Tutorial 1

Correcting Assembly Focus Errors

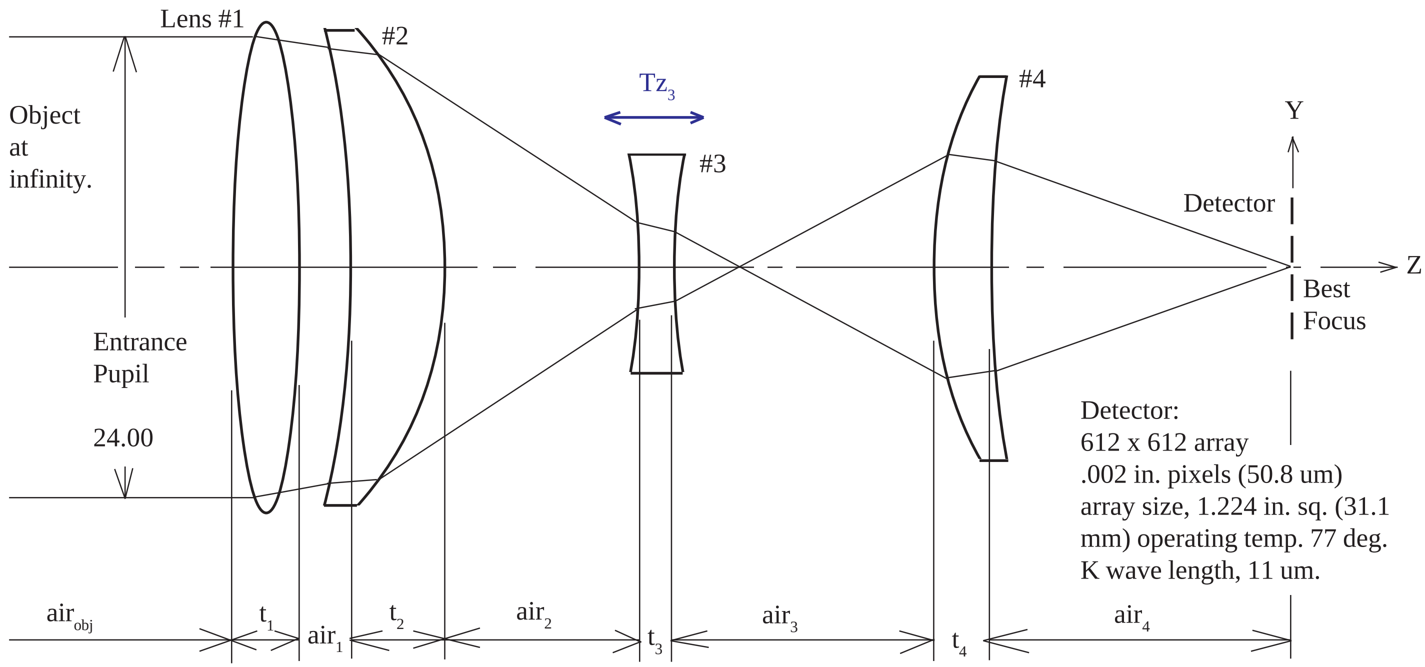
In this tutorial you will learn:

- how to set up a “project” directory for running Ivory
- how to put optical prescription data into Ivory’s project files
- how to run Ivory in both its SETUP and default Project modes
- how to read the Ivory output file into a Microsoft Excel spreadsheet
- how to put element displacements into the spreadsheet
- how to calculate the resulting worst case registration errors at the detector
- how to calculate the diffraction depth of focus for the system
- how to calculate the lens adjustment necessary to correct a predicted focus error

AEH.

Optomechanics

You have been assigned to an infrared receiver project. The optics looks like this ...



... and it has the following optical prescription:

Surface	Lens	Radius	Index	Thickness
1	obj.	inf.	1.0000	inf.
2	1	300.	4.0026	2.0000
3	1	-300.	1.0000	5.3566
4	2	-110.	4.0026	3.4500
5	2	-55.	1.0000	17.7750
6	3	-310.	4.0026	2.0000
7	3	215.	1.0000	11.9417
8	4	11.	4.0026	1.5000
9	4	22	1.0000	20.4727
10	det.	inf.	1.0000	0

(Dimensions are inches)

Task 1:

Your shop says they can probably locate each of the elements within 0.010 inches. How much focus error might you expect and how much motion of lens #3 would be necessary to correct it?

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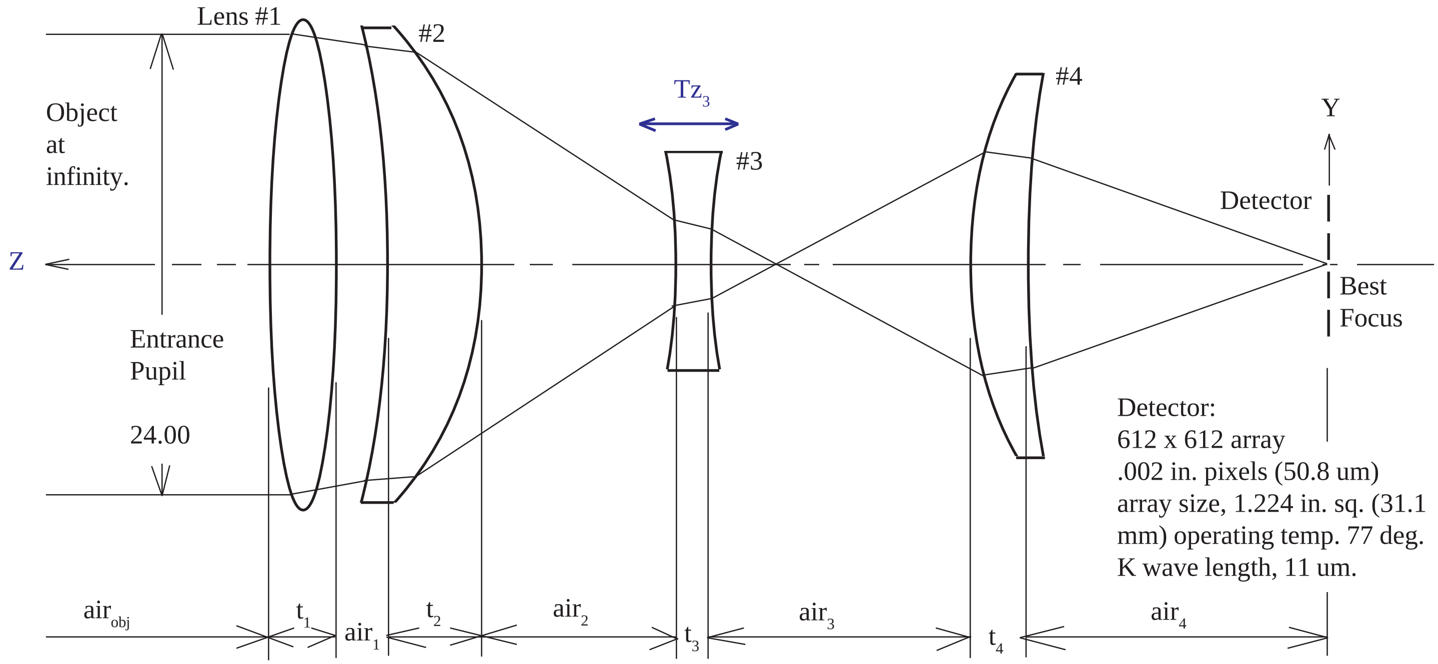

First you reverse the Z axis to agree with Ivory's mechanical conventions and adjust the signs in the optical prescription accordingly,

Surface	Lens	Radius	Index	Thickness
1	obj.	inf.	1.0000	inf.
2	1	-300.	4.0026	2.0000
3	1	300.	1.0000	5.3566
4	2	110.	4.0026	3.4500
5	2	55.	1.0000	17.7750
6	3	310.	4.0026	2.0000
7	3	-215.	1.0000	11.9417
8	4	-11.	4.0026	1.5000
9	4	-22.	1.0000	20.4727
10	det.	inf.	1.0000	0

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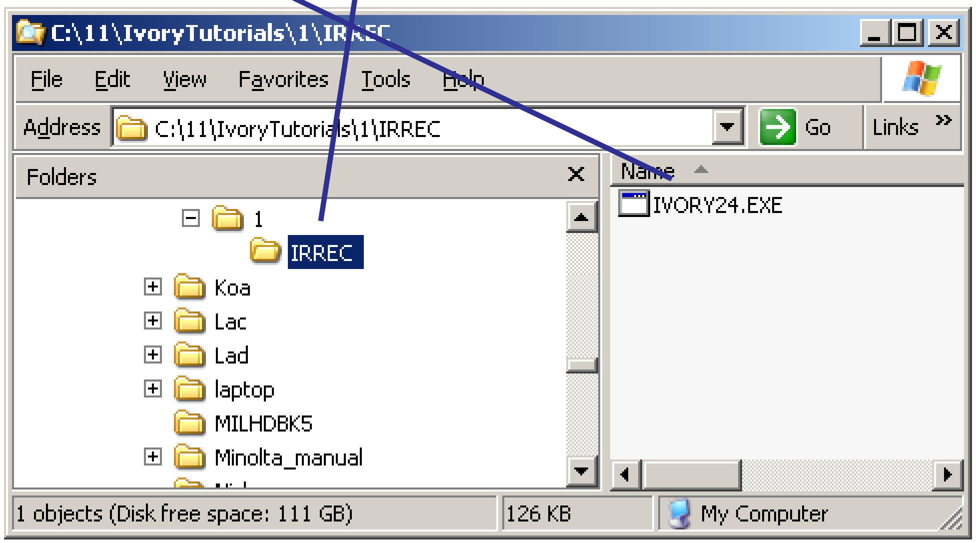
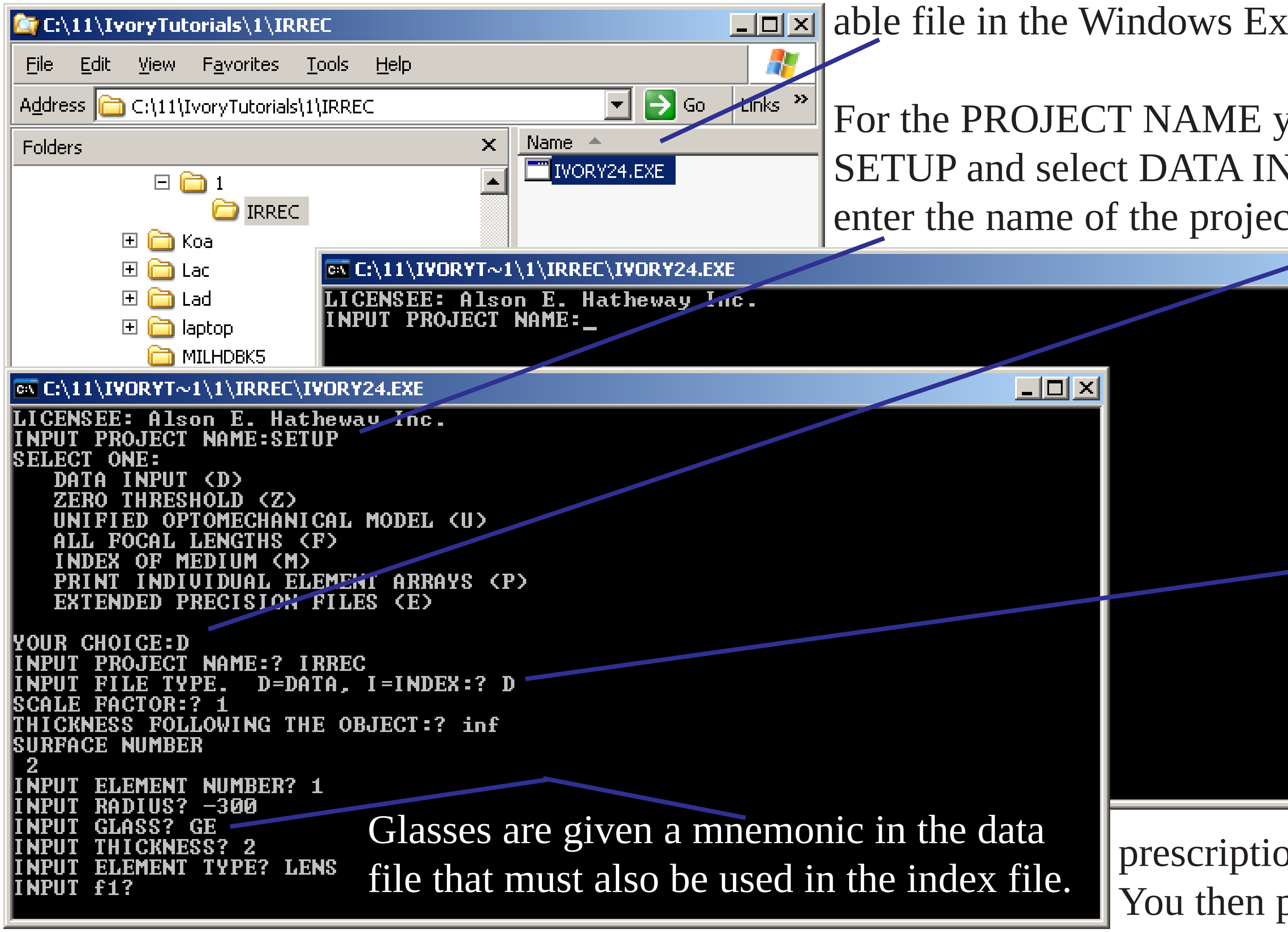
Then you create a new directory, say IRREC, in Windows Explorer. This will be where you will be working. You move a copy of the Ivory executable file into this directory.

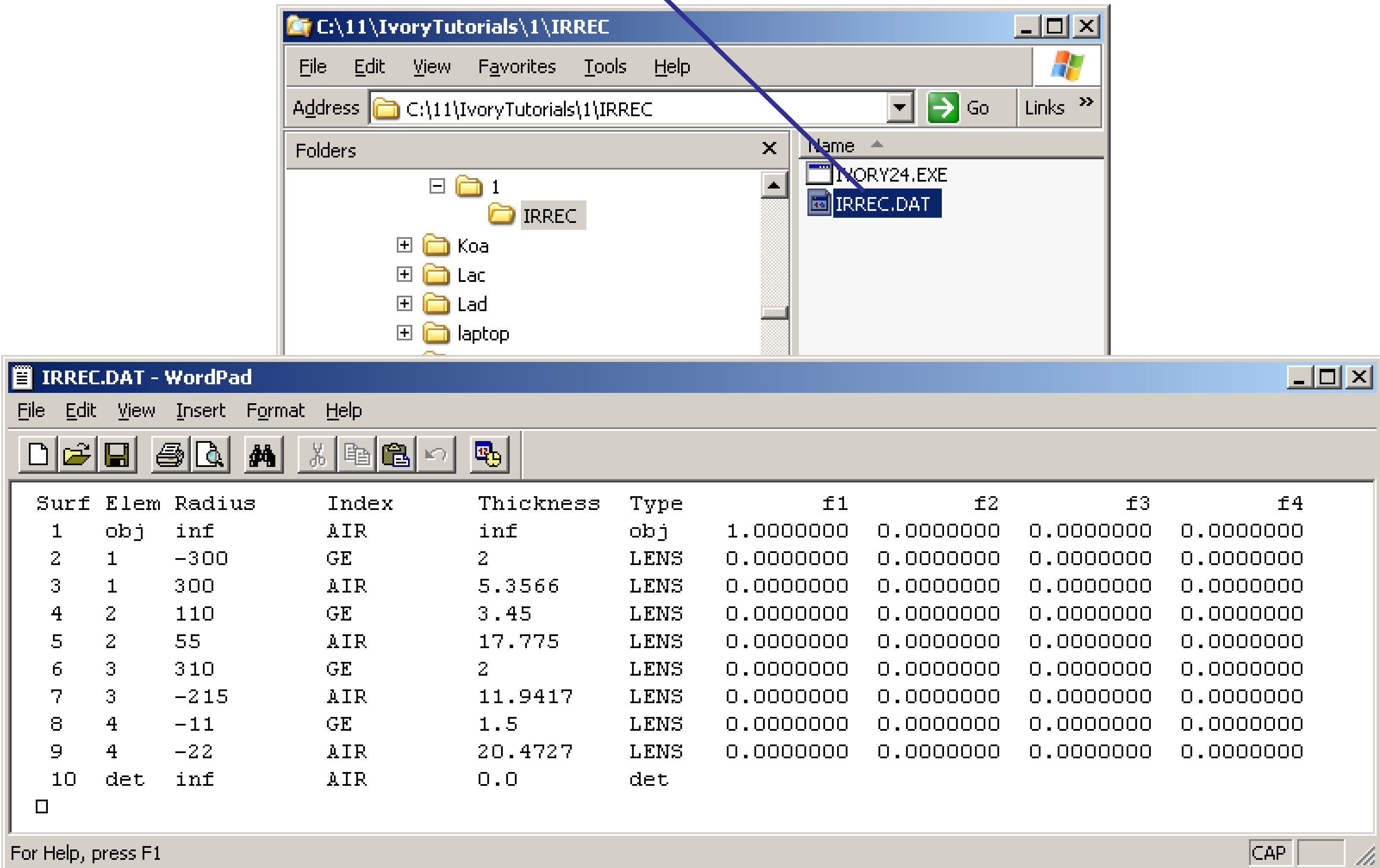


You now call up Ivory to prepare the project data files by double-clicking on the Ivory executable file in the Windows Explorer box.

For the PROJECT NAME you enter SETUP and select DATA INPUT (D). You enter the name of the project, in this case IRREC, and select the geometric data input, D. Ivory prompts you for a scale factor on the dimensions and you enter 1 (assuming the units of the optical prescription acceptable). You then proceed to enter the surface-by-surface data into Ivory. A blank entry for any surface will produce the detector entry automatically and close the file.



You may now double-click on IRREC.DAT to review (and edit, if necessary) the data file. It will open in either Notepad or WordPad.



Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4
1	obj	inf	AIR	inf	obj	1.0000000	0.0000000	0.0000000	0.0000000
2	1	-300	GE	2	LENS	0.0000000	0.0000000	0.0000000	0.0000000
3	1	300	AIR	5.3566	LENS	0.0000000	0.0000000	0.0000000	0.0000000
4	2	110	GE	3.45	LENS	0.0000000	0.0000000	0.0000000	0.0000000
5	2	55	AIR	17.775	LENS	0.0000000	0.0000000	0.0000000	0.0000000
6	3	310	GE	2	LENS	0.0000000	0.0000000	0.0000000	0.0000000
7	3	-215	AIR	11.9417	LENS	0.0000000	0.0000000	0.0000000	0.0000000
8	4	-11	GE	1.5	LENS	0.0000000	0.0000000	0.0000000	0.0000000
9	4	-22	AIR	20.4727	LENS	0.0000000	0.0000000	0.0000000	0.0000000
10	det	inf	AIR	0.0	det				

This is you chance to correct any typing mistakes you might have made while putting the data into Ivory. Make any corrections and save the file.

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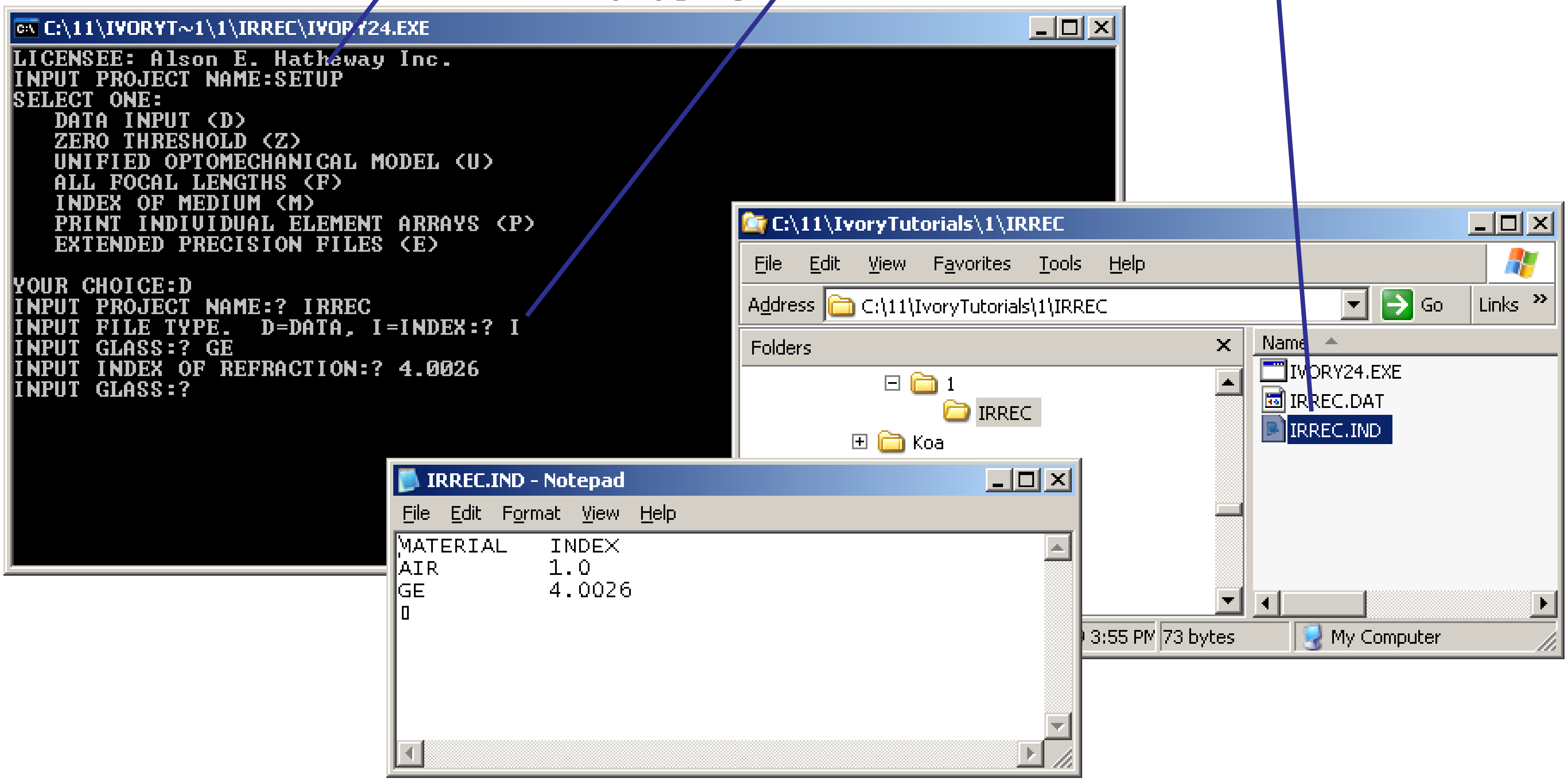
Now you need to re-enter SETUP to prepare the index of refraction data file. A blank entry for a glass input saves the file and closes the window. Double-click on IRREC.IND to review the contents of the file and correct any typing errors.



The lens material is germanium and is entered in the file with its mnemonic GE.
Note that Ivory automatically enters AIR at a value of 1.0.
Beware: The glass names are case sensitive between the *.DAT and *.IND files.

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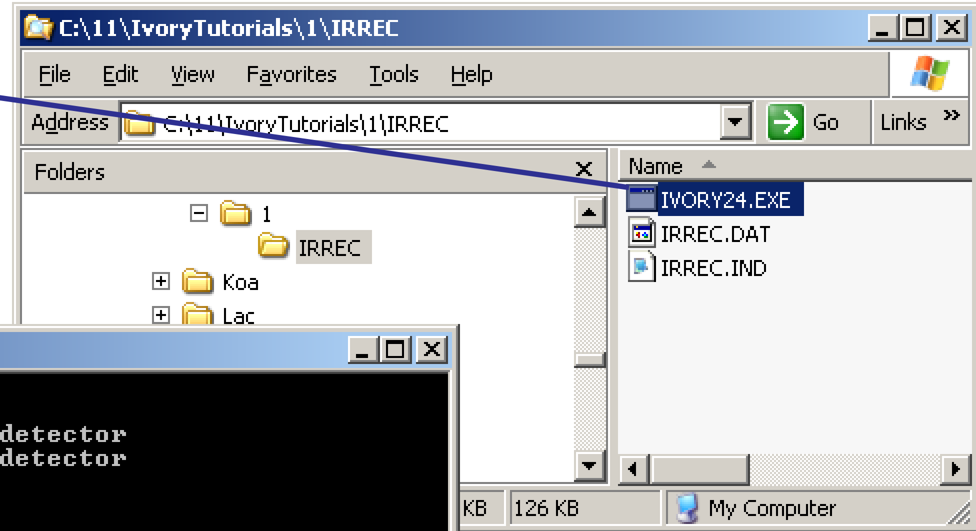
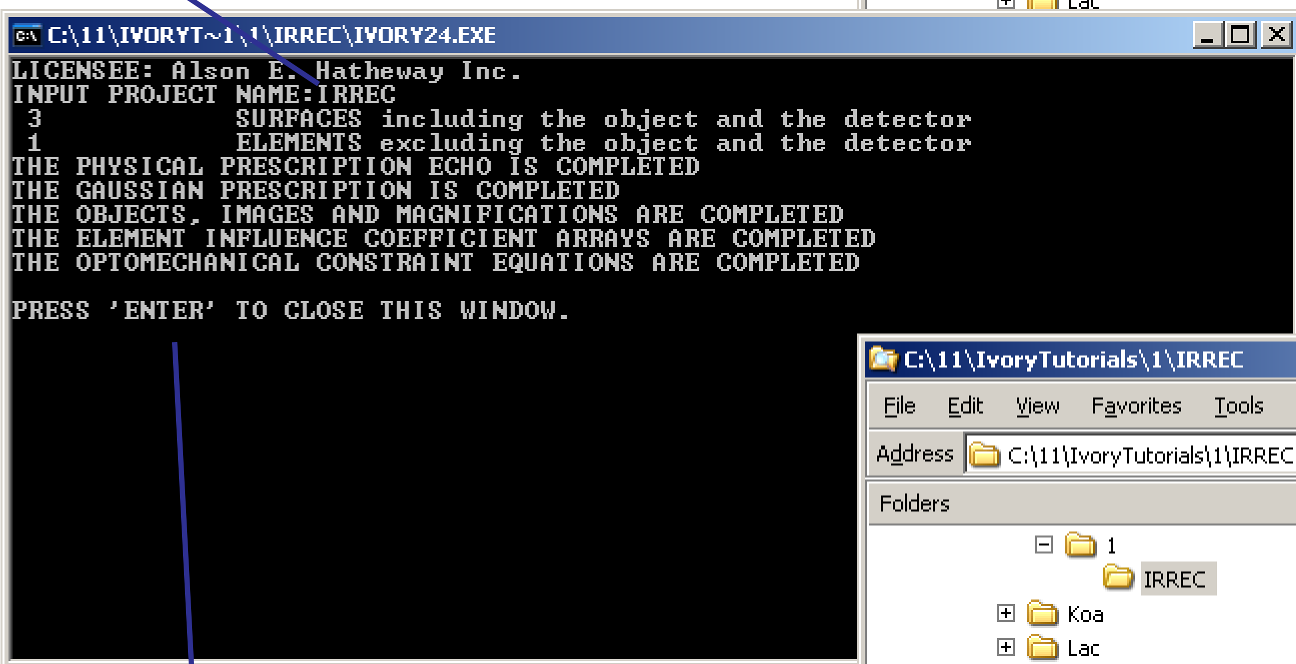
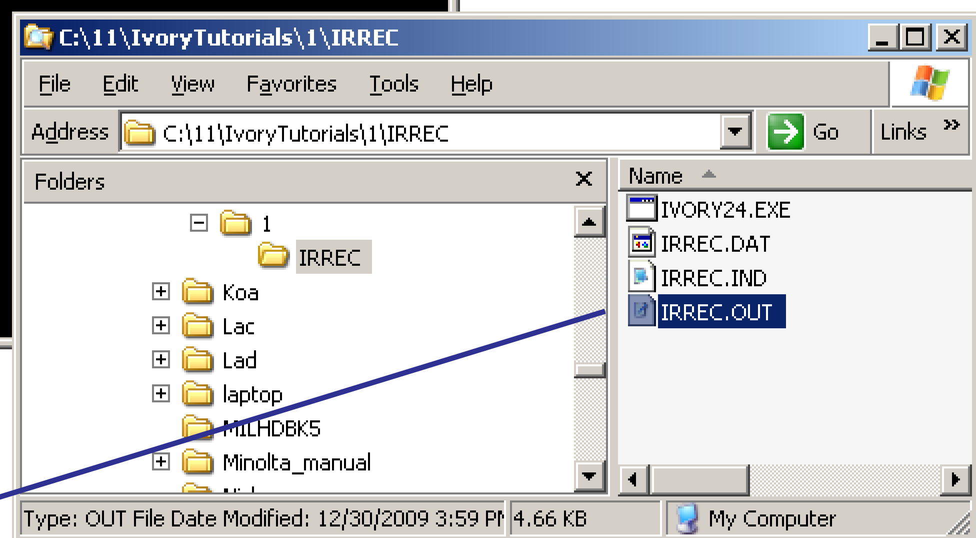
You may now run Ivory in its Project mode to produce the output file and the Optomechanical Constraint Equations. Double-click on the Ivory executable file and input IRREC as the PROJECT NAME.





Press “Enter” to close the window.



You may now double-click on IRREC.OUT to view the output file.

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Optomechanics

```
IRREC.OUT - Notepad
File  Edit  Format  View  Help

Output from -
                IVORY Optomechancial Modeling Tools
                                                   Version 2.4
                                                                 Copyright 2010, Alson E. Hatheway Inc.

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PROJECT NAME: 'IRREC'       TIME AND DATE: 18:02:35 12-19-2009

PHYSICAL PRESCRIPTION ECHO

 Surf         Elem         Radius       Index        Thickness    Type         f1           f2           f3           f4
  1           obj          inf          1.0          inf          obj          1            0            0            0
  2           1            -300          4.0026       2           LENS         0            0            0            0
  3           1             300         1.0           5.3566      LENS         0            0            0            0
  4           2             110          4.0026       3.45        LENS         0            0            0            0
  5           2             55          1.0           17.775      LENS         0            0            0            0
  6           3             310          4.0026       2           LENS         0            0            0            0
  7           3            -215         1.0           11.9417     LENS         0            0            0            0
  8           4            -11           4.0026       1.5         LENS         0            0            0            0
  9           4            -22          1.0           20.4727     LENS         0            0            0            0
  10          det          inf          1.0           0           det

INDEXES OF REFRACTION ARE RELATIVE TO THE VALUE OF  1.000292


GAUSSIAN PRESCRIPTION

 ELE          F            H1           H2           P            P/AIR        PHI          THETA        TYPE
 obj          0            0            0            0            inf          0            0             obj
 1             50.08193    -.2504639     .2504639     1.499072     7.25347     0            0            LENS
 2             34.98851    -1.646407    -.8232033     2.626797     17.246      0            0            LENS
 3            -42.16034    -.2942056     .2040458     1.501749     11.80577    0            0            LENS
 4             6.647026     .3399783     .6799567     1.160022     21.15266    0            0            LENS
 det          0            0            0            0            0            0            0             det

SYSTEM        -51.578990583  265.29299278 -72.045283594  381.36157697 -51.572580294


OBJECTS, IMAGES AND MAGNIFICATIONS

 ELE          F                S          S'         M         PHI      THETA          TYPE           e/Tzo
 obj          inf              0          0        +1.0000     0        0               obj
 1             50.08193      inf      -50.0819       0         0        0              LENS          +0.00D+00
 2             34.98851     -42.8285  -19.2568    +0.4496      0        0              LENS          +1.29D-02
 3            -42.16034      -2.0108   -2.1115    +1.0501      0        0              LENS          -2.49D-02
 4             6.647026      +9.6943  -21.1463    -2.1813      0        0              LENS          -3.28D-01
 det          inf          +6.39D-03 +6.39D-03    +1.0         0        0               det
```

This is the top half of the output file with the physical and Gaussian prescription data, the location of all the intermediate images and the magnification at which each lens is working.

Check the data in the output file. Two of the important values are --

The Gaussian focal length should agree well with the effective focal lenth (EFL) of the lens design ...

```
  6        3        310      4.0026    2        LENS     0      0      0      0
  7        3        -215     1.0       11.9417  LENS     0      0      0      0
  8        4        -11      4.0026    1.5      LENS     0      0      0      0
  9        4        -22      1.0       20.4727  LENS     0      0      0      0
  10       det      inf      1.0       0        det

INDEXES OF REFRACTION ARE RELATIVE TO THE VALUE OF  1.000292


GAUSSIAN PRESCRIPTION

 ELE       F           H1          H2          P          P/AIR       PHI     THETA    TYPE
 obj       0           0           0           0          inf         0       0         obj
 1          50.08193   -.2504639    .2504639    1.499072   7.25347    0       0        LENS
 2          34.98851   -1.646407   -.8232033    2.626797   17.246     0       0        LENS
 3         -42.16034   -.2942056    .2040458    1.501749   11.80577   0       0        LENS
 4          6.647026    .3399783    .6799567    1.160022   21.15266   0       0        LENS
 det       0           0           0           0          0           0       0         det

SYSTEM     -51.578990583  265.29299278 -72.045283594  381.36157697 -51.572580294

OBJECTS, IMAGES AND MAGNIFICATIONS

 ELE       F            S           S'         M         PHI     THETA        TYPE         e/Tzo
 obj       inf          0           0          +1.0000   0       0             obj
 1          50.08193    inf        -50.0819    0         0       0            LENS         +0.00D+00
 2          34.98851   -42.8285    -19.2568    +0.4496   0       0            LENS         +1.29D-02
 3         -42.16034    -2.0108     -2.1115    +1.0501   0       0            LENS         -2.49D-02
 4          6.647026    +9.6943    -21.1463    -2.1813   0       0            LENS         -3.28D-01
 det       inf         +6.39D-03   +6.39D-03   +1.0      0       0             det
```

...and the image distance at the detector should be very small.

AEH.

Optomechanics

IRREC.OUT - Notepad

File Edit Format View Help

OPTOMECHANICAL CONSTRAINT EQUATIONS (ABSOLUTE VALUES SMALLER THAN 0 ARE PRINTED AS 0.0)

REGISTRATION VARIABLES

	TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDesVar
Tx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Dt
Ty	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	DR1
Tz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	DR2
Rx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Dn
Ry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Rz	0.0	0.0	0.0	0.0	0.0	+1.00000	0.0	0.0	
Df,p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
SYSTEM-OBJECT									
Tx	-1.02989	0.0	0.0	0.0	0.0	0.0	0.0	+0.06277	Dt
Ty	0.0	-1.02989	0.0	0.0	0.0	0.0	0.0	-0.08326	DR1
Tz	0.0	0.0	+1.06068	0.0	0.0	0.0	-0.06534	+0.08326	DR2
Rx	0.0	-1.54389	0.0	-1.02989	0.0	0.0	0.0	-16.66907	Dn
Ry	+1.54389	0.0	0.0	0.0	-1.02989	0.0	0.0	0.0	
Rz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Df,p	0.0	0.0	-1.06068	0.0	0.0	0.0	+0.08531	0.0	
ELEMENT-1									
Tx	-1.26067	0.0	0.0	0.0	0.0	0.0	0.0	-0.45577	Dt
Ty	0.0	-1.26067	0.0	0.0	0.0	0.0	0.0	-0.28949	DR1
Tz	0.0	0.0	+4.18598	0.0	0.0	0.0	-0.32143	+1.24372	DR2
Rx	0.0	-6.01684	0.0	-1.26067	0.0	0.0	0.0	-11.78357	Dn
Ry	+6.01684	0.0	0.0	0.0	-1.26067	0.0	0.0	0.0	
Rz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Df,p	0.0	0.0	-1.58928	0.0	0.0	0.0	+0.13289	0.0	
ELEMENT-2									
Tx	+0.10925	0.0	0.0	0.0	0.0	0.0	0.0	+0.06007	Dt
Ty	0.0	+0.10925	0.0	0.0	0.0	0.0	0.0	-0.05592	DR1
Tz	0.0	0.0	-0.48854	0.0	0.0	0.0	+0.05860	+0.11602	DR2
Rx	0.0	-3.27578	0.0	+0.10925	0.0	0.0	0.0	+14.05127	Dn
Ry	+3.27578	0.0	0.0	0.0	+0.10925	0.0	0.0	0.0	
Rz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Df,p	0.0	0.0	-0.01193	0.0	0.0	0.0	+2.011E-03	0.0	
ELEMENT-3									
Tx	+3.18131	0.0	0.0	0.0	0.0	0.0	0.0	-0.41124	Dt
Ty	0.0	+3.18131	0.0	0.0	0.0	0.0	0.0	-1.15247	DR1
Tz	0.0	0.0	-3.75813	0.0	0.0	0.0	+0.32816	+0.24606	DR2
Rx	0.0	+1.16002	0.0	+3.18131	0.0	0.0	0.0	-2.26508	Dn
Ry	-1.16002	0.0	0.0	0.0	+3.18131	0.0	0.0	0.0	
Rz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Df,p	0.0	0.0	-10.12075	0.0	0.0	0.0	+0.47861	0.0	
ELEMENT-4									
Tx	-1.00000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Dt
Ty	0.0	-1.00000	0.0	0.0	0.0	0.0	0.0	0.0	DR1
Tz	0.0	0.0	-1.00000	0.0	0.0	0.0	0.0	0.0	DR2
Rx	0.0	0.0	0.0	-1.00000	0.0	0.0	0.0	0.0	Dn
Ry	0.0	0.0	0.0	0.0	-1.00000	0.0	0.0	0.0	
Rz	0.0	0.0	0.0	0.0	0.0	-1.00000	0.0	0.0	
Df,p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
DETECTOR									

The bottom half of the output file contains all of the influence coeficients in the form of the Opto-mechanical Constraint Equations. These should be checked for "reason-ableness," that is, very large and very small val-ues should be noted and verified.

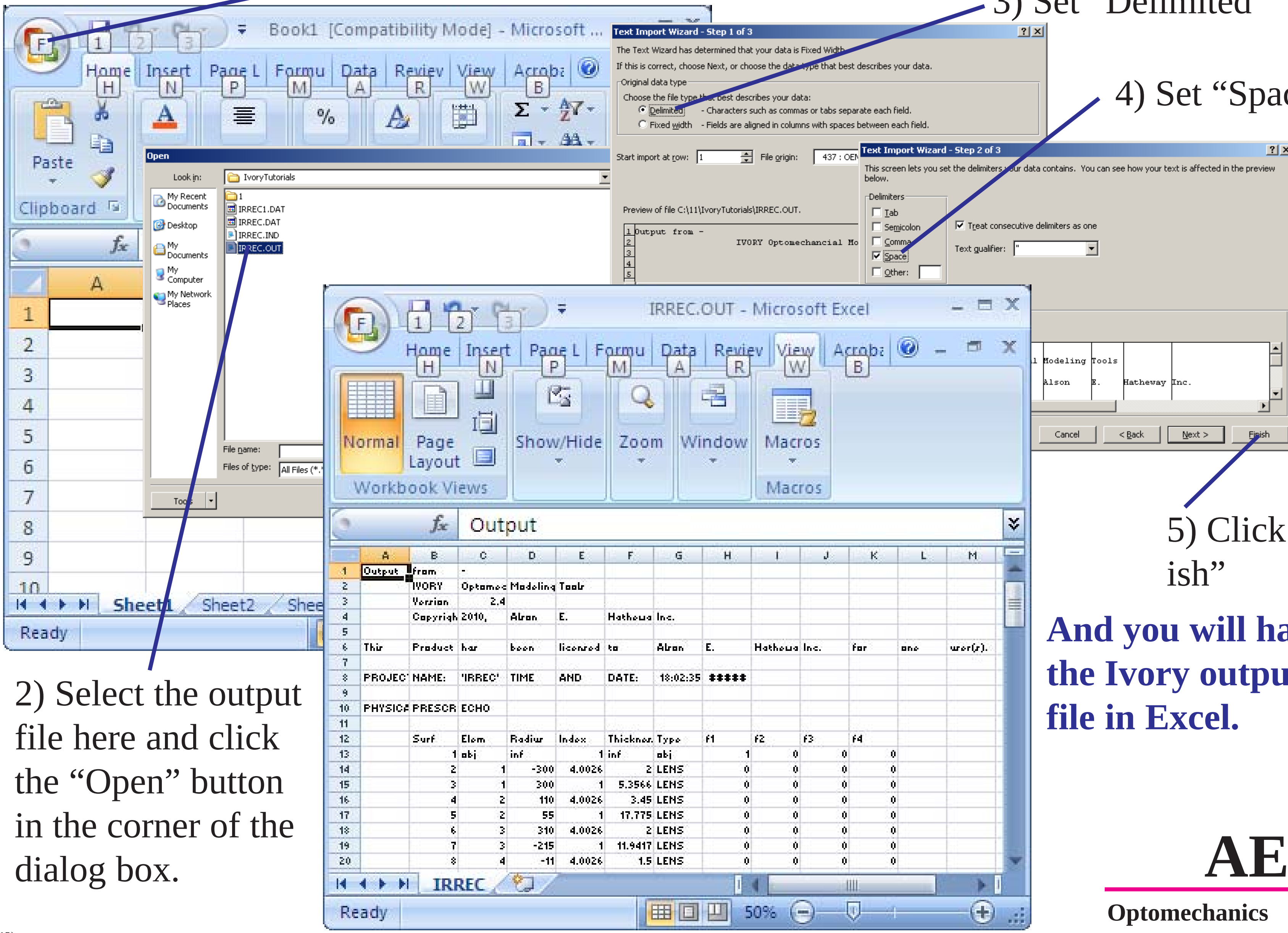
One method is to com-pare the coefficients to the related F and M val-ues in the top half of the output file. These seem reasonable so you'll pro-ceed with the Task 1.

To address Task 1 you will want to open the Ivory output file in a Microsoft Excel worksheet. In Excel,

1) Click here and on “Open”

3) Set “Delimited”

4) Set “Space”



5) Click “Finish”

2) Select the output file here and click the “Open” button in the corner of the dialog box.

And you will have the Ivory output file in Excel.

AEH.

Optomechanics

Check the data in the spreadsheet to be sure it was properly interpreted by Excel.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Output	from	-										
2		IVORY	Optomec	Modeling	Tools								
3		Version	2.4										
4		Copyrigh	2010,	Alson	E.	Hathawa	Inc.						
5													
6	This	Product	has	been	licensed	to	Alson	E.	Hathawa	Inc.	for	one	user(s).
7													
8	PROJEC'	NAME:	'IRREC'	TIME	AND	DATE:	18:02:35	#####					
9													
10	PHYSICA	PRESCR	ECHO										
11													
12		Surf	Elem	Radius	Index	Thicknes	Type	f1	f2	f3	f4		
13		1	obj	inf	1	inf	obj	1	0	0	0		
14		2	1	-300	4.0026	2	LENS	0	0	0	0		
15		3	1	300	1	5.3566	LENS	0	0	0	0		
16		4	2	110	4.0026	3.45	LENS	0	0	0	0		
17		5	2	55	1	17.775	LENS	0	0	0	0		
18		6	3	310	4.0026	2	LENS	0	0	0	0		
19		7	3	-215	1	11.9417	LENS	0	0	0	0		
20		8	4	-11	4.0026	1.5	LENS	0	0	0	0		
21		9	4	-22	1	20.4727	LENS	0	0	0	0		
22		10	det	inf	1	0	det						
23													
24	INDEXES	OF	REFRAC'	ARE	RELATIVI	TO	THE	VALUE	OF	1.00029			
25													
26													
27	GAUSSI/	PRESCRIPTION											
28													
29		ELE	F	H1	H2	P	P/AIR	PHI	THETA	TYPE			
30		obj	0	0	0	0	inf	0	0	obj			
31		1	50.0819	-0.2505	0.25046	1.49907	7.25347	0	0	LENS			
32		2	34.9885	-1.6464	-0.8232	2.6268	17.246	0	0	LENS			
33		3	-42.16	-0.2942	0.20405	1.50175	11.8058	0	0	LENS			
34		4	6.64703	0.33998	0.67996	1.16002	21.1527	0	0	LENS			
35		det	0	0	0	0	0	0	0	det			
36													
37	SYSTEM	-51.579	265.293	-72.045	381.362	-51.573							
38													
39													
40	OBJECTS	IMAGES	AND	MAGNIFICATIONS									
41													
42		ELE	F	S	S'	M	PHI	THETA	TYPE	s/Tza			
43		obj	inf	0	0	1	0	0	obj				
44		1	50.0819	inf	-50.082	0	0	0	LENS	+0.00D+00			
45		2	34.9885	-42.829	-19.257	0.4496	0	0	LENS	+1.29D-02			
46		3	-42.16	-2.0108	-2.1115	1.0501	0	0	LENS	-2.49D-02			
47		4	6.64703	9.6943	-21.146	-2.1813	0	0	LENS	-3.28D-01			
48		det	inf	+6.39D-0	+6.39D-0	1	0	0	det				
49													
50													
51	OPTOME	CONSTR	EQUATIO	(ABSOLU	VALUES	SMALLEI	THAN	0	ARE	PRINTED	AS	0.0)	
52													
53		REGISTR	VARIABLES										
54													

IRREC

Ready 50%

	A	B	C	D	E	F	G	H	I	J	K	L	M
54													
55		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDesVar			
56													
57	Tx	0	0	0	0	0	0	0	0	Dt			
58	Ty	0	0	0	0	0	0	0	0	DR1			
59	Tz	0	0	0	0	0	0	0	0	DR2			
60	Rx	0	0	0	0	0	0	0	0	Dn			
61	Ry	0	0	0	0	0	0	0	0				
62	Rz	0	0	0	0	0	1	0	0				
63	Df,p	0	0	0	0	0	0	0	0				
64	SYSTEM-OBJECT												
65													
66	Tx	-1.0299	0	0	0	0	0	0	0.06277	Dt			
67	Ty	0	-1.0299	0	0	0	0	0	-0.0833	DR1			
68	Tz	0	0	1.06068	0	0	0	-0.0653	0.08326	DR2			
69	Rx	0	-1.5439	0	-1.0299	0	0	0	-16.669	Dn			
70	Ry	1.54389	0	0	0	-1.0299	0	0	0				
71	Rz	0	0	0	0	0	0	0	0				
72	Df,p	0	0	-1.0607	0	0	0	0.08531	0				
73	ELEMENT-1												
74													
75	Tx	-1.2607	0	0	0	0	0	0	-0.4558	Dt			
76	Ty	0	-1.2607	0	0	0	0	0	-0.2895	DR1			
77	Tz	0	0	4.18598	0	0	0	-0.3214	1.24372	DR2			
78	Rx	0	-6.0168	0	-1.2607	0	0	0	-11.784	Dn			
79	Ry	6.01684	0	0	0	-1.2607	0	0	0				
80	Rz	0	0	0	0	0	0	0	0				
81	Df,p	0	0	-1.5893	0	0	0	0.13289	0				
82	ELEMENT-2												
83													
84	Tx	0.10925	0	0	0	0	0	0	0.06007	Dt			
85	Ty	0	0.10925	0	0	0	0	0	-0.0559	DR1			
86	Tz	0	0	-0.4885	0	0	0	0.0586	0.11602	DR2			
87	Rx	0	-3.2758	0	0.10925	0	0	0	14.0513	Dn			
88	Ry	3.27578	0	0	0	0.10925	0	0	0				
89	Rz	0	0	0	0	0	0	0	0				
90	Df,p	0	0	-0.0119	0	0	0	2.01E-03	0				
91	ELEMENT-3												
92													
93	Tx	3.18131	0	0	0	0	0	0	-0.4112	Dt			
94	Ty	0	3.18131	0	0	0	0	0	-1.1525	DR1			
95	Tz	0	0	-3.7581	0	0	0	0.32816	0.24606	DR2			
96	Rx	0	1.16002	0	3.18131	0	0	0	-2.2651	Dn			
97	Ry	-1.16	0	0	0	3.18131	0	0	0				
98	Rz	0	0	0	0	0	0	0	0				
99	Df,p	0	0	-10.121	0	0	0	0.47861	0				
100	ELEMENT-4												
101													
102	Tx	-1	0	0	0	0	0	0	0	Dt			
103	Ty	0	-1	0	0	0	0	0	0	DR1			
104	Tz	0	0	-1	0	0	0	0	0	DR2			
105	Rx	0	0	0	-1	0	0	0	0	Dn			
106	Ry	0	0	0	0	-1	0	0	0				
107	Rz	0	0	0	0	0	-1	0	0				
108	Df,p	0	0	0	0	0	0	0	0				
109	DETECTOR												

IRREC

Ready 50%

You'll be working with just this bottom half.

AEH.

Optomechanics

Now you can calculate the focus error caused by the ±0.010 position tolerances.

	A	B	C	D	E	F	G	H	I	J
54										
55		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDerVar
56										
57	Tx	0	0	0	0	0	0	0	0	Dt
58	Ty	0	0	0	0	0	0	0	0	DR1
59	Tz	0	0	0	0	0	0	0	0	DR2
60	Rx	0	0	0	0	0	0	0	0	Dn
61	Ry	0	0	0	0	0	0	0	0	
62	Rz	0	0	0	0	0	1	0	0	
63	Df,p	0	0	0	0	0	0	0	0	
64	SYSTEM-OBJECT									
65										
66	Tx	-1.0299	0	0	0	0	0	0	0.06277	Dt
67	Ty	0	-1.0299	0	0	0	0	0	-0.0833	DR1
68	Tz	0	0	1.06068	0	0	0	-0.0653	0.08326	DR2
69	Rx	0	-1.5439	0	-1.0299	0	0	0	-16.669	Dn
70	Ry	1.54389	0	0	0	-1.0299	0	0	0	
71	Rz	0	0	0	0	0	0	0	0	
72	Df,p	0	0	-1.0607	0	0	0	0.08531	0	
73	ELEMENT-1									
74										
75	Tx	-1.2607	0	0	0	0	0	0	-0.4558	Dt
76	Ty	0	-1.2607	0	0	0	0	0	-0.2895	DR1
77	Tz	0	0	4.18598	0	0	0	-0.3214	1.24372	DR2
78	Rx	0	-6.0168	0	-1.2607	0	0	0	-11.784	Dn
79	Ry	6.01684	0	0	0	-1.2607	0	0	0	
80	Rz	0	0	0	0	0	0	0	0	
81	Df,p	0	0	-1.5893	0	0	0	0.13289	0	
82	ELEMENT-2									
83										
84	Tx	0.10925	0	0	0	0	0	0	0.06007	Dt
85	Ty	0	0.10925	0	0	0	0	0	-0.0559	DR1
86	Tz	0	0	-0.4885	0	0	0	0.0586	0.11602	DR2
87	Rx	0	-3.2758	0	0.10925	0	0	0	14.0513	Dn
88	Ry	3.27578	0	0	0	0.10925	0	0	0	
89	Rz	0	0	0	0	0	0	0	0	
90	Df,p	0	0	-0.0119	0	0	0	2.01E-03	0	
91	ELEMENT-3									
92										
93	Tx	3.18131	0	0	0	0	0	0	-0.4112	Dt
94	Ty	0	3.18131	0	0	0	0	0	-1.1525	DR1
95	Tz	0	0	-3.7581	0	0	0	0.32816	0.24606	DR2
96	Rx	0	1.16002	0	3.18131	0	0	0	-2.2651	Dn
97	Ry	-1.16	0	0	0	3.18131	0	0	0	
98	Rz	0	0	0	0	0	0	0	0	
99	Df,p	0	0	-10.121	0	0	0	0.47861	0	
100	ELEMENT-4									
101										
102	Tx	-1	0	0	0	0	0	0	0	Dt
103	Ty	0	-1	0	0	0	0	0	0	DR1
104	Tz	0	0	-1	0	0	0	0	0	DR2
105	Rx	0	0	0	-1	0	0	0	0	Dn
106	Ry	0	0	0	0	-1	0	0	0	
107	Rz	0	0	0	0	0	-1	0	0	
108	Df,p	0	0	0	0	0	0	0	0	
109	DETECTOR									
110										

	L	N	O	P	Q	R	S	T
54	Position							
55	Tolerance	TX	TY	TZ	RX	RY	RZ	DM/M
56								
57		0	0	0	0	0	0	0
58		0	0	0	0	0	0	0
59		0	0	0	0	0	0	0
60		0	0	0	0	0	0	0
61		0	0	0	0	0	0	0
62		0	0	0	0	0	0	0
63		0	0	0	0	0	0	0
64		0	0	0	0	0	0	0
65		0	0	0	0	0	0	0
66	0.01	-0.0103	0	0	0	0	0	0
67	0.01	0	-0.0103	0	0	0	0	0
68	0.01	0	0	0.01061	0	0	0	-0.0007
69		0	0	0	0	0	0	0
70		0	0	0	0	0	0	0
71		0	0	0	0	0	0	0
72		0	0	0	0	0	0	0
73		0	0	0	0	0	0	0
74		0	0	0	0	0	0	0
75	0.01	-0.01261	0	0	0	0	0	0
76	0.01	0	-0.0126	0	0	0	0	0
77	0.01	0	0	0.04186	0	0	0	-0.0032
78		0	0	0	0	0	0	0
79		0	0	0	0	0	0	0
80		0	0	0	0	0	0	0
81		0	0	0	0	0	0	0
82		0	0	0	0	0	0	0
83		0	0	0	0	0	0	0
84	0.01	0.00109	0	0	0	0	0	0
85	0.01	0	0.00109	0	0	0	0	0
86	0.01	0	0	-0.0049	0	0	0	0.00059
87		0	0	0	0	0	0	0
88		0	0	0	0	0	0	0
89		0	0	0	0	0	0	0
90		0	0	0	0	0	0	0
91		0	0	0	0	0	0	0
92		0	0	0	0	0	0	0
93	0.01	0.03181	0	0	0	0	0	0
94	0.01	0	0.03181	0	0	0	0	0
95	0.01	0	0	-0.0376	0	0	0	0.00328
96		0	0	0	0	0	0	0
97		0	0	0	0	0	0	0
98		0	0	0	0	0	0	0
99		0	0	0	0	0	0	0
100		0	0	0	0	0	0	0
101		0	0	0	0	0	0	0
102	0.01	-0.01	0	0	0	0	0	0
103	0.01	0	-0.01	0	0	0	0	0
104	0.01	0	0	-0.01	0	0	0	0
105		0	0	0	0	0	0	0
106		0	0	0	0	0	0	0
107		0	0	0	0	0	0	0
108		0	0	0	0	0	0	0
109								
110		0.066	0.066	0.105	0	0	0	0.008

IRREC

1) Enter the *shop's estimate of tolerances.*

2) Multiply all the *coefficients* in the OCE by all the *tolerances* to get *contributions of each element* to registration error.

3) Sum the individual contributions vertically on an *absolute basis* to get the ***maximum registration errors*** possible at the detector.

AEH.

Optomechanics

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
54												Position								
55		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDevVar		Tolerance		TX	TY	TZ	RX	RY	RZ	DM/M
56																				
57	Tx	0	0	0	0	0	0	0	0	Dt				0	0	0	0	0	0	0
58	Ty	0	0	0	0	0	0	0	0	DR1				0	0	0	0	0	0	0
59	Tz	0	0	0	0	0	0	0	0	DR2				0	0	0	0	0	0	0
60	Rx	0	0	0	0	0	0	0	0	Dn				0	0	0	0	0	0	0
61	Ry	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0
62	Rz	0	0	0	0	0	1	0	0					0	0	0	0	0	0	0
63	Df,p	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0
64	SYSTEM-OBJECT													0	0	0	0	0	0	0
65														0	0	0	0	0	0	0
66	Tx	-1.0299	0	0	0	0	0	0	0.06277	Dt		0.01		-0.0103	0	0	0	0	0	0
67	Ty	0	-1.0299	0	0	0	0	0	-0.0833	DR1		0.01		0	-0.0103	0	0	0	0	0
68	Tz	0	0	1.06068	0	0	0	-0.0653	0.08326	DR2		0.01		0	0	0.010[illegible]1	0	0	0	[illegible]0.0007
69	Rx	0	-1.5439	0	-1.0299	0	0	0	-16.669	Dn				0	0	0	0	0	0	0
70	Ry	1.54389	0	0	0	-1.0299	0	0	0					0	0	0	0	0	0	0
71	Rz	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0
72	Df,p	0	0	-1.0607	0	0	0	0.08531	0					0	0	0	0	0	0	0
73	ELEMENT-1													0	0	0	0	0	0	0
74														0	0	0	0	0	0	0
75	Tx	-1.2607	0	0	0	0	0	0	-0.4558	Dt		0.01		[illegible]0.01261	0	0	0	0	0	0
76	Ty	0	-1.2607	0	0	0	0	0	-0.2895	DR1		0.01		0	-0.0126	0	0	0	0	0
77	Tz	0	0	4.18598	0	0	0	-0.3214	1.24372	DR2		0.01		0	0	0.04186	0	0	0	-0.0032
78	Rx	0	-6.0168	0	-1.2607	0	0	0	-11.784	Dn				0	0	0	0	0	0	0
79	Ry	6.01684	0	0	0	-1.2607	0	0	0					0	0	0	0	0	0	0
80	Rz	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0
81	Df,p	0	0	-1.5893	0	0	0	0.13289	0					0	0	0	0	0	0	0
82	ELEMENT-2													0	0	0	0	0	0	0
83														0	0	0	0	0	0	0
84	Tx	0.10925	0	0	0	0	0	0	0.06007	Dt		0.01		0.00109	0	0	0	0	0	0
85	Ty	0	0.10925	0	0	0	0	0	-0.0559	DR1		0.01		0	0.00109	0	0	0	0	0
86	Tz	0	0	-0.4885	0	0	0	0.0586	0.11602	DR2		0.01		0	0	-0.0049	0	0	0	0.00059
87	Rx	0	-3.2758	0	0.10925	0	0	0	14.0513	Dn				0	0	0	0	0	0	0
88	Ry	3.27578	0	0	0	0.10925	0	0	0					0	0	0	0	0	0	0
89	Rz	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0
90	Df,p	0	0	-0.0119	0	0	0	2.01E-03	0					0	0	0	0	0	0	0
91	ELEMENT-3													0	0	0	0	0	0	0
92														0	0	0	0	0	0	0
93	Tx	3.18131	0	0	0	0	0	0	-0.4112	Dt		0.01		0.03181	0	0	0	0	0	0
94	Ty	0	3.18131	0	0	0	0	0	-1.1525	DR1		0.01		0	0.03181	0	0	0	0	0
95	Tz	0	0	-3.7581	0	0	0	0.32816	0.24606	DR2		0.01		0	0	-0.0376	0	0	0	0.00328
96	Rx	0	1.16002	0	3.18131	0	0	0	-2.2651	Dn				0	0	0	0	0	0	0
97	Ry	-1.16	0	0	0	3.18131	0	0	0					0	0	0	0	0	0	0
98	Rz	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0
99	Df,p	0	0	-10.121	0	0	0	0.47861	0					0	0	0	0	0	0	0
100	ELEMENT-4													0	0	0	0	0	0	0
101														0	0	0	0	0	0	0
102	Tx	-1	0	0	0	0	0	0	0	Dt		0.01		-0.01	0	0	0	0	0	0
103	Ty	0	-1	0	0	0	0	0	0	DR1		0.01		0	-0.01	0	0	0	0	0
104	Tz	0	0	-1	0	0	0	0	0	DR2		0.01		0	0	-0.0[illegible]	0	0	0	0
105	Rx	0	0	0	-1	0	0	0	0	Dn				0	0	0	0	0	0	0
106	Ry	0	0	0	0	-1	0	0	0					0	0	0	0	0	0	0
107	Rz	0	0	0	0	0	-1	0	0					0	0	0	0	0	0	0
108	Df,p	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0
109	DETECTOR																			
110														0.066	0.066	0.1[illegible]5	0	0	0	0.008

IRREC

Ready

Note that the decentration tolerances,

Tx and Ty,

do not contribute to the

focus registration errors

on assembly.

AEH.

Optomechanics

Looking more closely at the results of the calculation, you see that you can expect a focus error of about 0.105 (±) inches, worst case.

	L	M	N	O	P	Q	R	S	T	U
95	0.01		0	0	-0.03758	0	0	0	0.003282	
96			0	0	0	0	0	0	0	
97			0	0	0	0	0	0	0	
98			0	0	0	0	0	0	0	
99			0	0	0	0	0	0	0	
100			0	0	0	0	0	0	0	
101			0	0	0	0	0	0	0	
102	0.01		-0.01	0	0	0	0	0	0	
103	0.01		0	-0.01	0	0	0	0	0	
104	0.01		0	0	-0.01	0	0	0	0	
105			0	0	0	0	0	0	0	
106			0	0	0	0	0	0	0	
107			0	0	0	0	0	0	0	
108			0	0	0	0	0	0	0	
109										
110			0.065811	0.065811	0.104933	0	0	0	0.007735	
111	for	'IRREC'.	TX	TY	TZ	RX	RY	RZ	DM/M	
112										

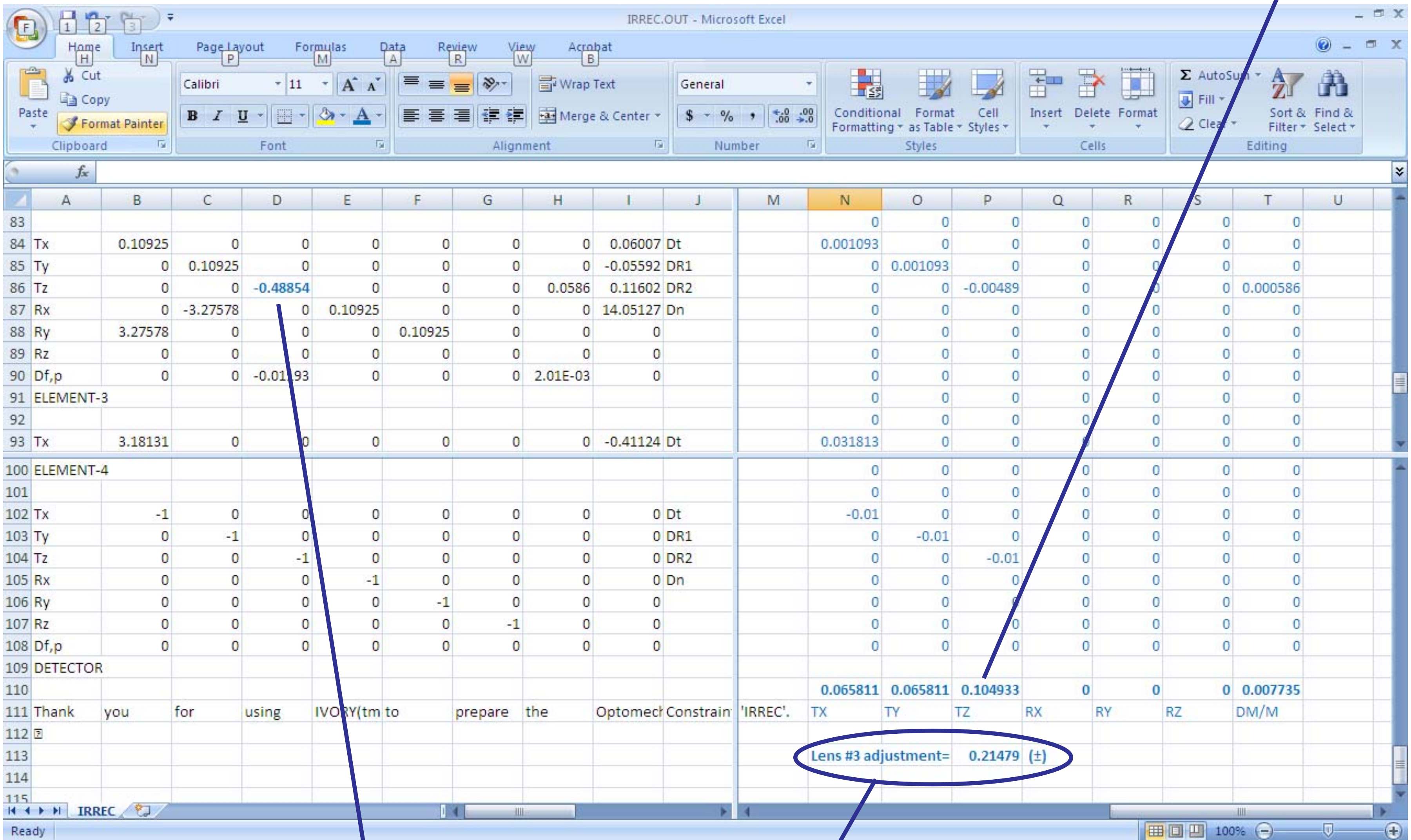
IRREC

Ready 100%

AEH.

Optomechanics

To determine the necessary range of adjustment for lens #3 you then divide the focus error...

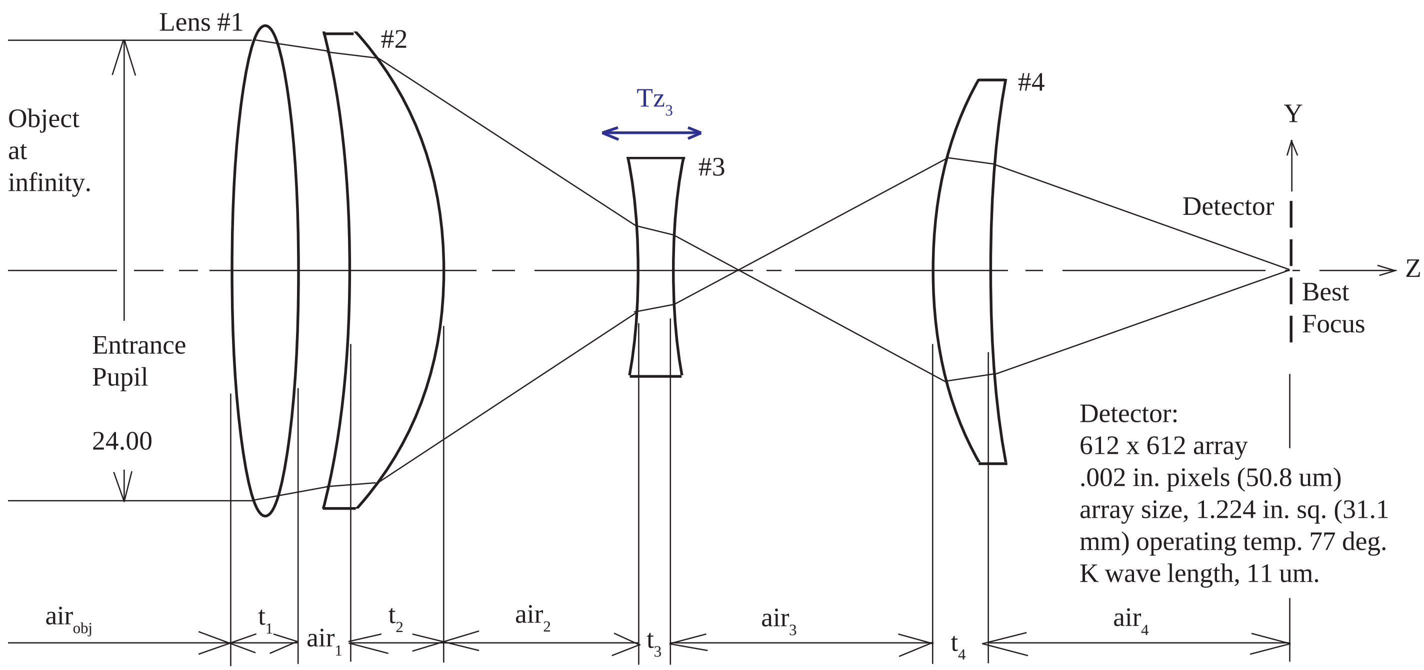


	A	B	C	D	E	F	G	H	I	J	M	N	O	P	Q	R	S	T	U
83												0	0	0	0	0	0	0	
84	Tx	0.10925	0	0	0	0	0	0	0.06007	Dt		0.001093	0	0	0	0	0	0	
85	Ty	0	0.10925	0	0	0	0	0	-0.05592	DR1		0	0.001093	0	0	0	0	0	
86	Tz	0	0	-0.48854	0	0	0	0.0586	0.11602	DR2		0	0	-0.00489	0	0	0	0.000586	
87	Rx	0	-3.27578	0	0.10925	0	0	0	14.05127	Dn		0	0	0	0	0	0	0	
88	Ry	3.27578	0	0	0	0.10925	0	0	0			0	0	0	0	0	0	0	
89	Rz	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	
90	Df,p	0	0	-0.01[illegible]93	0	0	0	2.01E-03	0			0	0	0	0	0	0	0	
91	ELEMENT-3											0	0	0	0	0	0	0	
92												0	0	0	0	0	0	0	
93	Tx	3.18131	0	0	0	0	0	0	-0.41124	Dt		0.031813	0	0	0	0	0	0	
100	ELEMENT-4											0	0	0	0	0	0	0	
101												0	0	0	0	0	0	0	
102	Tx	-1	0	0	0	0	0	0	0	Dt		-0.01	0	0	0	0	0	0	
103	Ty	0	-1	0	0	0	0	0	0	DR1		0	-0.01	0	0	0	0	0	
104	Tz	0	0	-1	0	0	0	0	0	DR2		0	0	-0.01	0	0	0	0	
105	Rx	0	0	0	-1	0	0	0	0	Dn		0	0	0	0	0	0	0	
106	Ry	0	0	0	0	-1	0	0	0			0	0	0	0	0	0	0	
107	Rz	0	0	0	0	0	-1	0	0			0	0	0	0	0	0	0	
108	Df,p	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	
109	DETECTOR																		
110												0.065811	0.065811	0.104933	0	0	0	0.007735	
111	Thank	you	for	using	IVORY(tm	to	prepare	the	Optomech	Constrain	'IRREC'.	TX	TY	TZ	RX	RY	RZ	DM/M	
112	▫																		
113												Lens #3 adjustment=		0.21479	(±)				
114																			

...by the Tz influence coefficient for lens #3.

The answer for Task 1 is $Tz_3=\pm0.215$ in.

AEH.
Optomechanics

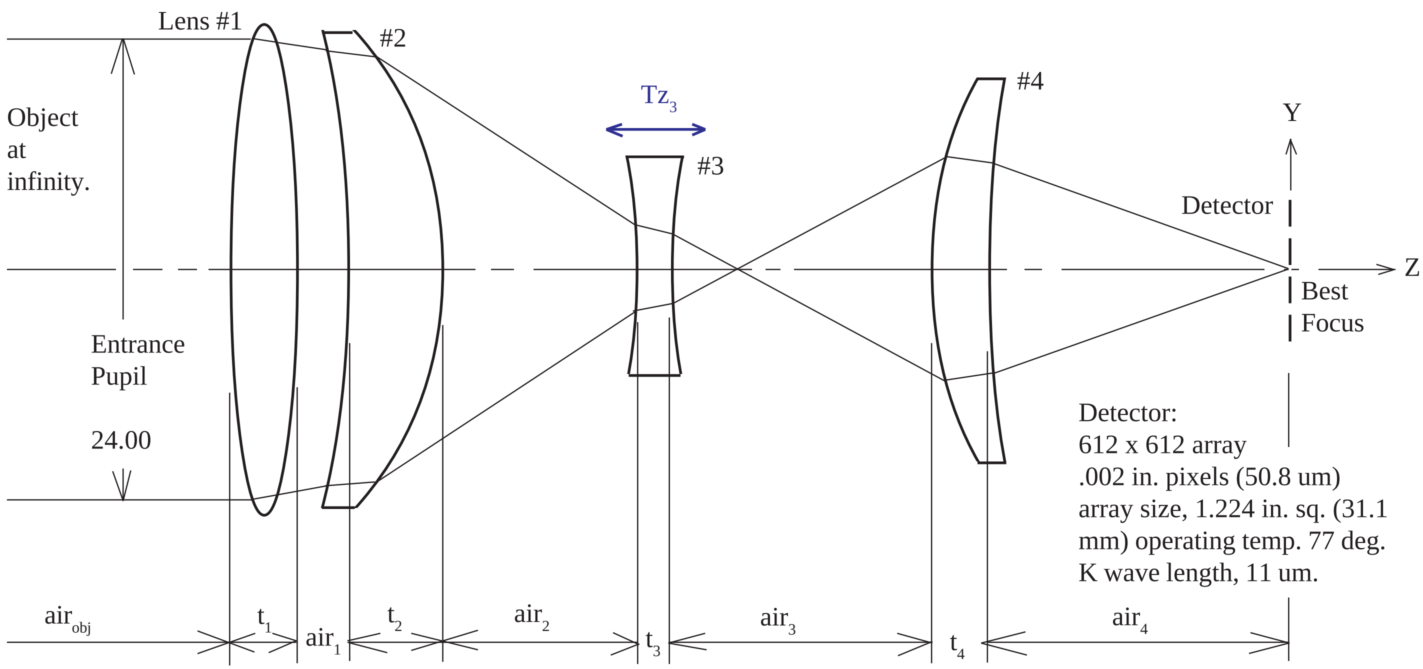


Task 1:

Your shop says they can probably locate each of the elements within 0.010 inches. How much focus error might you expect and how much motion of lens #3 would be necessary to correct it?

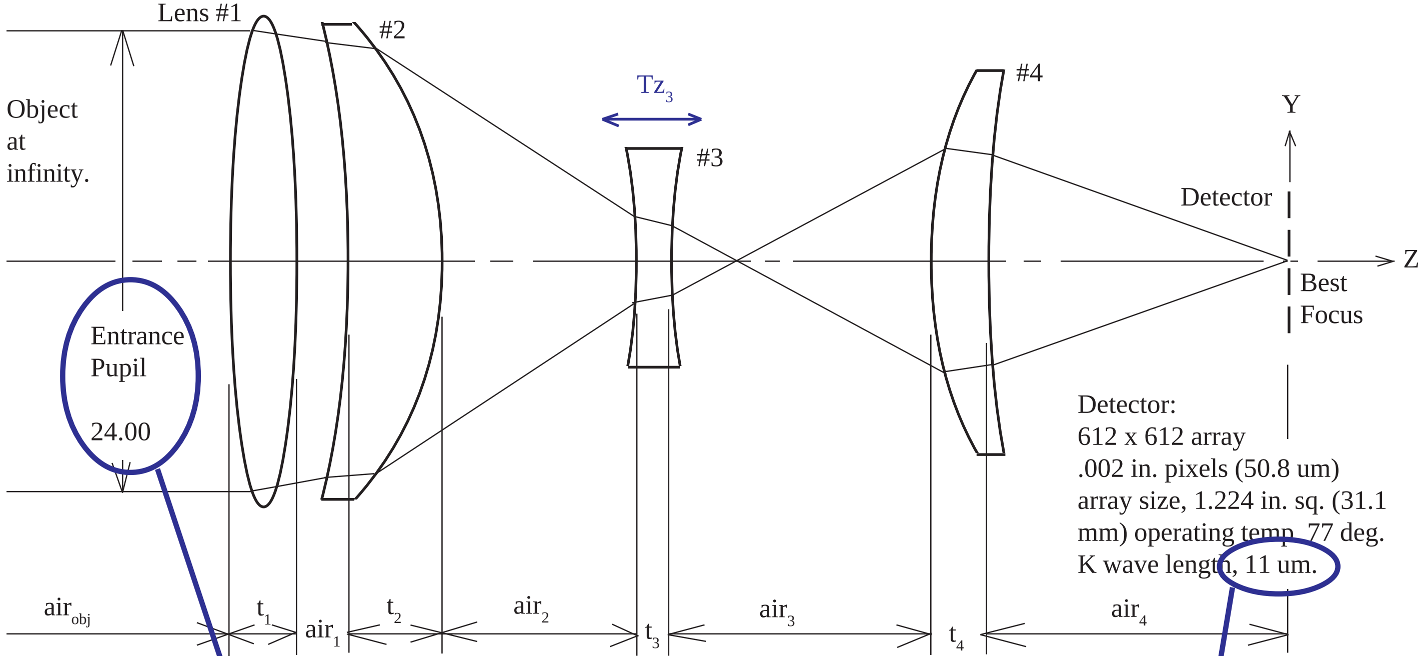
Answer:
You can expect as much as ±0.105 inches of focus error in the worst case combinations of assembly. If lens #3 is to be used to correct this assembly error it will require ±0.215 inches of Z axis motion.

AEH.
Optomechanics



Task 2:

How accurate does the mechanism for lens #3 need to be in order to preserve diffraction limited performance?



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
26																				
27	GAUSSIAN PRESCRIPTION																			
28																				
29		ELE	F	H1	H2	P	P/AIR	PHI	THETA	TYPE										
30		obj	0	0	0	0	inf	0	0	obj										
31		1	50.0819	-0.2505	0.25046	1.49907	7.25347	0	0	LENS										
32		2	34.9885	-1.6464	-0.8232	2.6268	17.246	0	0	LENS			wavelength=		11	microns=	0.00043	inches		
33		3	-42.16	-0.2942	0.20405	1.50175	11.8058	0	0	LENS			entrance pupil=				24	inches		
34		4	6.64703	0.33998	0.67996	1.16002	21.1527	0	0	LENS			f/#=				-2.1491			
35		det	0	0	0	0	0	0	0	det										
36													Diffraction depth of focus=				0.00815	inches=±	0.00407	inches
37		SYSTEM	-51.579	265.293	-72.045	381.362	-51.573													
38																				

IRREC

Ready 75%

Note that:

by Born and Wolf, 1980, p. 441, the diffraction depth of focus = $12.8(\lambda/\pi)(f/\#)^2$ = **0.00815**

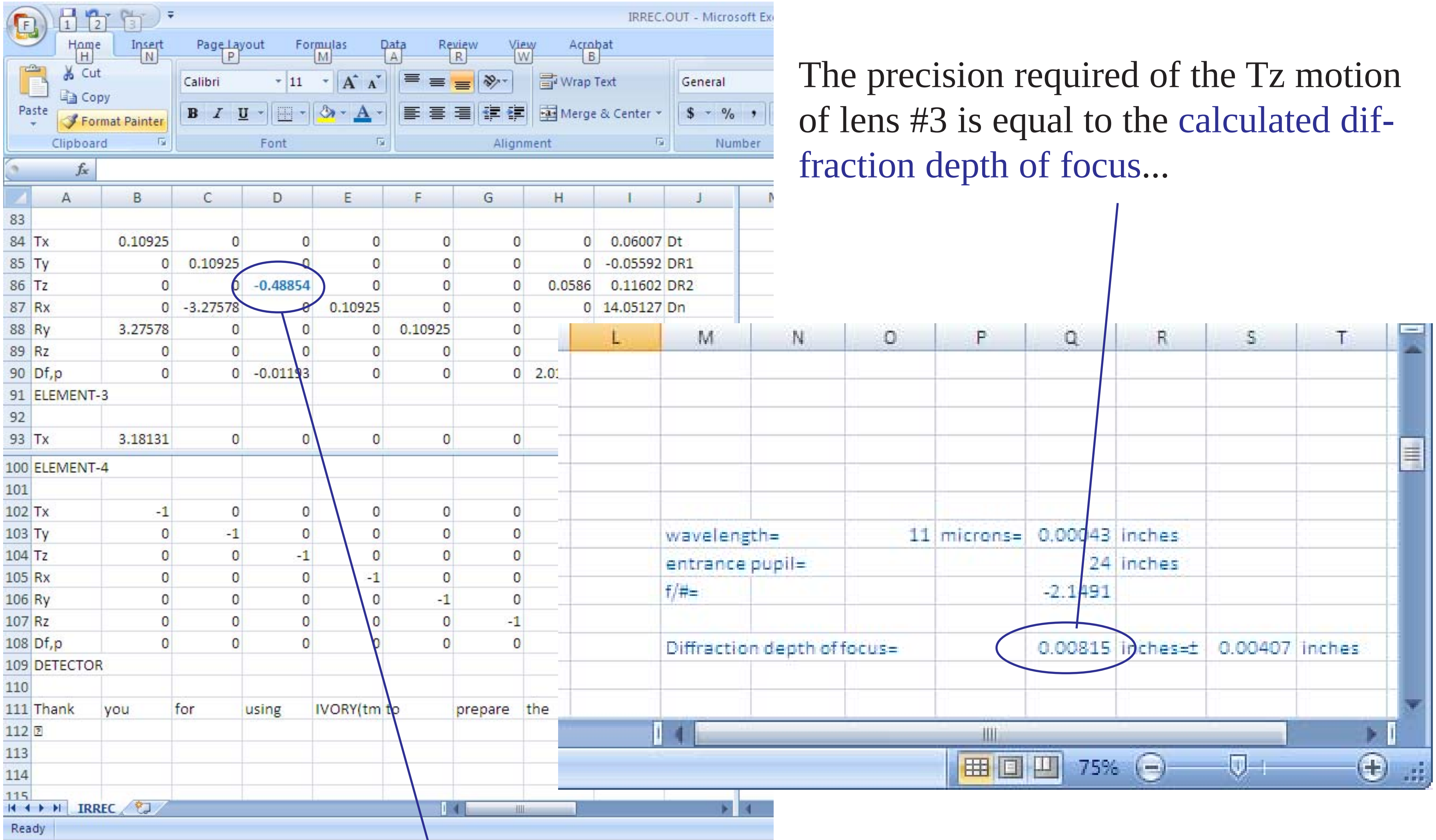
where f/# = (focal length)/(entrance pupil diameter) = -2.1491

These are calculated in the spreadsheet as shown.

AEH.

Optomechanics

The precision required of the Tz motion of lens #3 is equal to the calculated diffraction depth of focus...



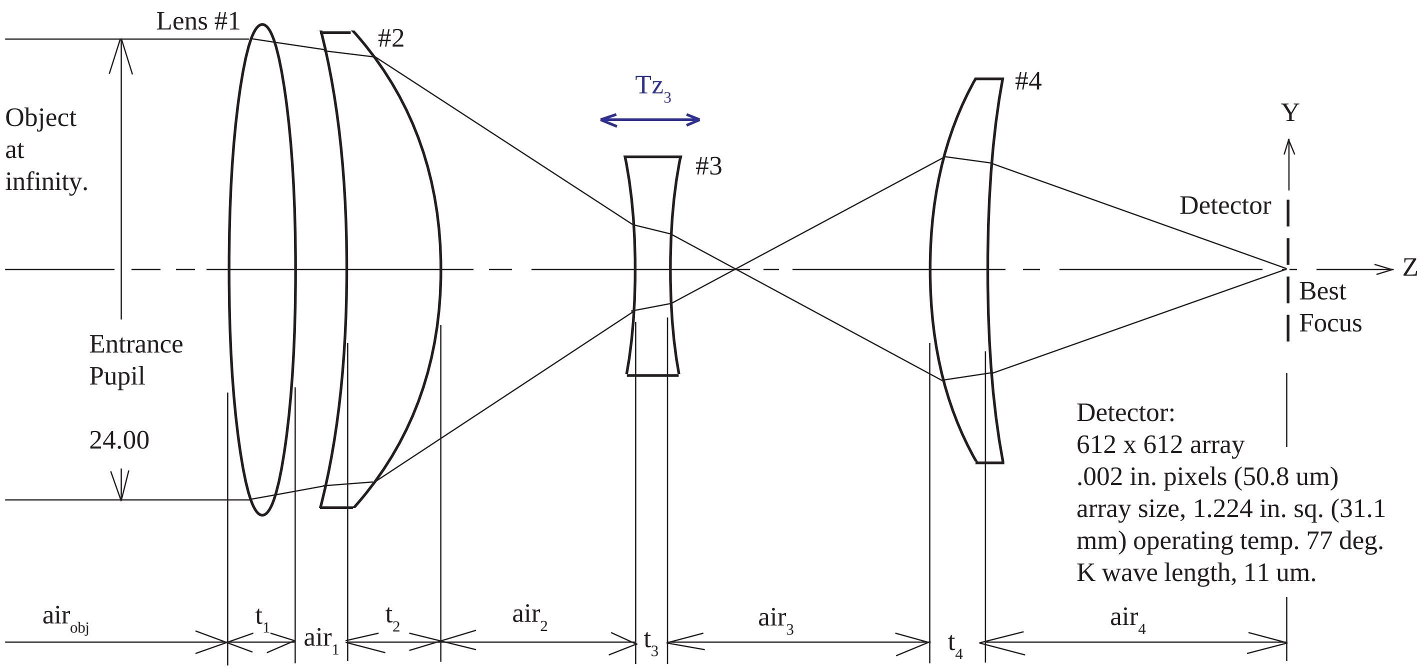
...divided by the Tz influence coefficient for lens #3

= 0.00815/0.48854 = 0.0167 inches.

AEH.

Optomechanics

Correcting Assembly Focus Errors



If the optical elements are located within ±0.010 inches and the focus is to be corrected by moving lens #3 in the Tz direction it will require an adjustment mechanicsm with:

Stroke = 2 x 0.215 = 0.430 inches
Accuracy = 0.0167 inches

AEH.
Optomechanics