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# PRAM

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## Propagate Rays and Aberrations by Matricies

### User's Manual



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## Preface

This manual contains an alphabetical listing of help files for all the commands and other command structures in the ion optics program PRAM.

For further technical assistance please contact MARC via the following email address:

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## Distribution

PRAM is available for DOS, unix and linux. The DOS version has not been updated since about 1996 and is no longer supported.

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## 1. The HELP file for program PRAM

PRAM stands for: Propagate Rays and Aberrations by Matricies

This file is based on the on-line help file designed to be read by the subroutine DJHELP in the DJLIB library of utility subroutines. It contains keywords indicated by a # in column 1 which are located by DJHELP and the text, up to the next key word, is then displayed on the screen.

## 2. Introduction to program PRAM

PRAM is a fast beam optics program that calculates geometrical properties of systems of various types of magnetic and electrostatic elements.

System data is read from a file with extension '.prm' which consists of a list of the elements comprising a system. When PRAM is first started you must load a system into PRAM before calculations may begin. This may be done with the DATA command before the interactive part of the program begins.

Although the program is interactive, it is possible to have a lot of first and third order properties put into a file on exiting the program, to save having to write them all down, see command EXIT. Also, a complete list of all coefficients up to third order can be written to a file with the COF command where they can be read by other programs for further calculation (e.g. OXSORT).

As PRAM has now had a long history, serving many different projects over the past decades, there are many relics from earlier versions of the program which are no longer in used very often. Some of these relics may no longer be reliable. One thing that has remained reliable is anything to do with quadrupole lenses, aberrations and the ray tracing capabilities.

Example of relics are the following: anything to do with velocity selectors, einzel lenses and accelerator sections.

If there are errors in the input file PRAM stops and a listing of the elements up to where the error occurs may be found in the output file. Output files always have the extension '.lpt'.

### 3. PRAM Quick Start

Make sure you have the data file for your system (with the extension '.prm') in the current directory. Then invoke PRAM with the 'pram' command.

The load your data file using the 'data' command. Note that this can be abbreviated to 'da'. The following example shows starting PRAM and loading the parameters of the Melbourne MP2 system from a file mp2.prm. **Bold font** shows the user input.

```
dnj@ELF:src/pram_data/% pram
      Program PRAM - Version 8.2
      Type DATA to load a filename to start....
prm> term 8
prm> def/q
Scale factor for next plot > +0.9
X and Y plot offsets (mm) > +20 20
prm> @
prm> da mp2
Title:      MP2 as at May 1999
prm>
```

Everything down to this '@' are commands executed from the 'login.pcm' file in the current directory.

As the prompt is 'prm>' then we know the system is in focus. If not, the prompt changes to 'sti>' warning the user that it should be focused (with the 'stig' command) before continuing.

In this example the contents of the login.pcm file was:

```
term 8      This sets the default graphics terminal device to x-term
def/q      This prepares to set the defaults for postscript plotting
0.9        Scale the plot down by 0.9
20 20      Offset the plot by 20,20 mm on the page
@          End of macro
```

Next the user can review the present pole tip field settings of the lenses with the 'ptf' command:

```
prm> ptf
 1 Variable      Magn Quadrupole  1 field =      0.21502 Tesla >
-2 Variable      Magn Quadrupole  2 field =     -0.25019 Tesla >
 2 Variable      Magn Quadrupole  3 field =      0.25019 Tesla >
-1 Variable      Magn Quadrupole  4 field =     -0.21502 Tesla > -0.1
sti>
```

The last lens has been changed to a new field (-0.1 T) which makes the system out of focus. The prompt changes to 'sti>' as a warning.

Now the system can be focused with the 'stig' command:

```
sti> stig
      Astigmatism      (X/TH) =     -1.7127      m/rad
                        (Y/PH) =      1.6084      m/rad
Initial combined astigmatism =      2.3496
(N) Comb. Astg. - FIELDS ( 2).....
 1  4.45220E-05  0.21502  0.25019
```

```

2  0.10574      0.21717      0.25019
3  0.10593      0.21287      0.25019
4  2.97221E-05  0.21502      0.25019
5  0.26831      0.21502      0.25270
6  0.26486      0.21502      0.24769
7  8.45719E-04  0.21502      0.25019
8  1.05932E-02  0.21524      0.25019
9  1.05734E-02  0.21481      0.25019
10 2.83649E-05  0.21502      0.25019
20 1.16010E-04  0.21502      0.25019
30 3.36824E-05  0.21502      0.25019
40 2.49085E-06  0.21502      0.25019
50 1.67648E-06  0.21502      0.25019
60 5.14174E-07  0.21502      0.25019
70 1.60459E-08  0.21502      0.25019
After minimisation (X/TH) = -1.54936E-08 m/rad
                   (Y/PH) = -4.17367E-09 m/rad
prm>

```

After many iterations, the system is brought back into focus.

Now the system parameters can be calculated with the 'sys' command:

```

prm> sys
From system B - matrix
13      System End
      Geometric Parameters      X-Plane      Y-Plane
      Focal length      0.29892      m      0.29892      m
      Object distance      8.0400      m      8.0400      m
      Image distance      0.16500      m      0.16500      m      theta      0.000E+00
      Magnification      -3.79031E-02      -3.79031E-02
      Demagnification      -26.383      -26.383
Entrance principle plane      8.1852      m      8.1852      m
Exit principle plane      0.31025      m      0.31025      m
      Particle energy      3.0000      MeV
      Particle Momentum      74.820      Mev/c
      Particle Speed      2.40026E+07 m/s ( 8.01 %c)
Tau = (1 - v**2/c**2)**0.5      0.9967897
Magnetic rigidity (u.MeV/e2)      3.0097      m.u.MeV/Q2
(th/th)= -26.383      (ph/ph)= -26.383
(x/th3)= -127.21      (y/ph3)= -299.09
Chris Ryan's Figure of Merit:
Q = [(th/th)*(ph/ph)]/[(x/th3)*(y/ph3)]^1/3 = 20.695
prm>

```

And then the spherical aberration coefficients:

```

prm> ab3
Third order coefficients defined for object plane divergences.
      Coeff      System      Quadrupole      Octupole
      X/TH3      -127.21      -127.21      0.00000E+00
      X/THPH2     -424.91      -424.91      0.00000E+00
      Y/PH3       -299.09      -299.09      0.00000E+00
      Y/TH2PH     -424.91      -424.91      0.00000E+00
Units: micron/milliradian3

```

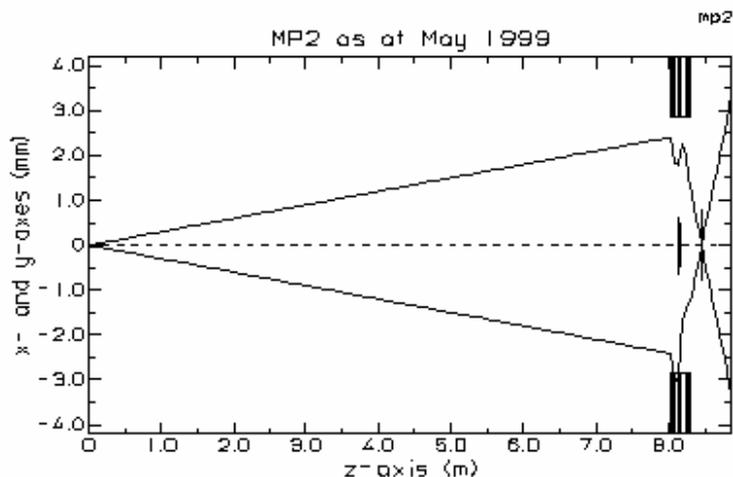
```
prm>
```

It is always useful to look at a plot of the ray trajectories on the screen using the 'trace' command::

```
prm> trace
Initial beam: ( 0.00000E+00um, 0.30000    mr, 0.00000E+00um, -0.30000    mr)
Trace performed to order      1
Perform a trace through the system.
Initial and final z-positions ( 0.00000E+00 to  8.8830    ) >
Step size =  35.532    mm
Initial:   3 Final:  13
          Extents in xoz plane:  -3.3480    to  2.4075    mm
          Extents in yoz plane:  -3.0558    to  3.3480    mm
          Extent for plot, mm (  -4.1850    to  4.1850    ) >
<At this point a TEK 4014 window should appear with the plot in it>
```

```
prm>
```

The image produced by this command is shown here. To get a higher quality plot, use the postscript option on the TRACE command.



Finally, save the present data file and exit back to the unix shell:

```
prm> save
Filename for output (CR for mp2) >
Data saved in file: mp2.prm
prm> exit
dnj@ELF:src/pram_data%
```

### 3.1 Pram's Prompt

The prompt of PRAM is usually

```
prm>
```

however this can change.

If the diagnostic is set to -2 (see the DIAG command), then PRAM continuously monitors the astigmatism of the system. If something is done to make the astigmatism increase above a certain level then the prompt will change to

```
sti>
```

This is a warning that the system should be re-stigmatised. The continual checking takes time and if the computer is VERY busy then response may slow down (this has not been a problem since about 1982). If this is the case the checking can be disabled by setting the diagnostic to -1. Note that for interactive work the diagnostic must always be less than zero.

It is also possible to do all calculations in the thin lens approximation. In this case the diagnostic should be set to -6, and the prompt will change to APR>.

Summary:

Prompt	Diagnostic	Meaning
PRM>	-1	Ready for the next command.
PRM>	<=-2	Ready for the next command and the system is stigmatic.
STI>	<=-2	The system is no longer stigmatic so it should be restigmatised before proceeding.
APR>	-6	The thin lens approximation is being used in all calculations and the system is stigmatic.

## 3.2 Input File Structure

The input file contains all the data for a particular system. It must be contained in a file with extension '.prm'. Whenever a filename required in PRAM as an argument of a command it is only necessary to give the name, not the extension.

Order of elements in the input file, by line number:

1. The input file must start with a title. If the file has been written by PRAM, a PRAM will appear at the end of the title.

After the title appear all the numerical data elements of the system. Each element is characterised by a particular type code, and all numerical data should be separated by commas.

2. The first numerical data element must be a particle element. A particle element has type code 0.00.

0.00, particle charge, particle mass, particle energy, Diagnostic.

units:           proton charge       a.m.u.                MeV

3. The second numerical data element must be a beam element. A beam element has type code 1.00.

1.00, 1/2X-extent, 1/2X-divergence, 1/2Y-extent, 1/2Y-divergence, ½ mom. spread

units:            m                rad                m                rad            %

4. The optical elements then follow.....

T.C, Length,       Excitation,            Radius.

units: none        m                Tesla or Volts        m

See TYPE CODES for more information on the T.C. parameter.

Note that some elements have different types of data entered in the third and fourth slots. Zero value data must be entered.

e.g A drift space of length 1 m:

3.00, 1.00, 0.0, 0.0

5. The last numerical data element must be an end element which has type code 9.00. No other data is included on a 9 element at this stage.

9.00, 0.000, 0.000, 0.000

6. The data set is ended by the word SENTINEL.

See EXAMPLE for an example data set.

### 3.3 *Supra elements*

It is possible to superimpose two lenses by including a 'supra' element after a normal element. For example it is possible to have a superimposed magnetic-electrostatic quadrupole by specifying the following sequence;

```
4.01,      0.10000,    0.09000,    0.00635
34.09,     0.10000,  1000.00000,  0.00500
```

This defines a magnetic quadrupole of length 0.1m, field 0.09T and radius 0.00635m with a superimposed electrostatic quadrupole of length 0.1m, field 1000.0V and radius 0.005m. Note that the supra element may have a separate vary code to the main element and that all of its parameters may be changed independently in a MASK (see below). Of course the length of the supra element must not exceed the length of the main element.

A magnetic octupole superimposed onto a magnetic quadrupole may be specified as follows;

```
4.10,      0.08000,    0.06000,    0.00635
28.02,     0.08000,   -0.00010,    0.00635
```

Most commonly this is done to calculate the sensitivity of the magnetic Quadrupole to parasitic multipole fields.

### 3.4 Dipole Elements

Use of Dipole elements in PRAM

PRAM can model the effects of electrostatic and magnetic dipole elements. It uses a weak dipole approximation devised by D.N. Jamieson in 2001/2. It treats the dipole element as a drift space that displaces the beam vector by an additional amount depending on the field in the dipole. The model makes some approximations:

- \* The ion beam radius of curvature in dipole element is assumed to be large compared to the length of the dipole element.
- \* The beam energy and speed is assumed to remain unchanged in the electric dipole. So only the direction of the velocity is assumed to change.
- \* The electric field vector is assumed to point always transverse to the beam velocity.

These approximations are valid for weak dipoles.

In PRAM, dipole elements are most often used to model scanning coils in a nuclear microprobe system. The easiest way of calculating the effect of the scanning coil is to set up the system with the scanning coil set to a round number (0.1 T for magnetic, 100,000 V/m for electric) and using the "vec" command to calculate the displacement of the central (Gaussian) ray of the system. The displacement of the x- or y-vector will then give the scan size for the given field setting.

The parameters of the dipole elements are as follows:

(i) Magnetic Dipoles

Type code = 2

2.00, L, Bx, By

where

L is the length of the dipole element

Bx is the strength of the magnetic field that causes a shift in the xoz plane in units of Tesla

By is the strength of the magnetic field that causes a shift in the yoz plane in units of Tesla

Either or both of Bx and By may be zero.

(ii) Electric Dipoles

Type code = 12

12.00, L, Ex, Ey

where

L is the length of the dipole element

Ex is the strength of the electric field that causes a shift in the xoz plane in units of Volts/metre

Ey is the strength of the electric field that causes a shift in the yoz plane in units of Volts/metre

Either or both of Ex and Ey may be zero.

### 3.5 Collimator elements

A collimator has no effect on the transfer matrix of the system, but can be used to collimate rays from the system when performing a TRACE through the system.

A collimator element has type code 5. It is only possible to specify rectangular collimators and the collimator is assumed to be zero length.

To specify a collimator in the x-direction use the type code 5.1:

The parameters of a collimator in the x-direction are:

5.10, 0.0, roff, rwidth

where:

roff is the offset of the centre of the collimator relative to the optical axis

rwidth is the width of the collimator

The parameters of a collimator in the y-direction are:

5.20, 0.0, roff, rwidth

where:

roff is the offset of the centre of the collimator relative to the optical axis

rwidth is the width of the collimator

Example: To specify a square collimator of width 1 mm in both x- and y- use these two elements

5.10, 0.0, 0.0, 0.001

5.20, 0.0, 0.0, 0.001

Note that all lenses are also defacto collimators, rays which intercept the pole tips of the lens (aperture assumed square) will be collimated.

See also the TRACE command.

### 3.6 Summary of type codes

Element	Type code
Particle	0.00
Beam	1.00
Magnetic Dipole	2.00
Drift	3.00
Magnetic Quadrupole	4.XY
Collimator	5.00
Magnetic Sextupole	6.XY
Velocity Selector*	7.00
Magnetic Octupole	8.00
End	9.00
Electrostatic Accelerator*	10.00
Magnetic Solenoid*	11.XY
Electrostatic Dipole	12.00
Charged Aperture*	13.00
Electrostatic Quadrupole	14.XY
Einzel Lens*	15.XY
Cylinder Lens*	17.XY
Electrostatic Octupole	18.XY
Magnetic Superimposed elements	2Z.XY
Electrostatic Superimposed elements	3Z.XY

\*indicates elements that have not had their subroutines debugged.

The X and Y specify the links.

X non zero means the lens always has a positive excitation.

Y non zero means the lens always has a negative excitation.

N.B. if X is non zero then Y must be zero. Octupoles are always variable and independent at this stage, otherwise if X=Y=0 the lens is constant.

### 3.7 Example, the Oxford microprobe;

Elements.....	Comments (not in file)
OXFORD TRIPLET SYSTEM	PRAM title element
0.00, 1.000000, 1.072765, 4.000000, -2.000000	particle element
1.00, 0.000001, 0.000100, 0.000001, 0.000100, 0.001000	beam element
3.00, 5.511900, 0.000000, 0.000000	drift space
4.10, 0.217100, 0.150941, 0.015000	quadrapole
3.00, 0.056900, 0.000000, 0.000000	more elements
4.01, 0.217100, -0.150941, 0.015000	:
3.00, 0.059900, 0.000000, 0.000000	:
4.20, 0.217100, 0.183697, 0.015000	:
3.00, 0.000000, 0.000000, 0.000000	zero drift
3.00, 0.170500, 0.000000, 0.000000	:
9.00, 0.000000, 0.000000, 0.000000	end element
SENTINEL	end of data.

## 4. PRAM COMMANDS

General form of all PRAM commands:

AAAAAA/B XXXXXXXXXXXX

Where:

AAAAAA is a six character or less command. The first character of the command is always alphabetical and the rest of the command may be in upper, lower, mixed case or numerical.

B is an option on the command which is used only by a few commands.

XXXXXXXXXX is a parameter. It may be either real or alphanumeric, depending on what is required for the command. If a parameter is necessary for the command and it is not given on the same line as the command then it will be prompted for. Some aspects of some commands are only available via a parameter.

### @

This indicates a PRAM command macro is to be executed. The macro name has extension '.pcm' and should already exist on disk. While the macro executes the prompt of PRAM changes to PRM>\_.

Parameters: @ Filename                      Filename is a macro name without extension.

### AB2

Type out the angle dependent second order aberration coefficients. These will only be non-zero if there are sextupoles in the system or there are quadrupoles with parasitic aberrations.

Parameters: AB2    A            Type all second order aberration coeffs.

Units: metre/radian<sup>2</sup>

Example output from a system containing a supra-sexturpole :

prm> ab2

Second order angle dependent aberration coeffs

```
(X/TH2)    -141.33            (Y/TH2)    0.00000E+00
(X/THPH)   0.00000E+00    (Y/THPH)   282.68
(X/PH2)    141.33            (Y/PH2)   0.00000E+00
```

Units: m/rad<sup>3</sup>

## AB3

Types out the first four third order aberration coefficients in the Geoff Grime style. These are (X/TH3), (X/THPH2), (Y/PH3) and (Y/TH2PH).

The unit is micron/(milliradian)<sup>3</sup>

These are useful coefficients but they conceal some good physics because the cross terms are not necessarily equal in non-orthomorphic systems. The rest of the coefficients will be typed if the parameter A is given.

Parameters: AB3 A Type all third order coeffs.

Example:

```
prm> ab3
```

Third order coefficients defined for object plane divergences.

Coeff	System	Quadrupole	Octupole
X/TH3	-127.21	-127.21	0.00000E+00
X/THPH2	-424.91	-424.91	0.00000E+00
Y/PH3	-299.09	-299.09	0.00000E+00
Y/TH2PH	-424.91	-424.91	0.00000E+00

Units: micron/milliradian<sup>3</sup>

## ACCEL

Identical to the QUAD command except for Accelerator sections. Note that this routine has not been debugged.

## CAP

Enables the title of the system to be changed. Prompts for the new title.

Parameters: None.

## CHROMA

Calculate the chromatic aberrations of the system using the perturbation method. i.e. the energy of the system is perturbed by a small percentage PERT and the increase in spot size gives the chromatic aberration. The coefficients are returned through common block /ABER0/. The X and Y dependent coefficients do not seem to be very reliable when calculated by this method.

Parameters: CHROMA PERT Real, small percentage perturbation.

Example:

```
prm> chrom
```

Chromatic Aberration Coefficients		Perturbation = 0.50000 %	
X/THDM	132.14	Y/PHDM	177.60
X/XDM	-0.13552	Y/YDM	-0.12975

Units: micron/milliradian/% momentum error

## CLEAR

To clear the screen of graphics use this command. It has the effect of changing the mode of the terminal from 4010 mode to ALPHA mode.

Parameters: CL Clear the screen. (Visual 500)

## CORR

Calculate a correlation matrix for the system. If no parameter is given then the correlation matrix is drawn on the screen. If a filename (without extension) is given as a parameter then the result is put into a file with extension '.lpt'.

This command is not implemented in most versions of PRAM.

Parameters: CORR FILENAME (for output file)  
<CR> (output to terminal)

## COUPLE

Gives a visual picture of the system by printing a list of the element names with their element numbers (for the ELE command) and their coupling codes.

Parameters: None.

Example for the MP2 system:

```
prm> co
  Element> Pa Be Dr Dr Qm Sm Dr Qm Dr Qm Dr Qm Dr En
Type-code> 0 1 3 3 4 26 3 4 3 4 3 4 3 9
  Links> 0 0 0 0 1 0 0 -2 0 2 0 -1 0 0
  Position> 1 2 3 4 5 6 7 8 9 10 11 12 13 14
```

## CRAM

Eliminates all spherical aberration from the system by adjusting the Octupole strengths. Units used in the output are the same as those used in the last PTF or P command. Teslas are always used in the output file. It is impressive to do a AB3 or a THIRD after a CRAM. This command is a generalisation of the old version of PRAM. See also FISHK.

N.B. There must be three octupoles to correct the spherical aberration, CRAM will not work with less than three.

Parameters: CRAM Unit (See the PTF command for units)  
S Use user supplied coeffs.

## DATA

Reads in a new system data file (i.e. opens a new infile). The command will prompt for the new filename if it has not been given as a parameter. The name of the file is FILENAME.prm

Parameters: DATA FILENAME (Without extension)

## DIAG

Allows the diagnostic to be changed quickly. The absolute value of the new diagnostic may be given as a parameter or alternatively when prompted for. It is not possible to give a positive diagnostic since it will be made negative before continuing. Possible diagnostics are:

```
Parameters:  DI -1          Fast response (for slow computers, no
              astigmatism checking. Not needed since
              about 1982)
              >= -2       Changes prompt to STI> if there is
              astigmatism
              3            %ELELAS diagnostics
              4            %QSPHER diagnostics
              5            unused
              6            Uses thin lens approximation throughout.
              (APR>)
              7            Echoes with the command in standard form.
              8            Use thin lens focal lengths in the
              aberration coefficient expressions.
              9            Uses approximate THIRD order expressions
              I            Where I is some other integral diagnostic.
```

## DISP

This command calculates the sensitivity of the image position to the sideways displacement of each lens in the system. It has not been fully tested.

Example:

```
prm> disp
  1 Order displacement aberration coefficients (offset 1.0000 mm) :
  Quadrupole      Position      (x/a)      (y/b)
    1              4            -1.7439     1.8470
    2              6             3.8548    -5.2104
    3              8            -4.5817     3.6545
    4             10             1.4194    -1.3425
              Units: m/m
  2 Order displacement aberration coefficients (offset 1.0000 mm) :
  Quadrupole      Position      (x/a)      (y/b)
    1              4            -1.7439     1.8470
    2              6             3.8548    -5.2104
```

3	8	-4.5817	3.6545
4	10	1.4194	-1.3425

Units: m/m

3 Order displacement aberration coefficients (offset 1.0000 mm) :

Quadrupole	Position	(x/a)	(y/b)
1	4	6.06228E+17	4.25000E+13
2	6	2.36925E+16	1.27703E+16
3	8	1.81328E+16	2.19499E+16
4	10	1.80572E+16	2.18443E+16

Units: m/m

## EFFECT

This command replaces all the quadrupole lens lengths with their effective lengths. That is the length of the quadrupole lens,  $l$ , is replaced with  $L = l + 1.1*r$  where  $r$  is the bore radius. A corresponding amount is shaved from the drift lengths on either side of the lens to keep the physical length of the system constant (if possible). It is not really necessary to use this command, since it is possible to enter the effective lengths directly.

## ELE

Lists the data for an element. The element number can be given as a parameter. If the element number is too large an error message is given and the last element number is typed. After the element data is listed PRAM asks if there are any changes to be made. Changes are made in the same way as those in the PTF command. Note that the type code on the particle element and the beam element cannot be changed. Quadrupoles can be changed, for example into Octupoles or Drift spaces by just changing the type code. This is a very handy command for making modifications to the optical elements in the system. See also the INSERT command.

Parameters: ELE I (where I is an element number)

Example on the use of the 'ele' command to review and possibly change element parameters:

prm> **ele 8**

```
ELEMENT - 8      Magn Quadrupole
Type code Length (m)  Field T,V  Radius (m)
4.02      6.000E-02  -0.250    6.000E-03
Z-center  Z:X-image  Z:Y-image  ALPHA    X-mag    Y-mag
8.12      7.92      8.29     -12.9    -1.20    -0.576
X-focal   Y-focal
-9.041E-02  0.111
```

New data? > **y**

Changing element 8

```
Magn Quadrupole Type code = 4.0200 new >
Magn Quadrupole Length (m) = 6.00000E-02 new >
Magn Quadrupole Field T,V = -0.25019 new >
Magn Quadrupole Radius (m) = 6.00000E-03 new >
prm>
```

## EXCIT

Calculates the excitation aberration coefficients and the chromatic and the chromatic aberration coefficients. The perturbation used, in percent, may be given as a parameter. The chromatic coeffs use 1/100 of this perturbation.

NB. The octupole excitation coefficients are still experimental and have not yet been compared with experiment.

Parameters: EXCIT S Use user supplied perturbation.  
P Use perturbation P where P is a real number.

Example for the MP2 system:

```
prm> excite
Excitation Aberration Coefficients ( % ) Perturbation = 0.500%
First Order
X/THE1 -101.10 Y/PHE1 110.13
X/THE2 2.80486E-03 Y/PHE2 -8.89998E-02
X/THE3 137.53 Y/PHE3 -375.21
X/THE4 -201.09 Y/PHE4 116.42
X/THE5 32.397 Y/PHE5 -29.814
Coupled excitation First order
X/THG1 -68.978 Y/PHG1 80.139
X/THG2 -64.353 Y/PHG2 -259.67
prm>
```

In this example, quadrupole lenses 1 and 4 are connected to the same power supply. Hence the excitation aberration coefficients for that power supply are also computed. Similarly for quadrupole lenses 2 and 3.

## EXIT

Exits the program. A diagnostic parameter can be used to cause various amounts of data to be put into the output file. No extra information is added if no parameter is specified.

Parameters: EX 0 Fast exit, no data file created.

Into a data file with extension '.lpt';

```
Parameters: EX 1 Print out elements and beam element
2 Print out the A-Matrix after each element
3 Print out the B-Matrix after each element
```

- 4 Print out geometrical parameters after each lens
- 5 Print out both geom. para. and A-Matrix
- 6 Print out third order contribution from each lens
- 7 Print out cumulative third order contribution

## FISHK

This is the nucleus of the original PRAM program. As a command of PRAM it calculates the spherical aberration coefficients for systems consisting of one, two, three or four Quadrupoles.

FISHK coefficients are a bit different to those of THIRD so it does a CRAM with its own coefficients if there are enough Octupoles.

This command also calculates a spherical aberration coefficient that is often used by electron microscopy people, particularly P. W. Hawkes et. al. The coefficient has a very vague definition as follows;

$$\begin{aligned}Csx/Fx &= \text{Max}(P, S) * MX^{**4} / Fx \\Csy/Fy &= \text{Max}(PB, SB) * MY^{**4} / Fy \\Cs/F &= \text{Max}(Csx/Fx, Csy/Fy) \quad \text{assumed definition.}\end{aligned}$$

It may be possible to use it as a quality factor to compare systems, but it seems to depend on system parameters (i.e. it depends on object lengths, etc.) FISHK coefficients are a bit different to those of THIRD so it does a CRAM with its own coefficients if there are enough Octupoles.

Parameters: CRAM Units (See PTF command for units.)

## HELP

Gives help on things. If no parameter is specified then a list of commands together with a list of additional topics is typed. To get help on an additional topic type HELP followed by a space and the initial letter of the additional topic.

Parameters: HELP TOPIC (Initial letter is enough)  
HELP/B TOPIC Gives a list of TOPICS  
HELP/S 'file' Set the help file (the file that contains this information) to 'file'.  
MENU List all possible commands.

The 'menu' command gives a short list of all possible commands. Not all of these are documented in this manual.

Example:

prm> menu

DJLIBRARY commands:

CLEAR FONT TERM MENU DEFINE LINE DEST CLOSE  
CFLAG MARKS

PRAM commands:

P PTF S STIG EXIT SAVE HELP THIRD  
DATA ELEMEN FISHK CRAM AB3 SMAT SYSTEM QUAD

```
OCTU    SOLEN  ACCEL   RUSS    EXCITE  CHROM   VECTOR  CAP
DIAG    COUPLE  OXRAY   ION     CORR    ROTN    MASK    SPEC
DIP     EINZ    VS      GAP     CYL     TRACE   SEXT    @
CLEAR   XSCTN   MENU    INSERT  REMOVE  AB2     COFOUT  AGP
SQUEEZ  EFFECT  $       PARASI  DISP    LABEL

prm>
```

## INSERT

Insert a zero length drift space after a specified element number. Note that you cannot insert an element between elements one (particle element) and two (beam element). Nor can you insert an element after the system end element. The element number may be given as a parameter, otherwise it is prompted for.

Parameters: INSERT N (where N is an element number)

## ION

As for OXRAY but it writes an IONBEAM data file. IONBEAM is a comprehensive Ion optics program written by Dieter Heck in Karlsruhe from before 1980. Subcommands allow for various types of fringe field to be included on each element and also for the inclusion of FIT elements. Typing 'H' in response to the subcommands gives more information.

Parameters: ION FILENAME

## MASK

Allows for generalised minimisation. The command prompts for variable masks and coefficient masks. A Mask is a quadruplet of integers that give the location of a variable or a coefficient in the variable or coefficient array. Variables in this case are any of the physical parameters of the system as given in the \*.prm data file. Coefficients are any of the first, second or third order coefficients calculated by PRAM.

### Variable Array and Mask

Mask I,J,K,L

Array

I	J	K	L is a coupling		
----- code					
1	2	3	4	5	6
1	1	nd	Charge	Mass	Energy
1	2	nd	X/2	Th/2	Y/2      Ph/2    Del/2
1	3	nd	Length	Field	Radius
:	:	:	:	:	:
:	:	:	:	:	:
1	40	nd	Length	Field	Radius
2	3	Thz	Dx	Thx	Dy      Thy
:	:	:	:	:	:
:	:	:	:	:	:
:	:	:	:	:	:

2      40      Thz      Dx                      Thx                      Dy                      Thy

nd = Not Defined

I = 1 Select out a variable from the initial data array of element J.

I = 2 Select out a parasitic misalignment for element J as a variable

J      Element number with the property to be varied.

K      Location of property to be varied within a particular element

L      Coupling code

**Example of a variable mask:**

1, 6,3,+1  
 1, 8,3,-2  
 1,10,3,+2  
 1,12,3,-1

Meaning:

Take the field of elements 6,8,10 and 12 to be varied, link the fields of elements 6 and 12 oppositely. i.e. any additions made to the field of element 6 are subtracted from the field of element 12, similarly elements 8 and 10.

**Coefficient Array and Mask**

Mask I,J,K,L

Array

I	J	K	1	2	3	4	5	6	7	8	9	10
1	1		(x/x)	(x/th)	(x/y)	(x/ph)	(th/x)	(th/th)	(th/y)	(th/ph)		
1	2		(y/x)	(y/th)	(y/y)	(y/ph)	(ph/x)	(ph/th)	(ph/y)	(ph/ph)		
2	1		(x/thd)	(x/xd)								
2	2		(y/phd)	(y/yd)								
3	1		(x/tE1)	(x/tE2)	.....							
3	2		(y/pE1)	(y/pE2)	.....							
4	1		(x/tG1)	(x/tG2)	.....							
4	2		(y/pG1)	(y/pG2)	.....							
5	1		(x/t3F1)	(x/T3F2)	.....							
5	2		(y/p3F1)	(y/p3F2)	.....							
6	1		(x/tR1)	(x/tR2)	.....							
6	2		(y/pR1)	(y/pR2)	.....							
7	1		(x/t3)	(x/tp2)	(x/t2x)	(x/xp2)	(x/tpy)	(x/tx2)	(x/ty2)	(x/xyp)	(x/x3)	(x/xy2)
7	2		(y/p3)	(y/t2p)	(y/p2y)	(y/yt2)	(y/ptx)	(y/py2)	(y/px2)	(y/ytx)	(y/y3)	(y/yx2)
8	1		Quadrupole contributions to the X third order coeffs.									
8	2		Quadrupole contributions to the Y third order coeffs.									



## OCTU

Identical to the QUAD command except for Octupoles.

## OXRAY

Writes out an OXRAY data file. OXRAY is a famous ion optics computer program written by Geoff Grime in Oxford starting in about 1980.

The OXRAY command writes a separate element data file for each element regardless of the presence of identical elements. It first checks for the presence of a particular element data file (starting with ELE60.DAT) and skips over files that already exist. A '#' is typed to indicate that data files have been found to exist and that the file number has been incremented. When suitable element data files have been found their names are typed. e.g.

```
ELE FILES> ##### ELE65 ## ELE68 ELE69 ELE70
```

indicates that ELE60,...,ELE64 were found to exist already. The links of the system and the polarity of each lens are also typed. The polarity is typed when the individual element data files are written.

The filename for the .RAY file may be given as a parameter or on the prompt. If <CR> is given to the prompt then the PRAM data file name is used.

Parameters: OXRAY FILENAME

P

Similar to the PTF command except only one of the coupled lenses is given.

This means if two lenses are coupled an excitation need only be entered once for all coupled lenses with a particular linking code. Default units of Tesla or kiloVolts are used.

Parameters: None.

## PARASI

Computes the parasitic aberration coefficients of the quadrupole lenses in the system. These coefficients are expressed in the reduced form, that is as a coefficient per percentage parasitic multipole component field in the quadrupole field. The default is to calculate all parasitic coefficients.

Parameters: PARA/S                    Compute the sextupole coefficients alone.  
          PARA/O                    Compute the octupole coefficients alone.  
          PARA x.xxx                x.xxx is the parasitic field percentage

The default parasitic field (as a percentage of the main quadrupole field) is 5% for sextupoles and 20\*5=100% for octupoles. The octupole perturbation is always 20\*sextupole since the octupole effect always appears superimposed on the intrinsic spherical aberration, hence for increased accuracy of the calculation, stronger fields are necessary.

Example for the MP2 system in Melbourne:

```
prm> par
```

```
Reduced Parasitic Sextupole Aberration Coefficients: (m/rad^2/%)
```

```
Quadrupole lens 1 in position 5 Parasitic lens field 1.07510E-02 ( 5.00%)  
(X/TH2S)        -141.33            (Y/TH2S)        0.00000E+00
```

```

(X/THPHS)  0.00000E+00  (Y/THPHS)  282.68
(X/PH2S)   141.33      (Y/PH2S)   0.00000E+00
Quadrupole lens  2 in position  8 Parasitic lens field -1.25097E-02 (  5.00%)
(X/TH2S)   71.043     (Y/TH2S)   0.00000E+00
(X/THPHS)  0.00000E+00 (Y/THPHS)  -759.02
(X/PH2S)  -387.73     (Y/PH2S)   0.00000E+00
Quadrupole lens  3 in position 10 Parasitic lens field  1.25097E-02 (  5.00%)
(X/TH2S)  -350.22     (Y/TH2S)   0.00000E+00
(X/THPHS)  0.00000E+00 (Y/THPHS)  302.96
(X/PH2S)   161.02     (Y/PH2S)   0.00000E+00
Quadrupole lens  4 in position 12 Parasitic lens field -1.07510E-02 (  5.00%)
(X/TH2S)  -5.5374     (Y/TH2S)   0.00000E+00
(X/THPHS)  0.00000E+00 (Y/THPHS)  11.381
(X/PH2S)   5.7153     (Y/PH2S)   0.00000E+00
Reduced Parasitic Octupole Aberration Coefficients: (micron/millirad^3/%)
Quadrupole lens  1 in position  5 Parasitic lens field  0.21502      ( 100.00%)
(X/TH30)   175.48     (Y/PH30)   208.53
(X/THPH20) -572.17     (Y/TH2PHO) -572.17
Quadrupole lens  2 in position  8 Parasitic lens field -0.25019      ( 100.00%)
(X/TH30)  -62.528     (Y/PH30)   -1512.7
(X/THPH20) 918.96     (Y/TH2PHO) 918.96
Quadrupole lens  3 in position 10 Parasitic lens field  0.25019      ( 100.00%)
(X/TH30)   438.96     (Y/PH30)   18.767
(X/THPH20) -254.02     (Y/TH2PHO) -254.02
Quadrupole lens  4 in position 12 Parasitic lens field -0.21502      ( 100.00%)
(X/TH30)  -9.3244     (Y/PH30)   -13.513
(X/THPH20) 33.505     (Y/TH2PHO) 33.505
prm>

```

## PTF

Shows and allows entry of the pole tip field of each lens. It also indicates if the lens can be varied in the stigmatisation section of the program and further, which lenses are linked together. The links are done by adding a fractional part to the element's type code. PTF may have options to set the units used for input/output although Tesla is used for all calculations.

Typical units available include, Melbourne Control Box Units, Gauss, kiloGauss, Oxford Control Box Units, etc.

```

Parameters:  PTF T      Tesla
              G        Gauss
              K        kiloGauss

```

B	Lens excitations 'Beta'
A	Ampere Turns
F	Field Gradient (tesla/metre^n)
V	Volts
M	Melbourne control box units (from 1982)
O	Oxford control box units (from 1981)

## QUAD

Gives the geometric parameters of a Quadrupole. The Quadrupole number can be specified either as a parameter or from the prompt. The Quadrupoles are numbered in the order the beam passes through them. The element number is given in the heading.

Parameters: QUAD I (where I designates the Ith multipole)

## REMOVE

This command removes a specified element. You cannot remove the particle or beam elements. The element number may be given as a parameter, otherwise it is prompted for.

Parameters: REMOVE N (Where N is an element number)

## ROTN

Calculate the parasitic rotation aberration coefficients of each lens. This is done by stepping through the system and selectively rotating each lens by a small amount and computing the cross coefficients from the first order transfer matrix. The rotational aberration is then this coefficient divided by the original rotation. The value of the coefficient is independent of the rotation value.

This command can also be used to select a rotation for each lens in the system on an individual basis through the use of some arguments:

Parameters: ROTN Z	Zero all rotations
ROT/A N	Set all rotations to N*PI (N may be real)
ROT/I	Set individual rotations
ROT/D	Calculate the rotation aberration coefficients in units of m/rad/degree instead of the default (m/rad^2).

This example is for the MP2 system in Melbourne.

prm> **rot**

Rotational aberration coefficients ( 1.0000 deg ) :			
Quadrupole	Position	(x/ph.rho)	(y/th.rho)
1	5	-21.093	-21.093
2	8	45.364	45.364

3	10	-30.472	-30.472
4	12	6.2010	6.2011

Units: m/rad^2

In this case a perturbation of 1 degree was used can the resulting expansion of the beam was calculated to obtain the reduced rotation parasitic aberration coefficient.

## RUSS

Similar to the SYS command, although all the information given is from formulae of the Russians. Gives the same results as SYS because all image and object distances are taken relative to the principle plane positions of the relevant lens. It also gives the difference between the image position calculated with the 'thin' lens formula;

$$\frac{1}{F} = \frac{1}{S_i} + \frac{1}{S_o} \quad \text{and the system total length.}$$

(Although in this case this is not really a thin lens formula because of the use of principle planes from which  $S_i$  and  $S_o$  are measured.)

Parameters: None.

Example for the MP2 system:

prm>  **russ**

RUSSIAN PARAMETERS	X-Plane	Y-Plane	
Focal Length	0.29892 m	0.29892 m	
Magnification	-0.03790 m	-0.03790 m	
Errors (Totlen-L.Quad Im.)	5.316E-02	-1.69	micron
Thin Lens Focal Length	0.28239 m		
System Total Length	8.46000 m		

The errors should be close to zero for a system properly focused (stigmatised) with the 'stig' command.

## S

This is the short form of the command STIG. It just types the current astigmatism in the X and Y planes.

Parameters: S Astigmatism rel. to object coordinates.  
S/I " " " image " .

Units: metre/radian

## SAVE

Saves the current data file. Prompts for the new filename. If <CR> is given the old filename is used.

Parameters: SAVE FILENAME New filename without extension

SAVE &lt;CR&gt;

Use old filename

## SMAT

Display the first order system transfer matrix. The units are meters and radians.

Parameters: SMAT First order system transfer matrix.

Example for the MP2 system:

```
prm> smat
```

System Beam Matrix:

```
(X/X)  -3.790E-02  (X/TH)  1.402E-06  (X/Y)   0.000E+00  (X/PH)  0.000E+00
(TH/X)  -3.35      (TH/TH) -26.4      (TH/Y)   0.000E+00  (TH/PH) 0.000E+00
(Y/X)   0.000E+00  (Y/TH)  0.000E+00  (Y/Y)  -3.791E-02  (Y/PH) -4.450E-05
(PH/X)  0.000E+00  (PH/TH) 0.000E+00  (PH/Y)  -3.35      (PH/PH) -26.4
```

Units: m, rad

## SOLEN

Identical to the QUAD command except for Solenoids. Note that this routine has not been debugged.

#SPEC

## SPEC

This command is reserved for special purposes.

## SQUEEZ

This command can be used to replace all consecutive drift spaces with a single drift space of the equivalent length. This will reduce the number of elements in the system to make room for more should you be approaching the limit of a maximum of 40 optical elements in the system.

## STIG

Does all the calculating of the first order beam matrix of the system and also the stigmatisation. The command has a short form S which just types out the (X/TH) and (Y/PH) matrix elements. The full command is used to stigmatise a system. Single letter parameters can be used to specify the nature of the fit. (e.g. Tight, Loose, Default.)

e.g. STIG T do a tight stigmatisation with default TOL and MAXCALL

```
Parameters:  STIG T      Tight fit TOL = 1.0d-10
              D          Default fit TOL = 1.0d-8
              L          Loose fit TOL = 1.0d-6
              X          Stigmatise only in the X plane
```

Y Stigmatise only in the Y plane

TOL is the maximum tolerable reduced astigmatism coefficient in units of (metre/radian)<sup>2</sup>. In practice, the system is in focus if TOL is less than 10<sup>-6</sup>.

## SYS

Types out all the geometrical optics of the system. All the information given is calculated from the first order system transfer matrix.

Parameters: None.

Example for the MP2 system:

```
prm> sys
      From system B - matrix
14      System End
      Geometric Parameters      X-Plane      Y-Plane
      Focal length      0.29892      m      0.29892      m
      Object distance      8.0400      m      8.0400      m
      Image distance      0.16500      m      0.16500      m      theta      0.000E+00
      Magnification      -3.79029E-02      -3.79087E-02
      Demagnification      -26.383      -26.383
      Entrance principle plane      8.1852      m      8.1852      m
      Exit principle plane      0.31025      m      0.31025      m
      Particle energy      3.0000      MeV
      Particle Momentum      74.820      Mev/c
      Particle Speed      2.40026E+07 m/s ( 8.01 %c)
      Tau = (1 - v**2/c**2)**0.5      0.9967897
      Magnetic rigidity (u.MeV/e2)      3.0097      m.u.MeV/Q2
      (th/th)= -26.383      (ph/ph)= -26.383
      (x/th3)= -127.21      (y/ph3)=-299.09
      Chris Ryan's Figure of Merit:
      Q = [(th/th)*(ph/ph)]/[(x/th3)*(y/ph3)]^1/3 = 20.695
```

## THIRD

Types out the first four third order aberration coefficients in the Russian style. These are defined as follows;

$$DX = MX( P*TH**3 + S*TH*PH**2 )$$

$$DY = MY( PB*PH**3 + SB*TH**2*PH )$$

where MX and MY are the magnifications in the X and Y planes and DX and DY are the perturbation at the image plane due to the spherical aberration. P, S, PB, SB are the spherical aberration coefficients. PRAM always calculates

with these aberration coefficients (along with the other 16 third order coeffs defined similarly) because for a stigmatic system,  $S = SB$ . The complete set of coefficients will be typed if the parameter A is given.

Parameters:   THIRD                   Spherical aberration coeffs (Russian defn.)  
                  THIRD A               All third order coeffs.  
                  THIRD/I             Third order coeffs in image coords.

Example for the MP2 system:

prm> **third**

Third order aberration coefficients defined as in the early papers of Yavor et al.

Coeff	System	Quadrupole	Octupole	
P	3.35632E+06	3.35632E+06	0.00000E+00	X-Plane
S	1.12105E+07	1.12105E+07	0.00000E+00	
PB	7.89080E+06	7.89080E+06	0.00000E+00	Y-Plane
SB	1.12105E+07	1.12105E+07	0.00000E+00	

Units: m, radians

## TRACE

Does a matrix raytrace through the system. The output may be displayed on a Tektronix 4010 or equivalent graphics terminal (including an X-term).

The X and Y starting coordinates are those of the BEAM element as stored in ELE 2.

The simplest form of the TRACE command is as follows;

```
prm> trace
Initial beam: ( 0.00000E+00um, 0.30000     mr, 0.00000E+00um, -0.30000     mr)
Trace performed to order     1
Perform a trace through the system.
Initial and final z-positions ( 0.00000E+00 to   9.0405     ) > <CR>
Step size =   36.162     mm
Initial:   3 Final:   12
          Extents in xoz plane:  -2.5144     to   2.5147     mm
          Extents in yoz plane:  -2.8597     to   2.5144     mm
          Extent for plot, mm (  -3.5747     to   3.5747     ) > <CR>
```

This will trace the ray defined in element 2 through the entire system and display the result on the screen.

Parameters:

TRACE/O 'I'       Sets the order for the calculations to 'I'. At present only first order ('I' = 1) is implemented.

TRACE/W 'R'       Sets the delay between clearing the screen and starting the plot to 'R' seconds ('R' can be less than 1). Not needed in the 21st C.

TRACE/F 'I'       Sets the font used for the characters in the plot to font number 'I'. Only useful numbers are 0, 1, 2 and 5.

TRACE/D C         Clear the automatic clear flag. That is the screen will

not be cleared before a plot is commenced. Not needed in the 21st C.

TRACE/S Causes the next set of traced trajectories to be saved in the file trace.dat

TRACE/C Turns off all the collimators in the system.

## VECTOR

Multiplies the current beam vector with the system matrix and types out the results. A new beam vector may be specified by changing the beam element using the ELE command. The order of the result may be specified as a parameter as follows;

Parameters: VECT First order only.  
VECT 1 First order only.  
2 Second order (First order plus Chromatic).  
3 Third order (First plus Second plus Third).  
4 Second order but neglecting the non angle chromatic aberrations.  
5 Third order but including only the spherical aberrations and neglecting the second order aberrations.  
6 Use only FISHK aberration coefficients.

Example:

prm> **vec**

Beam Vectors					
	Initial	Final Central	Final Actual	Order =	
X	0.00000E+00	4.20729E-04	4.20729E-04	micron	1
Theta	0.30000	-7.9149	-7.9149	mrad	
Y	0.00000E+00	1.33500E-02	1.33500E-02	micron	
Phi	-0.30000	7.9149	7.9149	mrad	

## XSCTN

This command draws a beam cross section on the screen. The cross section may be drawn to any order. The command accepts the order as a parameter and it prompts for the z coordinate for the cross section. It also allows the total scale of the drawing to be set. If <CR> is given then auto scaling is used. If at the end a further cross section is required simply respond with <CR> and the process is repeated, otherwise respond with 'N'.

This command is not implemented in most versions of PRAM.

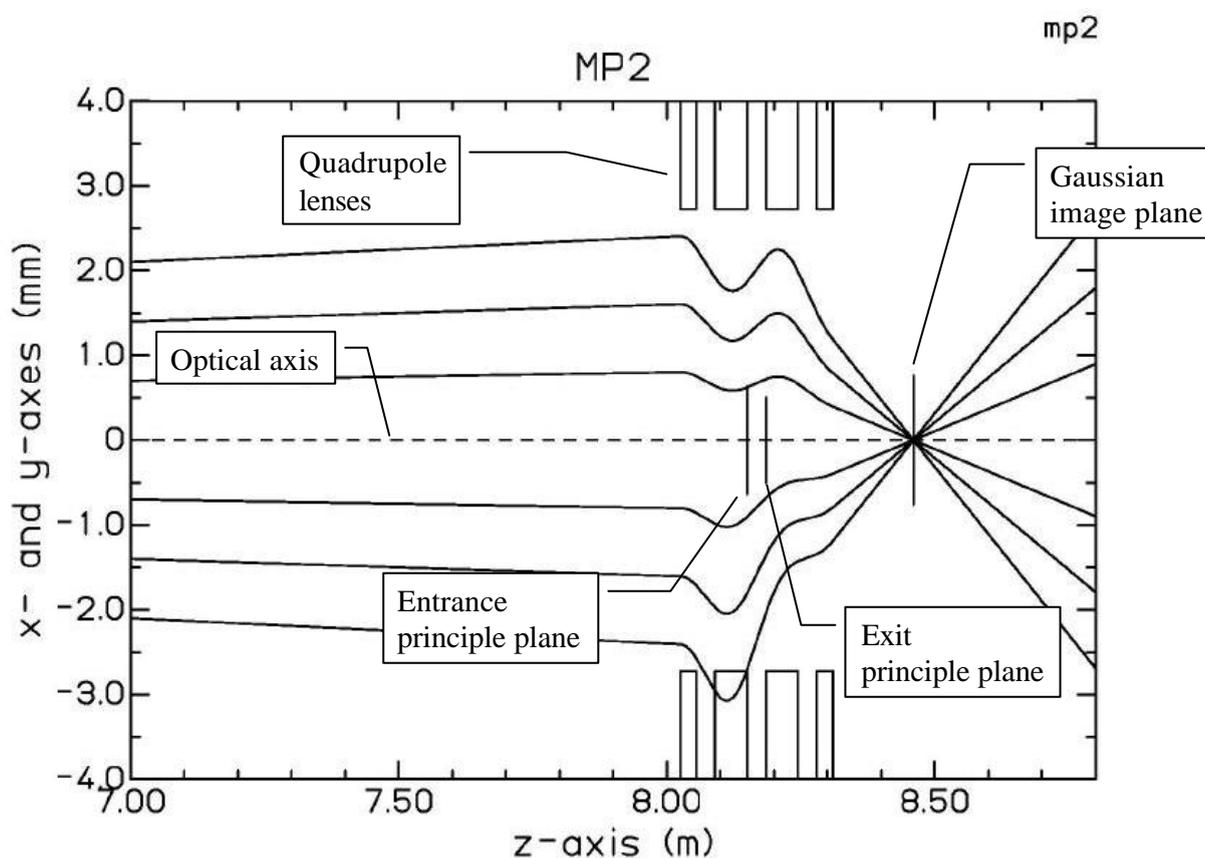
Parameters: XSCTN I I is an integral order.

## 5. Examples of the use of the TRACE command

### 5.1 Example 1: Simple raytracing

The simplest task for the TRACE command is to produce a plot of the beam path through the system. The ray vector coordinates at the origin are taken from the beam element (element 2). The plot gives an overview of the ray path through the system by plotting both the  $xoz$  and  $yoz$  planes on the same plot. It is therefore convenient to set the displacement and divergence of the ray in the  $yoz$  plane to negative values. This will conveniently show the profile of the ray trajectory in both planes on the same diagram.

The optical axis of the system is shown as a dashed line, together with vertical bars representing the positions of the entrance and exit principle planes and the end of the system where should also be located the Gaussian image plane. Also shown are the positions of the quadrupole lenses.



The data file used to make this plot was from 'mp2.prm'.

MP2 as at May 1999

0.00	,	1.000000,	1.000000,	3.000000,	-2.000000	
1.00	,	0.000000,	0.000300,	0.000000,	-0.000300,	0.000000
3.00	,	6.780000,	0.000000,	0.000000		
3.00	,	1.245000,	0.000000,	0.000000		
4.10	,	0.030000,	0.215020,	0.006000		
3.00	,	0.035000,	0.000000,	0.000000		

```
4.02 , 0.060000, -0.250194, 0.006000
3.00 , 0.035000, 0.000000, 0.000000
4.20 , 0.060000, 0.250194, 0.006000
3.00 , 0.035000, 0.000000, 0.000000
4.01 , 0.030000, -0.215020, 0.006000
3.00 , 0.150000, 0.000000, 0.000000
9.00 , 0.000000, 0.000000, 0.000000
SENTINEL
```

The plot itself was generated from a macro of PRAM commands in file 'mp2.pcm'.

```
line -3
da mp2
cap
MP2

tr/q
7,8.8
-4 4
ele 2
y
0
0.0002
0
-0.0002
0
tr/r

ele 2
y
0
0.0001
0
-0.0001
0
tr/r

close

@
```

For more detailed examination of the performance of an ion optical system, cross sections of the beam can be generated using the file of aberration coefficients calculated by PRAM using the program OXTRACE.

See separate documentation on OXTRACE.

## 5.2 Example 2: Modeling scanning coils in a Russian antisymmetric quadruplet

This TRACE plot shows the effect of a x-scanning coil. It was generated from the file of system parameters in mp2d.prm shown here:

```
MP2 as at May 1999 with dipole
 0.00 , 1.000000, 1.000000, 3.000000, -2.000000
 1.00 , 0.000000, 0.000300, 0.000000, 0.000000, 0.000000
 3.00 , 6.780000, 0.000000, 0.000000
 3.00 , 1.085000, 0.000000, 0.000000
 2.00 , 0.050000, 0.010000, 0.000000
 3.00 , 0.010000, 0.000000, 0.000000
 2.00 , 0.050000, 0.000000, 0.000000
 3.00 , 0.050000, 0.000000, 0.000000
 4.10 , 0.030000, 0.215020, 0.006000
 3.00 , 0.035000, 0.000000, 0.000000
 4.02 , 0.060000, -0.250194, 0.006000
 3.00 , 0.035000, 0.000000, 0.000000
 4.20 , 0.060000, 0.250194, 0.006000
 3.00 , 0.035000, 0.000000, 0.000000
 4.01 , 0.030000, -0.215020, 0.006000
 3.00 , 0.150000, 0.000000, 0.000000
 9.00 , 0.000000, 0.000000, 0.000000
SENTINEL
```

Magnetic dipole element  
with non-zero field in xoz  
plane

Zero dipole element

The plot itself was conveniently constructed from the macro mp2d.pcm shown here. In this context, the beam element is actually the coordinates of a ray vector to be traced through the system.

```
line -3                Set the line thickness to 3 times normal
da mp2dip              Load data
cap                   Change caption
MP2 with Scan coils
ele 2                 Set the beam element
y
0
0.0003
0
0
0

tr/q                  Trace the first ray, use postscript output
7,8.8                 Limits along the beam axis for plot
-4 4                  Limits for x- and y-directions for plot

ele 2                 Set the next beam element
y
0
-0.0003
0
0
0

tr/r                  Re-Trace the ray on the existing plot

ele 2                 Set the next beam element
y
0
0.0002
0
0
```

```

0
tr/r                               Re-Trace

ele 2                               Set the next beam element
y
0
-0.0002
0
0
0
tr/r                               Re-Trace

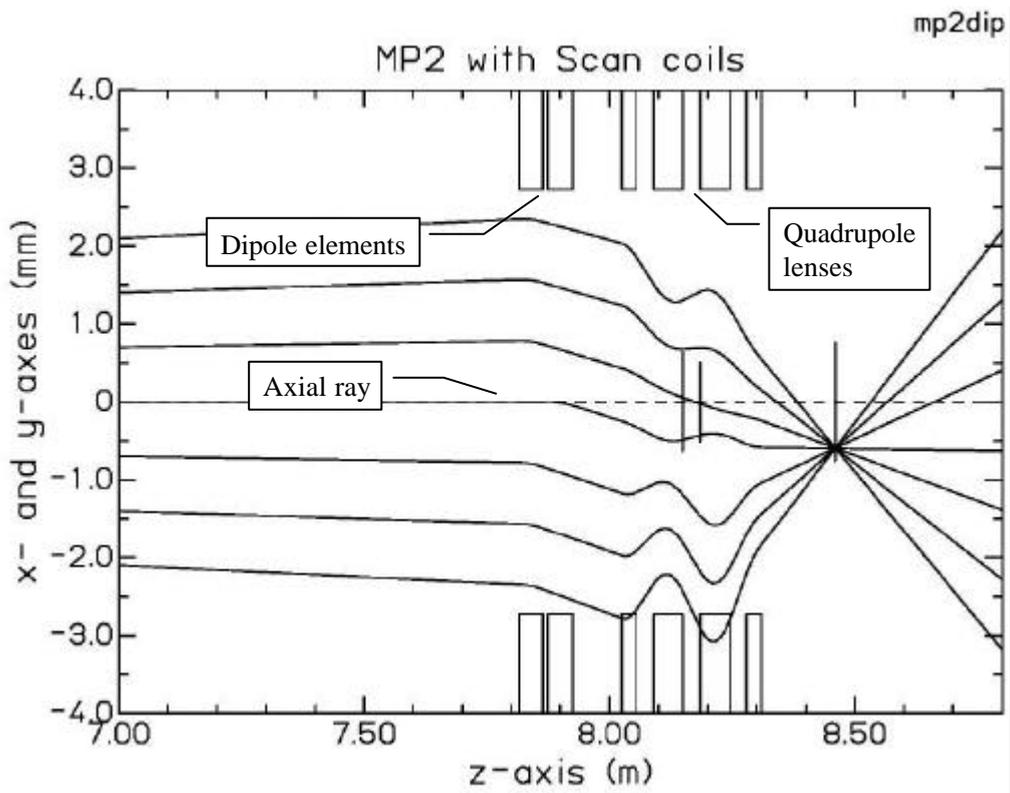
ele 2                               Set the next beam element
y
0
0.0001
0
0
0
tr/r                               Re-Trace

ele 2                               Set the next beam element
y
0
-0.0001
0
0
0
tr/r                               Re-Trace

close                               Close the plot file (filename generated
                                     automatically)

@                                   End of macro
    
```

The resulting plot:



### 5.3 Example 3: Modeling collimators

A set of collimators can be used to limit the beam envelope. The file 'mp2coll.prm' shows the system. The collimator elements define a 1 mm wide slit in the y- and x-directions.

```
MP2 as at May 1999 - with collimator
 0.00 , 1.000000, 1.000000, 3.000000, -2.000000
 1.00 , 0.000000, 0.000300, 0.000000, -0.000300, 0.000000
 3.00 , 6.780000, 0.000000, 0.000000
 5.20 , 0.000000, 0.000000, 0.001000
 5.10 , 0.000000, 0.000000, 0.001000
 3.00 , 1.245000, 0.000000, 0.000000
 4.10 , 0.030000, 0.215020, 0.006000
 3.00 , 0.035000, 0.000000, 0.000000
 4.02 , 0.060000, -0.250194, 0.006000
 3.00 , 0.035000, 0.000000, 0.000000
 4.20 , 0.060000, 0.250194, 0.006000
 3.00 , 0.035000, 0.000000, 0.000000
 4.01 , 0.030000, -0.215020, 0.006000
 3.00 , 0.150000, 0.000000, 0.000000
 9.00 , 0.000000, 0.000000, 0.000000
SENTINEL
```

Collimator element for yoz plane, width 1mm

Collimator element for xoz plane, width 1mm

Once again, the PRAM macro, 'mp2c.pcm', shown here was used to produce the plot.

```
line -3          Set line thickness in plot to 3 times normal
da mp2coll      Load data
cap            Change caption
MP2 with collimator
tr/q          Open plot file and perform trace (/q option makes postscript)
              Blank line free scales z plot file
              Limits for x- and y-direction are -3 to 3 mm
-3,3

ele 2          Change beam element
y
0
0.0001
0
-0.0001
0
tr/r          Re-Trace on same plot

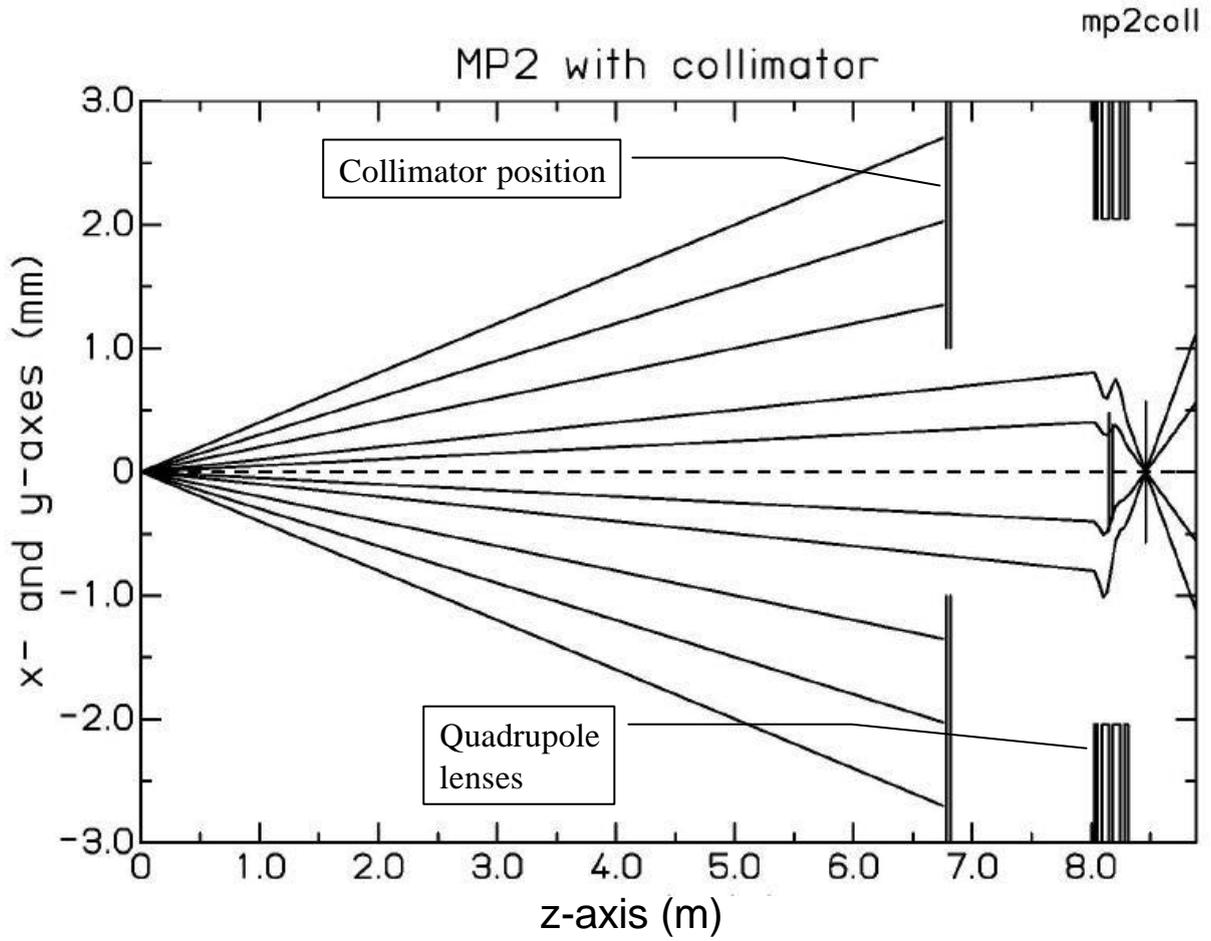
ele 2          Change beam element
y
0
0.0002
0
-0.0002
0
tr/r          Re-Trace on same plot

ele 2          Change beam element
y
0
0.00005
0
-0.00005
0
tr/r          Re-Trace

ele 2          Change beam element
y
```

```
0
0.0004
0
-0.0004
0
tr/r           Re-Trace
close         Close plot file
@            End macro
```

The resulting plot:



## 6. Use of OXTRACE to make image intensity maps and grid shadow patterns

This documentation gives an example of how to produce a theoretical grid shadow pattern using PRAM and OXTRACE.

It is part of the PRAM distribution package available on the web page of the Microanalytical Research Centre.

File: README.1ST

=====

EXAMPLE RUN OF PROGRAM PRAM

=====

Propagate Rays and Aberrations by Matricies

This is an example run of program PRAM showing how to calculate ion optical properties of the Shanghai nuclear microprobe system.

Comments are indicated by a ! in column 1.

User input appears after the >

! First, run the program

\$ **pram**

Program PRAM - Version 7

! You must always have data to run the program, in this case a data file  
! SHANG.PRM will be loaded initially.

! You can load new data with the DATA command: (note that the PRM  
! extension is added by the program).

PRM> **data**

Filename for input > **shang**

Title: Shanghai Microprobe System

PRM>

! The prompt of the program is usually PRM>. However if the lenses are  
! not in focus this changes to STI> as a warning that the system needs  
! to be stigmatised (focused). In this example, the lenses are set to  
! 0.1 and 0.2 Tesla (out of focus).

PRM> **p**

Lenses with coupling code 1 have fields 9.86670E-02 new > +0.1  
Lenses with coupling code 2 have fields .17823 new > +0.2

! Now the lens strengths are adjusted to bring the system back into  
! focus:

```
STI> stig
      Astigmatism      (X/TH) =  -1.5303      m/rad
                        (Y/PH) =  -3.3642      m/rad
Initial combined astigmatism =    3.6959
```

(N) Comb. Astg. - FIELDS ( 2).....

Calling STEPIT.....

1	3.6959	.10000	.20000
2	3.6066	.10100	.20000
3	3.4395	.10300	.20000
4	3.1563	.10700	.20000
5	2.8335	.11500	.20000
6	3.2691	.13100	.20000
7	2.8076	.11817	.20000
8	3.0824	.11817	.20200
9	2.5515	.11817	.19800
10	2.1118	.11817	.19400
20	.97539	.10543	.18600
30	1.0986	8.97856E-02	.16908
40	4.04854E-02	9.83465E-02	.17790
50	3.33325E-02	9.85352E-02	.17837
60	1.50595E-03	9.86621E-02	.17824
70	1.01562E-03	9.86699E-02	.17824
80	1.97044E-04	9.86693E-02	.17823
90	3.08789E-05	9.86670E-02	.17823
100	1.96953E-05	9.86667E-02	.17823
110	7.10444E-07	9.86669E-02	.17823
120	6.67549E-07	9.86669E-02	.17823

```
After minimisation (X/TH) = -1.51277E-08 m/rad
                  (Y/PH) = -1.13953E-08 m/rad
```

! Having refocused the lenses, the prompt changes back to PRM> and the  
! system is saved to disk. No filename is given, so the old filename is  
! used, however a new filename could have been entered.

```
PRM> save
Filename for output (CR for shang) >
Data saved in file: shang.prm
```

! Now some optical parameters are computed. First the first order  
! parameters of the system:

```
PRM> sys
      From system B - matrix

13      System End
      Geometric Parameters      X-Plane      Y-Plane
      Focal length      .43969      m      .44008      m
      Object distance      8.1148      m      8.1148      m
      Image distance      .32980      m      .32980      m      theta      .000
      Magnification      -5.62980E-02      -5.63511E-02
      Demagnification      -17.763      -17.746
```

## PRAM: Propagate Rays and Aberrations with Matricies

---

```
Entrance principle plane      8.2498      m      8.2496      m
Exit principle plane         .46445     m      .46487     m

      Particle Momentum          75.11805   MeV/c
      Particle Speed             2.39076E+07 m/s ( 7.97 %c)
Tau = (1 - v**2/c**2)**0.5    .9968151
      Gamma = 1.0/Tau           1.0031950
```

! Now the chromatic aberration coefficients:

PRM> **chrom**

```
Chromatic Aberration Coefficients      Perturbation =      .50000      %
      X/THDM      151.44      Y/PHDM      174.97
      X/XDM      -.20689      Y/YDM      -.20408
Units: micron/milliradian/% momentum error
```

! Now the sensitivity of the focused spot to the stability of the lens  
! power supplies:

PRM> **excit**

```
Excitation Aberration Coefficients ( % ) Perturbation =      .500%
```

First Order

```
      X/THE1      -134.56      Y/PHE1      159.25
      X/THE2      256.28      Y/PHE2      -495.72
      X/THE3      -356.22      Y/PHE3      231.79
      X/THE4      83.116      Y/PHE4      -70.286
```

Coupled excitation First order

```
      X/THG1      -51.915      Y/PHG1      88.486
      X/THG2      -101.30      Y/PHG2      -265.41
```

! Two sets of coefficients are given, (X/THEi) are for individual power  
! supplies connected to each lens and (X/THGi) are for one power supply  
! connected to each pair of coupled lenses in the system. In the latter  
! case the coefficients are smaller showing that it is better to run  
! the lenses from coupled power supplies.

! Now second order aberration coefficients. These are zero in perfect  
! lenses:

PRM> **ab2**

Second order angle dependent aberration coeffs

```
(X/TH2)      .00000      (Y/TH2)      .00000
(X/THPH)     .00000      (Y/THPH)     .00000
(X/PH2)      .00000      (Y/PH2)      .00000
```

Units: m/rad^3

! Now third order aberration coefficients. These are dominated by the  
! spherical aberration coefficients in microprobe lens systems:

PRM> **ab3**

Third order coefficients defined for object plane divergences.

Coeff	System	Quadrupole	Octupole
X/TH3	-162.42082	-162.42082	.00000
X/THPH2	-465.46587	-465.46587	.00000
Y/PH3	-260.27779	-260.27779	.00000
Y/TH2PH	-465.90539	-465.90539	.00000

Units: micron/milliradian3

! The remainder of the third order aberration coefficients can be  
! computed using the AB3 A command:

PRM> **ab3 a**

Third order coefficients defined for object plane divergences.

Coeff	System	Quadrupole	Octupole
X/TH3	-162.42082	-162.42082	.00000
X/THPH2	-465.46587	-465.46587	.00000
Y/PH3	-260.27779	-260.27779	.00000
Y/TH2PH	-465.90539	-465.90539	.00000

Units: micron/milliradian3

Remaining third order coefficients (same units):

X/XTH2	-.05875	-.05875	.00000	X-Plane
X/XPH2	-.05638	-.05638	.00000	
X/THYPH	-.00940	-.00940	.00000	
X/X2TH	-.00001	-.00001	.00000	
X/THY2	-.00001	-.00001	.00000	
X/XYPH	-.00001	-.00001	.00000	
X/X3	.00000	.00000	.00000	
X/XY2	.00000	.00000	.00000	
Y/YPH2	-.09542	-.09542	.00000	Y-Plane
Y/TH2Y	-.05675	-.05675	.00000	
Y/XTHPH	-.01540	-.01540	.00000	
Y/Y2PH	-.00001	-.00001	.00000	
Y/X2PH	-.00001	-.00001	.00000	
Y/XTHY	-.00001	-.00001	.00000	
Y/Y3	.00000	.00000	.00000	
Y/X2Y	.00000	.00000	.00000	

! The sensitivity of the system to the percentage of the parasitic  
! multipoles can be calculated with the PAR command. First the  
! sextupoles:

PRM> **par/s**

Reduced Parasitic Sextupole Aberration Coefficients: (m/rad^2/%)

Quadrupole lens 1 in position 5 Parasitic lens field 4.93334E-03 ( 5.00%)

(X/TH2S)	-186.34	(Y/TH2S)	.00000
(X/THPHS)	.00000	(Y/THPHS)	373.12
(X/PH2S)	186.34	(Y/PH2S)	.00000

Quadrupole lens 2 in position 7 Parasitic lens field -8.91151E-03 ( 5.00%)

(X/TH2S)	163.08	(Y/TH2S)	.00000
(X/THPHS)	.00000	(Y/THPHS)	-1175.1
(X/PH2S)	-611.93	(Y/PH2S)	.00000

```

Quadrupole lens 3 in position 9 Parasitic lens field 8.91151E-03 ( 5.00%)
(X/TH2S) -664.96 (Y/TH2S) .00000
(X/THPHS) .00000 (Y/THPHS) 460.74
(X/PH2S) 264.92 (Y/PH2S) .00000
    
```

```

Quadrupole lens 4 in position 11 Parasitic lens field -4.93334E-03 ( 5.00%)
(X/TH2S) 71.596 (Y/TH2S) .00000
(X/THPHS) .00000 (Y/THPHS) -140.41
(X/PH2S) -70.285 (Y/PH2S) .00000
    
```

! Notice how lens 2 is twice as sensitive to parasitic sextupole field  
! contamination compared to the other lenses.

! Now the octupoles:

PRM> **par/o**

Reduced Parasitic Octupole Aberration Coefficients: (micron/millirad<sup>3</sup>%)

```

Quadrupole lens 1 in position 5 Parasitic lens field 9.86669E-02 ( 100.00%)
(X/TH3O) 206.54 (Y/PH3O) 289.07
(X/THPH2O) -724.60 (Y/TH2PHO) -725.28
    
```

```

Quadrupole lens 2 in position 7 Parasitic lens field -.17823 ( 100.00%)
(X/TH3O) -104.25 (Y/PH3O) -1862.0
(X/THPH2O) 1307.4 (Y/TH2PHO) 1308.6
    
```

```

Quadrupole lens 3 in position 9 Parasitic lens field .17823 ( 100.00%)
(X/TH3O) 1100.0 (Y/PH3O) 27.563
(X/THPH2O) -458.55 (Y/TH2PHO) -458.98
    
```

```

Quadrupole lens 4 in position 11 Parasitic lens field -9.86669E-02 ( 100.00%)
(X/TH3O) -29.620 (Y/PH3O) -60.785
(X/THPH2O) 124.65 (Y/TH2PHO) 124.76
    
```

! Once again, lens 2 is most sensitive to parasitic field contamination.

! Finally it is possible to get help on any of the commands by using the  
! online help facility:

PRM> **help ab2**

AB2 Type out the angle dependent second order aberration coefficients.  
These will only be non-zero if there are sextupoles in the system or  
there are quadrupoles with parasitic aberrations.

Parameters: AB2 A Type all second order aberration coeffs.

! Finally, it is possible to see a raytrace through the entire system  
! by using the TRACE command:

PRM> **trace**

```

Initial beam: ( .00000 um, .30000 mr, .00000 um, -.30000 mr)
Perform a trace through the system.
Initial and final z-positions ( .00000 to 9.1279 ) >
Initial: 3 Final: 13
    
```

```
Extents in xoz plane:  -2.3162      to  2.4789      mm
Extents in yoz plane:  -2.9209      to  2.3140      mm
Extent for plot, mm (  -3.6511      to  3.6511      ) >
```

Press enter

```
! Note that all responses were blank, so a default raytrace through the
! entire system appears.  For this example, the divergence in the yoz
! plane was made negative to that it appears below the axis.
! You need to press enter to return to alpha-mode after graphics-mode.
```

```
! In preparation for the next computer program, we perform a calculation
! of all coefficients of the system then put them into a file so that
! they can be used to perform calculations by other programs (see
! below).  In this example we use lens 3 of the Shanghai system:
```

PRM> **da shang3**

```
! This is a single lens system, hence is stigmatic (only in focus in one
! direction) so the prompt becomes STI>.  Now the coefficients are put
! into a file shang3.cof:
```

STI> **cof shang3**

```
Collimator distance assumed to be      5.23300 m
Square or Circular aperture collimator? > Square aperture collimators.
Shadow plane distance assumed to be      .10000 m
Total system length      8.69320 m
Chromatic coefficients calculated with a  .50000 % energy spread.
(X/XDe and Y/YDe are probably inaccurate.)
```

STI>

```
! To exit the program:
```

PRM> **exit**

Some data files are included in the PDATA subdirectory of the disk:

MPNEW.PRM The Melbourne magnetic quadruplet.

HIAF.PRM The CSIRO-HIAF electrostatic quadruplet.

MPOCTU.PRM The MP system with three octupoles used to correct the spherical aberration. The CRAM command was used to compute the required octupole strengths.

LUNDA1.PRM Quadrupole 1 of the Lund system in achromatic mode. It consists of superimposed electrostatic and magnet lenses and was stigmatised with the electrostatic component alone, in the x--direction (STIG/X), then restigmatised with the magnetic component in the reverse polarity.

LONG.PRM The Ukrainian long system. Note the very large demagnification factor.

OLDQUAD.PRM The old Oxford system. Note the cross over in one

direction owing to the operation of this system in the high excitation mode.

SHANG.PRM The Shanghai system.

SHANG1.PRM Lens 1 of the Shanghai system. Similarly for lens 2,3 and 4. The single lens systems were used in the grid shadow measurements.

=====  
EXAMPLE RUN OF PROGRAM OXTRACE  
=====

This program simulates images of microprobe systems and analyses grid shadow patterns.

In this example we calculate the grid shadow pattern of a lens with the measured parasitic aberration coefficients of the Shanghai system so that the simulation can be compared with the experimental pattern.

! Run the program

\$ **oxtrace**

OXTRACE - High Resolution Image Intensity Mapping

Executing the login macro login.ocm

oxtrace> def/q

Scale factor for next plot > +0.9

X and Y plot offsets (mm) > +50,30

Plot rotation angle (degrees) > +90

Postscript output scaled by: .90000

Offsets: 50.000 , 30.000 mm

Plot rotation angle: 90.000 degrees

oxtrace> line -3

Line width set to 3.000000

oxtrace> @

! After the login macro has run we first simulate some rays from the ! aberration coefficients in the file shang3a.cof:

oxtrace>

oxtrace> **fake**

The time is --15:41:36--

Fraction of day elapsed .65389

<<< Obtain aberration coefficients and system parameters >>>

Filename for input > **shang3a**

Getting coefficients from shang3a.cof

```

On unit number 23
Opened file successfully.
Read title.
Read image/aperture sizes
read collimator.
read first order matrix
Read fifth order matrix.
shang3a.cof
  Modify/review the data in the coefficient file ? > n
    Random (1) or Regular (2) mode (CR for 2) > 1
      Number of rays > 20000
    Circular or Square apertures (CR for Circular) > S
      < SQUARE apertures selected. >
        Object X and Y diameter (micron) > 0,0
        Aperture X and Y diameter (mm) > 4,1
      < Maximum divergence = .38219 mrad.>
        Aperture offsets (x,y) in mm > 0,0
        Maximum beam energy half spread (%) > 0
Caption: Shanghai quad 3 with 0.28% sextupole
  Filename for rays file > shang3a

```

```

W: Rays file opened: shang3a.bin
  100 rays generated
  .
  .
  .
  20000 rays generated
  20000 rays generated total.

```

```

R: Rays file opened: shang3a.bin
Caption: Shanghai quad 3 with 0.28% sextupole
Finding number of rays.... 20002 rays in file.

```

! The simulated rays are put into a file shang3a.bin. Now a grid can be placed into the image plane:

```

oxtrace> shad
Filename for output rayset (CR for shang3as.bin) > shang3as
A: Rays file opened: shang3as.bin

  X Image = -1.75399E-04 um
  Y Image = -7.53755E+05 um
Plane for grid (micron, CR for 0) > 0.0
  Hole or Bar at origin? (CR for Hole) > h
  Period of grid (micron, CR for 12.7) > 12.7
  Bar full width (micron, CR for 6.35) > 6.35
  Rotation of grid (degrees, CR for 0.0) > 0.75
Grid specifications;
  Period 12.70000 um
  Bar full width 6.35000 um
  Hole full width 6.35000 um
  Position .00000 m
  Orientation .75000 deg
Grid hole centred at origin.

```

Proceed? > **y**

\*\*\*\*\*

Of 20000 rays processed, 4594 passed through the grid.  
The output rayset is in file shang3as.bin.

! The rays which went through the grid apertures are placed into a file  
! shang3as.bin. These can now be plotted on the screen, first they are  
! loaded from disk:

```
oxtrace> da shang3as
R: Rays file opened: shang3as.bin
Caption: Shanghai quad 3 with 0.28% sextupole
Finding number of rays.... 4594 rays in file.
```

! Now they are mapped on the screen:

```
oxtrace> map
Plane for image analysis (X, Y, or Other plane) > o
Y Image -7.53361E+05 micron
X Image -65.784 micron Distance (micron) > 2.93300E+05
Image plotted at Z = .29330 m
```

```
4594 rays.
Xmin = -2274.8 to Xmax = 2258.7 micron
Xrange = 4533.5 micron
Ymin = -2400.1 to Ymax = 2396.9 micron
Yrange = 4797.1 micron

Map done to +/- 2520.2 micron, other? > 2500.0
Run number 11 .....
X limits: -2500.0 to 2500.0
Y limits: -2500.0 to 2500.0
```

Rewinding file... Shanghai quad 3 with 0.28% sextupole

Press enter

! Press enter to return to alpha-mode. To exit the program, type exit:

```
oxtrace> exit
```

! There is a macro which runs this example. Simply run the program  
! and type:

```
oxtrace> @shang3a
```

! All the parts of this example will be done.

End of example.

## 7. PRAM Subroutines

This section provides a partial list of the FORTRAN subroutines that make up PRAM and OXTRACE.

### **SUBROUTINE COFPRINT(T,I)**

Print the third order matrix, T(2,10).

I is a switch which determines the heading to be put on the printout. I = 1,2 for lens or system coefficients, I=3,4 for lens or system OXRAY coefficients (i.e. magnification included).

Arguments: T(2,10)                      Real, Third order aberration coeffs  
          I                              Integer, Heading type.

### **SUBROUTINE DRIFT(IZ,A)**

Generate the drift transfer matrix for element IZ. If element IZ is not a drift print an error message.

Arguments: IZ            Integer, element number  
          A(4,4)            Real, transfer matrix

### **SUBROUTINE ELEMENT(IELE)**

Change the data associated with element number IELE. First print out the current data for element IELE (slots 1 to 4). If the element is a lens then also print out slots 5 to 12. After this, allow any of the data in slots 1 to 4 to be changed. If illegal type codes are given then produce an error printout.

Arguments: IELE    Integer, element number

### **SUBROUTINE ELEPRINT(IZ,M)**

Print out the element data for element IZ. M is a code that determines the amount of data to be printed. If IZ is greater than 40 (the maximum number of elements allowed in the system) then the element is printed as an error element.

Arguments: IZ,M    Integers

### **SUBROUTINE EXCITE(PERT)**

Calculate the excitation aberration coefficients for the system. Each lens excitation is independently perturbed by a small percentage PERT and from the change in spot size the coefficient is determined. The coupled excitation aberration coefficients are also determined. i.e. coupled lenses are both perturbed by the same amount (taking into consideration the sign of the excitation of each lens) and the from the change in size of the spot the coefficients are determined. The coefficients are returned through common block /ABER0/.

Arguments: PERT    Real, small percentage perturbation.

**SUBROUTINE FOCAL( IZ ,FX ,FY )**

Calculate the focal length of the system up to element IZ. FX and FY are the focal lengths in the X and Y directions respectively. Non-lenses, SUPRA-lenses and octupoles are ignored. Otherwise a lens is a lens with a non zero excitation (slot 3). If a subsystem with infinite focal length is found (zero magnification) then an error message is printed.

Arguments: IZ Integer, element number  
FX,FY Real, focal lengths

**SUBROUTINE GEOM( IZ ,A )**

Generate a print out of the geometrical parameters of element IZ given the transfer matrix, A, of lens IZ. A is a 4x4 matrix. The output goes either to the screen or an output file depending on the value of NTOUT. If IZ is the last element in the system (i.e. the element has type-code 9) then generate a print out of the geometrical parameters of the whole system.

Arguments: IZ Integer, element number  
A(4,4) Real, transfer matrix

**SUBROUTINE LIGHT( IZ ,A ,FX ,FY ,DMX ,DMY ,SIX ,SIY ,PPX1 ,PPX2 ,PPY1 ,PPY2 )**

For element IZ and transfer matrix A calculate the focal lengths, magnification, image distance, entrance principle plane and exit principle plane in the X and Y direction. The image distances are relative to the center of the lens and the magnifications have been corrected by the principle planes.

Arguments: IZ Integer  
A(4,4) Real  
FX ,FY ,DMX ,DMY ,SIX ,SIY ,PPX1 ,PPX2 ,PPY1 ,PPY2 Real

**SUBROUTINE MAG( IZ ,SMAGX ,SMAGY )**

Calculate the magnification up to element IZ. SMAGX and SMAGY are the magnifications in the X and Y directions. Non-lenses, SUPRA-lenses and octupoles are ignored. A lens is otherwise included if its excitation (slot 3) is non-zero. The individual magnifications are taken from slot 9 for X and slot 10 for Y. If an element has zero magnification an error message is printed.

Arguments: IZ Integer  
SMAGX ,SMAGY Real

**SUBROUTINE MATMUL( N ,A ,B )**

Multiply two NxN matricies together. N may have a maximum value of 14.

The result is put into B.

i.e.  $B = A * B$

Arguments: N Integer  
A(4,4) ,B(4,4) Real

**SUBROUTINE MATPRINT( ITYPE, A )**

Print out the transfer matrix A(4,4) for lens type ITYPE.

Arguments: ITYPE Integer  
A(4,4) Real

**SUBROUTINE PENGY( IZ, ENERGY )**

Determine the ENERGY of the beam up to element IZ. The starting value is assumed to be in slot 12 of the particle element. The energy of any accelerator sections is then added to this.

Arguments: IZ Integer  
ENERGY Real

**SUBROUTINE OCTU( IZ, A )**

Generate the octupole transfer matrix for the element in position IZ. If element IZ is not an octupole an error message is printed. The transfer matrix for an octupole is a drift space.

Arguments: IZ Integer  
A(4,4) Real

**SUBROUTINE QUAD( IZ, A )**

Generate the quadrupole transfer matrix for the element in position IZ. If element IZ is not a quad an error message is printed. The transfer matrix incorporates the effect of any misalignments. A is a 4x4 matrix.

Arguments: IZ Integer  
A(4,4) Real

**SUBROUTINE RCONV( IZ, W, R )**

Convert the third order transfer matrix W as used by PRAM to the third order matrix used by OXRAY and change the units to micron and milliradian. There are 10 coefficients for each plane and the conversion factor is as follows:

1-2 1.0E-3  
3-5 1.0E-6  
6-8 1.0E-9  
9-10 1.0E-12

Arguments: IZ Integer, total number of elements in the system  
W(2,10) Real, PRAM third order coefficients  
R(2,10) Real, OXRAY coefficients

**SUBROUTINE SEXT(IZ,A)**

Generate the sextupole transfer matrix A(4,4) for element IZ. If element IZ is not a sextupole print an error message. The transfer matrix for a sextupole is a drift matrix.

Arguments: IZ                    Lens position Integer\*4  
           A(4,4)                Sextupole first order transfer matrix (Drift) Real\*8

**SUBROUTINE SOLENOID(IZ,A)**

Generate the solenoid transfer matrix, A(4,4) for lens IZ. If lens IZ is not a solenoid an error message is printed. This subroutine has not been tested.

**SUBROUTINE STIGMAT(IORD,B)**

Calculate the transfer matrices of the system depending on the value of IORD. IORD takes the following values:

- IORD = 1      Calculate the first order matrix only
- IORD = 2      Calculate the first and second
- IORD = 3      Calculate the first, second and third

B is a 4x4 matrix that contains the first order matrix. The higher order matrices are  $B = A*B$

Arguments: N            Integer  
           A(4,4),B(4,4)      Real

**SUBROUTINE SWAP(A)**

Convert the transfer matrix A(4,4) calculated for a lens assumed to have a positive excitation to a transfer matrix for a lens with negative excitation. i.e. swap row 1 with row 3 and swap row 2 with row 4.  
 Arguments: A(4,4) Real\*8

**SUBROUTINE UNPACK(DTYPE,IT,IF,IS,IC)**

Unpack the element characteristics from the element type code (slot 1). If DTYPE is a decimal number of the form AB.CD then it is unpacked as follows:

IT = AB                    Type of element

CODE	POSSIBLE VALUES	ROLE
IT=AB	1,2,3,4,5,6,7,8,9,10,11,13,15 16,17,18,19,20	TYPE OF ELEMENT
IF	+1	MAGNETIC

0 NON LENS  
-1 ELECTROSTATIC  
The value of IF depends on IT and A.  
IS 0 NORMAL LENS  
1 SUPRA LENS  
The value of IS depends on IT and A.  
IC +-1,2,3,4,5,6,7,8,9 COUPLING CODE  
The value of IC is determined from CD.

Arguments: DVAL real\*8  
IT,IF,IS,IC integer

### **SUBROUTINE VECMUL( IORD, BEAM, TRAN )**

Transform then beam element BEAM(4) by a transformation of order IORD. If IORD is 1 the transformation is provided by TRAN(4,4). Higher order transforms are included as follows:

IORD	TRANSFORM
1	First order
2	Second order
3	Third order
4	First order plus angle chromatic
5	First order plus angle spherical
6	First order plus Fishk spherical (See also FISHK.)

The result of the transform goes back into BEAM (the beam matrix).

BEAM takes the following values:

BEAM(1) = X, BEAM(2) = THETA, BEAM(3) = Y and BEAM(4) = PHI.

### **HISTORY OF PROGRAM PRAM**

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by David N. Jamieson

School of Physics, University of Melbourne (1979--1985).

First version was subroutine FISHK in 1979, later considerably extended and improved up to 1985.

The program calculates the properties of systems of quadrupoles and octupoles. The program originated as the subroutine FISHK in 1979 when it could only handle antisymmetric systems of quadrupoles.

FISHK now handles all stigmatic systems up to antisymmetric quadruplets, including singlets and high excitation triplets.

The December 1981 version calculates all aberration coeffs to third order. Stigmatisation is done automatically by STEPIT. Electrostatic elements were introduced during January 1982.

Version 1.0 August-November 1979

Version 2.0 Oxford, April-May 1981

Version 3.X August-December 1981

Version 4.X January-June 1982

Version 5.X June- 1982

Extended to include a graphical raytrace of particle trajectories through the system.

Version 6.X October- 1985

Division of Applied Physics, California Institute of Technology (1986-1987).

Nuclear Physics Laboratory, University of Oxford (1988-1989).

Extended to include listing of all aberration coefficients into a '.COF' file for reading by program OXSORT, used for fitting grid shadow patterns to compute parasitic aberration coefficients of quadrupole lenses.

Version 7 1992

A version was hacked for a PC (DOS) in November 1992. As of 2000, this version was no longer supported.

END OF MANUAL