you back again to the TRACE ONE TO TWENTY FIVE RAYS screen (still holding your latest ray specifications).

6.) Change the default entry of 1 in the VERTICAL MAGNIFICATION cell to 4. Do NOT change any other entries on this screen.

Click OK and view the result. (Click HIDE CONTROLS for a cleaner screen). This vertically magnified view exaggerates the aberrations. This allows better QUALITATIVE viewing, but be aware that the angles in this vertically stretched view do NOT obey Snell's law - all vertical distances (vertical coordinates of ray points and lens points) are multiplied by 4; horizontal distances are untouched. The numerical data (presented by the VIEW NUMERICAL DATA control and saved by the SAVE DATA TO A DISK FILE control) are unaffected by the VERTICAL MAGNIFICATION.

7.) Click on ADD RAYS and add rays with positive RAY HEIGHTS of 1, 2, 3, and 4 to this vertically magnified plot - a variation of step 2.) above.

8.) Calculate the paraxial, thin lens focal length of this equiconvex lens and compare it to the results generated by SNELL TRACE.

B.) Curvature of Field aberrations

If the RAY PLOT screen still holds a previous plot (as from the above exercise) click on ERASE PLOT and then choose CONFIG DATA, from VIEW in the top-of-screen menu bar; then go to 1.) below. Otherwise, start the program "from scratch" and proceed as below:

1.) In the CONFIGURATION screen click on LOAD CONFIGURATION FROM FILE; then open the file "Equicnvx.ray". This should automatically fill in the configuration cells with data which defines the system as an equiconvex lens (with specified input and output planes). Now click on "ADD RAYS".

2.) In the TRACE ONE TO TWENTY FIVE RAYS screen enter a 0 (zero) in the first cell of the RAY HEIGHT row; erase any data in the other cells of this row. In the RAY ANGLE row of cells enter the numbers 0, 1, -1, 2, and -2. Enter a 1 in the VERTICAL MAGNIFICATION cell. Click OK. To plot the results.

3.) You should see a fan of five rays originating from an axial point at screen-left and converging through an axial image point to the right of the lens. In the paraxial, thin lens approximations this would illustrate imaging from a real object position of 2 focal lengths to a real image position of 2 focal lengths (Count the grid squares - does this Snell simulation make sense?). We will now add off-axis object points in the input plane. But first let us use some vertical magnification for better viewing:

4.) Click ERASE PLOT (top menu), then click ADD RAYS. Change the VERTICAL MAGNIFICATION to 4 and click OK. (As an option, at this point you could increase the angular extent of this fan of rays to show how the outer lens zones introduce spherical aberration even in this "equal-object-image" situation [a favored situation for an equiconvex lens].) Instead, we will now add other object points: click ADD RAYS.

5.) The RAY HEIGHT row now has a single entry of 0. Add to the right of this cell the RAY HEIGHTS 1, 2, and 3 (leave the last cell blank. Do not change any other data. Click OK.

6.) Note that the screen you are now seeing (20 rays) could have been produced in one "fell swoop". To show this, click on ERASE PLOT (top menu), then click ADD RAYS. Note that the TRACE ONE TO TWENTY FIVE RAYS screen specifies all 20 rays. Without changing anything, just click on OK and see the fans of 5 rays emanating from 4 object points, as before.

7.) Note the aberrations: in addition to the blurring of each image point, the relative POSITIONS of the image points are distorted. For example, they should all lie on a vertical line (as their conjugate object points do), instead they lie on a curve (the aberration called "curvature of field"). Actually this simulation is unfair to the lens. Note that the rays from the axial object point use only the center zones of the lens, while the off- axis points use only the outer lens zones. In reality, all object points would use all zones of a bare lens (no stops). But this plot clearly shows how different lens zones treat rays differently. Stops (restricting apertures) are introduced into optical systems precisely to control these effects. You may experiment to produce more realistic simulations of actual lens uses; for example, erase the RAY PLOT screen, click ADD RAYS and try this:

8.) Specify a single fan of rays with RAY HEIGHT = 0 and RAY ANGLE = 0, 1, -1, 2, -2 and a VERTICAL MAGNIFICATION of 4 , exactly as we did in 1.) through 4.) above. Then (without erasing this plot) add a fan of rays with RAY HEIGHT = 3 and RAY ANGLE = -6, -7, -8, -9, -10 . Note the improvement when all rays use only the central lens zones!

II THE COOKE TRIPLET

Invented in 1893 by H. Taylor of Cooke & Sons, the Cooke Triplet consists of the smallest number (3) of elements by which all seven aberrations can be made to "essentially vanish" to third order (Cf. Hecht's text). It is still a popular basis for camera lenses. This particular embodiment is taken from Pedrotti's text

A.) Spherical aberrations of the focal point:

1.) Load the file Cooke.ray into the CONFIGURATION screen. Click ADD RAYS.

2.) Specify 4 rays with RAY HEIGHT = 1, -1, 4, -4 and RAY ANGLE = 0.

3.) Enter a VERTICAL MAGNIFICATION of 4. Click OK.

4.) Click ADD RAYS.

5.) Specify 4 rays with RAY HEIGHT = 7, -7, 10, -10 and RAY ANGLE = 0. Keep VERTICAL MAGNIFICATION = 4. Click OK.

6.) Note the sharply defined focal point, even though the very edges of the system are used.

B.) Open ended studies:

1.) Explore imaging with this system by changing the first and last entries in the LENGTH column of the Cooke CONFIGURATION data, to re-locate the input and output planes. Specify a fan of rays emanating from each object point, using the techniques illustrated in the equiconvex lens study, above.

III The Plano Convex Telescope Objective

A.) Plane surface toward star.

1.) If necessary, clear the RAYPLOT screen with the ERASE PLOT menu command.

2.) Load the file Plcnvx.ray into the CONFIGURATION screen. Click ADD RAYS.

3.) Specify 5 rays with RAY HEIGHT = 0, 1, 2, 3, 4 and RAY ANGLE = 0. Click OK. This illustrates the imaging of an infinitely distant star on the optical axis. Note the terrible spherical aberration. Click on the ERASE PLOT menu command.

B.) Convex surface toward star

1.) Go to the CONFIGURATION screen and change the two entries in the RADIUS columns, so that the first (top row) radius is 10 and the second radius is 1E10. (This gives the same lens, but turned around.) Click ADD RAYS.

2.) Make no changes to this screen. Just click OK. Note the great improvement in the image. You can now see why a plano convex lens is a popular choice for a telescope objective (but the convex surface must face the starfield!).

3.) Can you explain how the spherical aberrations of the two refractions can tend to cancel in this configuration, but cannot in the configuration of part A above?

4.) Add a bundle of rays from a second (infinitely distant) star: Click ADD RAYS.

5.) Just change the RAY ANGLE from 0 to -5 (note the minus sign!). Click OK.

6.) Add a third star: Click ADD RAYS.

7.) Specify RAY HEIGHTS of -1, -2, -3, and -4 . Change the RAY ANGLE to 5 (a positive number!). Click OK.

8.) Experiment with using this lens to image close objects (as in a camera). It is not such a good performer in this role!