Garfield, a drift-chamber simulation program
User's guide
Version 4.29

30 November 1993

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Garfield is a computer program for the detailed simulation of two-dimensional drift chambers. The program can for instance calculate field maps, x(t) relations, arrival time distributions, induced signals and the drift velocity and diffusion in gas mixtures. Garfield can also assist in optimising the potential settings.

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Submitter: M.Marquina
Language: FORTRAN
Library: POOL-W5050

What is Garfield ?

Garfield tries to simulate the behaviour of drift-chambers: it calculates and plots the electrostatic field, the drift-lines of electrons and ions and the currents on the sense wires resulting from the passage of a charged particle through the chamber. The program can also assist you in finding optimal potential settings under certain constraints. For calibration purposes, Garfield can compute x(t)-relations and arrival time distributions.

The program is primarily meant for use with chambers that consist only of thin wires and infinite equipotential planes. Periodicity, magnetic fields and cylindrical geometry are allowed. Fancy electrodes can only be handled by approximation. Garfield can not deal with three-dimensional structures.

Garfield can be run interactively and in batch on most of the CERN central computers. One of the main features of the program is probably its friendliness; little knowledge about the computer system and no knowledge at all about programming languages is required to be able to run it.

Contents

1.0 Introduction

1.1 What the program can do

Garfield operates on drift-chambers made up of thin wires, up to two, not necessarily grounded, planes at constant x or r and up to two, not necessarily grounded, planes at constant y or ϕ. Infinite repetition of the cell in x and in y (or ϕ) can be taken into account. Radial repetition is not supported for technical reasons. The description of the chamber can either be in polar or in Cartesian coordinates and consists of a listing of the wire positions, potentials and diameters, of the plane positions and potentials, of the periodicities and of the dielectrica.

When doing drift line calculations, the program further needs a detailed description of the gas. This description can be provided by the user, but some frequently used gasses are built in the program (CO_2, methane, ethane, isobutane, argon-ethane, CO_2-ethane etc.). Garfield can also calculate the drift velocity and the diffusion in gas mixtures.

The tasks Garfield can perform, include the following:

- Plotting of (almost) any function of the field as a histogram, a vector plot, a set of contour lines, a 3 dimensional surface or a graph. The field in a given part of the chamber and on the surface of a group of wires can be tabulated. A command is provided that checks that the potential and the field are consistent, satisfy Maxwell's equations and satisfy the boundary conditions.
- Assisting you in finding optimum potential settings under a variety of constraints. The dependency of the field on the wire potentials can be printed.
- Calculation and plotting of electron and ion drift-lines and equal arrival time contours. The drift-lines may start at the wire-surface, at the edge of a user-defined drift-area or from a user-defined track. In the latter case, graphs of the drift-time, the mean drift-speed, the integrated diffusion and of the multiplication factor are made on request.
- Calculation of x(t)-relations, if required for inclined tracks, optionally estimating the longitudinal diffusion. The case your equipment counts electrons before it triggers is also handled by the program. Garfield can produce drift-time tables.
- Simulation of the signal induced on the sense wires when a charged particle traverses the cell. The effects which can be taken into account are: cluster-formation, longitudinal diffusion, avalanche near the wire-surface, electron-pulse and the ion-induced current. The simulated signal can be used as an input to the electronics circuitry simulation programs Spice or Sceptre.

A variety of routines to obtain data derived from field and drift-line calculations is available and it should therefore not be difficult for a user to write his/her own extensions.

1.2 What the program cannot do

The major limitations of the program are:

- All calculations are carried out in the thin-wire approximation, hence the wire-spacing should be at least 5-10 times the wire radius. Corrections such as dipole and quadrupole terms might be included in some future version.
- Strips or line-electrodes of finite length have to be replaced by rows of wires of appropriate diameter. You'll have to use another program if such an approximation is not adequate.
- Only infinite slabs of dielectric material will be handled by Garfield in a future release. Programs using finite element methods like Poisson will probably suit you better if dielectrica are an important component of your chamber.
- The program input allows only for simple, uniform magnetic fields but the distortion of the magnetic field due to the difference in susceptibility between the gas and the wire-material can be taken into account. This is not a true limitation since the user may provide her/his own routine returning the magnetic field if he/she wishes to do so.

- The program neglects lateral diffusion in its present version. This is not a fundamental limitation and it is conceivable that future versions will know about lateral diffusion, should there be sufficient interest (please send a message to the author).
- The field-calculation is 2-dimensional in an essential way. The main reason for this limitation is that analytic potentials for such simple configurations as two crossing wires, are not known. One should therefore use a finite element method program, such as TOSCA, whenever the chamber is truely 3-dimensional. Extending the drift-line routines to 3-dimensional situations is trivial and has been done to some extent in the current version.
- The program is not noted for its speed ! If the number of wires is large (over 1000) running Garfield may no longer be practicable; again Poisson or similar programs might be more like what you need. Sometimes, the efficiency can greatly be increased by making the chamber periodic, at least part of it. The number of wires kept in mind while writing the program, is about 50. Tests have been done up to 1000 wires.

  On some machines special compilations are available that make effective use of the vector facilities, making computations on chambers with 1000 wires feasible again.
- The author can not warrant correct functioning of any part of the program, it is the duty of the user to check that the accuracy of the results is adequate for her/his purposes !

1.3 In case of problems ...

A common source of problems is the use of an old manual with a new version of the program. While this may sometimes work, it should be kept in mind that Garfield changes continuously, trying to adapt to the needs of its users. No attempt is made to maintain backwards compatibility.

The best strategy is to contact me if you plan to make extensive use of the program. This allows me to keep track of the kind of thing the program is used for and to make the program better suited for your applications. I can then also warn you in case a serious bug is found.

Please tell me if you have suggestions for improvement. Great efforts have been made to make the program itself understandable because bugs are bound to be present. However, even if you manage to correct them, please send a message. My electronic mail addresses are:

```
VM/CMS at CERN:                 RJD@CERNVM
CERN central Vax:               VXCERN::VEENHOF
```

Conventional mail can be sent to:

```
Rob Veenhof                     Rob Veenhof
CERN /PPE-division              2, Rue du Reculet
CH-1211 Genève 23               F-01630 St Genis-Pouilly
Switzerland / Suisse            France
tel: + 41 22 7673897            tel: + 33 50421784
Fax: + 41 22 7830672
```

G.A. Erskine, who contributed essential routines and ideas, should not be called when problems occur. The person to contact in case of control-C problems on the Vax, is Carlo Mekenkamp.

I greatly appreciate receiving a copy of any note or publication for which this program has been used.

2. 0 Running the program

If you are not at CERN, you may have to compile and link Garfield yourself before you proceed. Instructions for doing so can be found in Chapter 5.0 on page 123. This chaper assumes compilation has been done and describes how you start the program. Other topics discussed are dataset usage and error messages.

2. 1 How to start the program on each of the syst

At CERN, and some other sites, you should not have any initialisation for Garfield in your profile, login command procedure etc. You may need some private initialisation for GKS.

The numerical parts of the program are identical on all machines; the plotting and I/O parts are definitely not. The program behaviour and appearance of the output can therefore vary somewhat between the various systems.

Garfield can be run interactively and in batch on most computers. If you run the program interactively, the program will first do some initialisation and then wait for you to type a command, execute the command and wait for the next. To stop the program, you have to enter the & STOP command. When Garfield is running in batch, the commands are taken from an input file and the program stops executing when the end of the input file is reached.

2. 1. 1 Running on Apollo and Unix systems

The executable files for Garfield are stored in the usual CERN directories, nothing special has to be done therefore to start the program. Garfield uses GKS and you may need to perform GKS initialisation as described in the CERN computer graphics guides. The format of the Garfield command is as follows:

```
$ garfield [-terminal {type T | GKS_id G connection_id C} ]
           [-noterminal]
           [-metafile {type T | GKS_id G offset O name F} ]
           [-nometafile]
           [-nodebug | -debug]
           [-noidentification | noidentification]
           [-RNDM_initialisation | -noRNDM_initialisation]
```

Note: all options and values have to be entered in the case shown. They may be abbreviated to some extent.

terminal Either specify the *type*, which can for instance be *DN300_bw*, *DN3000_bw*, *DN3000_colour*, *DN550_colour*, *DN660_colour* or *X_windows_2* for GTS-GRAL compilations. Or the *GKS_identifier* and the *connection_identifier* both of which are numeric.

Use *-noterminal* if you wish to suppress all graphics output on the screen.

metafile The kind of metafile output can, like the terminal type, be specified either via *type* or via the *GKS_identifier*, the *offset*, which is the difference between the logical unit which the metafile is opened and the connection identifier, and the *name*, the name of the metafile. The metafile is by default in PostScript format, the alternatives are Encapsulated PostScript, a format suitable for inclusion in other documents, and Appendix-E metafile, a format that is convenient for viewing the pictures on a terminal later on.

-debug Requests that debugging mode is initially on, that is, also during initialisation. This flag can be switched off when the program is reading input by means of the OPTION command. Default is *-nodebug*.

-identification Requests that tracing is on from the start of program execution onwards, also during initialisation. Default is *-noidentification*.

-RNDM_initialisation When the program starts executing, it calls the RNDM random generator a number of times that depends on the time of the day. This ensures that results for which Monte-Carlo techniques are used, are produced with different random number sequences in each run. In case you wish to do debugging, this may not be desirable; the *-noRNDM_initialisation* qualifier suppresses the initialisation.

There are two ways on Unix to make Garfield read an input file: via the program's own < command and via the Unix < on the command line. There is an important difference between the two: when you type

```
$ garfield
Main: < input
```

all plots will be displayed on the screen and, unless the input file ends on a & STOP, further input can be entered manually. If on the other hand you type

```
$ garfield < input
```

Garfield behaves as if running in batch, and a metafile will be produced rather than pictures on the screen.

Surface plots and some contour plots can not be made on most Unix machines.

2.1.2 Running on the Cray

Either log on to the Cray and start the program there:

```
/cern/pro/exe/garfield
```

and similarly for the OLD and NEW versions, or submit an input file from VM/CMS to the Cray. The latter is the more convenient method, see Section 2.1.3 for details.

Keep in mind that the NAG graphics library has not been compiled on this machine and that surface plots can therefore not be made.

2.1.3 Running under VM/CMS and Cray job submission

Type the following to start Garfield interactively:

```
(login sequence)
GARFIELD
```

The news will appear after a few seconds. You may have to switch the terminal back to α mode in order to see it. On Falco terminals, you have to hit the return key, once the terminal is switched to graphics mode.

Submitting a job to the Cray is almost as simple; given the very fast response of the CERN Cray and its excellent numeric quality, running on the Cray should be a very interesting option. First prepare an input file with Garfield commands. Next check your Cray user identifier by typing:

```
DEFAULTS SET GARFIELD CRAY
```

Hit return when you are ready. Running on the Cray is default from now on. The option *CRAY* on the command line is therefore not required:

```
GARFIELD your_input_file (CRAY
     (wait for the prompt)
passcode
```

After a while, the output and metafile will be returned to you. You may need additional files from VM, such as cell descriptions, and you may also wish to send datasets written by the program back to VM. This can be achieved by running the fetch and dispose commands in a separate shell (see also Section 3.12.8 on page 76). In the example below, a cell library is fetched from VM and a member of the file is read. Next, an output file for the field map is opened, the map is written, the file is closed and sent back to VM. The -dPU option is only needed if the dataset will be reread. You don't have to bother about sending files to VM in principle since all files are disposed when the job terminates.

```
& CELL
$ fetch cell.data -t'fn=CELL,ft=LIBRARY'
get "cell.data" DC1

& FIELD
> "field.map"
print ex,ey,e,v
>
$ dispose field.map -dPU -t'fn=FIELD,ft=MAP'
```

If you wish to run the same input file in batch on VM/CMS, type:

```
GARFIELD your_input_file (VM/CMS
```

The system name (Cray or VM/CMS) is by default the system for which you last updated the defaults. To change the default system back to VM, type:

```
GARFIELD (SET VM/CMS NOPANEL
```

The command GARFIELD is by itself enough to start the program. As the full command description below shows, several options not described above are at your disposal. One of the more useful amongst them is perhaps the terminal type. The two most commonly used command formats read:

```
GARFIELD [fn [fm [ft]]] [(options)]
BATCH SUBMIT [(batch options)] GARFIELD [fn [fm [ft]]] [(options)]

options: TERMINAL([TYPE type] [GKS_ID gksid] [CONNECTION_ID conid])
         NOTERMINAL
         METAFILE([TYPE type] [GKS_ID gksid] [OFFSET offset] [NAME name])
         NOMETAFILE
         NODEBUG | DEBUG
         NOIDENTIFICATION | IDENTIFICATION
         RNDM_INITIALISATION | NORNDM_INITIALISATION
         PFKEYS | NOPFKEYS | USERPFKEYS
         VM/CMS | CRAY
         PRO | EXP | NEW | OLD
         SCALAR | VECTOR
         LIST | SET
         PANEL | NOPANEL
         TIME_LIMIT min[:sec]
         CRAY_ACCOUNT cray_userid
         CRAY_QUEUE cray_queue
         RECIPIENT recipient
         PASSWORD password
```

The first format is meant for interactive use and for batch jobs that do not require batch submission options. This is also the appropriate format for submission to the Cray. The second format permits you to specify batch options manually but is not recommended.

terminal The program assumes you are sitting behind a Pericom Monterey MG600 graphics terminal. On other terminals, you should specify your terminal type. Examples of recognised *types* are MG600, 4014 and PG7800. Some of the terminal types Garfield recognises, are perhaps not known by the GKS on your system; you'll see a GKS error 23 in the GKSERROR LOG file if you specify one of them. Your system manager should be able to help you. See also the general remarks on terminals in Section 2.2 on page 9.

In case your terminal is not known by Garfield, you can specify the terminal model via the GKS identifier of the driver, *gksid*, and an appropriate connection identifier *conid*.

The option *NOTERMINAL* can be used to suppress all graphics output to the screen.

metafile Garfield will on most computers by default produce a PostScript formatted picture file, when running in batch. You can request Appendix-E metafile format (APPENDIX_E) and encapsulated PostScript instead. For the PostScript formats, you have the choice between black & white or colour and between landscape and portrait.

The metafile type can, like the terminal type, also be specified through a GKS identifier, the difference between logical unit and connection identifier, *offset*, and the name of the picture file *name*.

The option *NOMETAFILE* can be used to disable production of a picture file.

DEBUG Requests debugging output from the start of program execution onwards. When this option is specified, all error messages are printed for underflow, overflow, divide by zero and end of record.

IDENTIFICATION Requests tracing output from the start of program execution onwards. This option is rarely needed by the casual user.

RNDM_INITIALISATION When the program starts executing, it calls the RNDM random generator a number of times that depends on the time of the day. This ensures runs using Monte-Carlo techniques (mainly in the signal section) use different sequences of random numbers. In case you wish to do debugging, this may not be desirable; the *NORNDM_INITIALISATION* option suppresses the initialisation.

PFKEYS Sets the PF keys as shown below; if the program completes execution without being interrupted, the original PF keys are restored. If this option is specified in conjunction with the SET option, a further panel will be shown in which the PF key definitions can be edited. This option is ignored for running in VM/CMS batch and on the Cray.

USERPFKEYS Calls the USERPF EXEC to set PF key definitions. The EXEC usually resides on the user disk and can freely be customised. One of the advantages of USERPF over PFKEYS is that appropriate keys definitions are set when entering SUBSET mode. The options USERPF and PFKEYS are mutually exclusive.

VM/CMS Requests Garfield is run on VM/CMS, either in batch or interactively depending on the command format.

CRAY Submits a job reading the input file to the Cray. You will be prompted for your 'Passcode', this is your 4 digit identification code followed by the 6 digit code currently shown on your SecurID card. Additional input files from VM should be fetched from within the job. The output, the metafile and any file you create in the job are returned to your reader when the job finishes.

PRO Implies the current module is loaded. This is the recommended file to use; PRO is default.

EXP Takes the version on the disk of the author. Keep in mind that this file is used for debugging and sometimes contains deliberate errors. The disk that contains the module is password protected, the password being Garfield's favourite food. This version is normally not available outside CERN.

NEW Will replace the present PRO version at the next update cycle. This file can be replaced by a newer copy at any time but it should be reasonably bug free.

OLD Loads the module that was taken out of use at the last program library update cycle. It's there only for backward compatibility purposes - not one of the strong points of Garfield !

SCALAR Selects a module that does not access the vector units. This module is adequate for most purposes.

VECTOR In case your chamber has a large number of wires (over 1000), Garfield consumes prohibitive amounts of CPU time if run in scalar mode. The VECTOR option selects a module compiled and loaded for use (only) under VM/XA using the IBM 3090 VF vector units. This module needs, depending on the compilation parameters, 31 Mb or 100 Mb of storage and you need permission to use the vector facilities. When submitting a batch job that uses this module, you have to be sure you specify the batch options CMS CMSXA and STO 31M or STO 99M. This is done automatically in case of implied submission (first format).

Note that the vector module is slower than the scalar module if the number of wires is small (< 100-200).

There may be small numerical differences between the results obtained with the scalar and the vectorised version of Garfield. They are due to the use of different library routines for matrix handling (ESSL instead of CERNLIB) and also to the use of vectorisable field calculation routines inside Garfield. There is no intrinsic difference in numerical quality between the two versions.

The numerical quality of the results for chambers with a very large number of wires can not be guaranteed; contact the author for ways to check the accuracy.

LIST/SET Allows you to inspect and change the defaults. DEFAULTS SET GARFIELD and DEFAULTS LIST GARFIELD have the same effect as GARFIELD (SET and GARFIELD (LIST respectively. No other option should be specified along with LIST. These options should not be used in batch.

PANEL Requests that a panel is used to set new defaults. The IOS3270 facility has to be present for this. *NOPANEL* allows you only to change the options, not the file name. *PANEL* is default if the IOS3270 facility is available.

min, sec The amount of CPU time the job is allowed to use. Both the format *min* and *min:sec* are permitted. Separate CPU time limit defaults are remembered for VM/CMS and Cray.

cray_userid The Cray account on which the job is to be run. This is by default your own Cray account.

cray_queue The job queue on the Cray in which the job is to be run. If set to *any* , UNICOS is left free to choose a queue. This is default.

recipient The VM user who should receive the files sent from the Cray when the job terminates. This is by default the account from which the job is submitted.

password The read password of the RJD 192 mini-disk, needed only if you wish to run the EXP module on VM/CMS at CERN.

file-name The file from which the input is taken. The usual VM/CMS format should be used: fn fm ft. All fields can have defaults, initially GARFIELD, INPUT and *. Substitute an equal sign (=) for a field for which the default is acceptable. Only the file-mode may contain a wildcard character (*).

If a file-name is specified with the first format, the file is searched for and the program is resubmitted in BATCH along with the input file. Hence you may change the input file after submission.

Both variable length record and fixed length record files are acceptable.

The PF keys are by default set as follows when running interactively on VM:

```
PF7:  & Cell         PF8:  & Gas          PF9:  (retrieve backward)
PF4:  & Field        PF5:  & Optimise     PF6:  (retrieve forward)
PF1:  Help           PF2:  & Drift        PF3:  & Quit
PF10: & Signal       PF11: (subset)       PF12: (not defined)
```

All PF commands are executed immediately except for PF3. PF11 brings you to subset mode, type RETURN to get back.

The scalar module needs about 6 Mb to run. The recommended minimum machine size is 8 Mbyte; some space is needed to perform activities in SUBSET mode, both by the program for dataset operations and by you, for instance to edit a file. You'll be warned if your machine is too small to load the program.

When you run Garfield for the first time in batch on VM/CMS, a file called GARFIELD BATCHID will be written on your A disk. You may move this file to any disk for which you have RW access. You may also, with caution, modify the contents. This file ensures subsequent Garfield runs have different job names. You are advised not to discard it.

Interactive VM/CMS is an extremely fragile system when it comes to plotting. Any normal Fortran output sent to the screen while a plot is being made will causes a clash in the communication between the terminal, CMS and the communications-controller. Therefore all printed output should either be switched off (OPTION NOCLUSTER-PRINT, NODRIFT-PRINT and DRIFT NOLINE-PRINT) or be diverted to a file (> 'file_name file_type') before plotting starts.

The program writes temporary files to the A disk while it is running. These files have a file-name of GARFTEMP. Make sure you don't have valuable files by that name on your disk.

VM/CMS allows a user to be logged on without terminal connection. This can be exploited if you wish to suspend a long interactive session without loosing your data, by typing: (note the dollar sign)

```
$ EXEC GONE
```

The next time you log on, you'll find yourself in Garfield at the point where you left off, unless the system has been restarted in the mean time.

VM/CMS lacks normal program interrupt keys. To stop the program during long computations, either type HX and hit the return key or, if this doesn't work, hit the PA2 key, wait for the CP prompt to appear, type KILL * and hit return. Stopping the program when plots are being produced can be very tricky.

2.1.4 Running on Vax/VMS

Vax computers are perhaps the machines on which Garfield is run most often. Vax/VMS is also the system on which the program exploits most extensively the features the manufacturer offers. Good response is unfortunately only obtained on machines from the 8xxx and 9xxx series and on microVax III.

The program is started by the GARFIELD command, which has a set of optional qualifiers shown below:

```
$ GARFIELD [/TERMINAL=(TYPE=type,GKS_ID=gksid,CONNECTION_ID=conid)]
           [/NOTERMINAL]
           [/METAFILE=(TYPE=type,GKS_ID=gksid,OFFSET=offset,NAME=name)]
           [/NOMETAFILE]
           [/PRO | /OLD | /NEW | /EXP]
           [/NODEBUG | /DEBUG]
           [/NOIDENTIFICATION | /IDENTIFICATION]
           [/RNDM_INITIALISATION | /NORNDM_INITIALISATION]
```

terminal Garfield assumes as default terminal the Falco. The /TERMINAL qualifier should be used if you have a different model. The simplest format, e.g. /TERM=TYPE=MG600, can be used if your terminal model is known to Garfield, like for instance 4014 (Tektronix), MX8000 (a fancy Pericom colour terminal) or VT240 (Regis). If your favourite terminal is not recognised by Garfield, try to specify the driver via the GKS identifier *gksid* and the connection identifier *conid*.

See also the general remarks on terminals in Section 2.2 on page 9.

Use the /NOTERMINAL qualifier if you wish to suppress all graphics output to the screen, on an alphanumeric terminal for instance.

metafile Garfield will by default not produce a metafile during interactive running on a Vax. You can request one however by means of the /METAFILE qualifier. The format could for instance be PostScript or Appendix-E metafile format. For the PostScript formats, you have the choice between black & white or colour and between landscape and portrait.

The metafile type can, like the terminal type, also be specified through a GKS identifier, the difference between logical unit and connection identifier, *offset*, and the name of the picture file *name*.

The option */NOMETA FILE* can be used to disable production of a picture file.

/OLD The version which was taken out of use at the last Program Library update cycle. It's there only for backward compatibility purposes.

/PRO Is the default version introduced at the last Program Library update. This is the recommended file to use.

/NEW Will replace the present PRO version at the next update cycle. This file can be replaced by a newer copy at any time but it should be reasonably bug free.

/EXP The authors private version; contains sometimes deliberate bugs for testing purposes ! This version is normally not available outside CERN.

/DEBUG Requests that debugging mode is initially on, that is, also during initialisation. This flag can be switched off when the program is reading input by means of the OPTION command. Default is /NODEBUG.

/IDENTIFICATION Requests that tracing is on from the start of program execution onwards, also during initialisation. Default is /NOIDENTIFICATION.

/RNDM_INITIALISATION When the program starts executing, it calls the RNDM random generator a number of times that depends on the time of the day. This ensures runs using Monte-Carlo techniques (mainly in the signal section) use different sequences of random numbers. In case you wish to do debugging, this may not be desirable; the */NORNDM_INITIALISATION* qualifier suppresses the initialisation.

Digital offers a editor (LSE) that can be taught the syntax of a programming language. Although Garfield can hardly be termed a programming language, LSE is convenient to make input files. To use this facility, start Garfield once for the version of the program that you wish to use, this will define the appropriate logical names, and then type

```
$ LSE /ENV=DISK$GARFIELD:GARFIELD.ENV file.INPUT
$ GEDIT file.INPUT
```

The extensions .INP, .DAT, .DATA, .GARF and .GARFIELD may be used instead of .INPUT. Consult the LSE manual if you are not familiar with the language aspects of LSE; the keypad layout of EDT and LSE are the same. Pay particular attention to the control-E, -K, -N and -P commands which stand for Expand, Kill, Next and Preceding. Have a glance at the concepts of placeholder and token. The gold control-E sequence might also be of interest. The placeholders enclosed by braces { } must be filled in, the optional placeholders denoted by [ ] can be 'killed'. Repeatable items are followed by a series of three dots ... .

Please note that the LSE file is not updated any more since Garfield version 2.

To run the program in batch, create a command file like the one shown below and submit it to batch (SUBMIT command):

```
$ (Garfield initialisation if any)
$ SET DEF your_directory
$ GARFIELD
input statements
& STOP
$ EXIT
```

It is good practice to keep the true input statements in a separate file, which can then also be used for interactive use, and to have only *<input.file* lines in the command file.

DO NOT execute command files as shown above in interactive mode. The program expects you to hit the return key before and after each plot. When the input is taken from a command file, the program thinks the next line in the command file is the return typed by the user and it will ignore the contents -if any- of that line. (You could therefore add two blank lines per plot after commands generating graphics output and use the no-scroll key to keep the plot a little longer on the screen.) Datasets are read via a different channel when < is used, and the above remarks therefore do not apply.

You may interrupt the computations at any moment by typing control-C. Control is returned to the input reading routine of the section in which you were. Certain internal facilities (histograms, algebra) are not released in the event of a control-C interrupt - if you use control-C often during a single run, you may therefore run out of histogram, algebra space etc. Because of some peculiarities of the Fortran I/O system, control-C should only be used if Garfield has been linked with FIOPAT, which is the case for the public files at CERN.

2.2 Terminal types

Garfield currently recognises the following terminal types on VM and Vax, if the program has been compiled with GTS-GRAL, which is usually the case:

DEC terminals VT100_SELENAR, VT125_REGIS, VT240_REGIS VT241_REGIS, VT340, VAXSTATION

Pericom terminals PG7800, MG600, MX2000, MX7000, MX8000

Tektronix terminals: 4010, 4012, 4014, 4015, 4105, 4107, 4207, 4109 4209, 4111, 4113, 4114, 4115

Falco: FALCO

A few remarks are in order:

- 4014 is meant for line mode use only on true 4014 terminals. These terminals don't have separate α and graphics screens.
- MacIntosh users logging in via Versaterm PRO should ask for PG7800. This is equivalent to 4014 for graphics and to VT100 for the alphanumeric output. Screen switching should be automatic.
- FALCO is identical to PG7800 at CERN but not at IN2P3, where a dedicated Falco driver is used.

2.3 Datasets

2.3.1 Garfield output datasets

Garfield organises its output files as libraries. A member in a Garfield library could for instance be a compact cell description, a piece of program output or a signal in Spice readable format. Each member in a Garfield library has a name and a type, neither of which needs to be unique. The member name is usually specified by the user and is only required if she/he needs to distinguish several members of the same type in the same dataset (two cell descriptions for instance). Hence, you may ignore that the datasets are libraries as long as you write things to different datasets. The type is used internally to ensure that the cell description reading routine doesn't attempt to read a signal etc. Thus you are for instance allowed to give the cell and track descriptions associated with a single chamber the same member name, and therefore to use nearly identical retrieval calls in the cell, gas and signal sections.

Garfield libraries are things you would not normally wish to edit (except of course to extract an x(t)-relation or a piece of output). Instead, the program provides a set of instructions (described in Section 3.12.9 on page 77) that allow you to obtain directory listings, to list individual members, to delete members etc.

If you wish to add comments to the library, do so after the first line and before the first member (line starting with a precent sign).

Note: the information contained in the remainder of this paragraph is only needed if you contemplate writing additions to the program.

Garfield libraries are on most computers variable record length sequential files to the operating system. On IBM, the datasets are opened with a fixed record length of 133. The first record is a line of length 133 which is only there to make sure the operating system doesn't reduce the record length. This record is written automatically when a new file is opened. Each member starts with a header record formatted as follows:

field description

char 1 a percent sign (%) indicates the start of a new member,

char 2 is 'X' if the member has been deleted, a blank if not,

char 3- 10 the string "Created "

char 11- 18 day (dd/mm/yy) on which the member was written,

char 19- 22 the string " at "

char 23- 30 time (hh.mm.ss) at which the member was written,

char 31 is blank,

char 32- 39 member name,

char 40 is blank,

char 41- 48 type of this block (cell, gas, x(t)-plot, output, signal, track ...),

char 49 is blank,

char 50 - 80 remark (char 51-79) surrounded by double quotes.

New members are appended, they don't replace existing members even if the name is already in use.

2.3.2 File naming conventions and input file format

2.3.2.1 On Unix systems

Files created with the editor can be read without difficulty. The usual Unix file names can be used to reference the files:

```
write //heavenly/food/lasagne
< \odie
< ../odie
```

2.3.2.2 On the Cray

Adhere to the UNICOS conventions. Unix file names rarely contain special characters, but case matters. Be sure you use double quotes to avoid conversion to upper case, if this is not desired. Examples:

```
$ fetch cell.data -t'fn=CELL,ft=DATA,vaddr=192,pw=xxx'
get "cell.data"
write-track dataset "../chamber/lib" track1 remark "(-1,1) to (1,1)"
get ../gas
```

The first 2 lines show how to pick up a Garfield library from VM and read one of its members. In the last example the file GAS is read, not the file gas.

2.3.2.3 On Vax computers

Input datasets can be in any common format created by the editor, as Fortran output, with CREATE etc. Vax-dataset names often contain separators like colons, double quotes and blanks and then quotes have to surround the file name. Examples of legal Vax file references are the following:

```
> out.dat
write dataset 'vaxgarf"garfield lasagne"::[drink]lots_of.coffee'
get "disk$animal:[dogs]odie"
```

The quotes have been omitted in the first example because there are no separators. Single quotes must be used in the second example because double quotes are compulsory for the remote login string. The third example might have either kind of quote but quotes are required because of the colon separating the disk from the directory.

You may read and write Garfield libraries over Decnet; note however that libraries residing on VM/CMS at CERN should not be accessed from a Vax, even though CERNVM looks like a Vax. The reason for this restriction is that the BACKSPACE operation is not permitted over the Vax/CERNVM link. CERNVM files can be read via <.

You may choose yourself defaults for any part of the file names by means of the %DEFAULT statement, .DAT as extension is the initial default. In addition, wildcard characters (* and %) may occur in the file name provided only one file matches.

2.3.2.4 Under VM CMS

Prior to version 2.07, input files had to be fixed record format files with a record length of 80 characters. At present variable record format input files are also accepted; the records should not be longer than 500 characters. Datasets are referred to by their true name; since VM/CMS dataset names contain embedded blanks, the entire dataset name has to be delimited by (preferably single) quotes. Alternatively, you may omit the quotes and put dots between the file-name, the file-type and the file-mode. You may put additional blanks around the dots, if you wish. Garfield translates dataset names to upper case, even if surrounded by double quotes, since mixed case dataset names are impossible to handle with most VM utilities.

Defaults for the various components of the dataset name can be set with the %DEFAULTS dataset command.

Wildcards can be used for dataset names; * stands for any number of arbitrary characters, % stands for a single arbitrary character. See the description of %DEFAULTS for further details on wildcards. Both in the case of read and in the case of write access, several datasets are allowed to match the wildcard; the first dataset as listed by LISTFILE will be accessed. Libraries that are not fixed record format or have a record length less than 133 are not considered. Input files must also have fixed record format and a logical record length of at least 80, a restriction that is lifted in version 2.07 as noted before. If no dataset matches your specification in case of write access, the specification may not contain wildcard characters and must point to a disk to which you have write access. If no dataset matches your specification in case of read access, an error message is printed and of course no dataset will be read. Examples:

```
* Read a dataset from any accessed disk
< 'CELL DATA'

* Link to and access the disk of user ODIE with mode letter F
$ EXEC GIME ODIE F

* Read a dataset from his (her ?) disk
< 'GAS DESCRIPT F'
* which is equivalent to:
< gas.descript.f

* set a default dataset name, specifying only the file type
%def .output
* write to dataset JON OUTPUT D
> JON..D
```

Note the link and access at run-time using the dollar sign to pass the GIME command to CMS. The practice of issuing a GIME while running, is advisable although the program checks whether the disk from which the file is to be read, has been modified since it was last accessed and will automatically re-access the disk if needed.

2.4 Error messages

2.4.1 Garfield messages

Garfield messages are printed in one of 4 formats. Errors and warnings go as a rule to the terminal, even if output rerouting is switched on. Debugging output usually follows the normal output rules. Graphics related error messages and warnings are written to the GKS error logging file.

```
###### < routine > ERROR   : < explanation > ; < action taken >.
!!!!!! < routine > WARNING : < explanation > ; < action taken >.
------ < routine > MESSAGE : < information >.
++++++ < routine > DEBUG   : < information >.
```

Error messages warn the user if an error is found in the input, if array dimensions are too small and also in some cases if the program notices it made an error. A warning is printed if the error can be corrected by the routine that issues it. Messages inform the user that something has happened that is considered normal but worth noting. Debugging output appears in response to the DEBUG option and the debugging instructions.

The CMS version of Garfield has some jobs, like accessing files, done by REXX exec files. These exec files are written to disk from within the program, executed and then erased. Errors, warnings and messages issued by such exec files have the usual format, except that EXECERR is substituted for ERROR, EXECWRN for WARNING and EXECMSG for MESSAGE.

You'll find that the program occasionally produces warnings of the type:

```
!!!!!! < routine > WARNING : < text > ; increase MX< name >.
```

They are printed if the amount of storage space allocated to the program at compilation time is not sufficient to satisfy your request. Increase the appropriate dimension parameter in +KEEP sequence DIMENSIONS in patch COMMONS and recompile the program, if you are sure that more storage space is needed. Further details are to be found in Section 5.2 on page 124.

If the program detects inconsistencies and if a subroutine receives illegal arguments, a message is printed which contains the phrase:

```
Program bug, please report.
```

It the, rather unlikely, event you get one of these, even as a result of a clear input error, please send the following to RJD@CERNVM: (i) a copy of the complete input, (ii) the relevant parts of the output, and (iii) a description of the program version, of local modifications and of the computer being used.

2.4.2 GKS error messages

GKS errors are written to a file called GKSERROR.LOG, GKS_ERROR, GKSERROR LOG A or something similar. You may need a GKS manual to understand them, unless it is a common error and an interpretation is offered by the programs own GKS error handling subroutine (GERHND). If you use the NAG routines for plotting contours, you may also get error messages from them; they are printed like Garfield warnings.

Graphics under interactive CMS is very delicate, refer to Section 2.1.3 on page 4 for precautions you're supposed to take as a user.

With the exception of NAG errors and GKS errors marked 'please ignore', no graphics related error message should be output. Please follow the procedure outlined in the preceding paragraph if you get a graphics error of another type.

2.4.3 Fortran run-time error messages

2.4.3.1 Overflow, underflow

The program tries to avoid overflow by moving to a different algorithm. The protection mechanism for the field-calculation routines is known to fail in a small range of the ratio of the periodicities of doubly periodic cells on computers which have a small floating point range. This cannot be avoided without degrading the accuracy. Still, please contact me whenever you get an overflow related message.

In contrast, virtually no attempt is made to protect against underflow where such a protection is useless and all computer outcry about it can safely be ignored. Underflow messages are suppressed in the CERN load modules meant for general use.

2.4.3.2 Other messages

In the CERN load modules used for debugging purposes, printing of almost any message not generated by Garfield or by library routines, is enabled. Most of them are merely informatory and should be ignored. Please contact me whenever you get one that looks serious.

3. 0 Programi nput

The main subject of this chapter is a description of the instructions Garfield understands. The first paragraphs deal with the syntax conventions and the physical units the program expects you to use. The bulk of this chapter contains descriptions of the commands for each of the program's sections. The last paragraphs contain information about commands that are understood regardless of where you are in the program. You may skip that part on a first reading.

3. 1 Input format

Here is an example of a valid input file:

```
& CELL
opt cell-pr
write 'cell data' 2-wire "Simple demonstration cell"
plane x=-1
plane x=1, v=1000
rows
S * * 0   0   2000
P * * 0.5 0.5 2000

* Note that the preceding line is blank !
cell-id "S at 2000 V, P at 2000 V"

& FIELD
%dir 'cell data'
area -0.9 -0.5 0.9 1.0
opt key
plot surface arctan(ey/ex) angles 30 70, cont v

& DRIFT
area * -1 * 1.5
lines
drift wire nol-pr contour 0.2
tr -0.5 0 0.7 1.5
drift track contour 0.1
xt

& STOP
```

The input to the program is made up of **sections**. The sections begin with an **header**, prefixed by an ampersand '&'. The ampersand also marks the end of the preceding section. The header roughly indicates the kind of instruction to be expected, e.g. field plotting or printing if the header line is '& FIELD'. Blanks and other separators, see below, may be inserted between the ampersand and the header.

The order of the sections is of some importance: the cell and the gas section should appear before the sections using their data. Sections needing a gas will use CO_2 if you did not specify a gas yourself. Sections needing a cell are skipped if the cell is missing.

All sections may be repeated any number of times.

The sections consist of **instructions** e.g. requesting a plot or changing some parameters. The first word of each instruction line is the actual command, all the rest are arguments. Some of the arguments are **keywords** followed by a value or a series of values; this structure is sometimes nested. See for instance the PLOT statement, "plot" is the command, "surface" and "cont" are the keywords at this level. The keyword "surface" is followed by the value "arctan(ey/ex)" and the keyword "angles" that has values of its own: "30" and "70". The keyword "cont" has only one value following it, "v".

The listing of the rows of wires and of some gas data follow slightly different rules in that the instruction is followed by a series of lines containing the actual data. The end of such a block of data is signalled by a blank line.

Instructions that are normally used to set parameters, display the **current value** of the parameters if they are entered without arguments. See for instance the use of LINES in the example above. Other instructions commonly used in this way are OPTIONS, AREA and TRACK.

In the command descriptions, square brackets [ ] are used to indicate optional arguments, curly brackets { } mean that one of the enclosed items separated by bars | has to be present. The lower-case words represent data that must be supplied by the user. The words printed in upper-case are the commands and parameters. They must be entered as shown but may usually be **abbreviated** to some extent. Words that consists of several segments separated by a minus sign (-), like CELL-PRINT, may be abbreviated in each segment: e.g. C-PR, CELL-PR and C-PRINT are all equivalent. The minimal abbreviation is not shown in this manual and has to be found by inspection of the program source or by trial and error. As a general rule an abbreviation is accepted up to the point where it becomes ambiguous or could be confused with the context.

A statement can be spread over several lines, provided each line but the last ends on an ellipsis (...). Nothing is inserted between what is before the ... and the start of the next line; initial blanks on the **continuation lines** are respected. There is no limit on the number of continuation lines by itself but the total length of the line may not exceed some number of characters (at present set to 500). Also the maximum length of any one keyword is limited (at present 80).

All input is free format. The blank, the comma, the equal sign and the colon act as **separators**, you may use them in any way you like (e.g. PLANE=X=2 and PLANE X 2 and PLANE: X=2 etc. are equivalent). If a separator has to be taken literally, for instance in the cell identification or in a logical comparison, enclose the whole string by **quotes**.

Character input may be in upper, lower or mixed case but will be translated to upper-case, unless enclosed by double quotes. Commands and parameters should not be between double quotes. Strings between either single or double quotes are considered to be one input word. Quotes of one kind may be used inside a string enclosed by quotes of the other kind. For instance, Vax dataset names which contain a login string must be delimited by single quotes. Two consecutive quotes are taken to be the end and the beginning of two separate words; doubling quotes will therefore not lead to a quote inside a quoted string as is the case in Fortran.

Numeric input is only Fortran-read after the syntax has been checked in detail. There is no need to type the decimal dot when reals are expected but you will find that a warning message is issued for missing dots if a true error was found on the same line. **Default values** are indicated by a '*'.

The parameters are preset to the value indicated or, in case a choice has to be made between several alternatives (e.g. EDGE/WIRE/TRACK/ZERO), to the first that is mentioned (EDGE). Some of the parameters are remembered even after leaving a section. E.g. WIRE will become the default after the first DRIFT WIRE instruction.

Like the sections, the instructions may be repeated any number of times in a single section.

The program will not ask any questions nor will it carry out any calculation unless you ask for it, either explicitly or implicitly (by making something default).

3.2 Control structures

Garfield allows various simple control structures like IF-lines, IF-blocks and DO-loops. This is a new feature and users are encouraged to send comments on this to the author. The expressions that control them are written in terms of global variables, some of which are pre-defined.

3.2.1 Global variables

Global variables are mainly used to check IF conditions and to control the flow of a DO loop. Loop variables (see below) are automatically declared global. Global variables can also be used outside this context.

Some global variables are pre-defined, they are updated by the program if needed; their values can not be changed by the user. More such variables can be added if you wish (contact the author).

TIME_LEFT The amount of CPU time left in seconds.

MACHINE Is set to the type of computer for which the program has been compiled, e.g. CMS, Vax, DecStation etc.

INTERACT Is TRUE if you're using the program in interactive mode, and FALSE in batch.

BATCH Is TRUE if you run Garfield in batch, and FALSE when running interactively.

To declare or modify a global variable *var*, issue the command:

```
GLOBAL variable value
```

where *value* is an expression in terms of global variables, including *variable* if already defined. Curly brackets are not needed. All global variables and their values are listed if the GLOBAL command is entered without arguments.

The value of an expression in terms of global variables is substituted in any regular input statement if the expression is enclosed by curly brackets. The substitution is carried out before the statement is looked at by the section or sub-section you are currently in, but after the line has been split in words. Substitution should not be attempted in the control parts of IF-lines, IF-blocks and DO-loops; this may work but the result could well be different from what you expect, besides it's more efficient to use the variable itself. Example:

```
Global fac 1
For i From 1 To 50 Do
   Global fac fac*i
   Say "Factorial of {i} is {fac}, Time left is {time_left} sec."
Enddo
```

All global variables must be in upper case, they must start with an alphabetic characters and may not contain algebraic operators, blanks or separators.

3.2.2 IF-blocks and IF-lines

Statements can conditionally be executed as in Fortran. In the case of an IF-line, the *statement* is carried out if *cond* is satisfied:

```
IF cond THEN statement
```

The *statement* of an IF-line may not itself be an IF-line. IF-blocks consist of a series of branches, at most one of which is carried out:

```
IF cond THEN
     statement
     (repeated)

[ ELSEIF cond THEN
     statement
     (repeated)    ]

(several ELSEIF branches if needed)

[ ELSE
     statement
     (repeated)    ]

ENDIF
```

IF-blocks may be nested up to a compilation-time determined limit. They may also be mixed with DO loops as explained below.

3.2.3 DO loops

The syntax of loops is shown below:

```
[WHILE while_cond] [UNTIL until_cond] ...
      [FOR var FROM from [STEP step] TO to] DO

statement | LEAVE [var] | ITERATE [var]

ENDDO
```

Each loop may or may not have a loop variable *var* associated with it. If you specify one, you must also indicate the initial value and the final value, the step size defaults to 1. All of these are expressions in terms of global variables and loop variables, treated like other global variables. The expressions are reevaluated at each iteration and the values of all variables involved, including the loop variable, may be modified in the loop. The step size is allowed to be negative.

The WHILE condition is evaluated at the start of each pass through the loop, after the loop variable, if present, has been incremented. The loop is left as soon as the condition is no longer satisfied.

The UNTIL condition is evaluated at the end of each pass after the loop variable, if present, has been incremented for the next pass. The loop is not executed again is the condition is satisfied.

The loop identified by the loop variable, by default the inner most loop, is left as a result of LEAVE. Execution is resumed at the first line after the ENDDO.

The ITERATE statement will bypass the remainder of the loop identified by the loop variable, by default the inner-most loop. The WHILE, UNTIL and TO conditions are checked before a new iteration starts.

Loops may be nested, may be part of a branch of an IF block and may contain complete IF blocks. The DO, ITERATE and LEAVE lines are allowed to be conditional, the entire loop is skipped if the condition on the DO line fails.

Before a loop is executed, the entire loop is read from input and stored in the string buffer, all formulae (except those in in curly brackets) are translated and the syntax is checked as much as it will be checked. Nearly all error messages are therefore output *before* any instruction has actually been processed.

3.2.4 Procedure calls

Some of the service routines, e.g. those used for histogramming, can be accessed via CALL. The format of the CALL statement is:

```
CALL procedure(arg_1, arg_2, ... arg_n)
```

Where *arg_i* are expressions in terms of global variables. Some procedures modify the value of the global variable, for instance BOOK_HISTOGRAM and GET_HISTOGRAM return a reference to the histogram that is booked. If the variable receiving the value is not yet declared, then it is made into an unitialised global variable.

The following procedures are currently accessible:

```
CALL PRINT(any number of arguments)

CALL BOOK_HISTOGRAM(reference, number of bins, min, max[, autoscaling])
CALL FILL_HISTOGRAM(reference, entry[, weight])
CALL PRINT_HISTOGRAM(reference[, x-title[, title]])
CALL PLOT_HISTOGRAM(reference[, x-title[, title]])
CALL DELETE_HISTOGRAM(reference)
CALL WRITE_HISTOGRAM(reference, file[, member[, remark]])
CALL GET_HISTOGRAM(reference, file[, member])
CALL LIST_HISTOGRAMS

CALL GET_CELL_DATA(number of wires, cell type, coordinates, identifier)
CALL GET_CELL_SIZE(xmin, ymin, zmin, xmax, ymax, zmax)
CALL GET_WIRE_DATA(iw, x_iw, y_iw, V_iw, d_iw, q_iw, code_iw)
CALL GET_PLANE_DATA(yn_1, x_1, V_1, yn_2, x_2, V_2,
                    yn_3, y_3, V_3, yn_4, y_4, V_4)
CALL GET_PERIODICITY_DATA(yn_x, s_x, yn_y, s_y)

CALL ELECTRIC_FIELD(x, y, ex, ey, ex, e, v, status)

CALL PLOT_FRAME(xmin, ymin, xmax, ymax, x_label, y_label, title)
CALL PLOT_MARKER(x, y [, marker_type])
CALL PLOT_LINE(x1, y1, x2, y2 [, line_type])
CALL PLOT_TEXT(x1, y1, string
               [, text_type [, alignment [, orientation]]])
CALL PLOT_END( [description] )
```

The *yn* variables in the cell-related calls are logicals that are set to TRUE if the plane or periodicity is present and to FALSE otherwise. The parameters returned by GET_WIRE_DATA are respectively the wire position, the potential, the diameter, the charge and the label. The *cell_type* is the 3-letter cell classification code which is explained Section 4.1.2 on page 92, *coordinates* is a string variable that is set to either **Polar**, **Tube** or **Cartesian**, *identifier* is the label given to the cell via the CELL-IDENTIFIER command.

The *status* return parameter of ELECTRIC_FIELD is set to one of the values **Normal**, **Outside_Plane** or **In_X_Wire** where **X** is the wire label.

The last parameter of PLOT_MARKER and PLOT_LINE are optional and can be used to select a marker and line type, e.g. "CIRCLE" or "DASH-DOTTED" (upper case strings). The last 3 parameters of PLOT_TEXT are also optional. They can be used to request a text type (e.g. "GREEK", default is "ROMAN"), the text alignment (e.g. "CENTER,HALF", default is "LEFT,BOTTOM") and the orientation (in degrees, default is 90^0). Further information on the line, marker and text type can be found in Section 3.12.10 on page 79 (! REPRESENTATION instruction). The optional argument of PLOT_END will be shown in the list of plots displayed at the end of the run.

Other procedures can be added on request.

3.3 Physical units

The physical units used by the program for input and output are listed in table Table 1 on page 20.

Table 1. Physical units. Overview of physical units as used in Garfield		
quantity	**unit**	**symbol**
distances	centimeter	[cm]
angles	degrees	[deg]
times	micro second	[μsec]
currents	micro ampere	[μA]
voltages	volt	[V]
pressures	torr	[torr]
energies	electron volt	[eV]
magnetic field		[Vμsec/cm^2]
Note: Note the unusual unit for magnetic fields ! Internally, charges per unit length are expressed in multiples of $1/2\pi\varepsilon_0$ and angles in radians. The built-in trigonometric functions also work in radians.		

3.4 The cell section

This section provides a cell in which other sections can perform their calculations. Numerous checks are made on the input to ensure that they can operate successfully - in some cases the cell is modified. Type & CELL to enter this section.

Cells may either be listed in polar or in Cartesian coordinates, mixed coordinates are not permitted. The type of coordinate system is deduced from the format of the ROWS, PERIOD and PLANE statements. The default is Cartesian coordinates.

During the execution of this section the program merely stores information. This implies that the statements can be entered in an arbitrary order, with the obvious exception of DEFINE which has to appear ahead of ROWS. Only when leaving this section (which is equivalent to either entering another section or stopping the program via & STOP - not via an EOF), are the charges calculated, is the cell listing printed, is the layout plotted and is a dataset written.

CELL-IDENTIFIER

Format:

```
CELL-IDENTIFIER  cellid
```

The string *cellid* is used as an identifier of the cell in plots when relevant.

DEFINE

Format:

```
DEFINE  name  [value]
```

Defines a symbolic variable to be used in the listing of the rows. This instruction is most useful if you vary the potential and/or position of a group of wires within constraints to find an optimum setting; see example 2 below. The DEFINE statements should appear before the wire listing.

The variables controlled by the DEFINE instruction are of a different nature than the global variables, see Section 3.2.1 on page 17. Global variables can be used anywhere, but their substitution has to be requested explicitly. The cell variables are automatically evaluated but can only be used in a limited context. Suppose you have a global variable GLOBAL and a cell variable VOLT. In the ROWS listing, you should type {GLOBAL}*VOLT to obtain the product of the two.

name The name you wish to give to your variable. It may be up to 10 characters long and it should start with a letter, the rest of the name should be such that it can be distinguished from the context. Redefinition of a variable is permitted, also in terms of itself.

The variable "I" is reserved; see the ROWS instruction for details.

value The value assigned to the variable. It may be an expression in terms of previously defined variables. Remember that there should be no blanks in the formulae, unless you enclose them by quotes. The current value of *var* will be displayed if *value* is absent. All variables are shown if no argument is provided.

GET

Format:

```
GET  dataset  [member]
```

Retrieves a compact format cell description from a dataset.

Cell descriptions of this type are written by the WRITE statement. They should only be altered with great care because they contain both the user supplied data (wire position, potentials etc.) and data derived from it such as the charges, the cell-type etc. The program does not check whether they are compatible. Descriptions that are no longer readable because of a format change (Garfield prints a warning when it meets such a description) may be sent to the author for recovery.

dataset The name of the dataset in which the description can be found. Refer to Section 2.3.2 on page 10 for details about the file format and naming conventions.

member The member name of the description, a string of up to 8 characters. You may use a wildcard for this item: DC*1 will for instance match DC1 and DC-TST-1 but not DC-1-TST. The default is an asterisk, matching every member name. The first member in the dataset that is a cell description and matches the member name you specify, will be read. The %INDEX command can be used to find out which members have been stored in a given dataset.

OPTIONS

Format:

```
OPTIONS  [NOCELL-PRINT | CELL-PRINT]
         [NOLAYOUT | LAYOUT]
         [NOTISOMETRIC | ISOMETRIC]
         [NOWIRE-MARKERS | WIRE-MARKERS]
```

Sets a few options controlling the amount of output. The table and the plot are produced when leaving the section.

CELL-PRINT
Prints a table which contains everything the program knows about the cell.

LAYOUT
Plots the layout of the cell.

ISOMETRIC
The layout plot will not be distorted if this option is active.

WIRE-MARKERS
Wires are by default plotted circles with the size of the wire. You may prefer to have them represented by markers of different kinds. This can be achieved by choosing the WIRE-MARKERS option. The markers can be chosen via the !REPRESENT graphics command.

When the WIRE-MARKERS option is on, the wires are not labeled by their code letter in the LAYOUT plot.

Technical note: wires are by default plotted as hollow fill-area objects so that they can be pointed at in some commands like GRAPHICS-INPUT in the drift section. With the WIRE-MARKERS option on, they are plotted as polymarkers.

PERIOD

Format:

```
PERIOD   {X|Y|PHI}   length
```

Indicates that the cell should be periodic in x, y or ϕ, use two of these statements for doubly periodic cells.

X|Y|PHI The direction in which the cell should be periodic. Note that radial symmetry is not allowed.

length The distance after which the cell should repeat itself [in cm or ^{0}, no default is supplied].

PLANE

Format:

```
PLANE  {X|Y|R|PHI} coordinate   [VOLTAGE potential]
```

Enters an equipotential plane. The planes may be at constant x, y or ϕ, but circular planes at constant r are also allowed. One may not place a wire at the center of a circular plane, see the TUBE statement for an alternative.

X|Y|R|PHI
Should be obvious.

coordinate
The location of the plane, in cm if the plane is at constant x, y or r and in degrees if the plane is at a constant angle to the x-axis [default is 0, which is not acceptable for circular planes].

potential
The voltage of the plane [default: 0 V i.e. a grounded plane].

RESET

Format:

```
RESET  [COORDINATES]
       [DEFINITIONS]
       [DIELECTRICA]
       [PERIODICITIES]
       [PLANE]
       [ROWS or WIRES]
```

(Only in interactive mode) resets selectively the cell data entered so far. All data are erased if the arguments are omitted. The COORDINATES keyword is used to change from polar to Cartesian coordinates or vice versa.

ROWS

Format:

```
ROWS      [CARTESIAN | POLAR]
code   n   diameter   x_start   y_start   [V_start   [dx   [dy   [dV]]]]
code   n   diameter   x_start   y_start   [V_start   [dx   [dy   [dV]]]]
⋮
(blank line)
```

The lines following the ROWS statement should be a listing of the wire rows. A row is a set of regularly spaced wires; examples are a series of equidistant wires, a spiral a parabola etc. A blank line signals the end of the list.

The cell is by default assumed to be entered in Cartesian coordinates; specifying *POLAR* overrides this choice. Alternatively, you may first enter a plane or a periodicity, the format of which fixes the coordinate system. All elements of the cell (wires, planes and periodicities) must be entered in the same coordinate system.

A wire may not be positioned at the origin if polar coordinates are being used. This case can be added to the program if there is sufficient interest.

Make sure that all the wires are on one and the same side of the equipotential planes, if they are present in your chamber. The program counts the number of wires on either side of each plane and removes those that form the minority. The wires are moved into the basic cell (coordinate ranging from -s/2 to s/2, where s is the period) if the cell is periodic. This should not affect the validity of the results but it is worth noting since the copy of the wire in the basic cell plays a privileged role.

code One-letter code (all upper-case letters are acceptable) for the type of the wires. The 'S' wires are initially considered to be sense wires, i.e. the wires for which signals and x(t)-relations are calculated, from which drift-lines start in certain plots etc. You may at any time select a different set of sense wires. Convenient codes can be very useful, choose them carefully ! You may, if you wish, label the wires with more than one character but only the first will be remembered.

n Number of wires in the row [default is 1].

diameter The diameter (and not the radius !) of all the wires in the row [default: 0.010 cm]. If the diameter varies within the row, you may resort to using the loop-variable described below.

x_start x- or r-coordinate of the first wire in the row [in cm].

y_start y- or ϕ-coordinate of the first wire in the row [in cm or degrees].

V_start Voltage of the first wire in the row [default: 0.0 V].

dx Increment of the x- or r-coordinate [default: 0.0 cm]. The loop-variable described below offers considerably greater flexibility than increments.

dy Increment of the y- or ϕ-coordinate [default: 0.0 cm or ^{0}]. The loop-variable described below offers considerably greater flexibility than increments.

dV Increment of the voltage [default: 0.0 V]. The loop-variable described below offers considerably greater flexibility than increments.

n, *diameter*, *x_start*, *y_start*, *V_start*, *dx*, *dy* and *dv* are allowed to be expressions in terms of symbo parameters defined by DEFINE earlier on in the same section.

In addition to the variables *you* define via DEFINE, there is one variable the *program* defines for you: the loop-variable. This variable, called I, takes on the values 0 for the first wire in the row, 1 for the second ... and *n*-1 for the last. A typical use of this would be the construction of electrodes such as parabolas and ellipses (see the third example below). The approximation for these electrodes is very similar to that obtained with finite element methods but with the advantage that the sense wires are handled accurately. The loop-variable may only be used in *d*, *x_start*, *y_start* and *V_start*. When you use the loop-variable, you may still provide increments but they should not depend on I. Clearly, the loop-variable renders the increments obsolete: substitute *x_start + I*dx* for *x_start* and drop *dx* (and similarly for y and V). Refer to Section 4.5 on page 116 for details about the formulae.

TUBE

Format:

```
TUBE   RADIUS r   [VOLTAGE v]   [EDGES n]
```

Defines a tube surrounding the wires. The tube is by default circular, but can also be triangular, square, hexagonal etc. A tube is in many respects like a circular plane, with the following exceptions however:

- the coordinate system used for input and output is Cartesian, not polar;
- one is allowed to put a wire at the center of a tube, which is not allowed for circular planes;
- one can only have one tube per cell.

A tube can be combined with a ϕ-periodicity, but not with periodicities in x or y, nor with planes.

r The radius of the tube, for non-circular tubes *r* is the distance between the center and one of the corners.

v The potential at which the tube is placed.

[By default 0 V.]

n The number of corners of the tube. Instead of *EDGES=3* one can also type TRIANGLE, and similarly for SQUARE, PENTAGON, HEXAGON, HEPTAGON and OCTAGON. To obtain a cylindrical tube, one can specify CIRCLE, CYLINDER or *EDGES=0* .

[By default, the tube is cylindrical.]

WRITE

Format:

```
WRITE  DATASET dataset  [member]  [REMARK remark]
```

Writes, while leaving the cell section, all available cell data on a dataset. This instruction, which may appear anywhere in the cell section, can be very efficient if recalculating the wire charges takes a lot of time. Otherwise the < instruction is probably more flexible. The dataset may exist prior to program execution, in which case the data will be appended and a member name may be required to retrieve the data. The DATASET and REMARK keywords may be omitted, provided the order of the arguments is respected: e.g. *member* has to be specified if you wish to have a *remark*.

dataset The dataset you would like to write the description on. Refer to Section 2.3.2 on page 10 for details about the file format and naming conventions.

member An 8 character code, to be used when more than one cell description is stored in the dataset. All characters are permitted, case is only preserved if the member name is enclosed by double quotes.

remark An optional remark which could help in recognising the data.

Z-RANGE

Format:

```
Z-RANGE zmin zmax
```

Establishes the z-dimensions of the cell. This information is used as default z-component of the AREA in the drift section. Use of this statement is optional ans is only meaningful if you have a magnetic field.

Example 1, a simple valid cell section:

```
& CELL
OPTIONS  CELL-PRINT LAYOUT
WRITE    "garfield/cells/DC1"
ROWS
S 5 * 0.0 0.0 0.0 0.4

PLANE  X=-2,  V=-7000
PLANE  X=+2,  V=-7000
```

This cell (Cartesian coordinates are used) has 5 sense wires (they are all at 0 V, have a diameter of 100 µm and are on the y-axis spaced by 4 mm), 2 equipotential planes (one at x = −2 cm and one at x = +2 cm, both at −7000 V) and the cell is not periodic. A layout plot will be made, a description of the cell will be printed and the cell description will be written to the external dataset garfield/cells/DC1 (Unix file naming).

Example 2, demonstrating the use of DEFINE:

```
& CELL
define V_high -5000
define V_low  -2000
DEF VSENSE    0
ROWS
S 4 *  0 0 VSENSE 0 1
P 2 * -1 0 V_high 2
P 2 * -1 1 V_low+(V_high-V_low)/3 2
P 2 * -1 2 V_low+(V_high-V_low)/5 2
P 2 * -1 3 V_low 2

WRITE dataset 'CELL LIB' RESISTOR ...
      remark "Vhigh=-5000 V, Vlow=-2000 V"
```

The potentials of the P wires are derived from a resistor chain in this example. All potentials on the P wires are automatically corrected when *V_low* and *V_high* are changed. The description of the cell is written to the CMS dataset CELL LIB on the A disk of the user running the program. Note the use of single and double quotes in the WRITE statement, CMS requires that dataset names are in upper-case and hence single quotes are used for the dataset. The double quotes around the remark prevent the conversion to upper-case of the string. Example 3, the loop-variable:

```
& CELL
cell-id "Circle"
define n_wire 50
rows
p n_wire * cos(2*pi*i/n_wire) sin(2*pi*i/n_wire) -1000
s *      * 0                  0                  +5000
```

Or how to make a circle ... if you like spirals, try the next one:

```
& CELL
cell-id "Spiral"
define n 50
rows
p n * (1+i/20)*cos(3*pi*i/n) (1+i/20)*sin(3*pi*i/n) -1000
s * * 0                      0                      +5000
```

3.5 The magnetic field section

This program does not allow for complicated magnetic field patterns, unless a routine (called BFIELD, see Section 6.3 on page 129) is replaced. Simple linear magnetic fields may however be entered from the input and the distortion due to the wires will be taken into account if requested. The influence of the B-field on the behaviour of the electrons and ions is described in Section 4.3 on page 110.

WARNING: The calculated Lorentz angle may differ considerably from the experime high B. Apparently no simple formula matches the data for all B and ad hoc cor introduced in routine DLCVEL.

The header line for this section is & MAGNETIC and the following are valid instructions:

COMPONENTS

Format:

```
COMPONENTS  [bx by bz]  [GAUSS | TESLA]
```

Sets the components of the magnetic field.

bx by bz are the 3 components of the magnetic field. [default: 0 G for all three components, i.e. switching the field off; see below for the units.]

GAUSS Use this when the field is entered in Gauss, internal units of 100 Gauss are assumed if no unit is given.

TESLA Use this when the field is entered in Tesla, internal units of 0.01 Tesla are assumed if no unit is given.

OPTIONS

No specific options for this section.

SUSCEPTIBILITY

Format:

```
SUSCEPTIBILITY   [wires   gas]
```

May be used to set the magnetic susceptibilities of the wires and the gas [any unit: only the ratio matters, defaults are 1 and 0 which gives an α of 1, probably the only value of α you will ever need; see also Section 4.1.11 on page 105].

Example:

```
& MAGNETIC
components 0 0 3 Gauss
```

3.6 The gas section

The purpose of the gas section is to enter a description of the gas that you wish to have in your chamber. There are several ways to enter the gas description:

- For some built-in gasses and gas mixtures it is enough to type the name of the gas. This is for instance the case for Argon-Ethane 50/50.
- You can also ask the program to compute the drift velocity and diffusion for mixtures of gasses, using built-in tables of the elastic cross section and the fraction of the energy lost by electrons during collisions with the gas. See Section 3.6.1 for details.
- In case you measured e.g. the drift velocity, you may prefer to enter your experimental data directly. This can be done via the TABLE instruction described below. Details on this can be found in Section 3.6.2 on page 30.

The header line to enter this section is & GAS.

All data, whatever their origin, should apply to the zero magnetic field situation.

3.6.1 Built-in gasses

The following 2 lines are sufficient to use CO_2.

```
& GAS
CO2
```

Similar instructions exist for the other built-in pure gasses and commonly used gas mixtures:

ARGON-20-ETHANE-80
Loads a mixture of 20 % argon and 80 % ethane.

ARGON-50-ETHANE-50
Loads a mixture of 50 % argon and 50 % ethane.

ARGON-80-ETHANE-20
Loads a mixture of 80 % argon and 20 % ethane.

ARGON-73-METHAN-20-PROPANOL-7
Loads a mixture of 73 % argon, 20 % methane with 7 % propanol.

CO2
Loads pure CO_2.

CO2-80-ETHANE-20
Loads a mixture of 80 % CO_2 and 20 % ethane.

CO2-90-ETHANE-10
Loads a mixture of 90 % CO_2 and 10 % ethane.

CO2-90-ISOBUTANE-10
Loads a mixture of 90 % CO_2 and 10 % isobutane.

ETHANE
Loads pure ethane.

ISOBUTANE
Loads pure isobutane.

METHANE
Loads pure methane.

The origin of the data is quoted in the program listing, the quality is not guaranteed by the author of Garfield. The options GAS-PLOT and GAS-PRINT may be used to verify that the data are adequate.

MIX
Format:

```
MIX [ ARGON  frac ]          [ HELIUM  frac ]
    [ METHANE  frac ]        [ ETHANE  frac ]
    [ NEON  frac ]           [ NITROGEN  frac ]
    [ ISOBUTANE  frac ]      [ XENON  frac ]
    [ CO2  frac ]            [ METHYLAL  frac ]
    [ KRYPTON frac ]         [ AMMONIA  frac ]

    [ MINIMUM-ENERGY emin ]
    [ MAXIMUM-ENERGY emax ]
    [ STEPSIZE-ENERGY estep ]

    [ CRITICAL-F0-FRACTION frcrit ]

    [ RANGE epmin epmax ]    [ N n ]
    [ LINEAR-E/P-SCALE | LOGARITHMIC-E/P-SCALE ]

    [ PLOT-F0 | NOPLOT-F0 ]
    [ PLOT-ENERGY-LOSS | NOPLOT-ENERGY-LOSS ]
    [ PLOT-CROSS-SECTION | NOPLOT-CROSS-SECTION ]
    [ PLOT-PATH | NOPLOT-PATH ]

    [ PRINT-TABLES | NOPRINT-TABLES ]
```

Garfield computes the drift velocity and diffusion coefficient of gas mixtures following the treatment by G. Schultz and J.Gresser [2], using cross section and energy loss data provided by Fabio Sauli and Anna Peisert [3], from the paper cited above and from WIRCHA [4]. Although reasonably accurate for low E/p, the absence of a treatment of ionisation makes the results unuseable for large E/p. The program issues a warning if ionisation is likely to affect the results. One should note also that several other programs exist that do similar calculations, e.g. WIRCHA [4].

frac

The fraction of the mixture taken up by the gas. The fractions do not necessarily have to add up to 1.

[Each fraction is 0 by default.]

emin

The lowest point of the electron energy range in the cross section, energy loss, mean free path and F_0 plots.

The value of this parameter has no impact on the drift velocity and diffusion calculations.

[By default 0.01 eV.]

emax

The largest electron energy which is considered during the computations of F_0, the drift velocity and the diffusion. This is also the largest electron energy shown in the cross section, energy loss, mean free path and F_0 plots.

This parameter should be chosen sufficiently large. Results may be inaccurate results and the effect of ionisation may go undetected if this parameter is too small. The only negative result of choosing this parameter too large is an increased CPU time consumption.

[By default 25 eV.]

estep

The largest step size allowed during integration. One should keep in mind that integration in each step is done using a 6-point Gauss technique and that the steps never bridge a change-over between two parametrisations.

[By default 0.5 eV.]

frcrit

Garfield checks for each point of E/p that not more than a fraction *frcrit* of F_0 exceeds the lowest ionisation level of any of the gas components.

[By default 0.01, i.e. 1 %.]

epmin, epmax
The range of E/p.

[By default 0.5 to 50.]

n
Number of points in the drift velocity and diffusion tables.

[By default 20.]

LOGY LINEAR scale
Selects whether the spacing of the E/p points should be linear or logarithmical.

[Logarithmic by default.]

PLOT-F0
Requests a plot of F_0 for each value of E/p. This plot is useful when you wish to see which electron energies play a role.

[This plot is made by default.]

PLOT-ENERGY-LOSS
Requests a plot of the fraction of energy lost by an electron during collisions with the gas molecules / atoms.

[This plot is by default not made.]

PLOT-CROSS-SECTION
Requests a plot of the elastic electron scattering cross section.

[This plot is made by default.]

PLOT-PATH
Requests a plot of the mean free path of electrons in the gas.

[This plot is by default not made.]

PRINT-TABLES
Requests that the information contained in the 3 kinds of plots described before (energy loss, cross section, mean free path) be printed.

[This table is by default not printed.]

Instructions like EXTRAPOLATION, INTERPOLATION, PRESSURE and OPTION can be used to change various default settings. Replacing other data is in principle permitted, but the effect should be checked.

3.6.2 Entering a description of the gas

Using your own gas is potentially complicated because of the rather detailed information about the gas the program requires for some computations. You do not have to enter data you are not going to use and a message will be printed if something extra is needed. The following table states which elements of the gas description are required for some common tasks:

Table 2. Use of gas data. The table shows for some common tasks which elements of the gas description are required.

task	v_e	μ_{ion}	$\sigma_{diffusion}$	$\alpha_{Townsend}$	β_{att}	cluster data
field calculations	no	no	no	no	no	no
drifting electrons	yes	no	optional	optional	no	no
drifting ions	no	yes	optional	optional	no	no
x(t)-relations	yes	no	optional	no	no	no
arrival time	yes	no	yes	no	yes	yes
signals	yes	yes	optional	optional	yes	yes

Note: Users familiar with the interiors of the program may note that the columns in the table correspond with the GASOK bits.

It is often a good idea to store the gas description in a dataset to be input either via < file_name or via GET file_name.

CLUSTER

First format:

```
CLUSTER
P0, P1, ...
⋮
... Pn-1, Pn
(blank line)
```

If the primary cluster-size distribution has been measured, it is of course preferable to use it instead of the Landau approximation. The probabilities for the various cluster-sizes should be enumerated on one or more lines following this instruction. The first number is assumed to be the chance that a cluster has a size of 0 (!). The probabilities do not have to add up to 1. A blank line is interpreted as the end of the list.

Second format:

```
CLUSTER distribution [N n]
```

To be used if a parametrisation of the cluster-size distribution is known.

distribution

Should be a function of the symbolic parameter N, the cluster size. The function need not be normalised.

n

The number of data-points. The maximum cluster-size which can be generated will be n-1. [default: 20]

EXTRAPOLATIONS

Format:

```
EXTRAPOLATIONS
     [LOW-DRIFT-VELOCITY { LINEAR | CONSTANT | EXPONENTIAL } ]
     [LOW-ION-MOBILITY {...} ]
     [LOW-DIFFUSION-COEFFICIENT {...} ]
     [LOW-TOWNSEND-COEFFICIENT {...} ]
     [LOW-ATTACHMENT-COEFFICIENT {...} ]
     [HIGH-DRIFT-VELOCITY {...} ]
     [HIGH-ION-MOBILITY {...} ]
     [HIGH-DIFFUSION-COEFFICIENT {...} ]
     [HIGH-TOWNSEND-COEFFICIENT {...} ]
     [HIGH-ATTACHMENT-COEFFICIENT {...} ]
```

This instruction provides some flexibility in the way the program extrapolates to smaller and larger E/p values than those found in the table. EXTRAPOLATIONS will overrule the settings for built-in gasses and for gasses read via GET statements, provided the EXTRAPOLATIONS statement follows the command via which the gas data were obtained.

LINEAR
: A linear extrapolation based on the first and last two data-points, which should be chosen judiciously. The program warns if the extrapolation is negative beyond some E/p and the interpolation routine will return 0 from that point onwards.

EXPONENTIAL
: An exponential extrapolation taking only the first and last two data-points into consideration. They should be chosen very carefully, especially if the table does not extend to very small and large E/p (in which case this extrapolation method may prove disastrous, even though it has been protected against overflow).

CONSTANT
: The constant method sets the corresponding item to the value of the first and last data-point found in the table.

GAS-IDENTIFIER

Format:

```
GAS-IDENTIFIER gasid
```

The string *gasid* is used as an identifier for the gas. It will appear in the upper left hand corner of the plots when relevant.

GET

Format:

```
GET dataset [member]
```

Retrieves a compact format gas description from a dataset. Gas descriptions of this type are written by the WRITE statement.

They should only be altered with great care because they contain both the user-supplied data (tables and parameters) and data derived from it (interpolation coefficients, cluster-size distribution). The program does not check whether they are compatible. Descriptions that are no longer readable because of a format change (Garfield prints a warning when it meets such a description) may be sent to the author for recovery.

dataset The name of the dataset in which the description can be found. Refer to Section 2.3.2 on page 10 for details about the file format and naming conventions.

member The member name of the description, a string of up to 8 characters. You may use a wildcard for this item: AR*80 will for instance match AR20ET80 or AR80 but not AR80ET20. The default is an asterisk, matching every member name. The first member in the dataset that is a gas description and matches the member name you specify, will be read. The %INDEX command can be used to find out which members have been stored in a given dataset.

INTERPOLATION

Format:

```
INTERPOLATION
     [DRIFT-VELOCITY { SPLINES | NEWTON order } ]
     [ION-MOBILITY {...} ]
     [DIFFUSION-COEFFICIENT {...} ]
     [TOWNSEND-COEFFICIENT {...} ]
     [ATTACHMENT-COEFFICIENT {...} ]
```

This statement permits you to alter the interpolation scheme used to compute the drift-velocity, the diffusion, the attachment coefficient and the Townsend coefficient for E/p points that are within the range of the table.

SPLINES

Splines have continuity properties that make them attractive for use by integration routines, such as those used for calculation drift-lines. Cubic splines do however have a tendency to oscillate. [By default, all tables except those for some built-in gasses are interpolated using cubic splines.]

NEWTON

Newton polynomial interpolation is less affected by oscillations provided the order of the interpolating points is chosen sufficiently small. The result is not as smooth as splines however.

order

The order of the interpolating polynomial; 1 and 2 are recommended values. Values above the number of table entries - 1 or above 10 are not permitted, neither are negative numbers. [Default: 2].

OPTIONS

Format:

```
OPTIONS  [NOGAS-PLOT | GAS-PLOT]
         [NOGAS-PRINT | GAS-PRINT]
```

There are a few options for this section:

GAS-PLOT

Enables plotting the curves of v_e, v_{ion}, $\sigma_{diffusion}$, $\alpha_{Townsend}$ and β_{att} vs log(E/p), provided the data are available. Samples of this type of plot are shown in Figure 1 on page 34, Figure 2 on page 34 and Figure 3 on page 34.

GAS-PRINT

Enables printing of all available gas data.

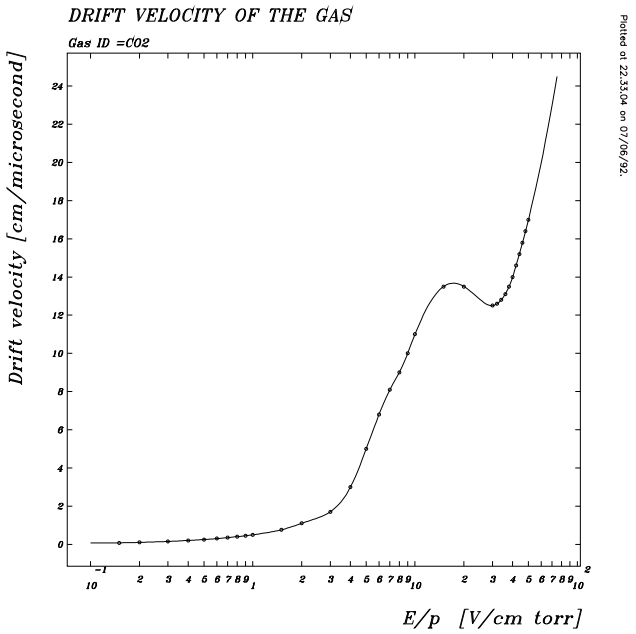


Figure 1. Drift-velocity in CO_2

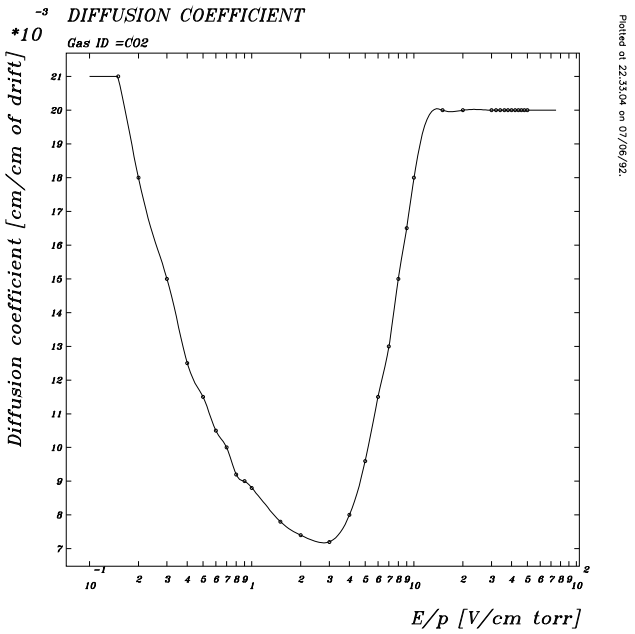


Figure 2. Diffusion coefficient of CO_2

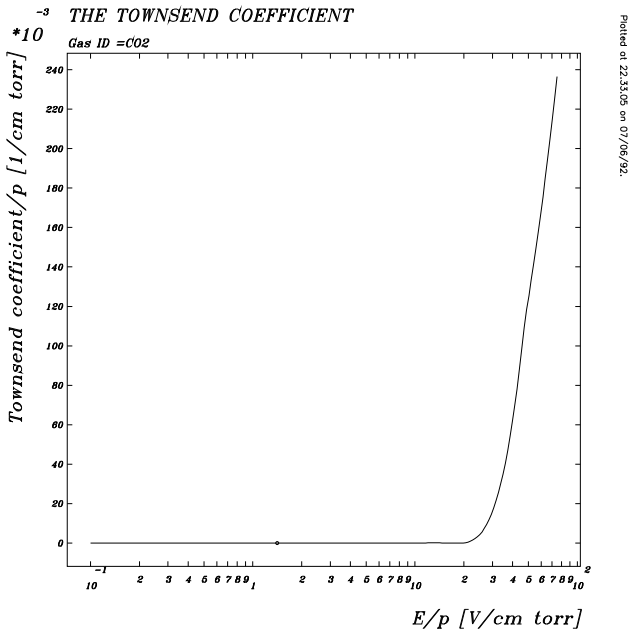


Figure 3. Townsend coefficient of CO_2

The plots on this page were produced with the following set of commands:

```
& GAS
opt gas-plot
CO2
```

PARAMETERS

Format:

```
PARAMETERS  [A a
             Z z
             E-MOST-PROBABLE e_mp
             E-PAIR e_pair
             RHO ρ]
            [MEAN n_mean]
```

This statement enters some parameters mainly used for the signal simulation. A, Z, E-MOST-PROBABLE, RHO and E-PAIR may be omitted if you enter the cluster-size distribution directly via CLUSTER, (see also Section 4.4.1.2 on page 113). MEAN is required for all signal simulations. The MOBILITY is needed for ion-drifting and hence amongst others for signals.

a Atomic number of the gas.

z Nuclear charge of the gas atoms or molecules.

e_mp Most probable energy loss per cm (at density ρ) [eV/cm].

e_pair Energy needed to form one electron ion pair [eV].

n_mean Average number of clusters per cm.

ρ Density of the gas [g/cm^3].

PRESSURE

Format:

```
PRESSURE p
```

Changes the gas pressure to *p* [in torr, default is 760 torr]. This instruction can be used to change the pressure of gasses read from a dataset (GET) or from a routine (like CO_2).

RESET

Clears the gas-data.

TABLE

Format:

```
TABLE [E/p]
      [DRIFT-VELOCITY [f_e] ]
      [ION-MOBILITY [f_ion] ]
      [DIFFUSION-COEFFICIENT [f_σ] ]
      [TOWNSEND-COEFFICIENT [f_a] ]
      [ATTACHMENT-COEFFICIENT [f_b] ]
      [RANGE ep_min ep_max]
      [N n]
(at least 3 lines of tabulated items)
(blank line)
```

This instruction enters the drift velocity, the diffusion coefficient, the Townsend coefficient and the attachment coefficient. You don't have to enter all of them; error messages are printed if some data are absent. The order in which the quantities are listed may be chosen freely. The next examples illustrate the various ways to use this statement.

E/p

Represents the field-strength [in V/cm] over the pressure [in torr] in the table. It cannot be a function. The values should be in strictly increasing order and all be > 0. E/p must be present if at least one of the items is tabulated and E/p may be used to set the ordinates for interpolated functions if logarithmic spacing is not convenient.

DRIFT-VELOCITY

Make sure that $v_e > 0$ [in cm/μsec].

ION-MOBILITY

Make sure that $v_{ion} > 0$ [in cm^2/Vμsec].

DIFFUSION-COEFFICIENT

Make sure that $\sigma_{diffusion} \geq 0$, [in cm for 1 cm of drift].

TOWNSEND-COEFFICIENT

enter $\alpha_{Townsend}/p$, not α, in view of the pressure scaling that will be applied. [in 1 / (cm torr)].

ATTACHMENT-COEFFICIENT

enter β_{att}/p, not β, in view of the pressure scaling that will be applied. [in 1 / (cm torr)].

f_e, f_{ion}, f_σ, f_α

Functions for the drift velocity, the diffusion coefficient and the Townsend and attachment coefficients divided by the pressure. EP should be used in the functions for E/p. You may, if you wish, use the symbolic variables BOLTZMANN ($k_B = 1.38066 \times 10^{-23}$J/K) and ECHARGE ($q_e = 1.6021892 \times 10^{-19}$C) in the expressions. All functions will be sampled at either the E/p values listed in the table or at logarithmically equidistant points. The data thus obtained are interpolated during the calculations, like tabulated data. Refer to Section 4.5 on page 116 for details about the syntax of the formulae.

ep_min

Lowest value of E/p for which the formulae are valid [default is 0.01]. The value at this point plays a major role if drift velocities, diffusion coefficients, Townsend coefficients or attachment coefficients for lower E/p are required. The range is optional and is only taken into account if no quantity is tabulated.

ep_max

Largest value of E/p for which the formulae are valid [default is 100]. Extrapolated values will be used if data for E/p > ep_max are required. The range is optional and is only taken into account if no quantity is tabulated.

n

Number of points the table will contain [default is 20]. This parameter is only taken into account if no quantity is tabulated.

tabulated items

Each input lines should contain those entries specified on the TABLE line that were not set equal to a function, in that order. A minimum of three lines is required, a blank line signals the end of the list. The last few points determine the extrapolation (see EXTRAPOLATE) and should therefore be chosen with care. Preferably, some points at high E/p (say 50 kV/cm torr) should be included.

TEMPERATURE

Format:

```
TEMPERATURE t
```

Changes the gas temperature to *t*. The gas temperature is used only for the computation of the drift velocity and the diffusion coefficient in gas mixtures (MIX).

[in K, default is 300 K].

WRITE

Format:

```
WRITE DATASET dataset [member] [REMARK remark]
```

Stores the gas data in compact format in member *member* of library *dataset*. A remark may be added for easier reference. A member is needed for retrieval if more than one gas description is stored in the dataset. The DATASET and REMARK keywords may be omitted, provided the order of the arguments is respected: e.g. *member* has to be specified if you wish to have a *remark*. Refer to Section 2.3.2 on page 10 for details about the file format and naming conventions.

Examples:

1. Tabulating each of the items

Tell the program on the TABLE line what information your table contains and use the subsequent lines to enter the data. The default contents is E/p, v_e and σ_{diff}; you don't have to supply arguments to TABLE if that is all you need. E/p must, of course, be one of the items.

Example:

```
TABLE E/P DRIFT DIFFUSION TOWNSEND
      1   2     3          4
      2   5     6          7
      3   8     9         10

* Note the blank line !
```

2. Tabulating some quantities, using functions for others

   Here you should still supply E/p because the E/p value for the functions will be taken from this column; RANGE and N are ignored. Those quantities which will not be listed in the table, should be equated to some expression.

   Example (Thermal limit for the diffusion assuming room temperature and atmospheric pressure (290 K, 760 torr):

```
TABLE E/p DRIFT-VELOCITY ...
      DIFFUSION=SQRT((2*Boltzmann*290)/(Echarge*Ep*760))
        1              2
        2              3
        3              4

* Note the blank line
```

3. Using only functions, logarithmic spacing

   RANGE and N should be specified (unless you accept the defaults), E/p should not. All quantities must be followed by an expression. Clearly, no table is needed.

   Example (simple parametrisation of α/p for CO_2):

```
table drift-velocity=EP, ...
Townsend-coefficient=20*exp(-466/EP), ...
range: 1 100, n=10
```

4. If you don't like logarithmic spacing ...

   Consider providing E/p in the table, the RANGE and N will then be ignored.

   Example:

```
TABLE  DRIFT=2+LOG(EP)  DIFFUSION=EP+2  E/P
1
2
3

* Note the blank line !
```

5. Some cluster data

```
CO2
cluster
0 1 1
```

   Here CO2 is loaded and the cluster size distribution is then overwritten. The effect can be verified by means of the CHECK CLUSTER instruction in the signal section.

6. Selecting an interpolation method

```
& GAS
table e/p drift-velocity
1 1
2 1
3 1
4 3
5 3
6 3

interpolation drift-velocity newton 1
opt gas-plot
```

The drift-velocity has a step in this (artificial) example. Splines will oscillate around such a jump and it is therefore preferable to use linear interpolation.

7. A complete gas section (CO_2)

```
& GAS
 write dataset='GAS DATA' CO2, remark="Standard CO2"
 table
  0.15   0.08   0.0210
  0.20   0.10   0.0180
  0.30   0.15   0.0150
  0.40   0.20   0.0125
  0.50   0.25   0.0115
  0.60   0.30   0.0105
  0.70   0.36   0.0100
  0.80   0.40   0.0092
  0.90   0.46   0.0090
  1.00   0.50   0.0088
  1.50   0.76   0.0078
  2.00   1.10   0.0074
  3.00   1.70   0.0072
  4.00   3.00   0.0080
  5.00   5.00   0.0096
  6.00   6.80   0.0115
  7.00   8.10   0.0130
  8.00   9.00   0.0150
  9.00  10.00   0.0165
 10.00  11.00   0.0180
 15.00  13.50   0.0200
 20.00  13.50   0.0200
 30.00  12.50   0.0200
 40.00  14.00   0.0200
 50.00  17.00   0.0200
 60.00  20.00   0.0200
 70.00  23.00   0.0200
 80.00  27.00   0.0200
 90.00  30.00   0.0200
100.00  33.00   0.0200


para A=22.0, Z=44.0, rho=0.0019, mean=31.0, E-m-prob=3010.0
para E-pair  33.0  mobil  0.11E-05
pressure 760.0

option   gas-plot gas-print
gas-id  "This is normal CO2."
```

3.7 The optimisation section

This section should assist in finding potential settings which satisfy some common requirements such as producing as homogeneous a field-strength or as straight equal-potential contours as possible. Typically, one would start selecting the wires of which one wishes to vary the potentials. Next one could vary the potentials in various directions. The potential settings can be saved and restored at any moment. Subsequent sections will see the settings that are in effect when this section is left.

This section also offers some tools to modify existing cells.

The header line to enter this section reads & OPTIMISE.

AREA

Format:

```
AREA  xmin  ymin  xmax  ymax
```

Refer to the field section for a description of this command.

CHANGE-VOLTAGES

Format:

```
CHANGE-VOLTAGES WIRE wire VOLTAGE voltage ...
```

Sets the voltages of one or more wires to the value you specify. You are allowed to change several voltages at the time.

wire The number of the wire of which you wish to change the voltage. This number can be found in the printout that results from the CELL-PRINT option in the cell section.

voltage The new voltage of the wire.

DISPLAY

Displays the current settings of the potentials.

FACTOR

Format:

```
FACTOR  [GRID | WIRE | TRACK]
        [NOGROUP | GROUP]
```

[Instruction temporarily withdrawn]

The field at any point in the cell is a linear function of the wire potentials:

$$V(z) = V_{reference} + V_{planes}(z) + \sum_{wires} q_i \, \phi(z - z_i)$$

$$= V_{reference} + V_{planes}(z) + \sum_{wires} (V_j - V_{reference} - V_{planes}(z_j)) \qquad \left\{ \sum_{wires} c_{ij} \, \phi(z - z_i) \right\}$$

Similar formulae hold for the electric field. The coefficients between braces are purely geometrical constants. Knowledge of these coefficients eases the task of finding potential settings corresponding to a given field.

GRID | WIRE | TRACK

Averaging can take place either over a given area (GRID - the default) or over a previously defined track (TRACK) or over the surfaces of the selected wires (WIRE).

GROUP | NOGROUP

Specifies whether the averages should be grouped following the selection by SELECT or not. Grouping is on by default.

GRID

Format:

```
GRID   grid_x   [grid_y]
```

Chooses the density of sampling points used by the SET ON GRID instruction. The points form a grid inside the AREA with regular x (or r, note that this implies an exponential spacing in internal coordinates) and y (or ϕ) steps. The first parameter, *grid_x*, is the number of x- (or r-) divisions; *grid_y* is the number of y- (or ϕ-) divisions. Instead of specifying the two arguments, you may specify only one in which case the value will be used for both x (or r) and y (or ϕ). Only values between 2 and MXGRID (usually 50) are acceptable [default: 25 for both].

OPTIONS

Refer to the field section for a description of this command.

POINTS

Format:

```
POINTS   points
```

Sets the number of sampling points on the TRACK for the SET ON GRID instruction.

RESTORE

Format:

```
RESTORE  [reference_number]
```

Restores the potential settings identified by *reference_number*, a number you obtained from the SAVE instruction. The original settings will be restored if you omit *reference_number* or give it a value of 1.

SAVE

Saves the potential settings in a temporary dataset. The program replies with a reference number which you'll need to restore the settings later on.

SELECT

Format:

```
SELECT  wire_codes
```

The potentials of the wires selected by this statement will be varied by the SET instruction. Grouping is important for SET and also for FACTOR if the GROUP option is on. The wire-codes of the wires that are to enter a group, should be enclosed by brackets. E.g. (QR) (S) T will place the Q and R wires together in one group, all the S wires in another and the T wires will each form a group.

SET

Format:

```
SET  [field_function]
     [TO {AVERAGE | target_function} ]
     [WEIGHT weight]
     [ON {GRID | TRACK | WIRE} ]
     [DISTANCE norm]
     [EPSILON e]
     [ITERATE-LIMIT itermax]
     [PRINT | NOPRINT]
```

This call plays with the potential settings in an attempt to make *field_function* as equal as possible to the *target_function* in the Euclidean norm with position dependent weighting function *weight* on a set of sampling points. Only the potentials of the SELECTed wires are touched. The potentials of wires forming a group are shifted by the same absolute amount. The sampling points can either be located on the track or on the grid or on the surfaces of the S-wires. In each case, you have the possibility to choose the density of points.

In a first stage, the covariance matrix between the wire potentials and the *field_function*-values on the sampling points is established. By means of a Householder inversion, new values for the wire potentials are computed that minimise the Euclidean distance between the two functions on the set of sampling points. Then, the new covariance matrix is calculated and a new iteration begins. The Euclidean distance between the field and target functions is never allowed to increase, the step may be shortened to achieve a decrease. Three conditions can cause the iteration to stop:

- the maximum distance between the field function and the target function drops below *norm*, which you are advised to set yourself,

- the sum of the distances-squared varies by less than a fraction ε between two iterations.

The iteration is aborted if

- the difference can not be made smaller by varying the wire potentials because the *field_function* does not depend on them to a sufficient extent, for any setting encountered during the minimisation procedure,
- varying the potential of one wire has numerically the same effect on the *field_function* as varying the potential of another, for any setting encountered during the minimisation procedure,
- the user-chosen maximum number of iterations is reached.

The computations differ slightly between IBM scalar and vector compilations; since the algorithm used in the vector compilations is numerically superior, convergence there tends to be faster. The difference stems from the modest accuracy of single precision reals on this machine.

field_function

A function of the position and the field [default is V]. The symbolic names you may use are X, Y (or R, PHI for cells in polar coordinates), V, EX, EY (or ER, EPHI) and E.

target_function

A function of the coordinates X, Y (or R, PHI) only, which is used as target for the minimisation procedure.

weight

A function of the coordinates X, Y (or R, PHI) only, which is used to weigh the difference between target function and current value of the field function. A larger absolute value of the weight causes the minimisation procedure to pay more attention to the point. All weights must be non-zero. [By default 1 for all points.]

AVERAGE

Specifies that the average of *field_function* is to be evaluated with the initial potential settings and that the result should be the target value for the *field_function* on all points of the track or the grid.

GRID

Requests that the sampling points form a regular grid of GRID × GRID points inside the AREA. [This is the initial default.]

TRACK

Requests that the sampling points are POINT points on the TRACK.

WIRE

Requests that the surfaces of the 'S' wires are being sampled, irrespective of the current set of SELECTed wires. The thin-wire approximation is used throughout in that the positional coordinates in all functions are taken to be the wire-coordinates (except when evaluating the average).

norm

The value of

$$\max_{\text{sampling points}} |\text{field\_function} - \text{target\_function}|$$

at which you will allow the iteration procedure to stop [default is 1].

ε

The quantity ε is used both to obtain the derivatives needed by the minimising procedure and for one of the stopping criteria mentioned before. A small value, say 10^{-4}, is suitable if you're already close to the optimum potential settings. Larger values, up to say 1, are more adequate if you are far away. Make sure you don't choose ε smaller than about the square root of the single precision accuracy of the computer since some of the derivatives involved in the minimising procedure are effectively second derivatives. [The default is 10^{-4}, which is the smallest meaningful value on 32 bit computers.]

itermax

The maximum number of iterations you permit [default: 10].

PRINT

Requests printing of summary information for each iteration cycle.

TRACK x_start y_start x_end y_end

Refer to the field section for a description of this command.

Example:

```
& OPTIMISE
track 1 1 1 3
sel (a) (b)
set v to average on track, distance=10, iterate=2, print
save
sel (c) (d)
set v to average on track, distance=5, iterate=10, print
restore 2
* Define a grouping and run the FACTOR instruction
SEL (S) (PR) Q
FACTOR GRID
```

3.8 The field section

This section allows you to obtain vector electric field plots, potential contours, a printed table of the field components etc. The header line for this section is & FIELD. The instructions this section recognises are:

AREA

Format:

```
AREA   xmin   ymin   xmax   ymax
```

This instruction changes the plotting window, you may wish to use it to obtain detailed pictures of only part of the cell or to get plots over several periods. Defaults are the previous boundaries, preset to the cell edges.

xmin x- or r-coordinate of the lower left hand corner of the plots [cm].

ymin y- or ϕ-coordinate of the lower left hand corner of the plots [cm or degrees].

xmax x- or r-coordinate of the upper right hand corner of the plots [cm].

ymax y- or ϕ-coordinate of the upper right hand corner of the plots [cm or degrees].

CHECK

Format:

```
CHECK  [WIRE]       [PLANE]
       [MAXWELL]    [TUBE]
       [FULL]
       [BINS bins]
       [EPSILON-WIRES eps_wire]
       [EPSILON-MAXWELL eps_Maxwell]
```

This is actually a debugging instruction, though it may also be of some use if you need the electric field on the surface of the wires.

WIRE

Prints the potential and the electric field-strength at the surface of the sense wires (as selected by SELECT) and checks that the charge per unit length the program has calculated agrees with the charge found by integrating the normal component of the electric field around a wire:

$$\frac{Q}{\varepsilon_0} = \int_{\text{surface}} E_{\text{normal}}\, d\sigma$$

The field at the wire surface is obtained by extrapolation using the Neville algorithm in which the spacing of the steps is controlled by the parameter *eps_wir*.

PLANE

Prints the potential and the electric field-strength at the surface of the planes.

TUBE

Prints the potential and the electric field-strength at the surface of the tube.

MAXWELL

Will check that the potential and electric field are consistent i.e. that $dV/dx = -E_x$, $dV/dy = -E_y$ and that the Maxwell equations $\nabla \cdot E = 0$ (outside the wires) and $\nabla \cdot B = 0$ are satisfied by the field the program has calculated. It produces a lot of printed output and 3 (or 4) histograms.

Each of the differentiations mentioned above is done by comparing the potentials at 2 points: one at higher and one at lower coordinate than the sampling points. The displacement is (for an x-differentiation) of the type $\varepsilon\ (1 + |x|)$ where ε is the parameter *eps_Maxwell*.

FULL

Switches on all three options. ALL is synonymous with FULL.

bins

The number of bins in the histograms plotted by the MAXWELL option. [Default: 100 bins.]

eps_wir

Spacing parameter for the WIRE option (see there). [The initial default is 10^{-5}.]

eps_Maxwell

Differentiation parameter for the MAXWELL option (see there). [The initial default is 10^{-3}.]

GRID

Format:

```
GRID  grid_x  [grid_y]
```

Chooses, together with AREA, the set of sampling points used by the PLOT, PRINT and CHECK instructions. The points form a grid inside the AREA with regular x (or r, note that this implies an exponential spacing in internal coordinates) and y (or ϕ) steps. The first parameter, *grid_x*, is the number of x- (or r-) divisions; *grid_y* is the number of y- (or ϕ-) divisions. Instead of specifying the two arguments, you may specify only one in which case the value will be used for both x (or r) and y (or ϕ). Only values between 2 and MXGRID (usually 50) are acceptable [default: 25 for both].

MULTIPOLE-MOMENTS

Format:

```
MULTIPOLE-MOMENTS WIRE wire
                  [FUNCTION f]
                  [ORDER order]
                  [RADIUS r]
                  [EPSILON eps]
                  [ITERATE-MAXIMUM iter]
                  [NOPLOT | PLOT]
                  [NOPRINT | PRINT]
```

Decomposes the potential around a wire in a sum of Legendre functions:

$$V(\phi) = m_0 + \sum_{i=1}^{n} m_i P_i(\cos(\phi - \phi_i))/r^i$$

The multipole moments m_i indicate whether the wire is subject to asymmetric forces, whether it has a dipole moment etc. This information can be useful when assessing the reliability of the field close to a wire.

The angles ϕ_i are free parameters in the fit, r is the distance from the wire at which the series is computed.

wire The wire for which the multipole moments are to be computed.

f The function to be fitted, using as variables ANGLE, EX, EY, E, V, BX, BY, BZ and B. [By default: V]

order The order of the highest moment to be calculated. [Default is 4.]

r The distance in wire-radii at which the decomposition must be done. [Default is 1, i.e. at the wire surface.]

eps Parameter used by the fitting procedure to compute the covariance matrix. [Default is 10^{-4}.]

iter Maximum number of iterations allowed to the fitting procedure. [Default is 20.]

PLOT Requests a plot showing the various contributions.

PRINT Requests printout from the fitting procedure.

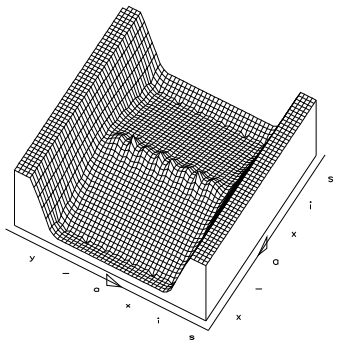


Figure 4. Example of a SURFACE plot.

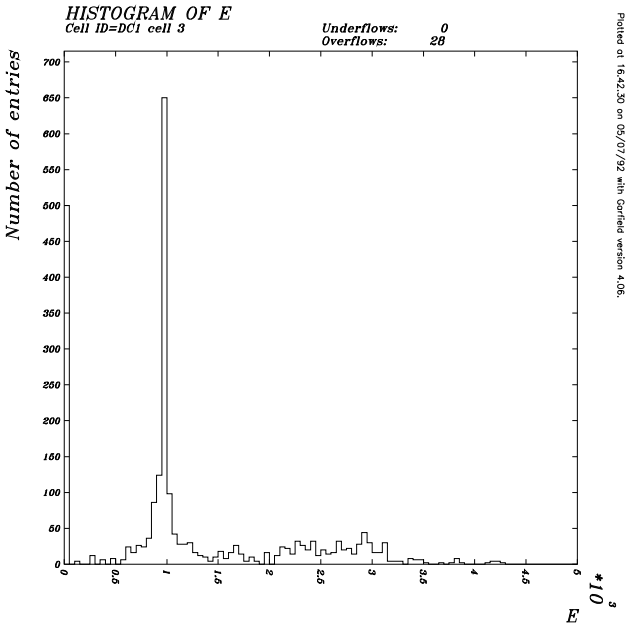


Figure 5. Example of a HISTOGRAM plot.

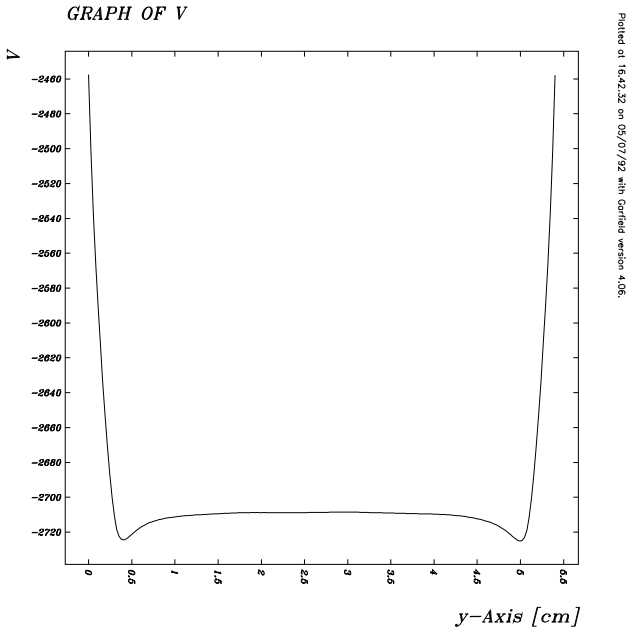


Figure 6. Example of a GRAPH plot.

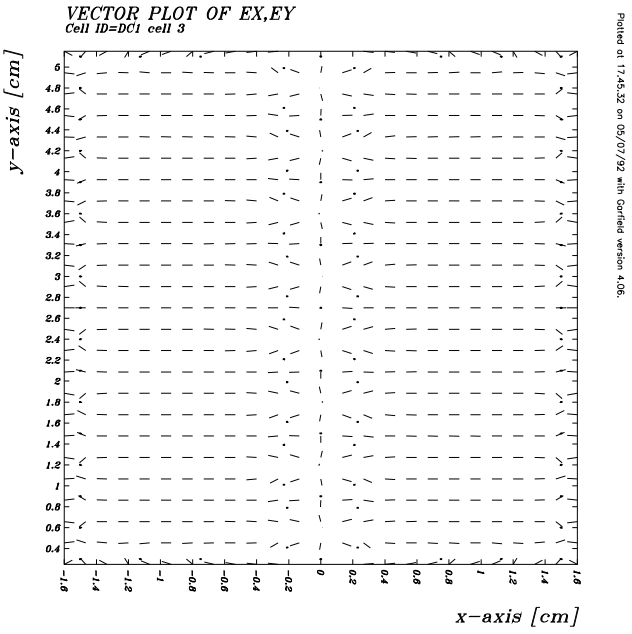


Figure 7. Example of a VECTOR plot.

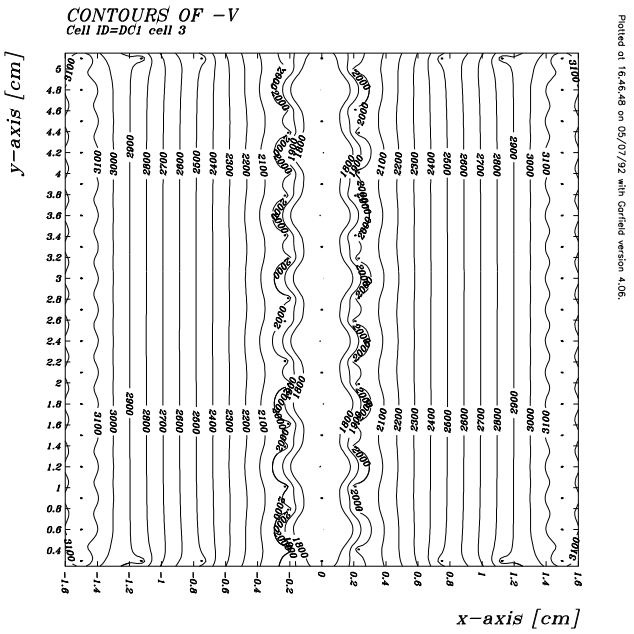


Figure 8. Example of a CONTOUR plot.

The plots on these pages were produced with the following set of commands:

```
& FIELD
grid 50
plot surf hist range 0 5000
track 1   0 1   5.4
area -1.6 0.25 1.6 5.15
plot graph
grid 30
plot cont -V label range 1800 3100 n=13
grid 25
plot vect
```

PLOT

Format:

```
PLOT [CONTOUR   [funct1]  [RANGE {cmin cmax | AUTOMATIC}]
                          [N ncont]
                          [LABEL | NOLABEL]                 ]
     [GRAPH     [funct2]                                    ]
     [HISTOGRAM [funct3]  [RANGE {hmin hmax | AUTOMATIC}]
                          [BINS n_bins]                     ]
     [SURFACE   [funct4]  [ANGLE φ Θ]                       ]
     [VECTOR    [funct5 ,funct6]                            ]
```

Plots the field in a variety of ways:

- as a set of contours (see Figure 8),
- as a 3-dimensional impression (see Figure 4 on page 45),
- as a histogram (see Figure 5 on page 45),
- as a vector plot (see Figure 7 on page 45),
- as a graph (see Figure 6 on page 45).

The vector, histogram and surface plots are obtained sampling over a grid of GRID × GRID points in the AREA. Contours are drawn inside the AREA, the GRID parameter determines the density of the initial searching grid. Graphs use the points on a predefined TRACK which need not be located inside the AREA. In each PLOT statement, one and only one plot of each type may be requested; CPU time can be saved if SURFACE, VECTOR and HISTOGRAM are combined because the field will be evaluated only once.

cmin cmax

The lowest and highest function value for which a contour will be plotted. AUTOMATIC means that *cmin* and *cmax* will be set such that the range of the function over the area is covered and all contours heights are round numbers. [Defaults are the extremes of the potential in the whole cell if contours of V are requested, 0 and 10000 else. However, automatic adjusting of the range is default and to obtain the settings described before, you have to specify RANGE * *.]

ncont

The number of contours to be plotted minus 1. [Default is 20.]

If you opt for automatic scaling, the number of contours you see, is sometimes larger than *ncont* +1. Your value of *ncont* is used to obtain a rough distance between two contours which is rounded downwards to the nearest power of 10 times 1, 2 or 5. The bounds of the range are set equal to multiples of the rounded distance.

LABEL

Requests labelling of the contours. [On by default, only available from version 2.01 onwards.]

hmin hmax

Lower and upper bound of the histogram. If you specify AUTOMATIC, the range of the histogram is set to the interval $[\bar{x} - 3\mathrm{MAD}_x, \bar{x} + 3\mathrm{MAD}_x]$ rounded outwards. The first few (usually 100) entries serve to compute the mean and MAD. These entries are not necessarily representative for the whole sample. [Default is automatic scaling.]

n_bins

The number of channels the histogram should have [default is 100].

ϕ θ

The viewing angles used to project the surface plots [in degrees, defaults: 30^0 for ϕ and 60^0 for θ].

funct.

Functions to be plotted. Variables allowed in the expressions are X, Y, EX, EY, E, V, BX, BY, BZ and B (the latter 4 only if there is a magnetic field). If the cell is described in polar coordinates, X, Y, EX and EY must be replaced by R, PHI, ER and EPHI. Note that there should be no blanks in the expressions. Defaults are V for contours, surface plots and graphs, E for histograms and (EX,EY) for vector plots.

You may substitute a commercial at @ for any of the functions. You will find yourself in the algebra editor where you can manually construct an instruction list. See also Section 4.5 on page 116 for details about the formulae.

PRINT

Format:

```
PRINT  funct1  [funct2  [funct3 ... ]]
```

Prints the value of the functions *funct 1, funct 2 . . .* of the field on a grid of GRID × GRID points in the AREA. Each set of tables contains 4 of the functions. Be careful, this command generates a lot of output (25 pages for GRID=50).

SAMPLE

Format:

```
SAMPLE   x   y
```

Prints the field at (x,y).

SELECT

Format:

```
SELECT   wire-codes
```

Selects groups of wires for special treatment by, in this section, CHECK WIRE. All wires of which the code or the wire number (see the table printed in response to the CELL-PRINT option in the cell section) appears in the argument string, will be considered by CHECK. The concept of wire groups is of no importance here - see the description of this command in other sections for details.

TIME

Format:

```
TIME   [n]
```

Times *n* field evaluations. [Default for *n* is 1000.]

TRACK

Format:

```
TRACK  x_start  y_start  x_end  y_end
```

Defines a track to be used by the PLOT GRAPH instruction. Defaults are the previous values, they are not preset.

x_start x- or r-coordinate of begin point [cm].

y_start y- or ϕ-coordinate of begin point [cm or degrees].

x_end x- or r-coordinate of end point [cm].

y_end y- or ϕ-coordinate of end point [cm or degrees].

Example of a valid field section:

```
& FIELD
* First set the options, DEBUG will make the output very bulky !
OPTIONS INPUT DEBUG
* Define a first large area to be used for the first table
AREA -1 -2 3 2
PR EX EY ARCTAN(EY/EX) V
* Override the previous area by a smaller one
AREA -0.5 -0.5 -0.4 -0.4
PR BX,BY,EX*BY-EY*BX
PLOT SURF X**2*SIN(Y) HIST E RANGE 500 1000
* Get the field at the wire-surface, store it in a dataset
> 'GARF OUT'
CHECK WIRE
* Make sure the rest of the output goes to the screen
>
```

3.9 The drift section

Calling this section enables you to plot drift-lines and/or equal arrival time contours via the DRIFT instruction. There are also facilities for making x(t) correlation plots. The header line is & DRIFT and valid instructions are:

AREA

This statement has two valis syntaxes:

```
AREA   xmin   ymin   xmax   ymax
AREA   xmin   ymin   zmin   xmax   ymax   zmax
```

This instruction allows you to set the boundaries of the drift-area, defaults are the previous boundaries, preset to the cell edges each time the drift section is entered.

Use the first syntax for normal 2-dimensional applications. The second format is to be used if you wish to observe the z-component of the drift-line, for instance when a magnetic field is applied to the chamber. The range in z must include z=0 since drift-lines always start at z=0 - the E and B fields don't have structure in z unless you replace the routines that calculate those fields.

xmin x- or r-coordinate of the lower left hand corner of the plots [cm].

ymin y- or ϕ-coordinate of the lower left hand corner of the plots [cm or degrees].

zmin lowest z-coordinate to which your chamber extends. [*zmin* Has the cm as unit, must be less than 0 and is by default set equal to the first argument of Z-RANGE in the cell section, which is by default -1.]

xmax x- or r-coordinate of the upper right hand corner of the plots [cm].

ymax y- or ϕ-coordinate of the upper right hand corner of the plots [cm or degrees].

zmax highest z-coordinate to which your chamber extends. [*zmax* Has the cm as unit, must be larger than 0 and is by default set equal to the second argument of Z-RANGE in the cell section, which is by default -1.]

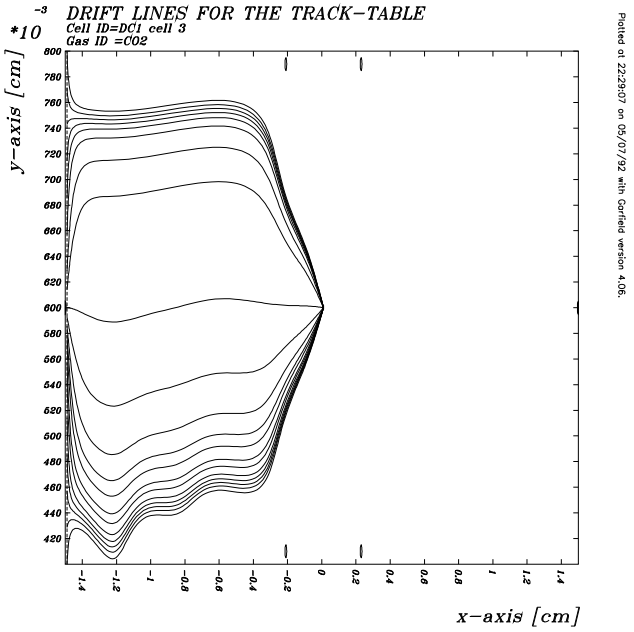


Figure 9. Track preparation. The track in this example is located at -1.5 cm. In a first stage, 15 drift-lines have been calculated from this track at regular y-intervals. Then, 5 drift-lines have been added around the centre to improve the interpolation table. This plot is made as a result of the DRIFT-PLOT option being on.

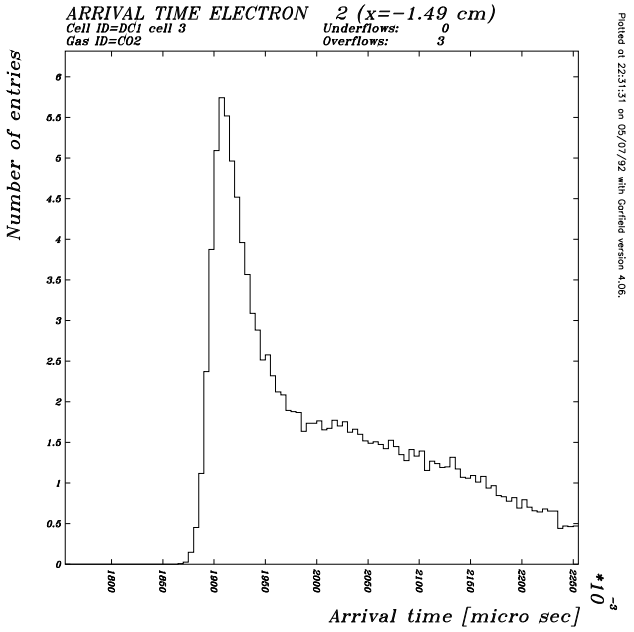


Figure 10. Single electron arrival time distribution for one given x. The entries in this histogram correspond to the times at which the second electron from the track shown in Figure 9 reaches the wire in the centre of that plot. A series of such plots is made if you request PLOT-EACH-X-SELECTED-ELECTRON.

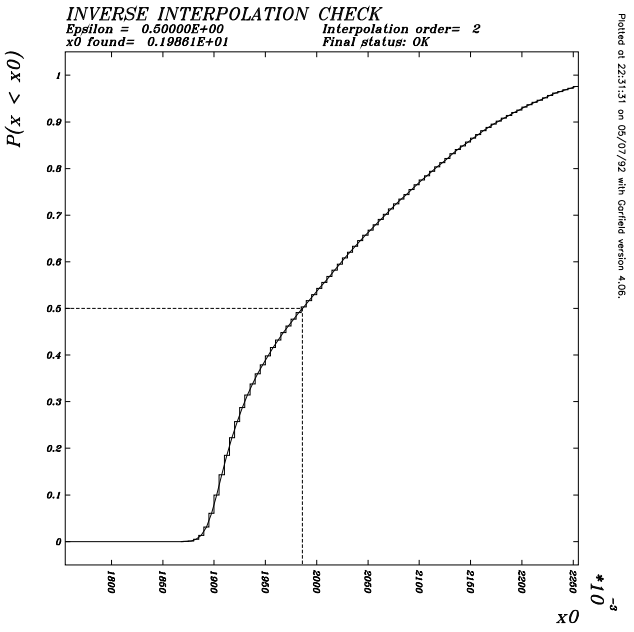


Figure 11. The inverse interpolation procedure. The histogram is the normalised cumulative version of the one shown in Figure 10. In this example, the second electron is required to have a probability of 0.5 to have reached the wire at the time shown in Figure 12. This plot is only made if you have the DEBUG option switched on.

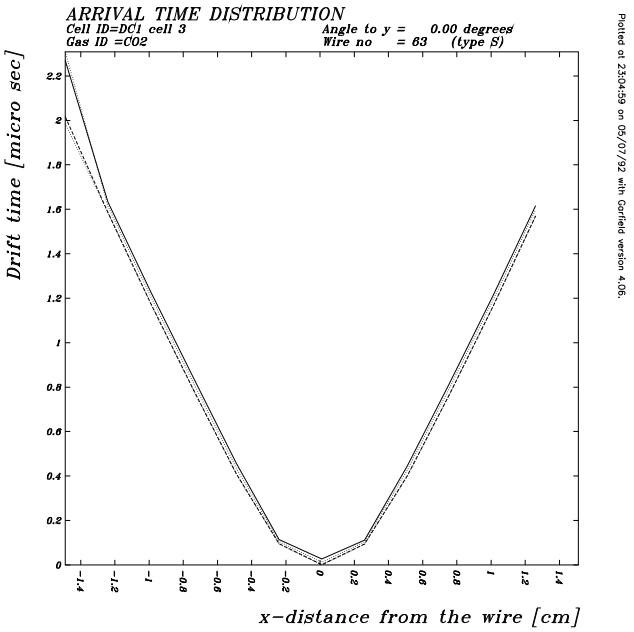


Figure 12. Overview plot of the arrival time distribution. The solid and dashed lines are the mean arrival time of all electrons resp. the second electrons from the track. The two dotted lines are the times at which any and the second electron have 0.5 chance to have arrived. This plot is made if PLOT-OVERVIEW is selected.

ARRIVAL-TIME-DISTRIBUTION

Format:

```
ARRIVAL-TIME-DISTRIBUTION
     [ELECTRON electron]      [THRESHOLD threshold]
     [NOAUTOSCALE-TIME-WINDOW | AUTOSCALE-TIME-WINDOW]
     [X-RANGE xmin xmax]      [X-STEP-SIZE x_step]
     [Y-RANGE ymin ymax]
     [LINES lines]            [ANGLE ϕ]
     [NOSINGLE-CLUSTER | SINGLE-CLUSTER]
     [DATASET dsname [member] ]  [REMARK remark]
     [BINS bins]              [MONTE-CARLO-LOOPS loops]
     [NOKEEP-HISTOGRAMS | KEEP-HISTOGRAMS]
     [POLYNOMIAL-ORDER order]
     [NOPLOT-EACH-X-OVERALL | PLOT-EACH-X-OVERALL]
     [NOPLOT-EACH-X-SELECTED-ELECTRON | PLOT-EACH-X-SELECTED-ELECTRON]
     [NOPRINT-EACH-X-OVERALL | PRINT-EACH-X-OVERALL]
     [NOPRINT-EACH-X-SELECTED-ELECTRON | PRINT-EACH-X-SELECTED-ELECTRON]
     [PLOT-OVERVIEW | NOPLOT-OVERVIEW]
```

The ARRIVAL instruction is a variant of the XT-PLOT instruction. XT-PLOT searches for each x the shortest drift-line from a track, disregarding clustering effects but informing you about the diffusion to be expected on that shortest drift-line. These calculations are carried out as accurately as possible.

ARRIVAL operates on the same tracks as XT-PLOT does, assuming that your readout triggers at a given electron count. On each track, the instruction generates clusters a specified number of times, computes the drift-time and generates integrated diffusion coefficients for each electron of each cluster and makes an histogram of the arrival time distribution of the n'th electron to arrive (n is the user specified parameter *electron*). The Monte-Carlo nature of the computations sometimes makes the results less precise than those produced by XT-PLOT but what is computed is closer to what is actually measured. The statistical errors can be made small by choosing proper binning and requesting a large number of iterations. Inaccuracies are also introduced by interpolation on the 'prepared track'; the track preparation is adopted throughout to make the computations reasonably fast. See Figure 9 on page 50. You can make the interpolation errors small by requesting a large number of table points.

This instruction loops over all SELECTed wires in the current AREA and produces plots and tables for each of them independently.

electron

Specify here the electron on which you trigger. This is usually a number between 5 and 10 but you are allowed to choose any positive integer number you wish. If you are in the tail of the distribution of the number of electrons from the track, you may have to generate clusters more often to obtain reasonable statistics.

Consider using automatic time window scaling if your favourite electron has a sharply peaked time distribution compared with the overall arrival time distribution.

[Default: 1, remembered across calls.]

threshold

The program outputs the mean arrival time of the *electron*'th electron (no histograming used here) but also the time at which the electron has arrived with a probability *threshold*.

This quantity is obtained by reverse interpolation in the cumulative arrival time distribution histogram using polynomial interpolation of order *order*.

The parameter *threshold* ranges from 0 to 1, neither 0 nor 1 are acceptable.

[Default: 0.5, or the median of the distribution, remembered across calls.]

AUTOSCALE-TIME-WINDOW

Both the time distributions of all electrons together and of the selected electrons are histogramed, see *threshold*, to estimate the time at which the electron has a certain probability to have arrived. For the overall arrival time distribution, a proper time window is obtained during track preparation. For the selected electron histogram, such a window is not available and the program uses by default the same window as for the overall timing

histogram. Both the global *DEBUG* option, which shows details about the reverse interpolation procedure (Figure 11 on page 50), and the instruction line option *SHOW EACH-X-SELECTED-ELECTRON* will tell you whether this window is indeed appropriate. If it isn't, you can specify *AUTOSCALE-TIME-WINDOW* which will choose a time window adapted to the points actually collected. An example of this kind of plot can be seen in Figure 10 on page 50. [Automatic scaling is the default.]

xmin, xmax
The range in x to be scanned. This range should be smaller than the x-range of the drift area.

[Default: the x-range of the current AREA.]

x_step
The tracks cross the line at constant y through the wire at x-distances
... –2 x_step, –x_step, 0, x_step, –2 x_step ... from the wire.

[Default: about 5 % of the x-range of the current AREA.]

ymin, ymax
The y-range to be scanned. If you are interested only in the first electron, there is no point in wasting time on the outer edges of the acceptance region of the wire. It is also a waste of time to have a y-range that extends far beyond the acceptance region of the wire - in addition, you loose accuracy. On the other hand, if your y-range is too small, you will obtain incorrect results and the program does not warn you if this happens.

[Default: the y-range of the current AREA.]

SINGLE-CLUSTER
Requests that only 1 cluster is generated on each track. This may be useful if you wish to simulate photons.

[Not default, setting remembered across calls.]

lines
Each track is first 'prepared': a table of drift-times and integrated diffusion coefficients is made. This table is subsequently interpolated for each of the clusters. The interpolation improves if the table is more detailed. Preparing a track is fairly costly in terms of CPU time but it is generally worthwhile investing in a reasonable high *lines* value.

[Default: the current setting of LINES.]

ϕ
The angle of the tracks with respect to the y-axis.

[Default: 0 degrees, remembered across calls.]

DATA SET
Requests the results are written to dataset *dsname*. You may optionally specify a member name and a remark.

bins
The number of bins in the arrival time distribution histogram.

[Default: 100, remembered across calls.]

KEEP-HISTOGRAMS
Requests that the arrival time histograms be kept. The histograms are available as global variables after command completion. The names of these global variables are printed, usually they are of the type SEL_n and ALL_n with n an integer. Most arithmetic operations can be applied on them, they can be displayed by the PLOT_HISTOGRAM procedure etc.

[Default: histograms are not kept.]

loops

The number of MC cycles.

[Default: 10000, remembered across calls.]

order

The order of the interpolating polynomial. Values above 3 are not recommended, you are better of if you choose smaller binning and larger statistics. See *threshold* for more information.

[Default: 2, parabolic interpolation, remembered across calls.]

PLOT-EACH-X-OVERALL

Requests a plot of the arrival time distribution of all electrons for each track.

[Default: off, remembered across calls.]

PLOT-EACH-X-SELECTED-ELECTRON

Requests a plot of the arrival time distribution of the selected electron for each track.

[Default: off, remembered across calls.]

PRINT-EACH-X-OVERALL

Requests a printout of the arrival time distribution of all electrons for each track. The printed version of the histogram provides additional information such as the width of the distribution.

[Default: off, remembered across calls.]

PRINT-EACH-X-SELECTED-ELECTRON

Requests a printout of the arrival time distribution of the selected electron for each track. The printed version of the histogram provides additional information such as the width of the distribution.

[Default: off, remembered across calls.]

PLOT-OVERVIEW

Requests a plot of the various curves obtained, as a function of x. An overview plot is shown in Figure 12 on page 50.

[Default: on, remembered across calls.]

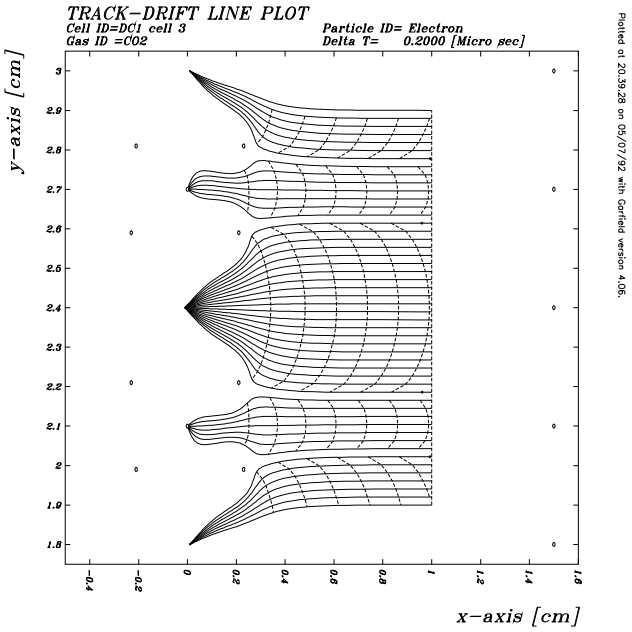


Figure 13. Example of a DRIFT TRACK plot.

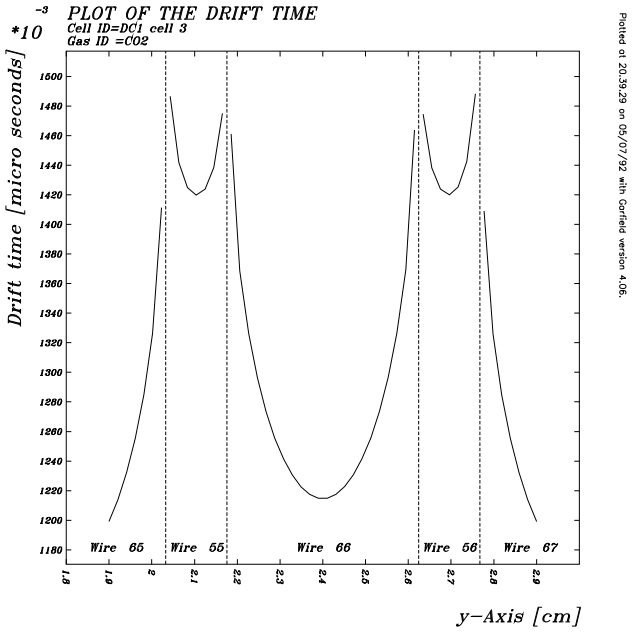
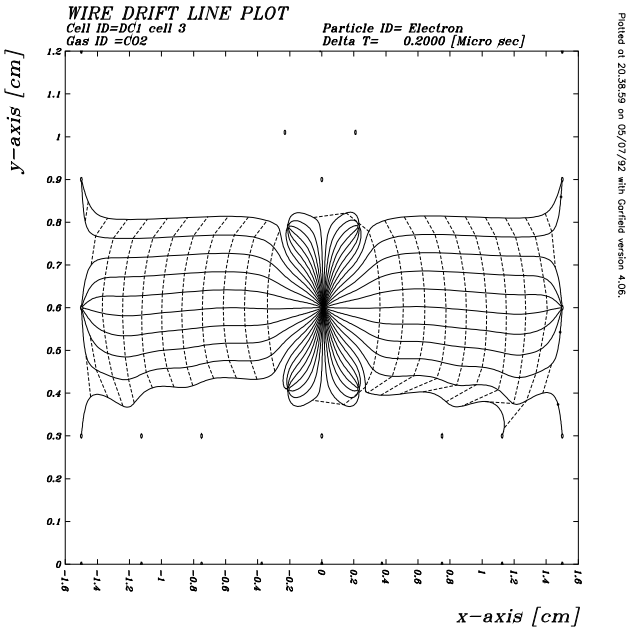


Figure 14. The TIME-GRAPH associated with the previous Figure.



The plots on this page were produced with the following set of commands:

```
& DRIFT
lines 50
area -1.6 0.0 1.6 1.2
drift wire l-pr contour 0.2
track 1.0 1.9 1.0 2.9
area -0.5 1.75 1.6 3.05
drift track time-graph contour 0.2 line-print
```

Figure 15. Example of a DRIFT WIRE plot.

DRIFT

Format:

```
DRIFT
      EDGE    [NOTDOWN | DOWN]     [LEFT | NOTLEFT]
              [RIGHT | NOTRIGHT]   [NOTUP | UP]                          |
      WIRE                                                               |
      TRACK   [AVALANCHE-GRAPH | NOAVALANCHE-GRAPH]
              [DIFFUSION-GRAPH | NODIFFUSION-GRAPH]
              [FUNCTION-GRAPH function | NOFUNCTION-GRAPH]
              [MARKER | SOLID]
              [TIME-GRAPH | NOTIME-GRAPH]
              [VELOCITY-GRAPH | NOVELOCITY-GRAPH]                        |
      ZERO

              [CONTOUR Δt | NOCONTOUR]
              [THRESHOLD thr]
              [ELECTRON | ION]
              [LINE-PLOT |NOLINE-PLOT]
              [LINE-PRINT | NOLINE-PRINT]
              [POSITIVE | NEGATIVE]
```

Plots and prints drift-lines and/or equal arrival time contours. By default electron drift-lines will start from the left and right edges. All parameters are remembered throughout program execution. The parameters EDGE, TRACK, WIRE and ZERO are mutually exclusive and the associated sub-keywords (such as UP, MARKER and TIME-GRAPH) have to follow them immediately.

EDGE

The particles start drifting at the edges. You may select the edges by setting UP, LEFT, RIGHT and DOWN.

DOWN

Drifting from the $y = y_{max}$ or $\phi = \phi_{max}$ border, not default.

LEFT

Drifting from the left or the $r = r_{max}$ border, default.

RIGHT

Drifting from the right or the $r = r_{min}$ border, default.

UP

Drifting from the $y = y_{min}$ or $\phi = \phi_{min}$ border, not default.

TRACK

The particles start drifting from points on a previously defined track. Graphs of the drift-time, the average drift-velocity, the integrated diffusion and the multiplication factor may be requested by specifying one or more of the -GRAPH options. The plot of the drift-lines and equal time contours (see for instance Figure 13 on page 53), can be suppressed by selecting the NOLINE-PLOT and NOCONTOUR options.

TIME-GRAPH

Produces a graph of the drift-time for the drift-lines from a track, an example is shown in Figure 14 on page 53.

VELOCITY-GRAPH

Produces a graph of the mean drift-velocity for the drift-lines from a track. (Note: this mean is simply the total drift-time divided by a zero'th order estimate of the total length of the drift-line.)

DIFFUSION-GRAPH

Produces a graph of the integrated diffusion (in μ seconds) for the drift-lines from a track. The routine performing the integration tries to reach full single precision accuracy, in view of a future upgrade, and is therefore rather slow.

AVALANCHE-GRAPH

Produces a graph of the multiplication factor for the drift-lines from a track, integrating the Townsend coefficient. The routine performing the integration tries to reach full single precision accuracy, in view of a future upgrade, and is therefore rather slow.

FUNCTION-GRAPH

Allows combining the numbers plotted in the preceding graphs to an almost arbitrary function. The string *function* should be a function of the following symbolic variables: LENGTH (length of the drift-line), TIME (drift-time), DIFFUSION (integrated diffusion coefficient) and AVALANCHE (integrated and exponentiated Townsend coefficient).

MARKER

The data in the output of the -GRAPH options are represented by markers, usually an asterisk '*'; the alternative (SOLID) is a continuous line. Track segments leading to different wires are always separated by a dashed vertical line, independent of this choice.

WIRE

The particles drift backwards from the wires selected as sense wire (by default those with a wire-code 'S'). This is the normal mode of drift for ions. This plot is useful with electrons to see where a wire collects charge. Figure 15 on page 54 shows an example of this type of plot.

ZERO

The particles drift from the zeros of the electric field. The plots obtained this way are useful in determining the acceptance boundaries of the various wires.

CONTOUR

Specifies that equal time contours are to be plotted, Δt is the separation between two equal time contours [in μsec]. Contours are drawn separately for each wire. The contours are represented by broken lines or by asterisks if the line joining two neighbouring points (i) crosses a drift-line or (ii) is longer than a threshold described below. It is perfectly possible to plot equal time contours but no drift-lines.

thr

Two points on an equal time contour are not joined if the distance between them is larger than a fraction *thr* of the screen size. [This fraction is initially set to 0.1.]

ELECTRON | ION

Drift electrons or ions [preset to electrons].

LINE-PLOT
Specifies that the drift-lines should be plotted.

LINE-PRINT
Requests that summary information about the drift-lines be printed.

POSITIVE | NEGATIVE
Forces the charge of the drifted particle to be positive respectively negative. Do not normally use this option, the charge is chosen according to the values of the other parameters: positive for drift from the wires, negative for drift from the edges and from the track. The option should however be used with DRIFT WIRE in case the selected wires repel electrons (the program detects this condition but will not modify the charge in order not to confuse the user). This parameter should, if used, be the last parameter of the statement.

EPSILON ε
Replaces the absolute integration accuracy by ε. The smaller ε the higher the accuracy, normal values are between 10^{-7} and 10^{-8}. Increasing ε can lower the CPU time consumption considerably. If the sense wires are very thin, a small ε may be needed to avoid that the particles travel around the wire, just outside the trap radius, before they are caught. This shows up very clearly in the DRIFT TRACK TIME-GRAPH plots and the x(t) calculations may fail partly. Another sign that ε is too large, is a wobbly drift-line. [Default: 5×10^{-7}].

GRAPHICS-INPUT
Format:

```
GRAPHICS-INPUT
     [CHOICE-PET chpet]      [LOCATOR-PET locpet1 locpet2]
     [PICK-PET pickpet]      [VALUATOR-PET valpet]
     [CHOICE-DEVICE chdev]   [LOCATOR-DEVICE locdev1 locdev2]
     [PICK-DEVICE pickdev]   [VALUATOR-DEVICE valdev]
     [WORK-STATION wkid]
```

(A minimum GKS level of 1b is required.) This is a graphics-menu driven command that enables you to do some simple drift-line calculations without being bothered too much by command syntax.

You may change the AREA and the TRACK by pointing on the screen; most of the other drift-line specific parameters (to be found in a submenu) can also be modified but their values have to be typed.

Typical things you can ask for are single drift-lines starting at a point you indicate on the screen, drift-lines from the current track and drift-lines from a wire chosen from those visible on the screen. (Drift-lines will also be plotted from the periodic repetitions of a wire, if there are any inside the area.)

This instruction is still experimental and suggestions are welcome. Instructions of this type may be added for other sections if the need arises.

pet The PET, short for Prompt-Echo Type, controls the method by which graphics input is obtained. For instance, selecting a point may be done using cross hairs, a mouse etc.

You have to specify 2 PET's for locator input since you may wish to use rubber banding to select the second point of an area, something that clearly does not make sense for the first point. Whenever only one point is required, only the first PET is used.

The PET's you have to enter are largely device dependent.

device By default all input is obtained from device 1, if you have other input devices attached to your display, you can ask the program to use them instead by specifying a device code.

wkid The identifier of the workstation over which this command should be run.

GRID
Format:

```
GRID   grid_x   [grid_y]
```

Sets, together with AREA, the grid for the TABLE instruction. The points form a grid inside the AREA with regular x (or r, note that this implies an exponential spacing in internal coordinates) and y (or ϕ) steps. The first parameter, *grid_x*, is the number of x- (or r-) divisions; *grid_y* is the number of

y- (or ϕ-) divisions. Instead of specifying the two arguments, you may specify only one in which case the value will be used for both x (or r) and y (or ϕ). Only values between 2 and MXGRID (usually 50) are acceptable. [Default: 25]

INTEGRATION-PARAMETERS

Format:

```
INTEGRATION-PARAMETERS
     [DIFFUSION-ACCURACY e_diff]
     [TOWNSEND-ACCURACY e_a]
     [DIFFUSION-STACK-DEPTH stack_diff]
     [TOWNSEND-STACK-DEPTH stack_a]
```

The diffusion and Townsend integration as used by the DRIFT TRACK and XT-PLOT instruction in this section and the SIGNAL instruction in the signal section, are performed via an adaptive Simpson method. In case for any drift-line step, the difference between the first and second order estimate differ by more than a fraction ε of a crude first order integral, the step is split and integration is attempted for the two parts independently.

The parameters ε and the maximum stack depth *stack*, can be chosen changed via this instruction. The accuracy parameters are preset to 10^{-3} and the maximum stack depth to MXSTCK, usually 20.

LINES

Format:

```
LINES   lines
```

lines Is the number of lines you would like to drift from the surface of each sense wire (DRIFT WIRE and XT-PLOT), from each side of the drift-area (DRIFT EDGE) and from the track (DRIFT TRACK). [Default: 20]

LORENTZ

Format:

```
LORENTZ   x   y
```

Prints the Lorentz angle (i.e. the angle between the electric field and the drift-speed vector) at the point (x,y).

MINIMISE

Format:

```
MINIMISE f_min
     [ON f_curve]
     [RANGE t_min t_max]
     [N n_t]
     [SELECT f_sel]
     [PRINT | NOPRINT]
     [FUNCTION-PRECISION e_f]
     [POSITIONAL-RESOLUTION e_p]
     [ELECTRON | ION]
     [NEGATIVE | POSITIVE]
     [DATASET dsn [member] [REMARK remark]]
```

Searches for the minimum of function the function *f_min* over the curve *f_curve*.

f_min

The function to be minimised, *f_min*, can depend on the variables TIME, LENGTH, DIFFUSION, AVALANCHE, LOSS, E, B and VELOCITY. The first 5 variables are calculated for a drift line, the last 3 are the local values on the curve of the electric and magnetic field and of the drift velocity.

[This function is by default TIME.]

f_curve

The curve parametrisation should have T as running variable. T assumes values in the range specified with the RANGE keyword. The function *f_curve* should return two values,

the (x, y) coordinate pair, but is treated as a single input word. The function should therefore be put between quotes.

[No default provided.]

RANGE

The range of the parameter T of the curve function.

[By default 0 to 1]

f_sel

A selection function *f_sel* may optionally be provided. Points on the curve which fail to satisfy the condition *f_sel* are not considered by the minimisation procedure. The function *f_sel* can depend on the variables TIME, LENGTH, DIFFUSION, AVALANCHE, LOSS and STATUS.

FUNCTION-PRECISION

The minimising loop is interrupted as soon as the minimum function value changes by less than a fraction ε_f between two iterations.

[Default is 10^{-4}.]

POSITIONAL-RESOLUTION

The minimising loop is interrupted as soon as the coordinate where the minimum function value was found, changes by less than a fraction ε_p between two iterations.

[Default is 10^{-4}.]

ELECTRON

Requests that minimisation be done for electrons.

[Default.]

ION

Requests that minimisation be done for ions.

[Not default.]

POSITIVE

Forces the charge of the particles to +1.

[Default for ions.]

NEGATIVE

Forces the charge of the particles to -1.

[Default for electrons.]

PRINT

Requests printout at intermediate stages of the minimisation.

[Default.]

DATA SET

Requests that the results be written to a file.

[Not default.]

The variable STATUS is assigned one of the following values: Hit_x_Wire, Hit_x_Replica, Left_Area, Hit_Plane, Abandoned, Too_Many_Steps, x being the wire type (one letter, upper case). LENGTH stands for the length of the drift line, DIFFUSION for the integrated diffusion coefficient, AVALANCHE for the integrated and exponentiated Townsend coefficient and LOSS for the integrated and exponentiated attachment coefficient.

OPTIONS

Format:

```
OPTIONS
     [DRIFT-PRINT | NODRIFT-PRINT]
     [DRIFT-PLOT | NODRIFT-PLOT]
     [KEY | NOKEY]
     [CHECK-ATTRACTING-WIRES | CHECK-ALL-WIRES]
```

The local options for the drift sections are listed below. They are valid also for the signal section with the exception of KEY.

DRIFT-PLOT

Enables plotting of the drift-lines used for XT-PLOT and TABLE. Various other calls will generate extra debugging output if this option has been selected. This option has no effect on the DRIFT instruction.

DRIFT-PRINT

Enables printing of summarised information about drift-lines used for XT-PLOT and TABLE. Various other calls will generate extra debugging output if this option has been selected. This option has no effect on the DRIFT instruction.

KEY

Specifies that the drift-time contours should be labeled and that a table of contour heights should be plotted. (only in NAG compilations).

CHECK-WIRES

When the option CHECK-ATTRACTING-WIRES is in effect, the program will only consider the wires that attract the particle being drifted as wires the particle can hit. This is adequate except when some of the wires have a clear dipole moment, i.e. wires that attract particles on one side and repel on the other. The CHECK-ALL-WIRES ensures proper drift-line termination under those circumstances. This option should also be selected when you intend to make a DRIFT WIRE plot for slightly repelling wires that have a strong dipole moment.

PLOT

Format:

```
PLOT [CONTOUR   [funct1]  [RANGE {cmin cmax | AUTOMATIC}]
                          [N ncont]
                          [LABEL | NOLABEL]                 ]
     [GRAPH     [funct2 ]                                   ]
     [HISTOGRAM [funct3]  [RANGE {hmin hmax | AUTOMATIC}]
                          [BINS n_bins]                     ]
     [SURFACE   [funct4]  [ANGLE ϕ Θ]           ]
     [VECTOR    [funct5 ,funct6]                           ]
```

An instruction which is very similar to the PLOT instruction of the field section, except that it plots information related to drift properties. The choice of plots is the same as in the field section: contours, graph, histogram, surface plot and vector plot. The vector, histogram and surface plots are obtained sampling over a grid of GRID × GRID points in the AREA. Contours are drawn inside the AREA; with a search density controlled by the GRID parameter. Graphs use the points on a predefined TRACK which need not be located inside the AREA. In each PLOT statement, one and only one plot of each type may be requested; CPU time can be saved if SURFACE, VECTOR and HISTOGRAM are combined because the field will be evaluated only once.

cmin cmax

The lowest and highest function value for which a contour will be plotted. AUTOMATIC means that *cmin* and *cmax* will be set such that the range of the function over the area is covered and all contours heights are round numbers. [Defaults are the extremes of the potential in the whole cell if contours of V are requested, 0 and 10000 else. However, automatic adjusting of the range is default and to obtain the settings described before, you have to specify RANGE * *.]

ncont

The number of contours to be plotted minus 1. [Default is 20.]

If you opt for automatic scaling, the number of contours you see, is sometimes larger than

ncont +1. Your value of *ncont* is used to obtain a rough distance between two contours which is rounded downwards to the nearest power of 10 times 1, 2 or 5. The bounds of the range are set equal to multiples of the rounded distance.

LABEL

Requests labelling of the contours. [On by default, only available from version 2.01 onwards.]

hmin hmax

Lower and upper bound of the histogram. If you specify AUTOMATIC, the range of the histogram is set to the interval $[\bar{x} - 3MAD_x, \bar{x} + 3MAD_x]$ rounded outwards. The first few (usually 100) entries serve to compute the mean and MAD. These entries are not necessarily representative for the whole sample. [Default is automatic scaling.]

n_bins

The number of channels the histogram should have [default is 100].

ϕ θ

The viewing angles used to project the surface plots [in degrees, defaults: 30^0 for ϕ and 60^0 for θ].

funct.

Functions to be plotted. Variables allowed in the expressions are X, Y (R, PHI for polar cells), EX, EY, E (ER, EPHI for polar cells), BX, BY, BZ, B (only if there is a B-field), VX, VY, VZ, V (local drift velocity, VR, VPHI for polar cells), LORENTZ (local Lorentz angle), TIME (integrated drift time), DIFFUSION (integrated diffusion coefficient), AVALANCHE (integrated, exponentiated Townsend coefficient), LOSS (integrated, exponentiated attachment coefficient), STATUS (drift line status cose), P (gas pressure). Note that there should be no blanks in the expressions.

You may substitute a commercial at @ for any of the functions. You will find yourself in the algebra editor where you can manually construct an instruction list. See also Section 4.5 on page 116 for details about the formulae.

PROJECT

Format:

```
PROJECT {XY | XZ | YZ}
```

Determines the way the DRIFT instruction displays the drift-lines. Unless you have a magnetic field, the default *XY* projection should do.

PREPARE-TRACK

Format:

```
PREPARE-TRACK
     [ATTACHMENT-COEFFICIENT | NOATTACHMENT-COEFFICIENT]
     [DIFFUSION-COEFFICIENT | NODIFFUSION-COEFFICIENT]
     [TOWNSEND-COEFFICIENT | NOTOWNSEND-COEFFICIENT]
     [LINES lines]
```

CPU-time consumption can be enormous when large amounts of signal calculations are called for. The PREPARE-TRACK statement helps avoiding the waste of time resulting from repeatedly calculating drift-lines from the same track in the same cell with the same gas. This call calculates drift-lines from a set of points on the current track, integrates the diffusion and Townsend coefficients for them and stores the information such that they can be interpolated during the signal calculation. The signal calculation does not use the interpolated information by default, you have to specify INTERPOLATE-TRACK on the SIGNAL statement to request this.

lines

The total number of drift-lines to be calculated, but the number is rounded to the next higher multiple of 4. Three quarters of the drift-lines start at equally spaced points on the track, one quarter is used to add points in areas where the interpolation would otherwise be poor (mainly segments with large jumps in drift-time). [The default is 20.]

ATTACHMENT-COEFFICIENT
Requests integrating the attachment coefficients.

DIFFUSION-COEFFICIENT
Requests integrating the diffusion coefficients.

TOWNSEND-COEFFICIENT
Requests integrating the Townsend coefficients.

SELECT

Format:

```
SELECT   wire-codes
```

SELECT enables you to select the wires for which x(t)- and DRIFT WIRE plots will be made. Their wire-codes should be listed in the argument, you may also refer to wires by number (obtained from the table you get by switching on the CELL-PRINT option in the cell section). The wire selection is shared between all sections. [Default: all 'S' wires.]

SINGLE

Format:

```
SINGLE  FROM  x y
        [PLOT f1 VS f2]
        [PRINT f3]
        [NEGATIVE | POSITIVE]
        [ELECTRON | ION]
```

This instruction allows to get information on a single drift-line that starts from a user specified point (x,y). The information can be presented as a table, with position, time and a user function at each point, but also as a plot of one user function vs another user function.

f1, f2, f3
Functions of the variables X, Y (R, PHI for polar cells), EX, EY, E (ER, EPHI for polar cells), BX, BY, BZ, B (only if there is a B-field), VX, VY, VZ, V (local drift velocity, VR, VPHI for polar cells), TIME (integrating drift time), PATH (integrating drift path length), DIFFUSION (local diffusion coefficient), TOWNSEND (local Townsend coefficient), ATTACHMENT (local attachment coefficient) and STATUS (drift line status code). [No meaningful default functions are provided.]

PRINT
Requests a printed table of the coordinate and integrated drift-time at each step and of the function *f3* . The table is by default not produced.

PLOT
Requests a graph of function *f1*, plotted along the y-axis, vs function *f2*, plotted along the x-axis. By default, a graph is not made.

ELECTRON
The drift-line will be calculated for an electron.

ION
The drift-line will be calculated for an ion.

POSITIVE
The particle which is drifted has a positive charge.

NEGATIVE
The particle which is drifted has a negative charge.

SPEED

Format:

```
SPEED  x  y  [NEGATIVE | POSITIVE]
             [ELECTRON | ION]
```

Prints the drift-speed at (x,y) for an electron or an ion.

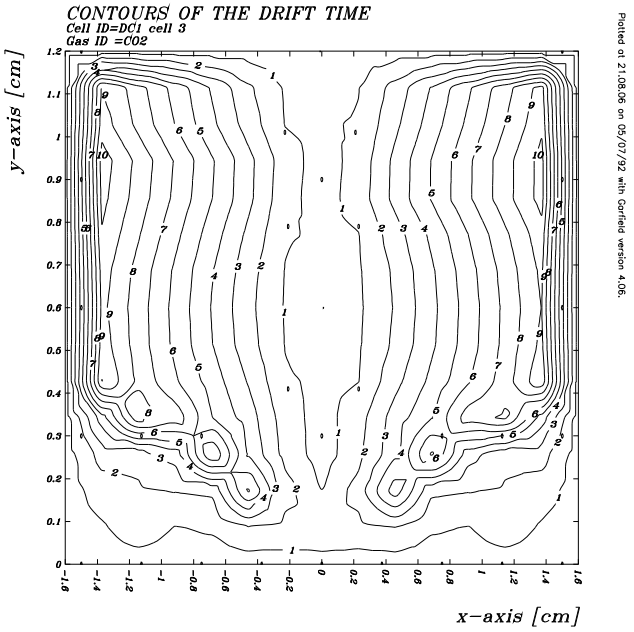


Figure 16. Example of a TABLE CONTOUR plot, clearly showing artefacts.

The plot on the left was produced with the following set of commands:

```
& DRIFT
grid 15
area -1.6 0.0 1.6 1.2
table contour
```

TABLE

Format:

```
TABLE  [TABLE | NOTABLE]
       [NOCONTOUR | CONTOUR]
       [ELECTRON | ION]
       [NEGATIVE | POSITIVE]
```

Produces a drift-time table, a table of the time a particle takes to reach a wire from a given point. The number of sampling points is controlled by GRID, the area by AREA.

TABLE
: Prints the drift-time table. The output can be very bulky if GRID is large.

CONTOUR
: Makes a contour plot based on the computed drift-time table. The contours may optionally be labelled via the KEY option. This plot is necessarily crude, especially if GRID is small, because no data-points between the mesh-points will be calculated. Beware also of artifacts produced by the smoothing of the lines. An example is shown in Figure 16. (This option is available only if the NAG graphics supplement routines have been linked to the program).

ELECTRON | *ION*
: Selects the particle to be drifted.

POSITIVE | *NEGATIVE*
: Changes the sign of the charge, if needed.

TIME

Format:

```
TIME  [n]
```

Measures the CPU time used for *n* [10 by default] drift-line calculations.

TRACK

This statement has two valid formats:

```
TRACK   x_start   y_start   x_end   y_end
TRACK   x_start   y_start   z_start   x_end   y_end   z_end
```

Defines a track to be used by the DRIFT TRACK instruction. Defaults are the previous values, they are not preset. The track is shared between the field, drift and signal sections. The track is always straight, even if the cell has been described in polar coordinates.

The second format is recognised only with future extensions in mind. All drift-lines start at z=0, no matter the z at which the track is located. See the remarks under AREA.

x_start x- or r-coordinate of begin point [cm].

y_start y- or ϕ-coordinate of begin point [cm or degrees].

z_start z-coordinate of begin point [cm].

x_end x- or r-coordinate of end point [cm].

y_end y- or ϕ-coordinate of end point [cm or degrees].

z_end z-coordinate of end point [cm].

TRAP

Format:

TRAP n

Determining that a particle hits a perhaps very thin wire, is a remarkably difficult task. One of the criteria used by Garfield is that every particle traveling by a wire at a distance smaller than *n* wire-radii, is considered to be caught, provided the wire can, given its charge, in principle attract the particle (unless the CHECK-ALL-WIRES option is in effect). Within this area, the alternate (dedicated) integration algorithm takes over and it might therefore be a good idea to choose a large value for *n*. [The default is 5.]

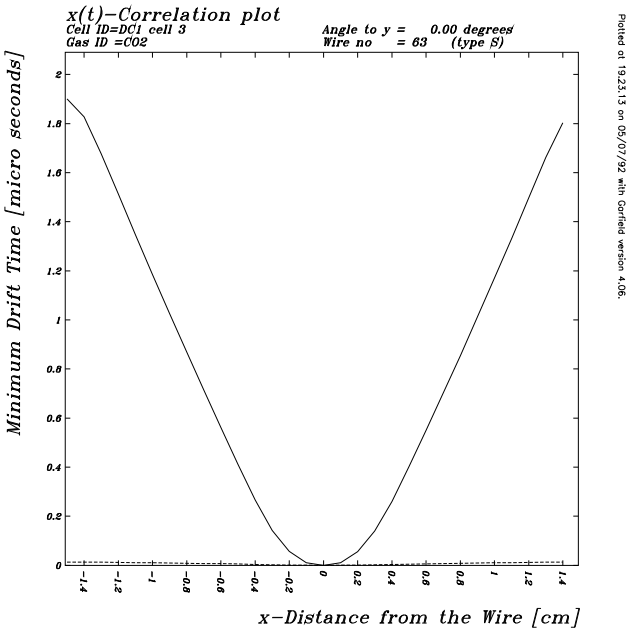


Figure 17. An example of an x(t)-correlation plot.

XY-PLOT

Format:

```
XT-PLOT      [DATASET dataset [ member ]]      [REMARK remark]
             [ANGLE φ]
             [X-RANGE xmin xmax]      [X-STEP x]      [JUMP jump]
             [ITERATIONS { iter_max | YES | NO or OFF } ]
             [PRECISION e]
             [LEFT-ANGLE-RANGE Θ^min_left Θ^max_left]
             [RIGHT-ANGLE-RANGE Θ^min_right Θ^max_right]
             [PRINT-XT-RELATION | NOPRINT-XT-RELATION]
             [PLOT-XT-RELATION | NOPLOT-XT-RELATION]
```

(Only for Cartesian cells; see also the more refined ARRIVAL instruction.) Calculates an ordinary x(t)-correlation for all sense wires located in the current area. XT-PLOT also calculates the integrated diffusion coefficient, and plots this as a dashed line in the graph. A description of the algorithm can be found in Section 4.3.3 on page 112.

The proper functioning of this call depends on the settings of several global variables: LINES, EPSILON, AREA. Greater or lesser precision can be obtained by playing with the local variable PRECISION and the ITERATIONS switch. Iterations are expensive in terms of CPU time and their number should therefore be limited; they are however instrumental in finding a good approximation of the true minimum. As a general rule, the number of iterations gets lower when the LINES parameter is increased (LINES drift-lines are used for an initial search from the wire to the edges). This search can be made more efficient by limiting the ANGLE-RANGE, even to the point that LINES can be made smaller.

The graph made by the XT-PLOT instruction consists of two lines: the drift time (drawn as FUNCTION-1, see the graphics REPRESENTATION instruction, Section 3.12.10) and the diffusion (drawn as FUNCTION-2). Points for which the results of the computation are not considered fully reliable, are not drawn. There may therefore be gaps in the curves. If a curve segment consists of only one point, then a marker is used to show the point.

An example of this kind of plot is shown in Figure 17 on page 63.

dataset The x(t)-relations will be written to the dataset if *dataset* is specified. The dataset may exist before program execution, in which case the new relations will be appended. A member name *member* may optionally be specified, but it is not used anywhere in the program. The dataset is written in the format '(L1,1X,4(E15.8,2X),A)', the logical indicates whether the point is reliable or not. The reals are x, the minimum t, the value of y for which the minimum occurs and the integrated diffusion. The text provides additional information on the quality of a point. A program reading the file should be able to recognise the phrase 'Not available' which is substituted for a number that has not been evaluated or that is not considered to be sufficiently reliable. Refer to Section 2.3.2 on page 10 for details about the file format and naming conventions.

remark By default, the remark states the number of the wire the present x(t)-relation applies to and the ϕ for which it has been calculated. This defaults is overriden if *remark* present.

ϕ The angle ϕ (defined in Section 4.3.3 on page 112) should be in the range -45^0 to $+45^0$.

x Sets the interval in x between 2 points for which the minimum t is calculated (the x-coordinate of the wire is one of the points, the range is taken from the AREA). The default value of *x* is some reasonable number (1, 2 or 5 times some power of 10) such that the x(t) will contain about 20 data-points.

xmin - xmax The x(t) relation is by default sampled at regularly spaced points on the whole x-range of the drift-area. By setting *xmin* and *xmax* you may restrict this range. [Defaults: respectively the lower and upper x-bound of the area.]

jump The drift-time for one every *jump* points is minimised, this is accurate but time-consuming. If the drift-line which minimises t for one x, gives a minimum t for other x in the neighbourhood too, an interpolation is usually adequate (skipping the minimising procedure). Note that interpolations on drift-lines are usually accurate only up to the 3rd digit. By default the parameter has a value of 1, i.e. all points are minimised.

iter_max The x(t) algorithm iterates at most *iter_max* [5, by default] times to find a minimum drift-time. Restricting the number of cycles should only be seen as a safeguard against looping without actually getting nearer to a minimum. It is normally preferable to relax the convergence criteria (see ε) if CPU time consumption becomes unbearable.

ε The local precision, used to check whether convergence has been achieved, see Section 4.3.3 on page 112. Values less than 10^{-4} are useless in single precision compilations.

θ_{min}, θ_{max} Limits the angles being explored in the initial search. The 0^0 line for θ^{min}_{right} and θ^{max}_{right} is the positive x-axis, for θ^{min}_{left} and θ^{max}_{left} the negative x-axis. The program will recover from an ill-chosen angle-range, be it at the expense of many iteration cycles. In the presence of a strong magnetic field, the drift-line over which the first electrons reach the wire, can have a substantial angle with respect to the x-axis. It is advisable under such circumstances to limit the search to angles around this drift-line; the DRIFT WIRE instruction can be used to make a good guess. [Defaults are -10^0 and $+10^0$, both left and right, irrespective of the magnetic field, if any.]

PRINT-XT-RELATION Requests a printout of the x(t) relation [default].

PLOT-XT-RELATION Requests a graph of the x(t) relation [default].

WRITE-EQUAL-TIME-CONTOURS

Format:

```
WRITE-EQUAL-TIME-CONTOURS
     DATASET dataset [member]  [REMARK remark]
```

A call that can be issued once a drift-line plot with contours has been made. The points that served to draw the equal drift-time contours are written to (member *member* of) the file *dataset*. For easier reference, you may add a remark. The DATASET and REMARK keywords may be omitted, provided the order of the arguments is respected: e.g. *member* has to be specified if you wish to have a *remark* Refer to Section 2.3.2 on page 10 for details about the file format and naming conventions.

WRITE-TRACK

Format:

```
WRITE-TRACK
     DATASET dataset [member]  [REMARK remark]
```

Writes a 'prepared track' (see PREPARE-TRACK) to a dataset. The dataset is written when the command is issued, in contrast to most other WRITE statements which are delayed until the data to be written are available. This statement should therefore be preceded by PREPARE-TRACK. The DATASET and REMARK keywords may be omitted, provided the order of the arguments is respected: e.g. *member* has to be specified if you wish to have a *remark* Refer to Section 2.3.2 on page 10 for details about the file format and naming conventions.

Example of a valid drift section:

```
& DRIFT
* Plot drift-lines starting from the surface of the D wires.
SELECT D
DRIFT WIRE
* Plot 100 drift-lines from a track, without equal time contours.
TRACK -1 -1 -1 1
LINES 100
DRIFT TRACK TIME-GRAPH, VELOCITY-GRAPH, NOCONTOUR
* Calculate x(t)-relations for the C wires, output them to a dataset.
SEL C
XT DATA 'DISK$USER:[MYDIR.XT]XT_DC1.DAT' ...
     REMARK "Override the default for fun."
```

3.10 The signal section

This section simulates the signal induced on the sense wires resulting from the passage of a charged particle through the chamber. It includes an option to write the signals to a file for analysis by Sceptre, Spice or an other electronic circuit analysis program. The header line to enter this section is & SIGNAL. The following instructions are valid:

AREA

See the drift-section, the drift and signal section have a common drift area.

AVALANCHE

Format:

```
AVALANCHE
     {EXPONENTIAL mean | FIXED factor | GAUSSIAN  mean rel_dev | TOWNSEND}
```

This instruction sets the multiplication factor to be used in the signal simulation. The avalanche multiplication factor is only used in the final stage as a global scaling factor for the signals. Multiplication factors smaller than 1 are always replaced by 1.

EXPONENTIAL

The multiplication factors are drawn from an exponential distribution with fixed average *mean*.

FIXED

All multiplication factors are set equal to *factor*.

GAUSSIAN

The multiplication factors are drawn from a Gaussian distribution with an average *mean* and a standard deviation relative to the average *rel_dev*.

TOWNSEND

The multiplication factors are drawn from an exponential distribution with an average equal to the exponential of the integrated Townsend coefficient over the electron drift-line. This option can only be used if the Townsend coefficients were entered during the most recent gas section. Note that the measurement of Townsend coefficients is notoriously difficult and that an inaccuracy in the Townsend coefficient is amplified by the exponentiation in the computation of the multiplication factor. The calculated multiplication factor can therefore easily be off by an order of magnitude.

CHECK

Format:

```
CHECK  {AVALANCHE | DIFFUSION | CLUSTER}
       [RANGE mult_min mult_max]
       [FROM x y]
       [N n]
       [BINS n_bins]
```

A debugging instruction that checks the proper functioning of the random number generators of the signal section.

AVALANCHE

Plots the avalanche multiplication factor distribution. If the avalanche type has been set to TOWNSEND, the starting point of the drift-line has to be specified via *FROM x y*.

CLUSTER

Plots a histogram of the number of clusters generated on the current track, the track has to be set and it may not be a point. In addition, a histogram of the cluster-size distribution will be generated (overlaid with the appropriate functions if available).

DIFFUSION

Plots the arrival time distribution for a drift-line starting from (*x*, *y*).

n

Sets the number of entries in the histograms (default 10000).

n_bins

Sets the number of bins in the histogram to be generated.

RANGE

Is only effective with *AVALANCHE*, sets the range of the histogram (default 1 to 10^{10}).

x, y

Starting point of the drift-line to be examined.

EPSILON

See the drift-section.

FOURIER

Format:

```
FOURIER   n_Fourier
```

(Only relevant for periodic cells). Sets the number of Fourier terms in the ion-tail calculations to *n_Fourier*. The convolution equations for the ion-tails are (in case of periodic cells) solved via Fourier transforms (each term in the series is a matrix similar to a capacitance matrix). Using a large number of terms increases the accuracy but may also lead to an enormous amount of disk I/O (the matrices are stored on an external scratch file). A doubly periodic cell with 100 wires for instance, requires (in the standard parameter setting) a frequent manipulation of 2.56×10^6 complex numbers, which makes it impracticable on most computers. You may choose *n_Fourier* yourself, it should be an integral power of 2 (in view of the FFT), 1 is allowed and is default.

GET-TRACK

Format:

```
GET-TRACK  dataset  [member]
```

Retrieves a 'prepared track' (see PREPARE-TRACK in the drift section) from a dataset written by a call to WRITE-TRACK. The track begin and end points are stored in such a dataset, hence there is no need to enter them again via TRACK. Be sure that you load the cell and gas data that were active when you created the dataset. The prepared track is not used in the signal calculations unless you specify INTERPOLATE-TRACK on the SIGNAL statement.

dataset The name of the dataset in which the prepared track can be found. Refer to Section 2.3.2 on page 10 for details about the file format and naming conventions.

member The member name of the prepared track, a string of up to 8 characters. You may use a wildcard for this item: TR*1 will for instance match TRACK-1 or TR1 but not TRACK122. The default is an asterisk, matching every member name. The first member in the dataset that is a prepared track and matches the member name you specify, will be read. The %INDEX command can be used to find out which members have been stored in a given dataset.

ION-LINES

Format:

```
ION-LINES   n_ions
```

The calculation of the ion-tails involves the drifting towards the anode of *n_ions* ions from equally spaced points around all sense wires (if CROSS-INDUCED has been inhibited) or from all wires (if CROSS-INDUCED has been enabled) hit by at least one cluster. One can sometimes save a lot of CPU time by reducing *n_ions* without loosing too much accuracy. [The default is 10.]

OPTIONS

Format:

```
OPTIONS  [CLUSTER-PRINT | NOCLUSTER-PRINT]
         [CLUSTER-PLOT | NOCLUSTER-PLOT]
         [ION-PLOT | NOION-PLOT]
         [SIGNAL-PLOT | NOSIGNAL-PLOT]
```

In addition to the general options and the options of the drift section, a few local options are available to control the amount of output:

CLUSTER-PLOT
: Plots the track of the charged particle, the positions of the clusters and drift-lines of the clusters.

CLUSTER-PRINT
: Prints the same data CLUSTER-PLOT plots.

ION-PLOT
: Controls the plotting of the ion-drift-lines used for the calculation of the ion-tail, if this part of the calculation has been requested. The ion-tail is calculated (and therefore plotted) only once per signal section unless a parameter affecting it is changed.

SIGNAL-PLOT
: Plots the signals on the sense wire; the signal is not plotted if it is identically zero, for instance due to a poor choice for RESOLUTION.

REPEAT

Format:

```
REPEAT   times
```

The next simulation instruction will be carried out *times* times [default is 1]. Note that the setting of this parameter has some bearing on the interpretation of the OLD and NEW keywords on SIGNAL.

Please consider using a DO-loop instead, REPEAT is scheduled to disappear in some future release.

RESOLUTION

Format:

```
RESOLUTION   t_start   t_step
```

This statement changes the time-window of the signals, both in the dataset and in the plots.

t_start The first point in time at which the signal is to be sampled relative to the time the particle traversed the cell [in µsec, default is 0 sec].

t_step The signal is output at MXLIST (usually 200) points spaced by *t_step* [in µseconds, default is 0.01 µsec].

SELECT

Format:

```
SELECT  wire-codes
```

SELECT will mark the wires with a code appearing in the argument so that the signal calculation handles them as the sense wires. The signals on wires with codes between brackets will be summed. For example: S(PT)R will give as output signals (i) separate signals for all 'S' wires, (ii) the signals on all 'P' and 'T' wires added together to give only one signal and (iii) a separate signal for each of the 'R' wires. Wires can also be selected using their number (consult the table obtained with the option CELL-PRINT). [By default all wires with code 'S' are used as sense wires.]

SIGNAL

Format:

```
SIGNAL [AVALANCHE | NOAVALANCHE]
       [DIFFUSION | NODIFFUSION]
       [ION-TAIL | NOION-TAIL]
       [NEW | ADD]
       [NOCROSS-INDUCED-SIGNAL | CROSS-INDUCED-SIGNAL]
       [NOELECTRON-PULSE | ELECTRON-PULSE]
       [NOINTERPOLATE-TRACK | INTERPOLATE-TRACK]
```

Marks the beginning of a simulation which will be repeated REPEAT times. It assumes that you have defined a track on beforehand (TRACK statement). You may also wish to select an avalanche type, a number of Fourier terms and a number of ion drift-lines before carrying out the simulation. Further, a

WRITE statement before this instruction is needed if you would like the signals to be written to a dataset. Note that at least some output has to be requested (via OPTIONS or WRITE), otherwise the simulation will not be performed. Signal simulations are potentially highly CPU time consuming operations.

AVALANCHE

Takes the avalanche near the wire-surface into account, the type of avalanche can be selected by the user, see AVALANCHE.

CROSS-INDUCED

Calculation/no calculation of the cross-induced signals i.e. the signal induced on wire i by ions drifting away from wire j ($i \neq j$). Be careful when using it: an external scratch file is used to store the intermediate results, considerable amounts of disk I/O may therefore result in particular if there are many (sense)wires.

DIFFUSION

Takes longitudinal diffusion of the electrons along the drift-lines into account. There is no way in this program to allow lateral diffusion.

E-PULSE

Adds spikes to the signal, indicating the time the electrons hit the wire. No detailed induced current calculation is performed, rendering this option rather useless.

INTERPOLATE-TRACK

Requests the prepared track (see PREPARE-TRACK) be interpolated during the signal simulations. By default all drift-lines are calculated when they are needed - this tends to be rather CPU-time consuming for large numbers of signals.

ION-TAIL

Adds ion-tails to the signal, the way the ion-tails are calculated is to some extent under user control (see FOURIER and ION-LINE). The program attempts to calculate the ion-tails fairly precisely.

NEW ADD

Create a new signal or add the results to the previous signals. NEW is default for the first call in the section ADD for all following calls. The signals are cleared each time if NEW has been specified and REPEAT has been set to a value different from 1. ADD can for instance be used to study two-track separation.

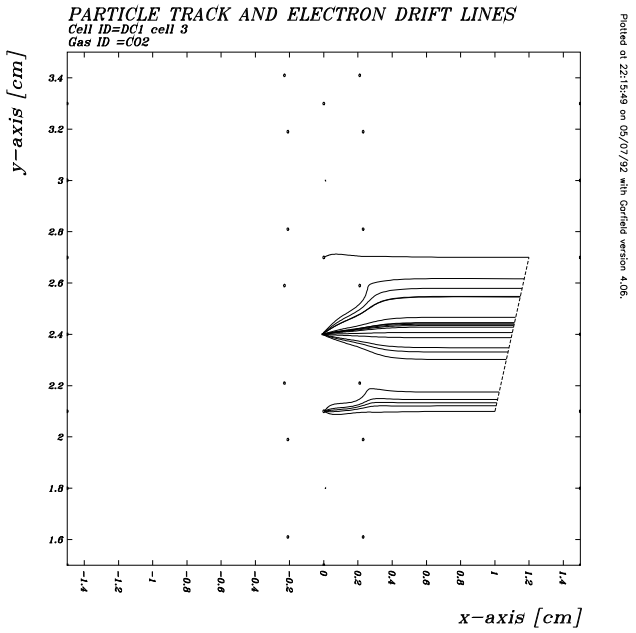


Figure 18. Clusters and electron drift-lines. The dashed line represents a track segment. At intervals generated according to an exponential distribution, clusters have been put. An electron drift-line has been calculated from each cluster and the integrated diffusion and integrated Townsend coefficient have been evaluated.

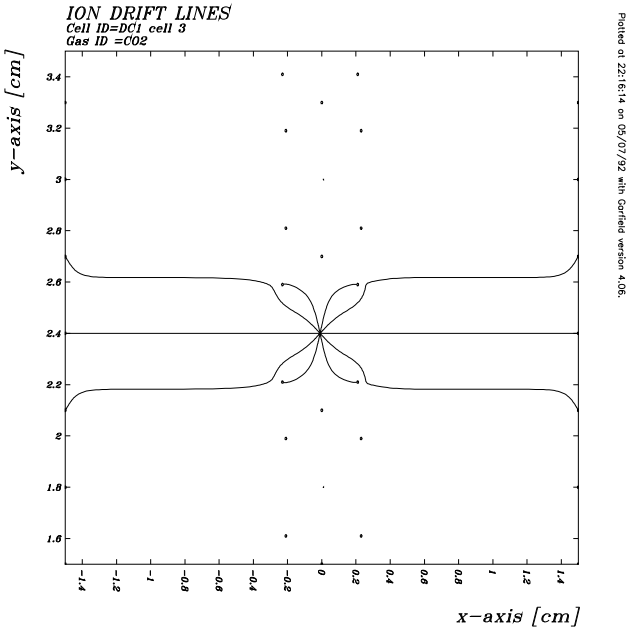


Figure 19. Ion drift lines. When the clusters shown in Figure 18 on page 70 reach a wire, they generate an avalanche. The ions that are produced in the avalanche drift (slowly) away from the wire as shown in this Figure.

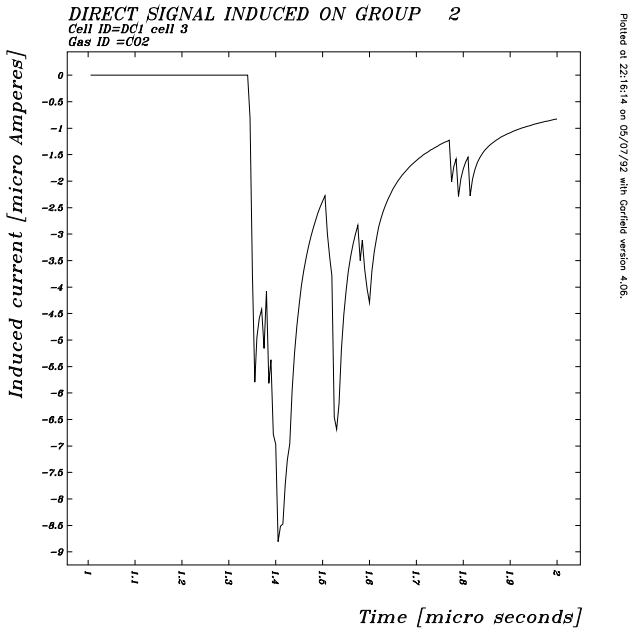


Figure 20. Example of a signal. This graph shows the signal induced by the ions moving away from the central wire of Figure 18. The small spikes are the result of diffusion, the broader structures reflect the various (groups of) clusters.

The plots shown on this page have been produced with the following set of commands:

```
& SIGNAL
opt cl-pl ion-pl debug drift-pl
area -1.5 1.5 +1.5 3.5
track  1.0 2.1 1.2 2.7
resolution 1 0.005
signal
```

TRACK

Format:

```
TRACK   x_start   y_start   x_end   y_end
```

Defines the track of a charged particle through the cell. The clusters will be generated at randomly distributed points on this track. The track will be clipped, if necessary, to ensure that it lies entirely in the drift-area. Defaults are the previous values, they are not preset. The tracks is shared between the field, optimise, drift and signal sections. The track is always straight, even if the cell has been described in polar coordinates.

x_start x- or r-coordinate of begin point [cm].

y_start y- or ϕ-coordinate of begin point [cm or degrees].

x_end x- or r-coordinate of end point [cm].

y_end y- or ϕ-coordinate of end point [cm or degrees].

TRAP

See the drift-section.

WRITE-SIGNAL

Format:

```
WRITE-SIGNAL
     [DATASET  dataset  [member] ]
     [REMARK  remark]
     [FORMAT  {SPICE | SCEPTRE} ]
     [STATE  {OPEN | CLOSE | RESUME | SUSPEND} ]
```

Controls the output to dataset of the signals produced by subsequent SIGNAL instructions, no signal is written immediately. The STATE keyword would not normally be used together with DATASET; such a usage is permitted however.

dataset

A dataset name like 'SIGNALS SCEPTRE A' (CMS, mind the quotes !) or [VEENHOF]SIGNAL.DAT (Vax). The new signals will be appended as a new member if the dataset exists at the time the signals are being written. In contrast to most other WRITE instructions, all keywords such as DATASET and REMARK are compulsory. Refer to Section 2.3.2 on page 10 for details about the file format and naming conventions.

remark

This string will override the default comment stating the wire-number and the angle. A *remark* may be specified by itself, i.e. without dataset, in which case only the previous remark (or the default) is replaced.

OPEN

Opens a dataset for writing signals, this is default when a dataset is specified explicitly.

CLOSE

Closes the dataset, forgetting its name.

RESUME

Resumes writing to the dataset previously opened, the dataset name need not be specified again.

SUSPEND

Temporarily suspends writing of signals to the dataset, writing may be resumed later on.

SPICE

The dataset will be written in a Spice readable format.

SCEPTRE

The dataset will be written in a Sceptre readable format.

Example 1: double track resolution (CMS file naming conventions)

```
& SIGNAL
* First define a track, then set starting time and time interval
TRACK  -0.5 -0.5 0.5 -0.5
RESOLUTION 1.0 0.05
* Open a file for the Spice output and select the sense wires
WR-SIG DATASET: 'SIGNALS SPICE B', FORMAT=SPICE
* The signals on all 'S' type wires are to be summed. All other
* wires are ignored. The simulation will therefore produce just
* one output signal.
SELECT  (S)
* Perform the simulation
SIGNAL  DIFFUSION NOAVALANCHE, NOE-PULSE ION-TAIL
* Open a new file, for Sceptre output this time:
WRITE-SIGNAL DATASET SIGNALS.SCEPTRE.B FORM SCEPTRE
* redefine the track,
TRACK  -0.5 -0.6 0.5 -0.6
* and add the new signals to the old ones, writing them to the
* dataset. The selection of the sense wires remains unchanged.
SIGNAL ADD
```

Example 2: using a prepared track (Vax file naming conventions)

```
& DRIFT
track 0.1 -0.9 0.1 0.9
prepare-track
write-track 'disk$v8:[veenhof.signal]test.dat'

& SIGNAL
write-signal [-]test.dat
signal interpolate-track diffusion noavalanche
```

A track is prepared and the result is written to a file which can be used for subsequent runs as shown below. Note that the command to save the track is issued **a f t e r** the track has been prepared whereas the instruction to write the signals to a dataset is issued **b e f or e** the signals are calculated. The INTERPOLATE-TRACK argument must be specified for the prepared track to be actually used.

```
& SIGNAL
get-track 'disk$v8:[veenhof.signal]test.dat'
write-signal [-]test.dat
signal interpolate-track diffusion noavalanche
```

It is good practice to store cell, gas, track and other data related to one chamber in the same dataset. No confusion can arise if there is only one member of each type because the GET instructions look only at members of the proper type. Use member-names to distinguish members of the same type.

3.11 The stop command

The & STOP command allows decent program termination. & STOP will close all input and output files, close the graphics system and then print a log of CPU time consumption, of plots produced during the run and a list of dataset accesses. An EOF (end of file, usually control-Z) has roughly the same effect. The null input line, the EOF mark in interactive VM/CMS, is intercepted and subsequently ignored. Rather use & STOP or an EOF than an interrupt, control-Y on Vax or control-Q on Apollo, if the program has been generating a metafile.

& STOP does not work from inside the various sub-sections: algebra, dataset, help, graphics etc.; control-Z does work. If you get stuck in one of those, try EXIT and then & STOP.

& EXIT and & QUIT are synonyms of & STOP.

3.12 Instructions valid in all sections

The instructions listed below are section independent. They may appear anywhere in the input (with the exception of the dataset, graphics and help sub-sections).

3.12.1 Global options

Options are switches that influence the behaviour of the instructions that follow. All sections have an instruction that allows changing and displaying the settings of the options. The options mentioned here are global in that they have a meaning in every section. The options mentioned in the beginning of this chapter have a bearing on only one or perhaps a couple of sections and should therefore only be specified in an OPTIONS command in the appropriate sections. You may freely mix global and local options in a single OPTIONS line.

OPTIONS Format:

```
OPTIONS  [NODEBUG | DEBUG]
         [INPUT-LISTING | NOINPUT-LISTING]
         [NOIDENTIFICATION | IDENTIFICATION]
```

DEBUG

Prints some critical intermediate results, useful only if you have a program listing. DEBUG does not require much CPU time but it tends to produce a lot of output.

Debugging is initially off by default but this can be overruled by the /DEBUG command qualifier (on Vax), the DEBUG command line option (VM/CMS) and the -debug command line option (Unix).

IDENTIFICATION

Prints the name of a few selected routines when they are called. Useful for tracing the program.

Tracing is initially off by default but this can be overruled by the /IDENTIFICATION command qualifier (on Vax), the IDENTIFICATION command line option (VM/CMS) and the -identification command line option (Unix).

INPUT

Echoes the input instructions. This option is off by default when running interactively but on in batch.

3.12.2 Kernlib error messages

Mainly for debugging purposes, you can control handling of error messages generated by the KERNLIB routines.

ERROR-HANDLING Format:

```
ERROR-HANDLING  MESSAGE mess_id
                [PRINT {ALWAYS | NEVER | nprint} ]
                [ABEND {NEVER | nabend} ]
```

Requests that the messages identified by *mess_id*, see the N001 writeup for details, are printed respectively always or never or *nprint* times. Program execution is respectively never terminated or at *nabend+1* 'th occurence of the error. Both *nprint* and *nabend* are meaningful only in the range 0 to 100.

3.12.3 Printing a comment

SAY Format:

```
SAY string
```

Will simply copy the *string* to the current output stream. Like in all other instructions, expressions inside curly brackets are evaluated before the instruction is processed, that is, in this case, before the *string* is printed. Thus, SAY can be used to do simple arithmetic. This instruction is frequently used inside loops to print out the value of some global variable (see Section 3.2.1 on page 17).

Examples:

```
Say "Time left: {entier(time_left/3600)} hours, ...
{entier((time_left-3600*entier(time_left/3600))/60)} ...
minutes, {time_left-60*entier(time_left/60)} seconds."

Say {arctanh(0.3)}
```

3.12.4 Comment lines

Comment Format:

```
* anything
```

The contents of the line is ignored. Mainly useful in input files and in batch.

3.12.5 Input translation tables

You may wish to have a character you type translated into another, for instance a character not found on your keyboard. The TRANSLATE command helps you to achieve this. The translation table can be updated any number of times; each modification is valid from the point it was entered onwards. The translation table can be written to a Garfield library and be retrieved from the library later on.

Reading of the translation commands is subject to the translation tables in effect at the moment the command is issued.

TRANSLATE Format:

```
TRANSLATE   [CYCLES ncycle]
            [INTEGER | HEXADECIMAL] char_in
            [INTEGER | HEXADECIMAL] char_out ...
```

Specifies which characters are to be translated; you may list several translations on one line. Previously specified translations remain in effect. Translations are cancelled by requesting a character is translated into itself; you may have to identify the character via its translation or its integer or hexadecimal code.

Translation of the input string is performed before the conversion to upper case, before the string is split into words and before special characters are acted on.

The current translation table is displayed if the TRANSLATE instruction is entered without arguments.

By default no translation is performed, except on Vax where the tab character (hex 9) is translated into a blank.

INTEGER

Means that *char_in* or *char_out* is the integer code, ASCII or EBCDIC as appropriate, of the character you wish to reference. The integer code must be in the range 0 to 255.

HEXADECIMAL

Means that *char_in* or *char_out* is the hexadecimal code, ASCII or EBCDIC as appropriate, of the character you wish to reference. The hexadecimal code must be in the range 00 to FF and should be entered pure, i.e. without leading X' etc.

char_in

The character to be translated: either the character itself or its integer code or its hexadecimal code.

char_out

The character *char_in* is to be translated into, either the character entered as-is or its integer code or its hexadecimal code.

ncycle

Number of times the translation table should be applied to each input string. By default each character is translated only once but you may request up to 256 translations. To switch translation temporarily off, specify 0.

GET-TRANSLATION-TABLE Format:

```
GET-TRANSLATION-TABLE   dsname   [member]
```

Retrieves the translation table *member* stored in the dataset *dsname*.

WRITE-TRANSLATION-TABLE Format:

```
WRITE-TRANSLATION-TABLE
     DATASET dsname [member]
     lsqb;REMARK remark]
```

Writes the current translation table to member *member* of dataset *dsname*. You may add a *remark* for easier identification later on.

3.12.6 Obtaining help

HELP Format:

```
? [search_string]
```

Provides on-line help, provided the additional files have been put in place. The help facility looks very similar to that on a Vax (where it *really is* the standard help utility). The information is organised in the form of a tree. The major branches are the sections and sub-sections. Some more general information is also available near the root. At each level you are presented with a list of sub-topics. Choosing one of them, you may use wildcards for this, will take you one level higher in the tree. In wildcards, the asterisk (*) can represent any number of arbitrary characters, *IX matches both ASTERIX and IDEFIX. An asterisk at the end is always assumed in the help facility, hence A*R matches both ABRARACOURCIX and ASTERIX. A blank return brings you down by one level. You may at any time type a question mark (?) instead of a sub-topic. The current item and the list of sub-topics are then displayed again.

HELP or INFORMATION may be typed instead of the question mark.

3.12.7 Input from and output to datasets

Input Format:

```
< file_name     [<< label]
```

The file is opened and its contents is read as input until the end of the file or the *label*, if specified, is reached. Within the alternate input file, input may be taken from another file and so forth (up to 10 times). The *label* should be a string of up to 80 characters; the file will be read up to the end of the file if specified as EOF, this is also the default action. Each file has its own *label*.

The input taken from a file is handled in exactly the same way as input from the terminal, hence the lines will be echoed if the INPUT option is on. Refer to Section 2.3.2 on page 10 for details about the file naming conventions and the file format.

Input recording Format:

```
>> [file_name]
```

Input typed to the terminal will be recorded in the specified file. Type >> without argument to stop recording input statements. Input recording is on by default in interactive runs and off in batch.

Output Format:

```
> [file_name]
```

Routes some of the output to the specified file. Type a > without argument to stop sending the output to a file. This instruction applies mainly to output which might otherwise interfere with plots. Error messages and warnings are always written to standard output. Refer to Section 2.3.2 on page 10 for details about the file naming conventions and the file format.

3.12.8 Shell commands

Shell Format:

```
$ command
```

The *command* after the $ sign is not interpreted by Garfield but passed on to the program environment (CMS, DCL, Aegis, Unix). The command is passed on as is, without case conversion. This feature can for instance be used to obtain a directory listing, to edit files, to send messages, to ask for the time etc.

Running another program from inside Garfield should be avoided under VM/CMS. Also, executing exec files will sometimes cause the program to abend. In addition some common VM/CMS commands cannot be executed, see the writeup for VMPACK (Z305), routine VMCMS. Finally, take care to enter CMS commands in upper case.

Such restrictions do not seem to be present on Apollo and Vax. Don't try to run Garfield inside itself: the program write locks some of its log and working files. Some Vaxes have a very low sub-process quota; ask your system manager for more if needed.

To make a longer excursions into CMS, type:

```
$
(CMS commands)
RETURN
```

The 'excursion' method uses the CMS SUBSET mode, which offers some protection against typing commands which are illegal in this context.

To make a longer excursions to DCL (on a Vax), type:

```
$
(DCL commands)
LO
```

The DCL commands are executed in a sub-process that is essentially independent from the main process.

To make a longer excursions to Aegis (on Unix) type:

```
$
(Aegis commands)
return
```

The Aegis commands are executed in a sub-shell and are independent from the shell in which the program runs but shell and sub-shell share the same I/O streams. The choice for Aegis as shell is arbitrary and could easily be changed to the C shell. Your environment on Unix systems (Cray, Sun) is a C shell:

```
$
(Unix commands)
exit
```

3.12.9 Garfield library manipulation commands

These commands allow obtaining information about a Garfield library, marking some of its members for deletion, purging the library, listing some members etc.

An editor can be used to modify the files, but this is not recommended since retrieval of some types of members (cell, gas, track ...) relies without checking on the integrity of the data. It is safe to remove complete members manually.

If the % is the only character on the line, further dataset commands can be entered without the % sign, until you type EXIT, which will return you to where you came from. There are a few commands that can not be executed in this fashion.

Both the *member* and the *type* may be of the wildcard type, the match-all character being the asterisk '*'. No asterisk at the end of the strings is assumed.

% DEFAULT

Format:

```
% DEFAULT   [default_dataset_name]
```

(VM/CMS and Vax only) This command allows you to establish defaults for the various components of a dataset name on Vax/VMS: node, disk, directory, file name, file type, version number and on VM/CMS: file-name, file-type and file-mode. All components can be overruled in the actual dataset specification. The initial value is .DAT without wildcard for Vax and file-type INPUT, file-mode * (any) for VM/CMS.

Under VM/CMS, an equal sign (=) should be substituted for a component of the dataset name for which you do not wish to establish a default. You do not have to enclose the dataset name by quotes here, except if you have used equal signs, since these are normally separators. Dots may be used instead of blanks to separate the fields. When a dataset is referenced, fields specified as = are replaced by the corresponding default. If the file-name or file-type is still an equal sign after this substitution, it is set to * (match anything). The file-mode is set to the letter of the first RW disk for write and read-write access and to * for read access, if both the default and the specified file have an equal sign as mode.

Examples: (VM/CMS)

```
%default '* input ='
% def GARFIELD.*.A
```

In the first example, the mode has to be entered explicitly, the type defaults to INPUT and the name can be anything.

This command can not be issued from within a dataset subsection.

% DELETE

Format:

```
% DELETE   dataset   member   [type]
```

Marks *member* in *dataset* for deletion. The member is not actually removed, that is done by the PURGE command. SCRATCH is a synonym for DELETE.

% DUMP-HELP-FILE

This debugging command dumps the entire contents of the help file, thus allowing to check the integrity of the tree structure.

This command can not be issued from within a dataset subsection.

% INDEX

Format:

```
% INDEX   dataset   [member   [type] ]
```

Prints a listing of the members contained in *dataset*. DIRECTORY is synonymous to INDEX.

% LIST

Format:

```
% LIST   dataset   [member   [type] ]
```

Prints the contents of *member* of type *type* in *dataset*. If the *member* is omitted, all members will be listed. PRINT is synonymous to LIST.

% RECOVER

Format:

```
% RECOVER   dataset   member   [type]
```

Is the converse of DELETE: unmarks *member* in *dataset*, thus making it readable again. RESCUE is synonymous to RECOVER.

% PACK HELP-FILE

Format:

```
% PACK-HELP-FILE     [TRANSLATE | NOTRANSLATE]
```

This command will translate the normally legible help file into a direct access file which can be read by the help routines. You should not have to do this yourself, unless you're responsible for file updating. Make sure that no version of the packed help file is available before you issue this instruction.

The legible help file should be called GARFIELD RAWHELP on VM/CMS, HELP_RAW$GARFIELD on Vax/VMS and garfield.rawhelp on Unix systems. The packed help file is called GARFIELD PACKHELP on VM/CMS, HELP$GARFIELD on Vax/VMS and garfield.packhelp on Unix systems.

This command can not be issued from within a dataset subsection.

The *TRANSLATE* options exists only on IBM interactive systems, where it helps to correct an error in some old ASCII to EBCDIC conversion tables. Curly brackets (8B and 9B) are sometimes improperly translated (C0 and D0).

% PURGE dataset

Format:

```
% PURGE   dataset
```

Removes deleted members from *dataset*. This instruction may hurt ! Once purged, no recovery is possible (unless you made a backup of course).

3.12.10 Graphics instructions

Modifies or displays the GKS graphics settings. The settings can be changed at all times and any number of times. They take effect immediately and do not affect plots that may already be on a metafile. If the exclamation mark is the only character on the line, further graphics commands can be entered without the ! sign, until you type EXIT, which will return you to where you came from.

For information about GKS, see for instance the excellent but slightly outdated book by Hopgood *et al.* [5]. Details about the most commonly used GKS at CERN and associated institutes, GTS-GRAL/GKS, are to be found in [6]. This facility was only tested with GTS-GRAL/GKS.

! ACTIVATE-WORKSTATION

Format:

```
! ACTIVATE-WORKSTATION wsname
```

Activates the workstation named *wsname*. The workstation should already be defined and open.

! ADD-WORKSTATION

Format:

```
! ADD-WORKSTATION wsname
     [TYPE type | GKS-IDENTIFIER gksid]
     [CONNECTION-IDENTIFIER conid | OFFSET offset]
     [FILE-NAME file]
```

Adds a workstation to the workstation table. Depending on the system, a workstation named TERMINAL or one named METAFILE, or both, can be predefined. The attributes of these two workstations are set with the command line qualifiers.

A workstation, once added, can be opened and then activated after which it will receive graphics output.

! CLOSE-WORKSTATION

Format:

```
! CLOSE-WORKSTATION wsname
```

Closes the workstation named *wsname*. The workstation should be defined and open but not active.

! COLOUR

Format:

```
! COLOUR colour_name
     [RED red]  [GREEN green]  [BLUE blue]
     [WORKSTATION   wkid]
```

Defines a new colour to be added to the workstation tables, provided it has colour facilities. If your terminal has them, take care to transmit the right workstation identifier to the program during start-up in order to use them. On Vax and CMS you can do so via command line parameters, on other machines

you may have to recompile. The program can not determine which device is going to be used to look at WISS and metafile output and allows all colours for these. You may redefine a colour any number of times; the total number of colours you may define depends on the GKS you're using but rarely more than 20 colours are allowed.

If you omit the *colour_name*, all known colour representations are listed. If you specify it but omit the colour intensities, only the representation of the chosen colour is displayed.

colour_name
: The name of the colour you wish to (re)define or to inquire about. This should be a string of at most 20 characters. The recommended format is that of the type used internally for input string matching: segment1-segment2-segment3... where each of the segments can have one hash (#) indicating the point of minimal abbreviation. For instance, 'BL' matches the colour names 'BL#UE' and 'BL#ACK', 'D-GR' matches 'D#ARK-GR#EEN' but not 'DARK-GR'.

  All workstations have 2 predefined colours: BACKGROUND, with zero intensity for each of the colours, and FOREGROUND, full intensity for each.

red
: The intensity of red on a scale of 0 to 1.

blue
: The intensity of blue on a scale of 0 to 1.

green
: The intensity of green on a scale of 0 to 1.

wid
: The workstation identifier on whose state list the colour is defined or is to be defined. This parameter should be left for the time being at its default [1].

! DEACTIVATE-WORKSTATION

Format:

```
! DEACTIVATE-WORKSTATION wsname
```

Deactivates the workstation named *wsname*. The workstation should already be defined, open and active.

! DELETE-WORKSTATION

Format:

```
! DELETE-WORKSTATION wsname
```

Deletes the workstation named *wsname*. The workstation should be defined. All information about a workstation is lost once it has been deleted.

EXIT

Leaves a graphics sub-section.

! GET-COLOURS

Format:

```
! GET-COLOURS dsname [member]
```

Reads a list of colours from a dataset, overwriting any colours you may have defined previously.

dsname
: The name of the Garfield library that contains the member you wish to load.

member
: The name to be member to be read.

! GET-REPRESENTATION

Format:

```
! GET-REPRESENTATION dsname [member]
```

This instruction retrieves a representation table written by ! WRITE-REPRESENTATION. Colour tables should be loaded before the representation tables since the representation colour references are resolved while reading. The colours may be redefined afterwards if needed; unresolved colours are set to FOREGROUND.

dsname
: The name of the dataset from which the representation table should be read.

member
: The name of the member you wish to read.

! INQUIRE-DEFERRAL-UPDATE-STATE

```
! INQUIRE-DEFERRAL-UPDATE-STATE [wsname]
```

Reports the deferral, update and regeneration mode and also the screen state for workstation *wsname*. If the workstation name is omitted or is set to a *, then the information is shown for all known workstations.

! INQUIRE-LEVEL-GKS

Returns the GKS level of the GKS with which you are running.

! INQUIRE-OPERATION-STATE

Returns the operation state, in order of increasing GKS activity: GKS closed, GKS open, workstation open, workstation active and segment active. Segment active should in principle not occur. Workstation active is the minimum required to produce output and this should be the normal state in which you find GKS.

! INQUIRE-WORKSTATIONS

Lists all workstations which have been defined, the state in which they are and the files associated with them, if any.

! OPEN-WORKSTATION

Format:

```
! OPEN-WORKSTATION wsname
```

Opens the workstation named *wsname*. The workstation should already be defined.

! OPTION

Format:

```
! OPTION  [NOCLEAR-AFTER-PLOT | CLEAR-AFTER-PLOT]
          [CLEAR-BEFORE-PLOT | NOCLEAR-BEFORE-PLOT]
          [NOGRID-PLOT | GRID-PLOT]
          [LINEAR-X | LOGARITHMIC-X]
          [LINEAR-Y | LOGARITHMIC-Y]
          [TIME-STAMP | NOTIME-STAMP]
```

A few aspects of plotting that do not fit in the REPRESENT command and are not workstation related either, have been grouped in the graphics OPTION command. Global options can not be mixed with graphics options.

CLEAR-AFTER-PLOT
: When a plot is complete, the program waits until you hit the return key before it proceeds. With this option on, which is not the case by default, the screen is cleared after you hit return. This is useful on Tektronix-4014 and similar terminals.

CLEAR-BEFORE-PLOT
: Clears the screen before a plot is made. This is default for all devices; you will want to switch this option off when overlaying 2 consecutive plots. The graphics REPRESENT command allows you to change for instance the colours in between the plots.

GRID
: Switching on *GRID-PLOT*, will cause a coordinate grid to be overlaid on the plot. The coordinate grid lines simplify reading values from the graphs.

The appearance of the coordinate grid can be modified to some extent by the !REPRESENTATION statement; by default dotted lines are used. The number of grid lines is determined by the program from the range of values the axis covers; an attempt is made to draw the grid lines at reasonable numerical values. The GRID parameter has no relation whatsoever with the coordinate grid.

Grids are drawn on all plots, until the option is switched off again.

log/linear
Allows to see certain plots on a log scale. Garfield feels free to change the value of these parameters, for instance for the gas plots.

TIME-STAMP
Will plot a line indicating date and time in the upper right hand corner of each graph that is sent to a metafile.

!REPRESENTATION

Format:

```
! REPRESENT item  [attribute_1 value_1]
                  [attribute_2 value_2]
                  ...
```

This instruction allows you to change the appearance of the plots. The term *item* is used here to designate a basic component of a plot, such as the axes, the title, a drift-line, a set of contours etc. The *item*s come in 4 types, called primitives in GKS terminology: polyline, polymarker, text and fill area. Some items, such as equal time contours, are plotted using more than one primitive, in this case polyline and polymarker. The way a primitive is rendered on the output device is controlled by a series of *attribute*s, for instance the colour of a line, the font of a piece of text etc. It are the *attribute*s that you can change using the REPRESENT graphics instruction.

item Per REPRESENT instruction, you may change the attributes of only one primitive associated with only one item. For instance, you are not allowed to request in a single REPRESENT statement that COMMENT must have line type DOTTED and text font -7 (COMMENT exists as a text and as a polyline item). The primitive is determined from the attributes you list.

If you omit *item*, the representation of all items will be displayed. If you specify *item* but omit the attributes, the representation of *item* will be displayed, once for each of the primitives it uses.

BOX-TICKMARKS
(Polyline) The lines used to draw the coordinate system.

COMMENT
(Polyline) Additional lines sometimes help to clarify the plot, such lines for instance separate in the drift-time graph the curves for different places where the particles end up.

COMMENT
(Text) The pieces of information about the cell, the gas etc plotted underneath the title.

CONTOUR-HIGHLIGHTED
(Polyline) Some contours, usually every 5th, are highlighted.

CONTOUR-NORMAL
(Polyline) The contours of the field but also of the drift-time when plotted via TABLE - for highlighted contours see above.

C-WIRE
(Polymarker) The marker to be used for C type wires when the WIRE-MARKERS option of the cell section is active.

DIELECTRICA
(Fill Area) The dielectrica in the cell.

DRIFT-CONTOUR
(Polyline) Contours of equal arrival time interpolated on drift-lines.

DRIFT-CONTOUR
(Polymarker) When the distance between interpolated points on the drift-lines is larger than a certain threshold value, a marker is put on the drift-line instead.

DRIFT-LINE
(Polyline) Drift-lines of electrons and ions.

FUNCTION-1
(Polyline) The main function in a plot, usually this is the only curve being drawn. This type of line is also used for the vector plot in the field section.

FUNCTION-1
(Polymarker) When a portion of the curve of the primary function consists of only one point, a marker is used rather than a line.

FUNCTION-2
(Polyline) The second function drawn in a plot, used for instance for the integrated diffusion in the x(t) plot.

FUNCTION-2
(Polymarker) When a portion of the second function consists of only one point, a marker is used rather than a line.

FUNCTION-3
(Polyline) The third function drawn in a plot. Not yet used.

FUNCTION-3
(Polymarker) When a portion of the third function consists of only one point, a marker is used rather than a line. Not yet used.

GRID
(Polyline) The grid indicating the coordinates in a plot.

LABELS
(Text) The labels are the annotations along the axes.

MESSAGE
(Text) The line asking you to hit return when you have seen enough of a plot.

NUMBERS
(Text) The numbers indicate the coordinate values along the axes.

OTHER-WIRE
(Polymarker) The marker to be used for wires with a code letter other than C, P or S when the WIRE-MARKERS option of the cell section is active.

PLANES
(Polyline) The equipotential planes in the cell.

P-WIRE
(Polymarker) The marker to be used for P type wires when the WIRE-MARKERS option of the cell section is active.

S-WIRE
(Polymarker) The marker to be used for S type wires when the WIRE-MARKERS option of the cell section is active.

TITLE
(Text) The global title of the plot.

TRACK

(Polyline) The track of a particle traversing the chamber as defined by the TRACK statement. Such tracks are not the drift-lines of electrons or ions.

TRACK

(Polymarker) If the track consists of a single point, a marker is plotted.

TUBE

(Polyline) The tube surrounding the wires as defined by the TUBE statement in the cell section.

WIRES

(Fill Area) Wires are plotted with fill area rather than polyline ! This is done to allow them to be picked in GRAPHICS-INPUT.

attribute The attributes you specify must be all of the same type and consistent with the *item* of which you wish to change the appearance. The labeling of the various attributes follows closely the GKS terminology (see [5]) with the exception of the colours. Colours are specified by a name previously defined using !COLOUR. Usually, drastic abbreviations are tolerated provided no confusion can arise.

CHARACTER-EXPANSION-FACTOR

(Text) The deviation from the designer specified ratio height/width of a character. [Default is 1.]

CHARACTER-SPACING

(Text) Adds more space between characters. [Default is 0.]

CHARACTER-HEIGHT

(Text) Height of the characters in world coordinates. Characters are plotted by Garfield using normalisation transformation 0, for which the scale of the whole plot, including the blank area surrounding the coordinate box, ranges from 0 to 1 both in x and in y. [Defaults: 0.01 for annotations and comments, 0.02 for the title.]

FILL-AREA-INTERIOR-STYLE

(Fill area) The way the areas are filled, you have the choice between 3 values:

HATCHED

The area will be filled by a series of parallel lines, the type of which can be chosen by the FILL-AREA-STYLE-INDEX. [Default for dielectrica.]

HOLLOW

This looks like a line: the border is drawn but the interior is left empty. [Default for wires.]

PATTERN

The area will be filled by the pattern selected by FILL-AREA-STYLE-INDEX.

SOLID

The area will be filled entirely in the colour you choose.

FILL-AREA-STYLE-INDEX

(Fill area) The hatch or pattern type you wish to use. [Default: -111 for dielectrica when using GTS-GRAL.]

FILL-AREA-COLOUR

(Fill area) The colour used to fill the area. This can be either BACKGROUND (in which case the corresponding item will not be visible), FOREGROUND or one of the colours you defined yourself via the !COLOUR command. [Default: foreground colour.]

FILL-AREA-PATTERN-SIZE

(Fill area) When you choose pattern as fill area style, you may change the size of the pattern box using this attribute. [Not used by default]

FILL-AREA-REFERENCE-POINT

(Fill area) When you choose pattern as fill area style, you may choose a reference point of the pattern box using this attribute. [Not used by default]

LINETYPE

(Polyline) The sort of line: you may either choose an implementation dependent (negative) number or one of the following values:

DASHED

The line will consist of a series of dashes: - - - - - - . [Default for comment lines and equal time contours.]

DASH-DOTTED

The line will be an alternating series of dashes and dots: .-.-.-.-.

DOTTED

The line will consist of a series of dots: .....

SOLID

The good old solid line. [Default for most lines.]

LINEWIDTH-SCALE-FACTOR

(Polyline) The width of the line compared to default. This attribute is frequently ignored. [Default: 1.]

MARKER-TYPE

(Polymarker) The sort of marker: you may either choose an implementation dependent (negative) number or one of the following values:

ASTERISK

The markers are small stars: '*'. [Default.]

CIRCLE

The markers are circles: '&cdot.',

CROSS

The markers are crosses: ×.

DOT

The markers are dots: '.'.

PLUS

The markers are plus signs: '+'.

MARKER-SIZE-SCALE-FACTOR

(Polymarker) The size of the markers compared to their default size. The size of a marker compared to the overall scale of the plot may vary from one output device to another. The plots in this manual have been made with a size of 0.5. [Default: 1, except for equal time contours where 0.25 is used.]

POLYLINE-COLOUR

(Polyline) The colour used for the lines. This can be either BACKGROUND (in which case the corresponding item will not be visible), FOREGROUND or one of the colours you defined yourself via the !COLOUR command. [Default: foreground colour.]

POLYMARKER-COLOUR

(Polymarker) The colour used for the marker. This can be either BACKGROUND (in which case the corresponding item will not be visible), FOREGROUND or one of the colours you defined yourself via the !COLOUR command. [Default: foreground colour.]

TEXT-COLOUR

(Text) The colour used for the text. This can be either BACKGROUND (in which case the corresponding item will not be visible), FOREGROUND or one of the colours you defined yourself via the !COLOUR command. [Default: foreground colour.]

TEXT-FONT

(Text) The font used to plot the text. Most of the 'special' fonts (greek, gothic, italics) are only available in STROKE quality, see TEXT-PRECISION below. Text fonts are largely implementation dependent; the GKS manual for your installation should contain a list of fonts. The plots in this manual have been made with GTS-GRAL font -104. [Default: 1.]

TEXT-PRECISION

The accuracy with which a piece of text is rendered. The higher the quality, the slower the plotting process becomes (with a few exceptions like Apollo). You have the choice between 3 values:

STRING

The poorest quality, normally an hardware font. The character size, the orientation and the positioning are usually only approximate but the result is legible. Very useful when you have a lot of plots to make and don't wish to waste time waiting for all the axis to be annotated. A synonym is LOW.

CHARACTER

The medium quality, sometimes a hardware font but the character size, the orientation and the positioning are usually respected. A synonym is MEDIUM. [This is the default.]

STROKE

The highest quality GKS has to offer, nearly always a software font. The characters may well be traced several times and it takes therefore a lot of time before the titles etc. have been plotted. This setting makes only sense if an appropriate font (see above) has been selected. Mainly suitable for plots that have to be used in presentations. Stroke quality characters have been used in this manual. HIGH is synonymous to STROKE.

! SET-DEFERRAL-STATE

Format:

```
! SET-DEFERRAL-STATE wsname defmode regmode
```

Changes the deferral and regeneration mode for workstation *wsname*.

defmode The deferral mode can either be AS-SOON-AS-POSSIBLE (ASAP), BEFORE-NEXT-INTERACTION-GLOBALLY (BNIG), BEFORE-NEXT-INTERACTION-LOCALLY (BNIL) or AT-SOME-TIME (AST). The current value is not changed if you specify * for *defmode*.

regmode The regeneration mode can either be SUPPRESSED or ALLOWED. The current value is not changed if you specify * for *regmode*.

! STAMP

Format:

```
! STAMP string
```

The time stamp on the plot always indicates when the plot was made. You can add a comment, *string*, to this. By default, *string* contains information about the version of Garfield that was used to make the plot. If *string* contains expressions in terms of global variables which are to be evaluated only when the plot is being made, make sure that you prefix the curly brackets by the escape character, by default a backslash.

! WRITE-COLOURS

Format:

```
! WRITE-COLOURS  DATASET dsname   [member]  [REMARK  remark]
```

Writes the list of colours currently known to a dataset.

dsname The name of the Garfield library to which the colour tables should be appended.

member The name to be assigned to the member.

remark An optional string of up to 29 characters that will help you to recognise the data when retrieving.

! WRITE-REPRESENTATIONS

Format:

```
! WRITE-REPRESENTATIONS
     DATASET  dsname  [member]   [REMARK remark]
```

Writes the current graphics representations to a dataset so that they can later on be retrieved easily with ! GET-REPRESENTATION. The colour references are written out by their full name, not the abbreviated name you may have used in the ! REPRESENTATION statements.

dsname The name of the Garfield library to which the representation description should be appended. The library may of course contain also members of other types, such as cell and gas descriptions. It should however be a file used only as Garfield library.

member The name to be assigned to the member. This argument is optional and is irrelevant if you keep only one description in the dataset. It's a good idea to keep the representations for different terminals in the same library, using for instance the terminal name as member name.

remark An optional string of up to 29 characters that will help you to recognise the data when retrieving.

3.12.11 The algebra instruction list editor

The algebra editor is strictly speaking a sub-section of the cell, gas, field and optimisation sections. This extremely simple editor is mainly provided for debugging purposes and it is unlikely that the casual user will ever need to use it. It processes instruction lists in their raw format, like in the examples in Section 4.5 on page 116 (which should be read before starting to use the editor !) but unlike the ALGPRT output. The escape character to enter the editor is the commercial at @, anywhere in the function; text around the @ sign is ignored.

Valid instructions are:

ADD-ENTRY-POINT

Updates the current entry point information and creates a new entry point.

CLEAR-ENTRY-POINT

Format:

```
CLEAR-ENTRY-POINT  [entry_reference_number]
```

Marks the entry point record with the reference number given as argument [default: the current entry point] for deletion.

COUNT

Displays the current number of instructions.

DELETE

Format:

```
DELETE  [first [LAST | last] ]
```

Deletes instructions, see also LIST. The entry point list is updated after the lines have been deleted since the instructions are immediately moved.

DISPLAY-ENTRY-POINT

Format:

```
DISPLAY-ENTRY-POINT  [entry_reference_number]
```

Displays the entry point record for the list with the reference number given as argument [default: the current entry point].

EXECUTE

Format:

```
EXECUTE      [first [LAST | last] ]
```

Has ALGEX2 execute some instructions; the RESULT, GOTO and RETURN instructions are skipped. The REGISTER command should be used to initialise the storage array. ALGPRT is invoked each time an error is detected, no matter the setting of the debugging option.

EXIT

Leaves the editor. The current entry point information is updated.

FUNCTION

Format:

```
FUNCTION  function
```

Calls ALGPRE with *function* as argument. The usual syntax conventions are relaxed here: the whole line apart from the first word is passed to ALGPRE, you don't need to worry about quotes therefore if you like having blanks in the formulae.

GARBAGE-COLLECT

Performs a garbage collect: removal of the entry point records that have been cleared, removal and reassignment of constants and instruction storage no longer used.

INSERT

Format:

```
INSERT  [before]
```

Inserts new instruction lines before line *before*, pushing this line ahead if it already exists. Enter a blank return when you have finished adding lines. [New lines are appended by default.]

LIST

Format:

```
LIST  [first [LAST | last] ]
```

Lists the instructions from line *first* to line *last* in raw format. The whole list is printed if no arguments are provided; a single line is printed if only one argument is present. *LAST*, which is default, represents the last instruction.

MEMORY

Displays the amount of storage used by the instruction list.

OPTIONS

Format:

```
OPTIONS  [NO-SYNTAX-CHECK |
          ALGEBRA-SYNTAX-CHECK |
          PROCEDURE-SYNTAX-CHECK]
```

You may request the editor to check instruction list lines while they're added. The most useful (and default) mode is ALGEBRA: only arithmetic, assignment and results are accepted. In procedure instruction lists, additional instructions like IF, GOTO, RETURN and CALL are used; the PROCEDURE checking mode allows them but does not check out of bounds references. Any 4 integer instruction is accepted when you select NO-SYNTAX-CHECK. Both the algebra and the procedure executing routines check the instructions in detail during execution.

PRINT

Format:

```
PRINT  [first [LAST | last] ]
```

Prints instructions using ALGPRT, see also LIST.

REGISTER

Format:

```
REGISTER  reg  [value]
```

The current value of REG(*reg*) will be displayed if *value* is absent. If *value* is specified, REG(*reg*) will be set equal to *value*.

RESET

Does a general cleanup of all buffers, deleting all instructions, all constants and all entry points. This instruction should be used with care since sub-lists used by other instructions than the one via which you entered the editor may still be stored and needed.

RESULTS

Shows the number of results expected by the calling section.

SIMPLIFY

Simplifies the instruction list by calling the second part of ALGPRE.

TEST

Format:

```
TEST  var1  var2  var3  ...
```

Evaluates the current instruction list using *var1*, *var2* . . . as values for the variables. There should be precisely one number for each variable.

VARIABLES

Lists the valid variable names.

4.0 Description of the physical model

This chapter tries to give some idea of the physical and numerical ideas used in this program. It does not pretend to be an introduction to drift-chambers: firstly the author of the present writeup is not qualified to write one, secondly this writeup covers only those points that are sometimes hard to find in the journals. The reader is referred to the extensive literature on drift-chambers for the aspects of drift-chamber operation that have been omitted in this writeup, δ-rays for instance. The lecture notes by F. Sauli [7] are useful as an informal introduction; the formulae in this reference should not be taken too literally. For instance the function named Landau distribution by this reference is not the Landau distribution [8], but an approximation to it, the Moyal function, which behaves quite differently in the tail [9]. Also the expressions for the induced currents have a limited validity. For a more careful account of the various processes, the original references should be consulted.

This chapter can roughly be divided into four main parts:

- electrostatics and magnetostatics, Section 4.1;
- gas properties, Section 4.2 on page 105;
- motion of electrons and ions and Section 4.3 on page 110;
- signal calculation Section 4.4 on page 112.

4.1 Electrostatics, magnetostatics

The computation of the electrostatic field and potential is a two-step process:

1. the calculation of charges (per unit length) on the wires and of a reference potential reproducing the wire-potentials at the wire-surfaces in step 2. Various boundary conditions may have to be satisfied. The equations solved in this step are known as capacitance equations.
2. the summation of the contributions of each wire to the field and potential at any given position, using the charges calculated step 1.

Both steps require an expression for the electrostatic potential, which will be derived for the various situations in the first part of this chapter. It will also be shown in this chapter that most cylindrical geometries can be reduced to Cartesian geometries by applying suitable coordinate transformations. The last part of this chapter deals with magnetostatics.

4.1.1 Notation

We will use the following notation in this section:

n	number of wires,
(x_j, y_j)	position of wire j,
z_j	$= x_j + iy_j$, the two notations are equivalent,
r_j	radius of wire j,
q_j	charge of wire j,
V_j	surface potential of wire j,
X_1, X_2	positions of the planes at constant x,
Y_1, Y_2	positions of the planes at constant y,
$W(z)$ or $W(x, y)$	complex potential at z or at (x, y),
$V(z)$ or $V(x, y)$	$=$ Re $W(z)$,
$\phi(z)$ or $\phi(x, y)$	potential at z of a unit charge at the origin,
s_x and s_y	x and y periodicities.

4.1.2 Cell types

Garfield should be able to handle all rectangular and some cylindrical 2-dimensional cells not involving more than 2 equipotential planes in either the x (r)- or the y (ϕ)-direction. Repetition of the cell in the x (r)- and/or the y-direction is allowed. The table below shows the names used in the program for each of the potentials; the mention 'mirror' means that mirror charges are introduced in the field calculations.

The positions of the charges and their mirror images for each of the potentials is shown in Figure 21 on page 93. As can be seen from the plot, the A potentials are for single charges, the B potentials for rows and the C potentials for grids of charges.

No distinction will be made between the physical charges and the (mathematical) mirror charges in the rest of this chapter unless otherwise stated.

Table 3. Table of the cell types.

Planes		**Periodicities**			
x	**y**	**none**	**in x**	**in y**	**both x and y**
0	0	A	B1x	B1y	C1
1	0	A mirror	B2x	B1y mirror	C2y
2	0	B2x	B2x	C2y	C2y
0	1	A mirror	B1x mirror	B2y	C2x
1	1	A mirror	B2x mirror	B2y mirror	C3
2	1	B2x mirror	B2x mirror	C3	C3
0	2	B2y	C2x	B2y	C2x
1	2	B2y mirror	C3	B2y mirror	C3
2	2	C3	C3	C3	C3

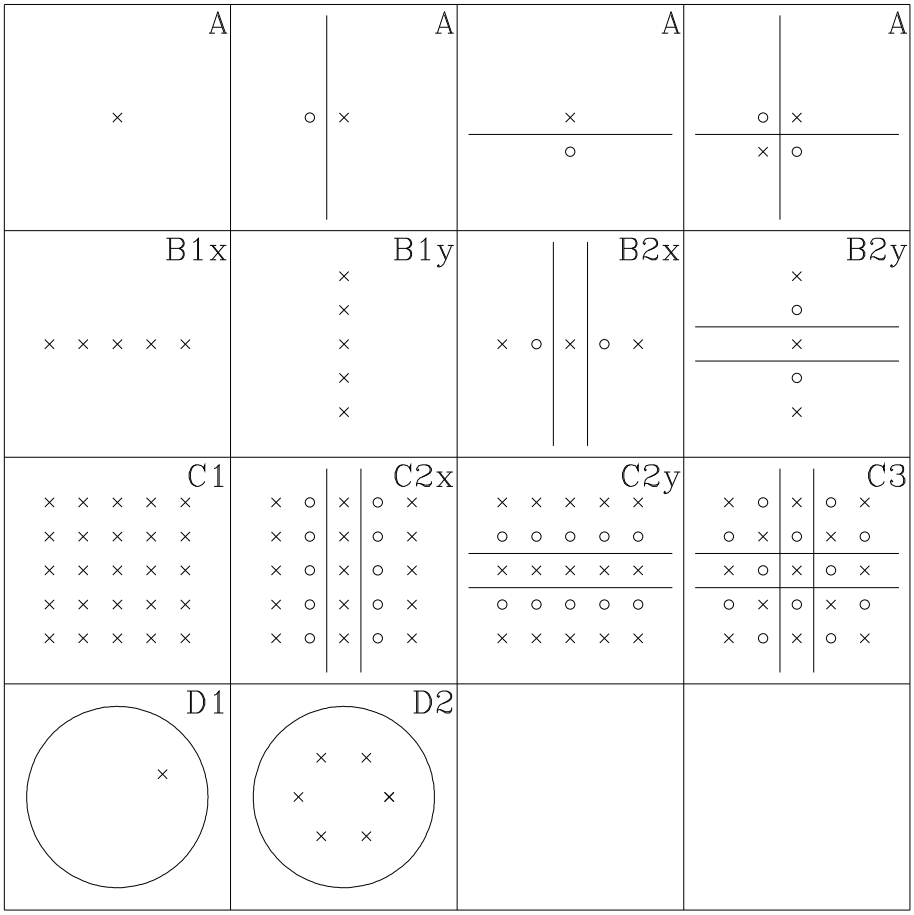


Figure 21. Schematic arrangement of the charges.

4.1.3 Isolated charges (type A)

The potential for a single point charge at the origin is:

$$\phi(x,\ y) = \frac{1}{2\pi\varepsilon_0}\ \log\ \sqrt{x^2+y^2}$$

One might object that it is not permissible to take the log because its argument has the dimension of length. It is readily seen however that ϕ is independent of the unit-system: the following potential is perhaps more acceptable from a physical point of view but it is numerically fully equivalent to the one mentioned above.

$$\phi(x,\ y) = V_0 + \frac{1}{2\pi\varepsilon_0}\ \log\frac{\sqrt{x^2+y^2}}{r_0}$$

where V_0 is the potential at a distance r_0 from the origin.

4.1.4 Rows of charges (types B1x, B1y, B2x and B2y

We will use the following scheme to find these potentials:

1. Determine a complex entire function $F^+(z)$ satisfying the following requirements:
   a. $F^+(z)$ has simple zeros at the positions of the wires and their even images,
   b. the coefficient of z in the expansion of $F^+(z)$ around z =0 equals 1, as required by the Maxwell equations.
2. Determine a similar function $F^-(z)$ for the odd images. Set $F^-(z) = 1$ if these do not exist.
3. Define the function F(z):

$$F(z) = \frac{F^{+}(z)}{F^{-}(z)}$$

4. Then, a potential solving our problem is:

   $$\phi(x,\ y) = -\frac{1}{2\pi\varepsilon_0}\ \mathrm{Re}\ \ \log\ F(z)$$

   and after some algebra the corresponding electric field turns out to be:

   $$E_x + iE_y = \frac{1}{2\pi\varepsilon_0}\left(\frac{F'(z)}{F(z)}\right)^{*}$$

We will first of all deal with type B1x. The obvious choice for an F which has a zero at each of the replicas of the wire is the following:

$$F_{B1x}(z) = (z - z_0)\prod_{n=1}^{\infty}\left(1 - \frac{z - z_0}{ns_x}\right)\left(1 + \frac{z - z_0}{ns_x}\right)$$

Using the sine-product, see for instance [10]:

$$\sin(z) = z\prod_{n=1}^{\infty} 1 - \left(\frac{z}{n\pi}\right)^2$$

the following simple expression follows:

$$F_{B1x}(z) = \sin\left(\pi\frac{z - z_0}{s_x}\right)$$

The hyperbolic analog of the sine-product:

$$\sinh(z) = z\prod_{n=1}^{\infty} 1 + \left(\frac{z}{n\pi}\right)^2$$

leads to the B1y potential:

$$F_{B1y}(z) = \sinh\left(\pi\frac{z - z_0}{s_x}\right)$$

The B2x and B2y potentials are mere superpositions of the B1x and B1y potentials:

$$F_{B2x} = \frac{\sin\left(\pi\dfrac{z - z_0}{2(X_2 - X_1)}\right)}{\sin\left(\pi\dfrac{z - z'_0}{2(X_2 - X_1)}\right)}$$

where $z'_0 = 2(X_2 - X_1) + iy$

$$F_{B2y} = \frac{\sinh\left(\pi\dfrac{z - z_0}{2(X_2 - X_1)}\right)}{\sinh\left(\pi\dfrac{z - z'_0}{2(X_2 - X_1)}\right)}$$

where $z'_0 = x + 2i(Y_2 - Y_1)$

4.1.5 Electrostatic field of a doubly periodic wire ar

(Contributed by G. A. Erskine)

4.1.5.1 Specification of the array

We consider a doubly periodic array of thin wires, the array consisting of replicas of a basic rectangular cell defined by $0 \le x \le s_x$, $0 \le y \le s_y$. This cell contains n wires, where wire j is characterised by:

Position . . . $z_j = x_j + iy_j$,
Radius . . . r_j,
Potential . . . V_j.

Wires identical to wire j (j=1, 2, ... , n) are situated at:

$z_j + \lambda s_x + i\mu s_y \qquad (\lambda, \mu = 0, \pm 1, \pm 2, \ldots).$

4.1.5.2 The thin-wire potential approximation

We shall obtain a potential function V(z) which satisfies the following conditions:

$$\frac{\partial^2 V(z)}{\partial x^2} + \frac{\partial^2 V(z)}{\partial y^2} = 0, \qquad z \neq z_j, \quad j = \pm 1, \pm 2, \ldots, \pm n. \tag{1}$$

$$V(z_k + r_k e^{i\phi}) = V_k + o(r_k), \qquad 0 \le \phi \le 2\pi, \ k = 1, 2, \ldots, n. \tag{2}$$

$$V(z + s_x) = V(z), \qquad \text{'for all z.'} \tag{3}$$

$$V(z + is_y) = V(z), \qquad \text{'for all z.'} \tag{4}$$

The exact potential function would be defined by the same conditions without any term $o(r_k)$ on the right-hand side of (2). To simplify the formulae, electrostatic units are used.

We define V(z) = Re W(z) where

$$W(z) = \sum_{j=1}^{n} q_j \left\{ -2 \log \vartheta_1\left[\frac{\pi}{s_x}(z - z_j), \ e^{-\pi s_y/s_x} \right] + i \frac{4\pi}{s_x s_y} y_j z \right\} + c \tag{5}$$

with the theta function ϑ_1 [11] defined by

$$\vartheta_1(\zeta, p) = 2p^{1/4} \sum_{m=0}^{\infty} (-1)^m p^{m(m+1)} \sin(2m+1)\zeta, \tag{6}$$

and with the n+1 real constants q_j (j=1,2, ... ,n) and c determined by the system of equations

$$\sum_{j=1}^{n} \left\{ -2 \log \left| \vartheta_1\left[\frac{\pi}{s_x}(z_i - z_j), \ e^{-\pi s_y/s_x} \right] \right| - \frac{4\pi y_i y_j}{s_x s_y} \right\} q_j + c = V_i, \quad (i = 1, 2, \ldots, n), \tag{7}$$

$$\sum_{j=1}^{n} q_j = 0. \tag{8}$$

In (7) first line we use the convention that, for the terms with i =j,

$$\begin{aligned} \vartheta_1\left[\frac{\pi}{s_x}(z_i - z_j),\ p \right] &= \frac{\pi r_i}{s_x}\ \vartheta_1(0,\ p) \\ &= \frac{\pi r_i}{s_x}\ 2p^{1/4} \sum_{m=0}^{\infty} (-1)^m (2m+1)\, p^{m(m+1)} \end{aligned} \tag{9}$$

The coefficient q_j in (5) is the charge per unit length on wire j.

Condition (1) is satisfied because V(z) is the real part of a function (5) which is analytic everywhere except at the points z_j (j=1,2, ... ,n). Condition (2) follows from (7) and (9). Condition (3) is an immediate consequence of (5) and (6).

To show that condition (4) is satisfied, define

$$w_j(z) = -2\ \log \vartheta_1\left[\frac{\pi}{s_x}(z - z_j),\ e^{-\pi s_y/s_x} \right] + i\ \frac{4\pi}{s_x s_y}\ y_j z.$$

Then, from the quasi-periodicity of the function ϑ_1 [12], neglecting integral multiples of $2\pi i$,

$$w_j(z + is_y) = w_j(z) + i4\pi \frac{z - x_j}{s_x} - 2\pi \frac{s_y}{s_x},$$

and hence

$$\mathrm{Re}\ w_j(z + is_y) = \mathrm{Re}\ w_j(z) - \frac{2\pi}{s_x}\ (2y + s_y)$$

Therefore, using (8),

$$\begin{aligned} \mathrm{Re}\ W(z + is_y) &= \mathrm{Re} \sum_{j=1}^{n} q_j\, w_j(z + is_y) + c \\ &= \mathrm{Re} \sum_{j=1}^{n} q_j\, w_j(z) + c \\ &= \mathrm{Re}\ W(z). \end{aligned}$$

4.1.5.3 Alternative expression for the thin-wire potential

By considering the array obtained by rotating the original array through 90^0, we see that the real part of the function obtained from W(z) by replacing z by iz, z_j by iz_j (j=1,2, ... ,n), and interchanging s_x and s_y, also satisfies the conditions (1) through (4). We thus obtain the alternative expression:

$$W(z) = \sum_{j=1}^{n} q_j \left\{ -2\ \log\ \vartheta_1\left[\frac{i\pi}{s_y}(z - z_j),\ e^{-\pi s_x/s_y} \right] - \frac{4\pi}{s_x s_y}\ x_j z \right\} + c, \tag{10}$$

where q_j (j=1,2, ... , n) and c are determined by

$$\sum_{j=1}^{n} \left\{ -2\ \log \left| \vartheta_1\left[\frac{i\pi}{s_y}(z_i - z_j),\ e^{-\pi s_x/s_y} \right] \right| - \frac{4\pi x_i x_j}{s_x s_y} \right\} q_j + c = V_i, \quad (i = 1,\ 2,\ \ldots,\ n), \tag{11}$$

$$\sum_{j=1}^{n} q_j = 0. \qquad (12)$$

The parameter p in the series (6) has the value $e^{-\pi s_y/s_x}$ when the expression (5) is used for W(z), and the value $e^{-\pi s_x/s_y}$ when expression (10) is used. We therefore adopt the following rule:

If $s_x \leq s_y$, compute W(z) from (5).
If $s_x > s_y$, compute W(z) from (10).

This rule ensures that, for all values of s_x and s_y, we have $p \leq e^{-\pi} = 0.043....$

4.1.5.4 Field intensity

The components (E_x, E_y) of the electrostatic field intensity vector at z are given by:

$$E_x = -\frac{\partial V}{\partial x} = -\mathrm{Re}\ W'(z),$$
$$E_y = -\frac{\partial V}{\partial y} = +\mathrm{Im}\ W'(z),$$

where, depending upon whether we use (5) or (10) for W(z),

$$W'(z) = \sum_{j=1}^{n} q_j \left\{ -\frac{2\pi}{s_x} \frac{\vartheta_1[\frac{\pi}{s_x}(z-z_j),\ e^{-\pi s_y/s_x}]}{\vartheta_1[\frac{\pi}{s_x}(z-z_j),\ e^{-\pi s_y/s_x}]} + i\frac{4\pi}{s_x s_y} y_j \right\}$$

or

$$W'(z) = \sum_{j=1}^{n} q_j \left\{ -i\frac{2\pi}{s_y} \frac{\vartheta_1[\frac{i\pi}{s_y}(z-z_j),\ e^{-\pi s_x/s_y}]}{\vartheta_1[\frac{i\pi}{s_y}(z-z_j),\ e^{-\pi s_x/s_y}]} - \frac{4\pi}{s_x s_y} x_j \right\}$$

4.1.5.5 Periodic wire array between parallel electrodes

The complex potential of an array of wires which is periodic in the direction of one of the axes, and is bounded by two parallel zero-potential planes, is identical (in the region between the planes) to that of a doubly periodic array whose basic cell contains the original wires together with their reflections (with reversed sign for the wire potential) in one of the planes. If the planes are not at zero potential it is merely necessary to add a term linear in z.

Consider an array consisting of replicas in the x-direction of a group of n wires lying between zero-potential planes situated at $y = Y_1$ and $y = Y_2$. Let the wire positions be z_j and the wire potentials V_j $(j = 1, 2, ..., n)$, and let the x-periodicity be s_x. If $\bar{z}$ is the complex conjugate of z, the reflection z'_j of z_j in the plane $y = Y_1$ is given by

$$z'_j = \bar{z}_j + i\,2\,Y_1.$$

We now define a y-periodicity

$$s_y = 2\,(Y_2 - Y_1),$$

and consider the doubly periodic array with periods (s_x, s_y) consisting of replicas of a basic cell (enclosed by the broken line in Figure 22 on page 98) containing 2n wires:

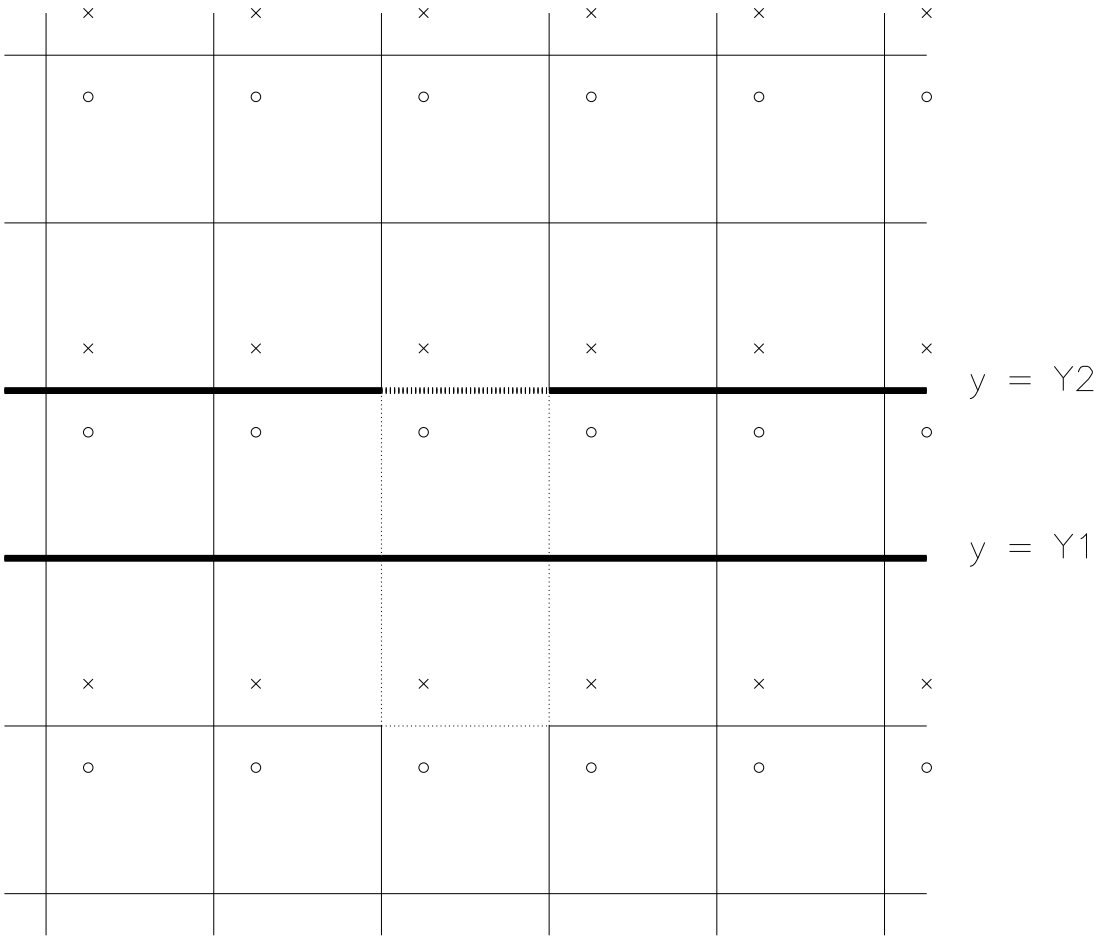


Figure 22. Periodic wire array between grounded parallel planes

Position	Potential	Charge
z_j	V_j	q_j
z'_j	$-V_j$	$-q_j$

From the symmetry of the positive and negative charges with respect to each of the planes $y = Y_1$ and $y = Y_2$ (Figure 22) it follows that these planes are at zero potential, and hence that the field of the doubly periodic array is the same as that of the original array. Using (5) and (10) respectively, we obtain the following expressions for the complex potential:

Case 1. $s_x \leq 2\,(Y_2 - Y_1)$.

$$W(z) = \sum_{j=1}^{n} q_j \left\{ w_a(z - z_j) - w_a(z - z'_j) + i\,\frac{8\pi}{s_x s_y}\,(y_j - Y_1)\,z \right\} \tag{13}$$

where

$$w_a(z) = -2 \log \vartheta_1\left[\frac{\pi z}{s_x}, e^{-\pi s_y/s_x}\right]. \tag{14}$$

Case 2. $s_x > 2(Y_2 - Y_1)$.

$$W(z) = \sum_{j=1}^{n} q_j \{w_b(z - z_j) - w_b(z - z'_j)\}, \tag{15}$$

where

$$w_b(z) = -2 \log \vartheta_1\left[\frac{i\pi z}{s_y}, e^{-\pi s_x/s_y}\right]. \tag{16}$$

In both cases the q_j are determined by the system of linear equations

$$\sum_{j=1}^{n} \{\mathrm{Re}\ W(z_i)\}_{q_j} = V_i, \qquad (i = 1, 2, \ldots, n), \tag{17}$$

where the convention defined by (9) is used for the terms with i = j.

Note that the sum $\Sigma(q_j + q'_j)$ of the 2n charges in the unit cell of the doubly periodic array is equal to zero, but that the sum Σq_j of the n physical charges is not necessarily equal to zero.

If, instead of being at zero potential, the planes $y = Y_1$ and $y = Y_2$ are at potentials v_1 and v_2 respectively, it is necessary to add to the complex potential W(z) a term representing the superimposed uniform field, namely

$$\frac{(Y_2 v_1 - Y_1 v_2) + i(v_1 - v_2)\, z}{Y_2 - Y_1}.$$

[Expressions equivalent to (13) through (16) were obtained by Buchholz [13] by direct summation of the contributions of the individual wires and of their multiple reflections in the planes.]

4.1.5.6 Wire array inside a rectangular tube

We consider n wires with positions z_j and potentials V_j, $(j = 1, 2, \ldots, n)$ lying inside a rectangular zero-potential tube defined by $X_1 \le x \le X_2$, $Y_1 \le y \le Y_2$. The complex potential inside the tube is the same as that of a two-dimensional periodic array of image charges having the symmetry shown in Figure 23 on page 100. The periods of this two-dimensional array are

$$s_x = 2(X_2 - X_1), \qquad s_y = 2(Y_2 - Y_1),$$

and the basic cell (enclosed by the broken line in Figure 23 on page 100) contains 4n wires:

Position	Potential	Charge	Description
$z_j^{(0)} = z_j$	V_j	q_j	Physical wire
$z_j^{(1)} = \bar{z}_j + i2Y_1$	$-V_j$	$-q_j$	Reflection in the line $y = Y_1$
$z_j^{(2)} = -z_j + 2(X_1 + iY_1)$	V_j	q_j	Reflection in the point $X_1 + iY_1$
$z_j^{(3)} = -\bar{z}_j + 2X_1$	$-V_j$	$-q_j$	Reflection in the line $x = X_1$

On defining, in terms of (14) and (16),

$w(z) = w_a(z)$ if $X_2 - X_1 \le Y_2 - Y_1$,
$w(z) = w_b(z)$ if $X_2 - X_1 > Y_2 - Y_1$,

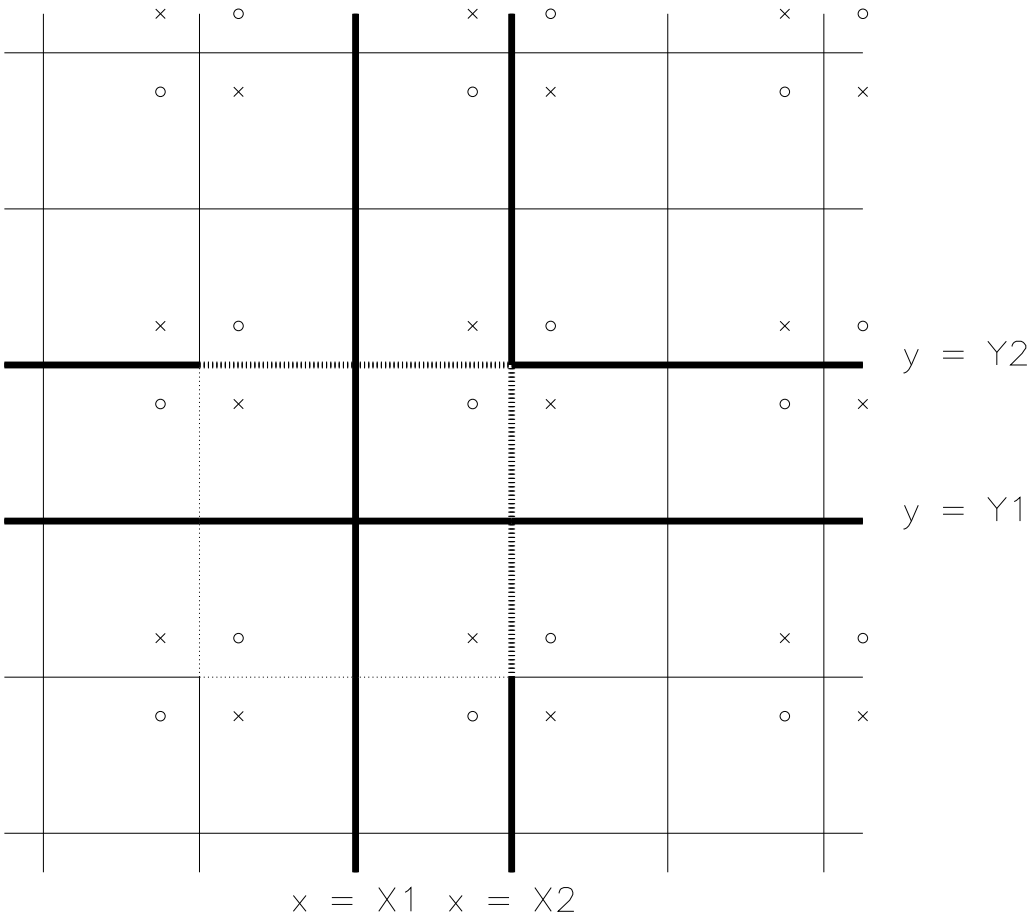


Figure 23. Wire array in a grounded rectangular tube

we obtain the required complex potential:

$$W(z) = \sum_{j=1}^{n} q_j \left\{ w(z - z_j^{(0)}) - w(z - z_j^{(1)}) + w(z - z_j^{(2)}) - w(z - z_j^{(3)}) \right\} \tag{18}$$

where the q_j are determined by a system of linear equations (17) in which W(z) is computed from (18).

4.1.5.7 Computational considerations

Because the expressions for W(z) either assume the relation $\sum q_j = 0$ or depend only on the ratio of two ϑ functions, the constant $2\,p^{1/4}$ in (6) makes no contribution. The series which need to be evaluated numerically are therefore of the form

$$\sum_{m=0}^{\infty} (-1)^m\, p^{m(m+1)}\, \sin(2m+1)\zeta \qquad \text{[for W and W′]}, \tag{19}$$

$$\sum_{m=0}^{\infty} (-1)^m\, (2m+1)\, p^{m(m+1)}\, \cos(2m+1)\zeta \qquad \text{[for W′ only]}, \tag{20}$$

where

$$p = e^{-\pi s_y/s_x}, \zeta = \frac{\pi}{s_x}(z - z_j) \quad \text{when } s_x \le s_y,$$

$$p = e^{-\pi s_x/s_y}, \quad \zeta = \frac{i\pi}{s_y}(z - z_j) \quad \text{when } s_x > s_y.$$

If terms with $m \ge M$ are neglected when evaluating (19), the relative error in the sum is bounded approximately by

$$\rho_M = p^{M(M+1)} \left| \frac{\sin(2M+1)\zeta}{\sin \zeta} \right| \le (2M+1)\, p^{M(M+1)}\, e^{2M|\mathrm{Im}\,\zeta|}.$$

Assuming, as we may without loss of generality, that $|x - x_j| \le s_x$ and $|y - y_j| \le s_y$, we find for both (5) and (10) that $e^{|\mathrm{Im}\zeta|} \le 1/p$. Hence,

$$\rho_M \le (2M+1)\, p^{M(M-1)} \le (2M+1)\, e^{-\pi M(M-1)}.$$

In the same way, we may show that the relative error resulting from the neglect of terms with $m \ge M$ in the evaluation of (20) is bounded approximately by $\sigma_M = (2M+1)\rho_M$. Setting $M = 3$, and using $p \le e^{-\pi}$,

$$\rho_3 \le 4.6 \times 10^{-8}.$$
$$\sigma_3 \le 3.2 \times 10^{-7}.$$

Therefore, for practical computation, the expressions to be evaluated are:

$$\sin\zeta - p^2 \sin 3\zeta + p^6 \sin 5\zeta \qquad \text{[for W and W′]},$$

$$\cos\zeta - 3p^2 \cos 3\zeta + 5p^6 \cos 5\zeta \qquad \text{[for W′ only]}.$$

To reduce the number of evaluations of sines and cosines of complex argument, we make use of the summation algorithm [14], which in the present case takes the following form:

1. To evaluate $S_n = \sum_{m=0}^{n} a_m \sin(2m+1)\zeta$:

$s = \sin\zeta$
$\alpha = 2 - 4s^2 \qquad [= 2\cos 2\zeta\,]$
$u_n = a_n$
$u_{n-1} = a_{n-1} + \alpha a_n$
for $j = n-2\ (-1)\ 0$ **do** $u_j = a_j + \alpha u_{j+1} - u_{j+2}$
$S_n = (u_0 + u_1)\, s$

2. To evaluate $C_n = \sum_{m=0}^{n} b_m \cos(2m+1)\zeta$:

$c = \cos\zeta$
$\alpha = 4c^2 - 2 \qquad [= 2\cos 2\zeta\,]$
$u_n = b_n$
$u_{n-1} = b_{n-1} + \alpha b_n$
for $j = n-2\ (-1)\ 0$ **do** $u_j = b_j + \alpha u_{j+1} - u_{j+2}$
$C_n = (u_0 - u_1)\, c$

4.1.6 Isolated charges in a tube (type D1)

Isolated charges in a tube are handled by conformally mapping the charge onto the centre of the tube using the function:

$$z \rightarrow \frac{1}{r} \frac{z - z_0}{1 - z\bar{z}_0/r^2}$$

After that, the type A potentials are applied.

4.1.7 Ring of charges in a tube (type D2)

A ring of charges in a tube is dealt with using the conformal mapping

$$z \rightarrow \frac{1}{r^n} \frac{z^n - z_0^n}{1 - (z\bar{z}_0/r^2)^n}$$

provided $z_0 \neq 0$, otherwise the mapping for the D1 potential is used. The presence of two different potentials in the same cell makes that the capacitance matrix can be asymmetric.

4.1.8 The capacitance equations, boundary conditions

The equations to be solved to find the wire charges are known as capacitance equations, they are obtained by expressing the (known) potential of wire i in the (unknown) charges per unit length q_j on the wires j =1 to n.

The equipotential planes can be treated as if they were grounded if the linear potential V_{planes} generated by the planes alone is subtracted from all wire-potentials before the charges are calculated and added separately when the potential and electrostatic field are evaluated. The equipotential planes are assumed to be grounded in the rest of this chapter.

Explicit charge calculations for equipotential planes may be avoided if (multiple) mirror charges are introduced. See Figure 21 on page 93 for their positions (&cdot. = original wire and even mirror images, × = odd image).

The sum of all charges should always be zero (the energy of the electric field would be infinite). If there is at least one equipotential plane, the sum of all charges is automatically zero: the charges and mirror charges cancel. The reference potential is set equal to zero in this case. The freedom to choose a reference potential can be exploited when planes are absent. To find the charges, we therefore have to solve the following equations:

$$V_i = \sum_{j=1}^{n_{wires}} C_{ij}^{-1} q_j + V_{planes}(z) + V_{reference} \qquad \sum_{\text{wires + mirror wires}} q_j = 0$$

where q_j are the charges to be found
C^{-1} is the inverted capacitance matrix

Making use of the expressions earlier on in this chapter, the elements of the capacitance matrix can be written as:

$$C_{ij}^{-1} \equiv \begin{cases} -\frac{1}{2\pi\varepsilon_0} \operatorname{Re} \log F(z_i - z_j) & (i \neq j) \\ -\frac{1}{2\pi\varepsilon_0} \operatorname{Re} \log \left(d_i \lim_{z \rightarrow 0} \frac{F(z)}{z} \right) & (i = j) \end{cases}$$

and where F is a complex entire function such that

$$\operatorname{Re} \log F(z) = \phi(z)$$

Once the charges per unit length are known, the potential at z can be evaluated from the formula:

$$V(z) = \sum_{j=1}^{n_{wires}} \lambda_j \phi(z - z_j) + V_{planes}(z) + V_{reference}$$

4.1.9 Cylindrical geometry, internal coordinates

This version of the program can perform some computations on certain types of cells which are more conveniently described in polar coordinates for instance because of the presence of a circular plane. The program handles such cells by transforming the polar coordinates to internal coordinates (ρ, ϕ) related to (x,y) via the conformal mapping (see for instance [15] for details):

$$(x, y) = e^{(\rho, \phi)} = (r \cos\phi, r \sin\phi) \tag{21}$$

which translates circles into lines at constant ρ and radial lines into lines at constant ϕ. Radial symmetry in the normal sense cannot be handled this way because this symmetry is absent in the internal coordinates (ρ is not linear in r). A slightly subtle point is the boundary condition at $+\pi$ and $-\pi$ if the cell does not have a ϕ periodicity. The proper way to handle this is to impose a cyclic ϕ boundary condition with period 2π in the internal coordinates. 2π period in polar cells) Circular and radial planes and also symmetry in ϕ do not present problems. All calculations can be performed using the normal routines, transforming to polar coordinates when plotting.

The transformation properties of some common geometrical objects can easily be derived using the transformation law (21):

scalars Scalars are, by definition, invariant.

Example: the electrostatic potential.

local vectors Local vectors behave like infinitesimal transformation, not like coordinates:

$$\begin{pmatrix} dx \\ dy \end{pmatrix} = e^{\rho} \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} d\rho \\ d\phi \end{pmatrix}$$

Example: the drift-velocity.

co-vectors Co-vectors are derivatives of a scalar, it follows that they transform according to:

$$\begin{pmatrix} \partial_x \\ \partial_y \end{pmatrix} = e^{-\rho} \begin{pmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} \partial_\rho \\ \partial_\phi \end{pmatrix}$$

Example: the components of the electrostatic field. The expression in terms of polar coordinates is somewhat simpler:

$$E_{r,\,polar} = \frac{E_{\rho,\,internal}}{r}$$
$$E_{\phi,\,polar} = \frac{E_{\phi,\,internal}}{r}$$

axial vectors Of course the concept of an axial vector is weird in two-dimensional space. Embedding our two-dimensional space in a three-dimensional space, it makes sense to speak about an axial vector parallel with the z-axis. We will call A an axial vector in this sense if

$\forall$ vectors V: $V \times A$ is a co-vector

With this definition, the transformation of an axial vector simply reads:

$$A_\zeta = e^{2\rho} A_z$$

Example: a magnetic field parallel to the z-axis.

inner products Inner products of vectors and co-vectors are as usual scalars.

Example: the product encountered in the signal calculations.

4.1.10 Zeros of the electric field

The points where $E = 0$ is satisfied are the natural counterparts of the singularities at the wire positions and as such play a key role in the understanding of the behaviour of drifting particles in the chamber. Wires (and their mirror images) are the end points of the drift-lines whereas zeros are bifurcation points in the drift-field. It follows that the drift-lines from these points delimit the various acceptance regions. It should be noted on the outset that limiting oneself to the no-B case is not a true constraint since the drift-velocity vector is zero wherever E is zero, no matter the B field (see Section 4.3 on page 110).

4.1.10.1 The saddle shape of the zeros

E has a saddle point at its zeros owing to the harmonicity of the potential, as can be seen from a Taylor-expansion around the zero:

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix} = -\begin{pmatrix} \frac{\partial^2 V}{\partial x^2} & \frac{\partial^2 V}{\partial y \partial x} \\ \frac{\partial^2 V}{\partial x \partial y} & \frac{\partial^2 V}{\partial y^2} \end{pmatrix} \begin{pmatrix} \delta x \\ \delta y \end{pmatrix} + \ldots$$

Assuming V satisfies the usual regularity conditions and using the harmonicity of V, one obtains after rotating over an angle

$$\tan \phi = \frac{\partial^2 V}{\partial x^2} \Big/ \frac{\partial^2 V}{\partial x \partial y}$$

a diagonal form:

$$\begin{pmatrix} E_u \\ E_v \end{pmatrix} = -\begin{pmatrix} \lambda & 0 \\ 0 & -\lambda \end{pmatrix} \begin{pmatrix} \delta u \\ \delta v \end{pmatrix} + \ldots$$

where λ is some (in the interesting case) non-zero number. The above treatment is valid for first order zeros, which are certainly the only ones one meets in practice; it would be interesting to investigate the existence of higher order zeros though.

The saddle shape can easily be inferred from this formula. An immediate -and important- consequence of this simple fact is that the argument of E (i.e. the angle of the E vector) changes by -2π over one full counter-clockwise loop around the saddle point. This is in marked contrast to wires where the argument changes by -2π.

4.1.10.2 The principle of the argument

The principle of the argument is a convenient tool for counting the number of zeros and singularities (or poles) of a complex analytic function inside a given area. It simply states that for a closed loop γ and an meromorphic function f which has simple zeros and simple poles none of which lie on γ:

$$\Delta_\gamma \operatorname{Arg} f = 2\pi (\text{number of zeros} - \text{number of poles})$$

This is not the most general phrasing of the theorem but it is adequate for our purposes (see [16] for a proof). Recall that E (complex version) is *not* a meromorphic function but the complex conjugate of one that is. One merely has to change the sign of the change in argument to compensate for this. Hence, we find that:

$$\Delta_\gamma \operatorname{Arg} E = 2\pi (\text{number of wires} - \text{number of zeros})$$

4.1.10.3 Locating zeros

The principle of the argument can directly be applied to obtain via bisection regions that contain precisely one zero. The program uses a random search inside these areas to find good starting points and then steps towards the zeros with a first (!) order stepping method that assumes a saddle shape; higher order methods, no matter how sophisticated, are inevitably inefficient.

4.1.11 Magnetic field calculation

The program does not contain routines for detailed magnetic field calculation; they may be added by the user however. The magnetic field routines the program supplies, are adequate for linear magnetic fields even if the difference in magnetic susceptibility between the wires and the gas is to be taken into account. The distortion is calculated from the formulae [17]:

$$B_x(x,\ y) = B_x^0 + \alpha B_{xy}^0 \sum_{\text{wires}} \frac{r_i^2}{d_i^4} \left\{ +\left((x-x_i)^2 - (y-y_i)^2 \right) \cos\phi + 2(x-x_i)(y-y_i) \sin\phi \right\}$$

$$B_y(x,\ y) = B_y^0 + \alpha B_{xy}^0 \sum_{\text{wires}} \frac{r_i^2}{d_i^4} \left\{ -2(x-x_i)(y-y_i) \cos\phi + \left((x-x_i)^2 - (y-y_i)^2 \right) \sin\phi \right\}$$

$$B_z(x,\ y) = B_z^0$$

where

B_x^0 = x-component of the undisturbed magnetic field,
B_y^0 = y-component of the undisturbed magnetic field,
B_z^0 = z-component of the undisturbed magnetic field,
$B_{xy}^0 = \sqrt{B_x^{0^2} + B_y^{0^2}}$,
ϕ = angle of the magnetic field vector to the x-axis,
$\alpha = \frac{\mu_{wires} - \mu_{gas}}{\mu_{wires} + \mu_{gas}}$,
μ_{wires} = magnetic susceptibility of the wires,
μ_{gas} = magnetic susceptibility of the gas,
r_i = radius of wire i,
d_i = distance from (x, y) to (x_i, y_i).

These formulae are valid outside the wires, which is the region of interest. The program will correctly calculate the field inside the wires as well.

4.2 Mixing gasses

The method used in Garfield to calculate the drift velocity and diffusion in gas mixtures, has been taken from the work of G. Schultz and J. Gresser [2].

The outline of this method is as follows: $F(\varepsilon)$ represents the energy distribution function of electrons under the influence of an electric field E in the gas under consideration. $F(\varepsilon)$ is decomposed in a series of Legendre polynomials around the axis of the electric field and only the first two terms, $F_0(\varepsilon)$ and $F_1(\varepsilon)$ are kept. Using the transport equations, one can express $F_1(\varepsilon)$ in terms of $F_0(\varepsilon)$. Under certain assumptions on inelastic collisions and excitation processes, one can derive the following relation:

$$F_0(\varepsilon) = C\sqrt{\varepsilon}\ \ e^{-\int_0^{\varepsilon} \frac{3\Lambda(\varepsilon')\varepsilon'\, d\varepsilon'}{(El(\varepsilon'))^2 + 3\Lambda(\varepsilon')\varepsilon' k_B T}}$$

where C is a normalisation constant, $\Lambda(\varepsilon)$ is the fraction of the energy lost by an electron during a collision with a gas atom or molecule and $l(\varepsilon)$ is the mean free path of electrons. The mean free path is inversely proportional to the cross section, σ.

When mixing gasses, one uses the following effective values for the mean free path and the energy loss fraction:

$$\sigma = \sum_i f_i \sigma_i$$

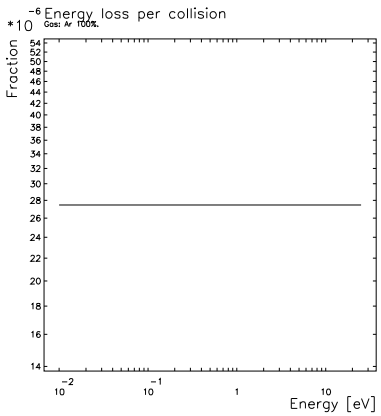
$$\sigma\Lambda = \sum_i f_i \sigma_i \Lambda_i$$

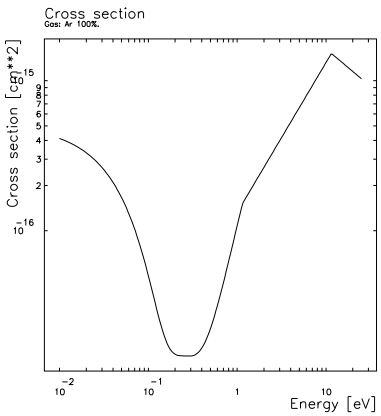
The drift velocity and diffusion are written as follows:

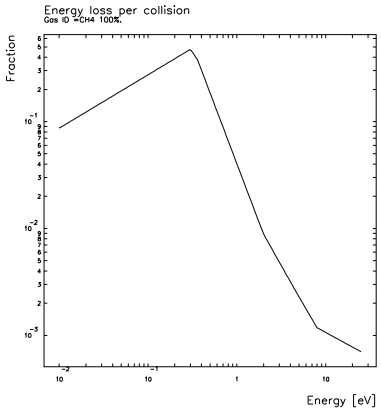
$$w_{drift} = \frac{2}{3} E \sqrt{\frac{q_e}{2m_e}} \int_0^\infty d\varepsilon \, (\varepsilon l'(\varepsilon) + l(\varepsilon)) F_0(\varepsilon)$$

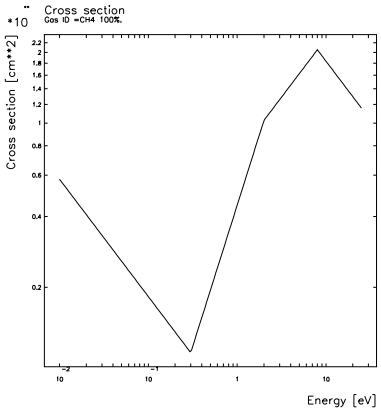
$$D = \frac{1}{3} \int_0^\infty d\varepsilon \, l(\varepsilon) \sqrt{\frac{2\varepsilon}{m_e}} F_0(\varepsilon)$$

The input parameters for these calculations, the cross section and the energy loss fraction, have been provided by Fabio Sauli and Anna Peisert:

<table>
<tr>
<td>Gas
Argon (Ar)
First ionisation level
15.759 eV
Parametrised range
0.3 ≤ ε ≤ 11.5 eV
Origin
Wircha (J. Fehlmann)</td>
<td> 

Argon: energy loss</td>
<td> 

Argon: cross section</td>
</tr>
<tr>
<td>Gas
Methane (CH_4)
First ionisation level
12.6 eV
Parametrised range
0.3 ≤ ε ≤ 8 eV
Origin
Fabio Sauli & Anna Peisert</td>
<td> 

Methane: energy loss</td>
<td> 

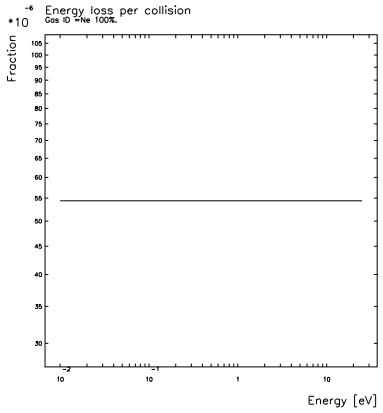
Methane: cross section</td>
</tr>
</table>

Gas
Neon (Ne)

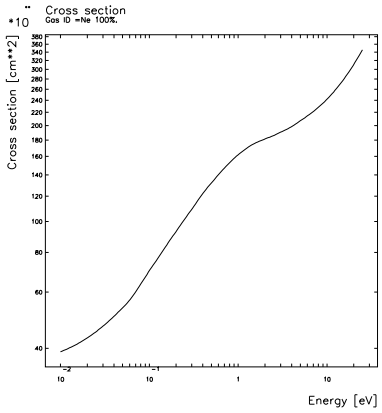
First ionisation level
21.564 eV

Parametrised range
$0.03 \leq \varepsilon \leq 7$ eV

Origin
Fabio Sauli & Anna Peisert



Neon: energy loss



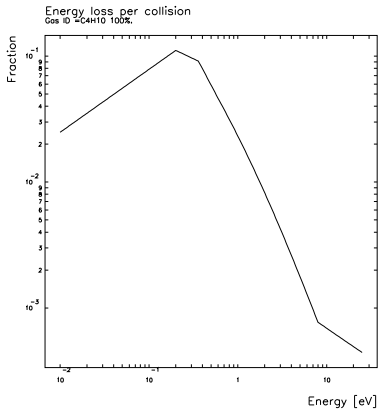
Neon: cross section

Gas
Isobutane (C_4H_{10})

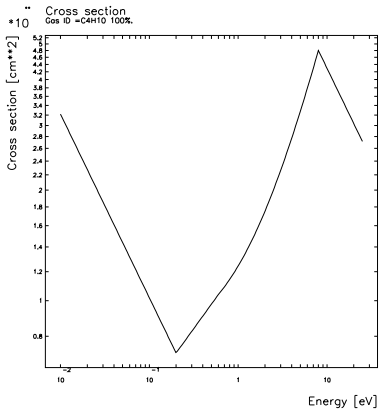
First ionisation level
10.6 eV

Parametrised range
$0.2 \leq \varepsilon \leq 8$ eV

Origin
Fabio Sauli & Anna Peisert



Isobutane: energy loss



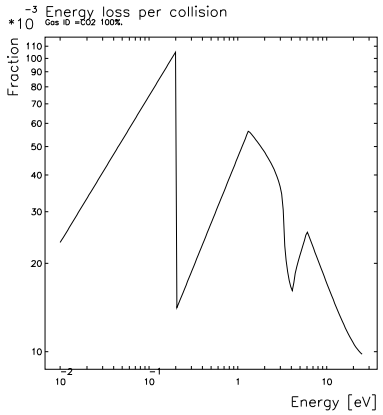
Isobutane: cross section

Gas
Carbon dioxide (CO_2)

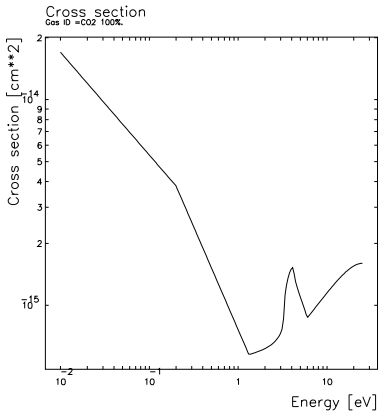
First ionisation level
13.769 eV

Parametrised range
$0.2 \leq \varepsilon \leq 25$ eV

Origin
Fabio Sauli & Anna Peisert



Carbon dioxide: energy loss



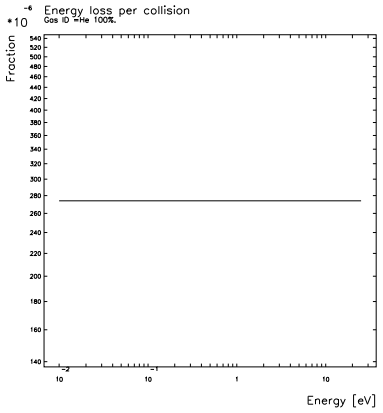
Carbon dioxide: cross section

Gas
Helium (He)

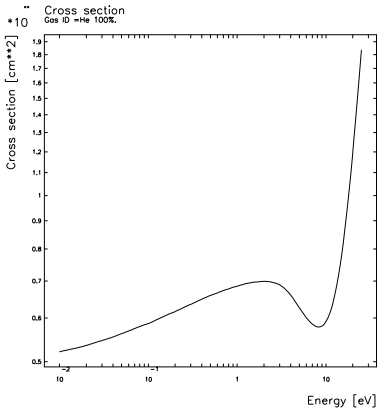
First ionisation level
24.587 eV

Parametrised range
$0.008 \leq \varepsilon \leq 6$ eV

Origin
Fabio Sauli & Anna Peisert



Helium: energy loss



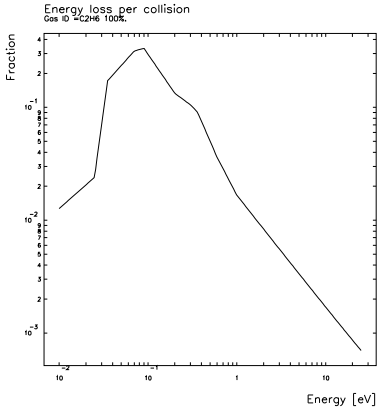
Helium: cross section

Gas
Ethane (C_2H_6)

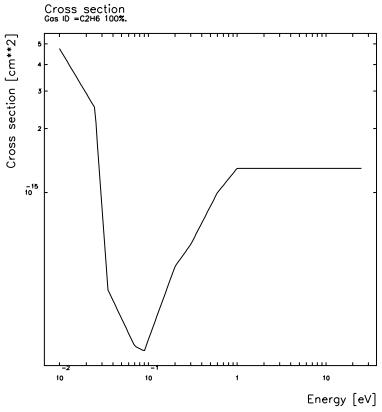
First ionisation level
11.5 eV

Parametrised range
$0.025 \leq \varepsilon \leq 1$ eV

Origin
Fabio Sauli & Anna Peisert



Ethane: energy loss



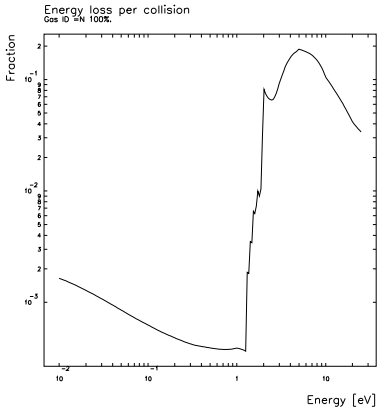
Ethane: cross section

Gas
Nitrogen (N)

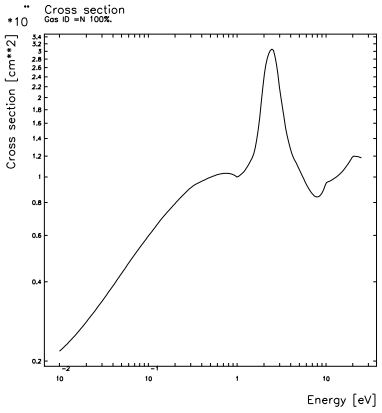
First ionisation level
14.534 eV

Parametrised range
$0.0016 \leq \varepsilon \leq 40$ eV

Origin
Fabio Sauli & Anna Peisert



Nitrogen: energy loss



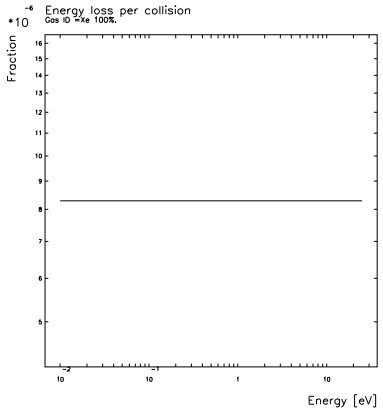
Nitrogen: cross section

Gas
Xenon (Xe)

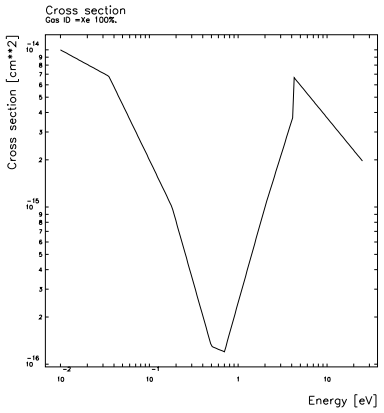
First ionisation level
12.130 eV

Parametrised range
$0.01 \leq \varepsilon \leq 10$ eV

Origin
Fabio Sauli & Anna Peisert



Xenon: energy loss



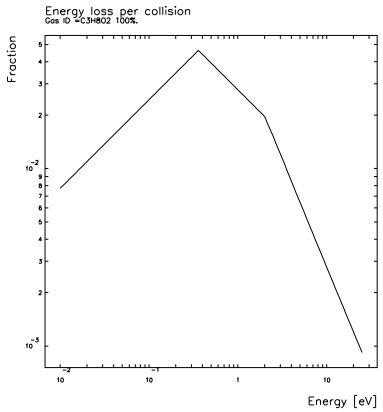
Xenon: cross section

Gas
Methylal ($C_3H_8O_2$)

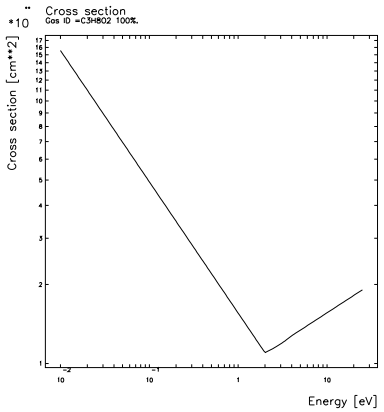
First ionisation level
$\approx$ 10.1 eV

Parametrised range
$2 \leq \varepsilon \leq 4$ eV

Origin
Fabio Sauli & Anna Peisert



Methylal: energy loss



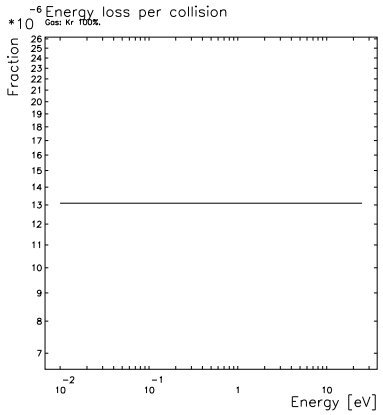
Methylal: cross section

Gas
Krypton (Kr)

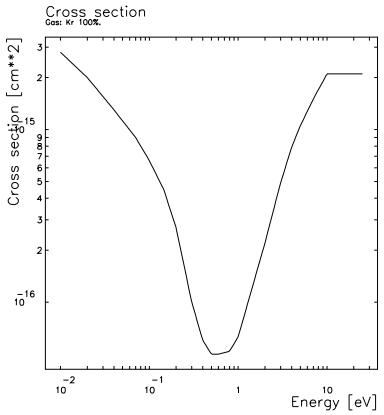
First ionisation level
13.99961 eV

Parametrised range
$0.01 \leq \varepsilon \leq 10$ eV

Origin
Wircha (J. Fehlmann)



Krypton: energy loss



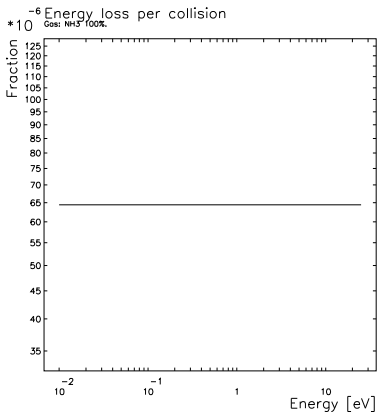
Krypton: cross section

Gas
Ammonia (NH_3)

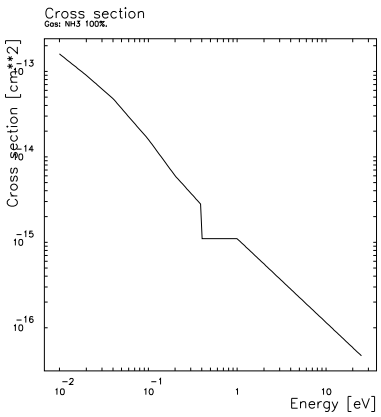
First ionisation level
$\approx$ 10.16 eV

Parametrised range
$0.01 \leq \varepsilon \leq 10$ eV

Origin
Wircha (J. Fehlmann)



Methylal: energy loss



Methylal: cross section

4.3 Motion of electrons and ions

This section briefly recalls the equations of motion for electrons and ions in a gas and the numerical method used by Garfield to solve them. Two of the less straight-forward applications of drift-line calculation, x(t)-correlation and arrival time distributions, are dealt with in more detail.

4.3.1 The equation of motion

The drift-velocity of both electrons and ions is assumed to be determined entirely by the electric and magnetic field at their current position. This is justified by the short mean free path as compared to the length of normal drift-lines. The equation of motion is therefore a set of 2 coupled first order differential equations:

$$(\dot{x},\ \dot{y}) = \vec{v}_{drift}(x,\ y)$$

$\vec{v}_{drift}$ takes, in the absence of a magnetic field, the simple form:

$$\vec{v}_{drift}(x,\ y) = \vec{E}(x,\ y)\,\mu(E)$$

where $\mu(E)$ is called the mobility.

The drift-velocity of a particle under the influence of both a magnetic and an electric field is given by:

$$\vec{v}_{drift} = \frac{\mu}{1+\omega^2\tau^2}\left(\vec{E} + \frac{\vec{E}\times\vec{B}}{|B|}\ \omega\tau + \frac{\left(\vec{E}\cdot\vec{B}\right)\vec{B}}{B^2}\ \omega^2\tau^2\right)$$

where ω = the cyclotron frequency,
τ = the average time between atomic collisions,
E and B are to be evaluated at (x,y).

This formula is proven in [18]. It might be appropriate to note that $\omega\tau$ equals $\mu|\vec{B}$ in this approximation. Hence the third term (or the second if $\vec{E}$ and $\vec{B}$ happen to be orthogonal) will dominate in the case of electrons, for which usually $\omega\tau >> 1$. For ions on the other hand, where typically $\omega\tau < 1$, the first term tends to be largest.

The Lorentz angle calculated from the above formula does not describe the experimental data very well.

The mobility μ has been tabulated for many gasses as a function of E/p (p is the pressure, the mobility scales roughly in E/p). The tables are interpolated using cubic splines [19] or Newton polynomials via the CERN library routine DIVDIF (E105).

4.3.2 Numerical solution of the equation of motion

The differential equation of motion is solved numerically using a 2^{nd}-3^{rd} order Runge-Kutta-Fehlberg (RKF) method [20], which adjusts the step-size such that the overall accuracy increases, while the amount of CPU time used remains comparatively low.

The method works as follows. The drift-velocity at the initial position z_0, $\vec{v}_{drift}(z_0)$ is used to obtain an initial step-size (in time) using:

$$\delta t = \frac{\varepsilon}{|\vec{v}_{drift}(z_0)|}$$

where ε is the absolute integration accuracy

This estimate of the step-size is usually on the safe side, but this is harmless because its value can increase rapidly. Next, the algorithm repeatedly makes a second and a third order estimate of the next step to take from the current point z, initially z_0:

$$\Delta\vec{y}_I = \sum_{k=0}^{2} c_I^k \vec{v}_k$$

$$\Delta\vec{y}_{II} = \sum_{k=0}^{3} c_{II}^k \vec{v}_k$$

where

$$\vec{v}_k = \vec{v}_{drift}\left(z + \delta t \sum_{l=0}^{k-1} \beta_{kl} \vec{v}_l \right)$$

The coefficients, which have been chosen such that one field evaluation from the previous cycle can be reused, can be found in the reference. The difference between the two estimates is used to update the step-size:

$$\delta t_{new} = \sqrt{\frac{\varepsilon\, \delta t_{old}}{|\Delta\vec{y}_I - \Delta\vec{y}_{II}|}}$$

After each step, a guess is made of the most likely target wire. Only wires charged oppositely to the particle are considered. During the evaluation of the $\vec{v}_k$ for the next step, checks are made to ensure that none of the 'sensing' points lies at the other side of the target wire or at the other side of a plane. If the target wire has been crossed, another algorithm for stepping towards a wire takes over. If a plane has been crossed, a simple linear step towards the surface is made. After each step, a check is made to ensure that the particle is still within the user-defined drift-area; if it is not, the last step is trimmed. A few other conditions, such as exceeding the maximum number of steps (MXLIST), stopping and returning, may cause early abandoning of the calculations at this stage. Also after each step, the wire closest to which the particle passed by is determined (this may, but need not, be the target wire). If the minimum distance is smaller than the radius times a user-defined multiplication factor (TRAP), the wire is considered to be hit and the drift-line is terminated by the wire algorithm.

Terminating a drift-line once the target wire is known, is a great deal simpler than free drift-line calculation. It is however surprisingly important to do the final stepping accurately because the success of for instance the x(t) calculation hinges on a better than 0.1 % accuracy of the total drift-time estimate.

As a first step, the amount of time needed to reach the wire from the current last point, is estimated. A tentative step of this length is made of which the accuracy is tested by means of an intermediate point. If not satisfactory, the step-length is repeatedly halved. A step is truncated if it would end up insider the wire. The method terminates if either of two conditions is satisfied: the particle moves away from the wire (for instance if the wire has a large dipole moment) or if the last step reaches the wire-surface. The time is integrated using the Simpson rule, making use of the fact that the field near the surface is roughly logarithmic. This method emphasises accurate timing and neglects accurate positional tracking, this is justified by the circumstance that the path is almost straight near the wires.

The routines involved in calculating drift-lines communicate with little more than a status code (ISTAT) which tells on which wire the drift-line ends or whether it ended on a plane etc. The routines asking for drift-lines usually examine the code. The meaning of the various values is explained in Section 6.3 on page 129, under the heading DLCSTA and DLCALC.

The equal arrival time points are interpolated on the drift-lines, using third-order splines.

4.3.3 Calculation of x(t)-relations

The x(t)-correlation for a wire at (x_{wire}, y_{wire}) is the relation between x and the minimum time an electron starting on a line through (x, y_{wire}) at an angle ϕ to the y-axis needs to reach the wire. x(t)-Relations are used in the offline event reconstruction in order to correlate the measured time of a hit with a position in the chamber. The x(t)-correlations calculated by Garfield should merely be seen as a rough indication, not as immediate input to a reconstruction program, even though the algorithm can usually achieve a better than 0.1 % internal consistency if the parameters have been adjusted with care. The main reason is that the drift-velocity is usually not known with enough accuracy, something no simulation program can correct for ! T_0 and slope corrections are almost certainly needed.

The algorithm used by Garfield for calculating x(t)-correlations is the following.

- Drift-lines are calculated starting from the wire surface between the user-specified limiting angles. Each of these drift-lines is interpolated on all of the x points for which a t has been requested. For each x a table is maintained of the 3 shortest interpolated times.
- The algorithm recalculates the drift-line corresponding with the shortest time. The algorithm stops at this point if three data-points for a given x have been obtained already and the relative difference between the parabolic minimum of these 3 points and the recalculated value does not exceed ε. The algorithm stops also if no optimisation has been requested.
- Otherwise, additional data-points are sought for the x for which less than 3 points have been found so far. None of these 3 points is left in the interpolated state.
- The last stage is a parabolic minimisation in which a new optimum replaces the worst of the 3 data-points until convergence is achieved:

  $|t_{parabolic} - t_{minimal}| < \varepsilon |t_{parabolic} + t_{best}|$

  The calculations are abandoned if no convergence can be achieved within the user-specified maximum number of iterations. Checks are made to ensure that the stationary point of the parabola is not a maximum.

The parameter ε can be set by the user via the PRECISION keyword.

4.4 Signal simulation

The signal on the sense wires which results from the passage of a charged particle through the chamber, is simulated in Garfield by simple Monte-Carlo techniques. Three main steps may be distinguished in this simulation:

4.4.1 Track generation

The path of the particle is part of the input to the program.

4.4.1.1 Cluster positions

We assume that the energy of the charged particle is much larger than energy lost on average in collisions with gas-molecules. Hence, the distance between 2 clusters is in excellent approximation independent of the location of the other clusters. The number of clusters per unit length is therefore Poisson distributed or equivalently, the distance between two clusters is exponentially distributed:

$$f(d) = e^{-\bar{n}\ d}$$

where $\bar{n}$ is the average number of clusters per unit length.

4.4.1.2 The cluster-size distribution

If the cluster-size distribution has been measured, it is of course preferable to use it. However the distribution is very often not available and one has to resort to some more or less sophisticated means of calculating it from known parameters. This section explains the fairly simple method this program puts at your disposal.

According to Landau the energy deposited by a charged particle passing through some material, is given by the distribution (the so-called Landau distribution):

$$\begin{aligned} f_{Landau}(\lambda) &= \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} e^{s\ \log(s)+s\lambda}\,ds \\ &= L^{-1}e^{s\ \log(s)} \end{aligned}$$

where
- λ: dimensionless, linear in the energy,
- L^{-1}: the inverse Laplace transform

In our case the energy is deposited in clusters rather than continuously as required for the Landau distribution. We should therefore draw the required energies from a modified Landau distribution $f_{\bar{n}}^{Landau}(\lambda)$ which has the property that the sum of $\bar{n}$ numbers drawn from this distribution is Landau distributed:

$$f_{\bar{n}}^{Landau\ *\ \bar{n}} = f_{Landau}$$

(The "*" stands for a multiple convolution.) Since the Landau distribution takes the form of an inverse Laplace transform, the relation between $f_{\bar{n}}^{Landau}$ and f_{Landau} is:

$$\begin{aligned} f_{\bar{n}}^{Landau}(\lambda) &= L^{-1}e^{\frac{s\log(s)}{\bar{n}}} \\ &= \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} e^{\frac{s}{\bar{n}}\log(\frac{s}{\bar{n}})+\frac{s}{\bar{n}}(\log(\bar{n})+\lambda-\bar{n})}\,d(\frac{s}{\bar{n}}) \\ &= \bar{n}\ f_{Landau}(\bar{n}\lambda+\log(\bar{n})) \end{aligned}$$

Hence the distribution function of the primary cluster-size reads in this simple approximation:

$$P_{size}(m) = \frac{\bar{n}}{\xi}\int_{m\,E_{pair}}^{(m+1)\,E_{pair}} f_{Landau}\left(\bar{n}\frac{E-E_{mostprob}}{\xi}+\log(\bar{n})\right)dE \qquad (22)$$

where
- m: the actual cluster-size,
- $E_{mostprob}$: the most probable energy loss per unit length,
- E_{pair}: the energy required for one electron ion pair,
- $\xi = K\frac{Z}{A}\rho$, assuming the particle travels at the speed of light,
- K: a numerical constant,
- A, Z: suitably weighed atomic number and nuclear charge,
- ρ: the density.

The parameter ξ can be interpreted as the energy loss calculated to first order with the Bethe-Bloch formula. Some details about the Laplace transforms can for instance be found in [21].

Formula (22) shows that the present version of the program assumes a fixed amount of energy E_{pair} has to be present in the cluster to generate one primary electron-ion pair. It is pointed out in [22] that this is a rough approximation for small cluster-sizes and the reference describes a method to improve on this part of the program.

Random cluster-sizes are obtained from HISRAN and HISPRE (V150) for a probability distribution calculated with (22). The Landau probability density is obtained from the CERN library routine DENLAN (G110).

4.4.2 Drift of the clusters towards the anode

Using the drift-line routines, a drift-line is calculated starting at the location of the cluster. If it leads to a sense wire, the remaining steps (diffusion, avalanche, electron pulse and ion-tail) come into effect.

4.4.2.1 Taking longitudinal diffusion into account

Only the time of passage through the points on the drift-line is uncertain since lateral diffusion is neglected. The distribution of the arrival times is given by ($N(\mu, \sigma^2)$ stands for a normal distribution):

$$N\left(t_{mean}, \int_{\text{drift-line}} \frac{\sigma_{diffusion}(z)^2}{v_{drift}(z)^2} dz \right)$$

where z is a point on the drift-line

The addition property of normal distributions has been used. The integration is carried out in Simpson-style with a step-size which varies according to the difference between the first and second order estimates of parts of the integral. Note that the RKF method guarantees that steps are small where v_e is changing rapidly.

4.4.2.2 The avalanche near the wire-surface

The user may choose between 4 types of avalanche multiplication factors:

1. a fixed number;
2. a Gaussian distribution;
3. an exponential distribution with fixed mean;
4. an exponential distribution with a mean obtained from an integration of the Townsend coefficient over the electron drift-line giving rise to the avalanche:

   $$\text{multiplication} = e^{\int \alpha(z)dz}$$

The integration method for the Townsend coefficient is analogous to the one used for the diffusion.

4.4.2.3 The electron pulse

Electrons move significantly faster than ions, and hence induce a proportionally larger current. However, the number of electrons is only significant during the avalanche process, which normally takes place close to the wire. Moreover the avalanche process is several orders of magnitude more important in many chambers than the difference between the electron and ion drift-velocities. Hence the current due to the electrons hitting a sense wire is of very short duration compared to the current induced by the moving ions and its magnitude is also smaller, unless the multiplication factor is deliberately kept low (about 10^3).

The present version of the program can only produce spikes at the arrival time interval, with a width equal to the time-resolution. One should seriously consider not to include electron pulses at all; they are left out by default.

4.4.3 Calculation of the ion-tail

The ions created during the avalanche account for a large fraction of the visible signal in drift-chamber experiments and it is therefore appropriate that the currents they induce on the sense wires when drifting towards the cathodes are accurately calculated. This part of the signal is known as 'ion-tail'. The method used in this program is inspired by [23].

An exact expression for the induced charge λ_i may be obtained using the Green reciprocity equations [24, 25] to calculate the induced charges; differentiation to time gives the induced current. Consider the following physically acceptable situations:

1. The configuration of interest to us:

charge of the ion	Q_{ion}
potential at the ions position	? (not relevant)
charge on wire i	$q_i + \lambda_i$
potential of wire i	V_i

   Note that the potential on the surface of wire i is unchanged as compared to the rest situation where the wire charges are q_i. The extra charge λ_i on the wires is assumed to be removed instantly.

2. In this configuration only wire j carries a charge, the other wires and the ion being uncharged.

charge of the ion	0
potential at the position of the ion	$q_j\ \phi(z_{ion} - z_j)$
charge of wire j	q_j
potential of wire j	$q_j\ \phi(z_j - z_j)$
charge of wire $i \neq j$	0
potential of wire $i \neq j$	$q_j\ \phi(z_i - z_j)$

In both cases the reference potential and the potential due to the equipotential planes are assumed to have been subtracted.

Applying the Green reciprocity equations and differentiating yields:

$$\sum_{i=1}^{n_{wires}} \lambda_i\ \phi(z_j - z_i) = -Q_{ion}\ \phi(z_{ion} - z_j)$$

$$\sum_{wires} I_j\ \phi(z_j - z_i) = Q_{ion}\ \vec{\varepsilon}(z_{ion} - z_j) \cdot \vec{v}_{ion}$$

where $\vec{\varepsilon}(z) = -\vec{\nabla}\phi(z)$,
$\vec{v}_{ion}$ is the drift-velocity of the ion,
$I_i = \frac{d\lambda_i}{dt}$, the induced current

I_i is therefore determined by a system of linear equations if the cell is not periodic.

If the cell is truely periodic however, the potential used for the field calculations is no longer applicable since, clearly, the signal on the replicas of a wire is different from the signal on the wire in the basic cell. Instead potentials which do not have true periodicities should be taken:

B1A→
B1A→
C2B2x
C2B2y

The complexity of the equations to be solved is also considerably greater in the periodic case since we then have matrix convolution equations:

$$\sum_{m=-\infty}^{+\infty}\sum_{j=1}^{n_{wires}} I_j[m]\,\phi(z_j[n]-z_i[m]) \;=\; Q_{ion}\;\vec{\varepsilon}(z_{ion}-z_j[n])\cdot\vec{v}_{ion}$$

where $\begin{cases} z_j[m] = z_j + ms, \text{ s the periodicity of the cell,} \\ I_i[m] \text{ is the induced current on the wire at } z_i + ms. \end{cases}$

Similar equations hold for the doubly periodic case.

These equations are best solved by means of Fourier transforms, provided some care is taken to avoid aliasing and convergence problems. [This is something to be done by the user in the present version of the program]. Indeed a solution to the above set of equations is:

$$I_i[n] = Q_{ion}\sum_{m=-\infty}^{+\infty}\sum_{j=1}^{n_{wires}} F^{-1}\{F\,\phi(z_j[n]-z_i[m])\}^{-1}\;\vec{\varepsilon}(z_{ion}-z_j[n])\cdot\vec{v}_{ion}$$

where F is a forward Fourier transform and F^{-1} its inverse. It should be clear that especially the doubly periodic case demands the manipulation of huge amounts of numbers, if a high degree of accuracy is needed.

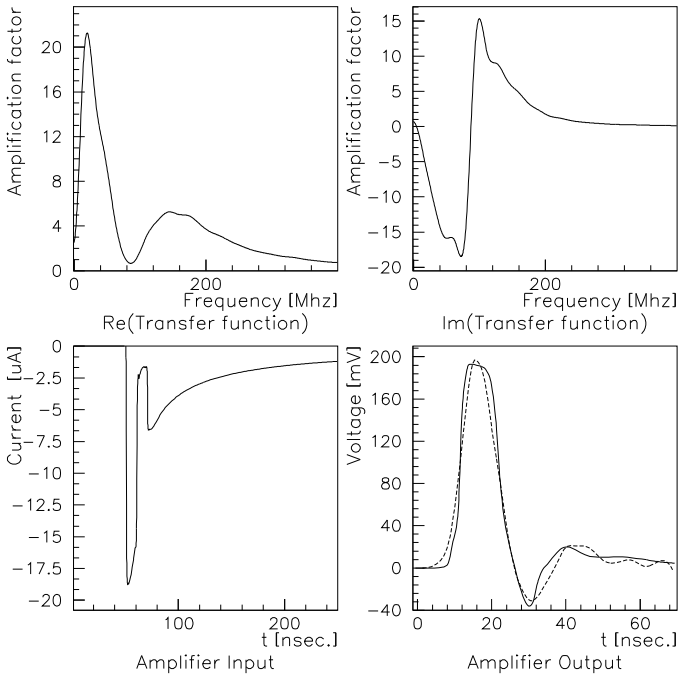


Figure 24. Comparison of a measured and simulated signal. The simulated signal has been corrected for reflection and is folded with the transfer function of the read-out electronics. (Courtesy Matthias Grosse Perdekamp [26].)

4.5 Evaluation of symbolic formulæ

The program frequently needs general expressions in terms of a set of variables. Although the user could in principle provide these relations as Fortran functions, it would be inconvenient to do so (the program has to be recompiled and reloaded each time a formula is changed). It is for this reason that the program contains a set of subroutines capable of evaluating symbolic formulae.

Roughly speaking, each formula is translated into an instruction list (independent of the current value and type of the variables) which can be executed any number of times.

This section explains in detail how symbolic formulae are handled by the program. It also contains some guidelines for constructing formulae. Refer to Section 3.12.11 on page 87 to see how the instruction lists can be edited.

4.5.1 Guidelines

The format of the formulae closely resembles Fortran, there are however a few differences:

- Not all Fortran functions are available and some intrinsic functions have a different name (see the table below),
- The data types recognised by these routines are: string, number, logical and histogram. No distinction is made between integers and reals and the Fortran data types DOUBLE PRECISION and COMPLEX are not known.
- Blanks are significant in such formulae as EXP X or SIN COS X, both of which are correct provided X is a legal variable. Blanks inside variable and function names should be avoided. On input, a blank is treated as a separator and formulae which contain blanks are therefore split into pieces unless they have been put between quotes (both single and double quotes will do).
- Identifier names may be up to 10 characters long.
- Constants and constant intermediate results differing less than a fraction 10^{-4} (machines other than Cray) or 10^{-8} (Cray) from an already stored constant, are considered to be equal to that constant.

The symbol PI may be used in all formulae for π, e.g. to convert degrees into radians as input for the functions SIN, COS and TAN.

The program tries to make instruction list which are fast. E.g. it will try to avoid repeated evaluation of identical subexpressions. The program will succeed only if the subexpressions look alike and it helps if you put them between brackets.

Fortran compiled functions execute up to 5 times faster than the corresponding instruction lists. In case you intend to make heavy use of functions, it might therefore be a better idea to modify the program. Alternatively you could try and make an optimised instruction list yourself, see Section 3.12.11 on page 87 on editing.

4.5.2 Details about the translation process

First, each formula is translated by ALGPRE into a list of instructions (similar to the programming of a pocket calculator). Then, each time ALGEXE is called, the variables in the formula are replaced by their values, the instructions are carried out one by one (by ALGEX2) and the result(s) are passed to the calling subroutine.

The translation carried out by ALGPRE, is in fact a 4 step process:

1. The input string T is copied into a string S and an integer array P, during which the following substitutions are made:

Table 4 (Page 1 of 3). Formula translation table. Translation of formulae

Input	S	P	Notes
(, [	(	0	Yes, square brackets are allowed !
),]	)	0	
constant	R	≤0	See comments on step 3.
variable	R	>0	See comments on step 3.
TRUE	R	-1	Logical value TRUE.
FALSE	R	0	Logical value FALSE.
+	O	1	Numbers: add, Logicals: or, Strings: concatenate.

Table 4 (Page 2 of 3). Formula translation table. Translation of formulae			
Input	**S**	**P**	**Notes**
-	O	2	Numbers: subtract, Logicals: exclusive or.
*	O	3	Numbers: multiply, Logicals: and.
/	O	4	Divide.
**	O	5	For $Arg_1 > 0$ or Arg_2 integer.
=	O	10	Numbers: $\|Arg_1 - Arg_2\| < 10^{-5}$, Logicals: $Arg_1 \Leftrightarrow Arg_2$.
#, < >, > <	O	11	Numbers: $\|Arg_1 - Arg_2\| > 10^{-5}$, Logicals: $Arg_1 \not\Leftrightarrow Arg_2$.
<	O	12	Returns TRUE if $Arg_1 < Arg_2$.
<=, =<	O	13	Returns TRUE if $Arg_1 \leq Arg_2$.
>	O	14	Returns TRUE if $Arg_1 > Arg_2$.
>=, =>	O	15	Returns TRUE if $Arg_1 \geq Arg_2$.
&	O	16	Logical AND between logicals.
|	O	17	Logical OR between logicals.
EXP	F	1	
LOG	F	-1	For $Arg > 0$.
SIN	F	2	
ARCSIN	F	-2	For $\|Arg\| \leq 1$.
COS	F	3	
ARCCOS	F	-3	For $\|Arg\| \leq 1$.
TAN	F	4	
ARCTAN	F	-4	
ABS	F	5	
SQRT	F	-5	For $Arg \geq 0$.
+	F	6	As a monadic function (e.g. +2.0).
-	F	-6	As a monadic function (e.g. -3.0).
SINH	F	7	
ARCSINH	F	-7	Not an intrinsic function.
COSH	F	8	
ARCCOSH	F	-8	For $\|Arg\| \geq 1$, not intrinsic.
TANH	F	9	
ARCTANH	F	-9	For $\|Arg\| \leq 1$, not intrinsic.
NOT	F	10	NOT function, also hat and tilde.
ENTIER	F	11	Entier function.
TRAILING	F	-11	$\equiv$ Arg –Entier(Arg).
STRING	F	12	Converts a number or logical to a string.
NUMBER	F	-12	Converts a string to a number.
SUM	F	13	Sum of histogram contents.

Table 4 (Page 3 of 3). Formula translation table. Translation of formulae			
Input	**S**	**P**	**Notes**
PRODUCT	F	14	Product of histogram contents.
REFERENCE	F	14	Reference to histogram.
RND_UNIFORM	F	-21	Uniform random number between 0 and 1
RND_GAUSS	F	-22	Gaussian random number, G(0, 1)
RND_EXP	F	-23	Exponential random number, mean 1
RND_LANDAU	F	-24	Landau random number
RND_POISSON	F	-25	Poisson random number
,	$	0	Separates formulae.

Other symbols are ignored and an error message is issued. Note on powers: negative numbers can only be raised to powers that are (near) integer, the sign being negative for negative numbers to an odd power, even for other cases. Zero can be raised to any power larger than zero.

Example:

```
T =    TAN ( SIN ( + X ** 2 + ABS ( Y ) ) ) + 1
S = $   F   (   F   ( F R O R O   F   ( R ) ) ) O R $          (23)
P = 0   4   0   2   0 6 1 5 2 1   5   0 2 0 0 0 1 1 0
```

At the same time, the balance of the brackets is checked. The formula is not accepted if unknown variable or function names have been used.

2. The string S is checked for illegal sequences of symbols, like functions without argument or * followed by / etc.
3. The string S and the array P are used to create the instruction list. This process identifies the deepest level, assigns the result to an element in REG, looks for the next deepest level etc.:

Table 5. Instruction list building. Substitutions made when building the instruction list		
input	**output**	**conditions**
FR	R	Always
ROR)	R)	If not preceded by a higher precedence O
ROR$	R$	Idem
RORO	RO	idem, if the second O has lower precedence
(R)	R	Always

The order of precedence of the operators is established by the P-code except that arithmetic operators have precedence over comparisons, and comparisons have precedence over binary logical operators. Thus, an expression like i=5|i=6 needs no brackets.

Each instruction is made up of 4 integers:

a. either a function-specification (code as in P) or an index in REG,

b. code for the operation (same as in P, 0=result, 6=function),

c. an index in REG,

d. the index in REG of the result or the index in the output array RES in case of a final result (both the first and the second element are 0 in this case).

The array indices in 3a, 3c and 3d are identical to the code in P for constants and variables (except for functions and final results).

There are a few more instruction list codes which are recognised by both the instruction list execution routines and the instruction list printing routine. They are not generated in the translation process as performed by ALGPRE but can be used to construct loops, call procedures and to jump. Use the editor (Section 3.12.11 on page 87) to enter them.

Table 6. Additional instruction list codes. The instruction list execution routines recognises the following instructions which can be used to make control structures.

Function	Ins(1)	Ins(2)	Ins(3)	Ins(4)	Notes
Return	i	-9	0	-	If R_i =True Then leave procedure
Exit	i	-9	1	-	If R_i =True Then leave procedure nest
Quit	i	-9	2	-	If R_i =True Then leave program
Goto	i	7	j	-	If R_i =True Go to instruction R_j
Argument	0	8	i	j	$Arg_j := R_i$, modifiable
Argument	1	8	i	j	$Arg_j := R_i$, not modifiable
Call	i	9	j	-	Call $Proc_i$ with j arguments

The array REG mentioned in the previous paragraph stores all constants, variables and intermediate results. The variables occupy the first n places from REG(1) onwards, n being the number of variables. Constants have indices from -4 downwards, except 0, 1, 2 and π which are always kept in REG(0), REG(-1), REG(-2) and REG(-3). Constant intermediate results are stored 'below' the last constant appearing in the formula, non-constant intermediate results 'above' the last variable. Logicals are represented as 0 for FALSE and as 1 for TRUE.

All elements of the array REG have a type: string (code 1), number (code 2) or logical (code 3). The type is propagated during the execution of an instruction list. The instruction list by itself has no data type information and it may therefore be possible to execute one and the same list for different data types. For instance, A+B will work for strings, numbers and logicals, respectively carrying out a concatenation, an addition and an or.

Table 7. Instruction list. This example shows the instruction list for formula (23).

Ins(1)	Ins(2)	Ins(3)	Ins(4)	Notes
6	6	1	5	+X →REG(5), 4 variables are assumed
5	6	2	6	ABS(Y) →REG(6)
5	5	-2	7	$REG(5)^2$ →REG(7), REG(-2)=2
7	1	6	8	REG(7)+REG(6) →REG(8)
2	6	8	9	SIN(REG(8)) →REG(9)
4	6	9	10	TAN(REG(9)) →REG(10)
10	1	-1	11	REG(10)+1 →REG(11), REG(-1)=1
0	0	11	1	REG(11) is the first (and only) result

4. The instruction list is simplified: constant expressions are evaluated, complementary functions and operators are (to some extent) removed, repeated evaluation of identical subexpressions is avoided etc. Most of these steps are not performed when GOTO's occur. Finally unused constants (excluding 0, 1, 2 and π), auxiliary variables and instructions are removed. The subroutine tells the calling routine which variables are effectively used.

Table 8. Instruction list simplication. The instruction list shown in Table 7 is simplified to the following:				
Ins(1)	**Ins(2)**	**Ins(3)**	**Ins(4)**	**Notes**
5	6	2	5	ABS(Y) →REG(5)
1	3	1	6	X*X →REG(6)
5	1	6	7	REG(5)+REG(6) →REG(7)
2	6	7	8	SIN(REG(7)) →REG(8)
4	6	8	9	TAN(REG(8)) →REG(9)
0	1	9	10	1+REG(9) →REG(10), REG(0)=1 by now !
0	0	10	1	REG(10) is the first (and only) result

Example 2: to illustrate the (in)efficiency of this part of the routine: X-Y-Z+Y-X+Z is not simplified whereas EXP(LOG(X-X+1.0)) is replaced by 1.0.

The program can handle several instruction lists, with perhaps different sets of variables, simultaneously. Each sub-list is translated independently as described above and is then assigned a reference number. The reference number points in an array of entry points, in which the first and last instruction of the sub-list, the number of variables expected, the number of results produced, the first and last constant referenced by the sub-list etc. are stored. When a sub-list is no longer needed, it can be marked for deletion (by ALGCLR) and when total storage is short, the deleted sub-lists and memory associated with them is freed. The entry point list can be inspected and to some extent modified in the algebra editor.

5.0 Compiling the program

This chapter explains how an executable module can be made. The main steps in this process are:

- obtaining the source files;
- adapting explicit file locations to your installation;
- running YPATCHY to make a Fortran compile input file and perhaps to generate auxiliary files;
- compilation of the program, and of the help, message, command language definition, LSE and assembler files;
- linking the compiled (object) file with library routines,

Executable modules ready for use, are stored on many computers at CERN and outside.

5.1 Obtaining the source file

5.1.1 Distribution conditions

Garfield is distributed by the CERN Program Library Office following the general guidelines and conditions applied to Program Library material. The text of the distribution conditions can be requested from:

```
CERN Program Library Office
CERN-CN Division
CH-1211 Geneva 23
Switzerland

Tel:          +41 22 767 4951
Fax:          +41 22 767 7155

EARN/Bitnet:  CERNLIB@CERNVM
DECnet:       VXCERN::CERNLIB (node 22.190)
Internet:     CERNLIB@CERNVM.CERN.CH
```

5.1.2 File location

The program is distributed as a set of 2 files in Patchy format, one is a CARDS file and the other a CRADLE file. Both can also be found in the locations shown in Table 9.

Table 9. File location. The current, past and future versions of the source file for Garfield can be found in the places listed in the table. The name shown is for the CARDS file, for the CRADLE file only the suffix is different: "cra" instead of "car".

Computer	File location	Access
CERNVM	old: GARFIELD CAR on CERNLIB 301 pro: GARFIELD CAR on CERNLIB 311 new: GARFIELD CAR on CERNLIB 321	ftp from cernvm.cern.ch, IP address 128.141.2.4
VXCERN	old: CERN:[OLD.SRC.CAR]GARFIELD.CAR pro: CERN:[PRO.SRC.CAR]GARFIELD.CAR new: CERN:[NEW.SRC.CAR]GARFIELD.CAR	Decnet
Unix	old: /cern/old/src/car/garfield.car pro: /cern/pro/src/car/garfield.car new: /cern/new/src/car/garfield.car	-

5.1.3 Source file contents

The source file as you receive it from CERN contains the components shown in Table 10 on page 124.

Table 10. Source file contents. The Garfield source file contains the components listed below.

Name	Relevant for	Purpose	Processing
-	All computers	Main program	YPATCHY, Fortran. On Vax link with FIOPAT and GARFIELDCLD
FIOPAT.MAR	Vax/VMS	Alternate I/O library, see writeup Z037,	MACRO
GARFIELDCLD.CLD	Vax/VMS	Command language definition	SET COMMAND /OBJ
garfield.hlp	All computers	On-line help file	%pack-help in Garfield
garfield.l	Unix	Introductory help file	nroff -man catl/garfield.l > manl/garfield.l
GARFRUN.FOR	Vax/VMS	Front-end program	Fortran, link with GARFRUNMSG
GARFRUNMSG.MSG	Vax/VMS	Message definitions for GARFRUN.FOR	MESSAGE
GARFRUN.HLP	Vax/VMS	Introductory help file	LIBRARY/CR/HELP
GARFIELD.LSE	Vax/VMS	LSE template file	LSE/NODISP/INIT=GARFIELD.LSE
GARFIELD EXEC	VM	Front-end exec	optionally, REXXD
GARFMINI EXEC	VM	Minimal front-end exec	none
GARFIELD PANEL	VM	Panels used by GARFIELD EXEC	none
GARFIELD SHLPCMS	VM	Introductory help file	CONVHELP

5.2 The YPATCHY step

Running Patchy would normally be done by the make procedure described in Section 5.3 on page 126. One therefore, in principle, does not need to understand the meaning of the various Patchy flags. Since modification of the Patchy cradle file is frequently needed however, details of the Patchy step are given here.

The Patchy step plays a key role in the compilation process. Not only does it serve to insert the common blocks, it is also the time a specific program version (computer, plotting package, interfaces) is chosen.

Choices are made depending on the settings of so-called Patchy switches which are in fact simply patch names. This program adheres to the convention that the switches of which the name starts on a *, are true patches in which other switches are set. Such patches are called pilot patches because they are never used in +SELF statements. (+SELF statements are sort of IF directives to Patchy.) They do not contain Fortran. Thus, there is a fundamental difference between the switch *CMS and the switch CMS: the first selects CMS, NAG and GKS whereas the latter merely stands for itself.

The correct choice of the target machine during the Patchy step is of importance. Although extensions to the Fortran standard have been avoided, there are some on nearly all machines. In particular on VM/CMS, machine specific calls are heavily used for file access.

The plotting package is normally chosen in one of the pilot patches but this choice can be overruled by the user using the more specific switches listed below.

If the program size without arrays is too large, you may wish to exclude some sections from compilation. This is achieved by inserting +USE,P=< section >,T=INHIBIT cards as shown below.

Storage space allocation is largely static (i.e. there is no dynamic memory management on the numerical arrays); the array dimensions are fixed during the YPATCHY run. The program prints a message telling you which parameter to increase when it hits the maximum size of an array. You may also wish to decrease some compilation parameters in order to reduce the storage space needed by the program. In both cases, a +REP,P=COMMONS,C= card has to be inserted in the cradle. The correct card numbers can be found in a YLIST listing of the program. Some care has to be exercised because the parameters are not completely independent; at present the program does not perform error checking on the consistency of the array dimensions.

Suggested Patchy cards are:

```
+EXE.
+USE,< section name >,T=INHIBIT.          (one per unused section)
+REP,P=COMMONS,C= ... .                   (change array dimensions)
       PARAMETER(MXWIRE=200)
+USE,*< computer name >.
+USE,*GARFIELD.
     (correction cards, other options)
+PAM.   or   +PAM,T=CARDS.                (depends on PAM type)
     (user decks if any)
+QUIT.
```

The < computer name > can be APOLLO, CMS, CRAY, MVS, SUN or VAX. The flag *GARFIELD requests a compiler input file to be written with all sections of the program that were not explicitly de-selected by the user (+USE,< section name >,T=INHIBIT. cards).

The +USE,*< computer name >. cards refer to pilot patches which contain amongst others the Patchy switches listed below. You may use them directly if none of the *< computer name > patches suits you.

APOLLO To be used when compiling on an Apollo. A few Apollo extensions to Fortran-77 are used in non-critical parts of the program. Operating system SR10 is assumed.

AST (Effective only together with the VAX flag.) Enables control-C interception on a Vax. The routines taking care of the interrupt handling have been written in Vax Fortran-77; they were kindly provided by Carlo Mekenkamp, Rijks Universiteit Leiden. The program runs perfectly well when this flag has been disabled. When compiling with this flag, be sure you link with FIOPAT. The linker will scream that there are multiply defined symbols, this is normal since FIOPAT replaces the RTL I/O routines. Interrupt handling for other computers might be added as the need arises provided the expertise is available.

ATCGKS When this flag is enabled, Patchy assumes the program will be linked with ATC GKS.

CERN Enables calls to some packages, like NAG, which are not generally available outside CERN.

CMS To be used when compiling with VS-Fortran under VM/CMS. This switch is essential for proper functioning under CMS as explained above. Make sure a library routine equivalent to VMCMS is available. A skeleton of such a routine is provided in deck VMCMS, patch ROUTINES of the PAM file; the assembly language part of it has not been written by the author of Garfield. Garfield assumes in the routine providing help a version 2 of VS Fortran.

CRAY To be used when compiling for a Cray computer. Debugging of the program has by now shifted to the CERN Cray XMP-48 and compilation with the cft77 compiler as well as loading with segldr works well. The program has only be run under UNICOS. There are still some areas in the program to be checked. A few CPU intensive routines are provided in vectorisable format.

DECGKS When this flag is enabled, Patchy assumes the program will be linked with DEC standard GKS. The flag should only be selected in conjunction with the VAX flag.

DECS Use this flag when you intend to run on a DecStation or similar Unix workstation.

GTSGRAL Switch to be set if the program will be loaded with GTS-GRAL/GKS, default on all machines except Sun. Since versions of GTS-GRAL up to 2.6 have a different calling sequence for GPREC than from 3.5 onwards, there is an additional flag GTS26 which should be set if you load with an old library. This flag should not be used together with other GKS flavours since they conform to the standard.

IBMRT Use this flag when you intend to run on an IBM RT or similar Unix workstation.

MVS To be used when compiling with the Siemens Fortran compiler on MVS. It generates excellent diagnostics and it is therefore a good idea to compile the program once with this compiler after you modified something.

Note: MVS is not currently available at CERN and this flag has therefore not been tested recently.

MANYWIRE A common block for a large number of wires is loaded if this flag is on. Recommended only in conjunction with the CMS and VECTOR flags.

NAG Specifies that the NAG graphics routines may be called for plotting.

NAGNUM If this switch is set, some of the CERN numerical routines are replaced by interfaces to NAG routines. These routines require roughly double the storage space of the CERN routines. On the other hand, their accuracy is somewhat higher and they are also slightly better at detecting errors.

PLOT10GKS Switch to be set if the program will be loaded with PLOT-10/GKS.

SAVE Explicit SAVE statements are inserted for variables which have to be kept from one call of a subroutine to the next. SAVE should not be selected when you compile with the Siemens compiler and use Editlib to keep the compiled routines (the variables would explicitly be unsaved). It is essential on the Apollo to set the -SAVE compiler directive, if the SAVE flag is not set. The switch is harmless in all other cases.

SUN Use this flag when you intend to run on a Sun computer or similar Unix workstation. (Courtesy of François Marabelle.)

SUNGKS Switch to be set if the program will be loaded with Sun GKS.

TEST A call to the (user-supplied) subroutine UTEST (no arguments) is made when the header &TEST is entered (see Section 6.2 on page 129).

VAX To be used when compiling the program on a Vax. Free use of the non-standard Fortran-77 features of Vax-Fortran (the READONLY and APPEND attributes when opening files, some RTL routines, the HELP Utility, error handling etc.) are used when this switch has been set.

VECTOR Selects IBM vectorisable routines rather than their scalar equivalents.

The machine flags (APOLLO, CMS, CRAY, DECS, IBMRT, MVS, SUN, VAX) are mutually exclusive and at least one of them must be present. The NAG flag may optionally be specified. The flags ATCGKS, DECGKS, GTSGRAL, PLOT10GKS and SUNGKS are mutually exclusive; mGKS is assumed if none of them is specified. The DECGKS flag is meaningful only together with the VAX flag - the default GKS package on Vax computers is however GTS-GRAL. The SUNGKS flag is meaningful only together with the SUN flag. All other flags are optional and compatible with those mentioned above.

The input file for the compiler has an approximate size of 52000 lines if no sections have been suppressed.

Please send me a message in case you do not have Patchy on your computer; I have a simple replacement that can do the Patchy work required for Garfield.

5.3 Making the executable and related files

(Contributed by Miguel Marquina, CERN program library office) In the following, the string *xxx* stands for the version and has to be replaced by *old*, *pro* or *new*

5.3.1 UNIX

The command:

```
make garfield &
```

will take care of:

- generating the module garfield in /cern/xxx/bin
- placing the garfield.l man page in /cern/xxx/doc/man

- placing garfield.rawhelp in /tmp and run garfield to generate
- garfield.packhelp in /cern/xxx/bin

In order to make the man page visible to the man command, you need to install it in the local man section /usr/man/manl. You may either copy the man page or set up a symbolic link:

```
cd /usr/man/manl
ln -s /cern/xxx/doc/man/garfield.l garfield.l
```

You may generate yourself a formatted man page suitable for man by typing:

```
cd /usr/man/catl
nroff -man ../manl/garfield.l >garfield
```

otherwise man will format on the fly.

5.3.2 VM/CMS

The command

```
makelib garfield
```

will take care of:

- generating the files GARF MODULE, GARFIELD EXEC, GARFIELD HELPCMS GARFIELD PANEL and GARFMINI EXEC on the Q-disk
- placing garfield.rawhelp in an scratch disk and run garfield to generate garfield.packhelp in the Q-disk

5.3.3 VAX/VMS

The command

```
make garfield &
```

will take care of:

- generating the files CERN:[xxx.EXE]GARFIELD.EXE,GARFRUN.EXE and GARFIELD.HLP,GARFRUN.HLP,GARFIELD.LSE in an scratch area
- create the help library CERN:[xxx.DOC]GARFIELD.HLB add an entry in CERN:[xxx.DOC]CERNLIB.HLB using GARFRUN.HLP
- compiling the LSE template file

The GARFIELD command will be enabled once the symbol:

```
GARFIELD :== "$CERN:[xxx.EXE]GARFRUN"
```

is defined. Please run GARFIELD once before using the LSE facilities

6.0 Details about the program

6.1 I/O units

The use of the I/O logical unit numbers (LUN's) is as follows:

1 - 4 free for user additions;

5 standard input;

6 standard output;

7 reserved;

8 alternative output file;

9 temporary scratch file;

10 GKS error messages (PLOT-10/GKS sends its error messages to a unit determined by UOPSF);

11 GKS metafile;

12 reading and writing (e.g. gas, cell, signal) datasets;

13 scratch file storing signal matrices;

14 scratch file storing ion-tails;

15 scratch file used in threshold calculations;

16 scratch file for intermediate optimisation stages;

17 direct-access (so-called packed) help file reading and writing;

18 terminal input recording;

19 reserved;

20 - 30 alternative input files;

31 - 33 auxiliary files for PLOT-10/GKS;

41 - 49 additional metafiles;

91 - 94 auxiliary files for GTS-GRAL/GKS.

The safest units to use in additions to the program are 1 through 4, 9 or 12 (provided the latter two are released before returning control to the program) and 50 through 90.

6.2 Debugging

The main debugging tools the program puts at your disposal are the debugging instructions, most of which were mentioned in Chapter 2.0 on page 3, and the DEBUG option. A program listing will probably prove helpful.

At the Fortran level, you can link a routine of your own (named UTEST) into the program. The routine should be put in the cradle, after the +PAM card if you wish to pick up some common blocks, and the TEST flag should be set. The routine is invoked by the header & TEST. It may access all common blocks and it may also use the input file either using Fortran read or using the programs own input routines. Care should be exercised when accessing files, see Section 6.1. The main program will, after returning from UTEST, read records until it finds a valid header line. The input line which is stored internally upon return, is ignored.

6.3 Brief description of all routines

Each routine is briefly described in this section. A program listing should be consulted for more precise information.

MAIN This patch contains the program and some of its auxiliary routines.

MAIN This is the main program. Its main task is calling the reading routine of one of the other patches when a header line is encountered. Checks are made on the existance of correct cell and gas data.

INIT Presets most of the variables in COMMON. It calls the initialisation routines of the graphics, input, algebra and dataset sections.

JOBLOG Generates a log entry each time the program is run. Working version for CMS, MVS and Vax; dummy on other machines.

QUIT First deactivates and closes all active respectively open workstations (lists obtained by GKS inquiry) and then closes GKS and the various graphics files. Before terminating program execution, it prints the amount of CPU time used by the various steps, the frame numbers of the plots and a list of datasets accessed during the run.

SKIP This routine skips lines until a new header is found. It is used when a section cannot be executed.

INPUT The routines in this patch open files for input, read the input, check the syntax of numbers and accumulate error messages etc.

INPCALL Processes CALL statements in ordinary input, i.e. outside IF blocks and DO loops.

INPCDO Deallocates the entry points and strings used by a DO loop.

INPCHK Checks the syntax of integers (format code 1), reals (format code 2) and hexadecimal numbers (format code 3) before they are Fortran read.

INPCMP Compares a given string with a word read by INPWRD. The reference string may contain a hash (#) in each of the segments delimited by minus signs. Abbreviations must be at least as long as the part of the segment up to the hash, all additional characters have to match the reference string.

INPCMX Similar to INPCMP but for strings both of which are external to the normal input processing routines.

INPDEL Deletes an input word.

INPERR Prints the error messages generated by INPCHK and INPMSG.

INPESC Removes escape characters from the input string.

INPFIX Makes a comparison string as used by INPCMP more pretty.

INPGET Reads a record from the current input file and stores the number of words and the individual words. It converts lower-case to upper-case. On EOF, the current unit is closed and input will continue from the previously opened file. On EOF on standard input, program execution will be terminated in batch and a rewind will be executed in interactive mode (a blank line is interpreted as an EOF mark under CMS).

INPGLB Stores and updates global variables.

INPINT Initialises the common block used by the routines in this patch. This routine is called by INIT.

INPIOS This routine is called when an I/O error problem occurs. It tries to figure out what happened and accordingly prints some more or less understandable message. The Vax version matches the Fortran run-time error code as returned by ERRSNS with a symbolic code picked up from FORSYSDEF($FORDEF). The Apollo version calls ERROR_$PRINT with the IOSTAT error code. Versions for other machines may be added if the need arises.

INPIFT Handles IF structures outside DO loops.

INPLUN Returns the current input logical unit number.

INPMSG Assigns a message to a specified word, to be printed by INPERR.

INPNUM Returns the number of words the last read string contains.

INPPRM Modifies the prompt string.

INPRAW Returns the entire input string as read from the input stream.

INPRDH Reads an hexadecimal number from a specified word, returns an integer.

INPRDI Reads an integer from a specified word, which should have been checked previously by INPCHK.

INPRDO Reads a DO loop, stores all lines in it, translates all algebra.

INPRDR Reads a real number from a specified word, which should have been checked previously by INPCHK.

INPRIC Checks a integer on syntax, reads it and returns it to the calling routine. This routine does not use the information from INPWRD.

INPRRC Checks a real on syntax, reads it and returns it to the calling routine. This routine does not use the information from INPWRD.

INPSTR Returns part of the string last read.

INPSUB Substitutes global variables in a string about to be passed back.

INPTRA Does input translation. The routine has entries INPTRI for initialisation, INPTRD for display of the table, INPTRG for table retrieval, INPTRR reading the translation commands and INPTRW for writing the table to a dataset.

INPTYP Does a crude type determination for a given input word.

INPWRD Calls INPGET to read a line and checks the line on use of special symbols as follows:

- first character '<': a new input file is opened,
- first character '>': output is redirected,
- first character '$': command is passed to the environment,
- first character '*': line is ignored,
- first character '%': the line is passed to DSNINP,
- first character '!': the line is passed to GRAINP,
- first character '?': the line is passed to HLPINP.

In all these cases, a new line will be read by INPGET. This routine also takes care of calling sub-sections, having DO-loops, IF-lines and IF-blocks processed, definition of global variables etc. The net result is that the sections calling this routine do not see input not meant for them.

INPXDO Executes a DO loop, including any IF statement embedded in it.

HELP A patch providing on-line help.

HLPCNT (Not on Vax.) This routine calculates the number of records the packed help file will contain.

HLPDEB Prints the entire help file, used for debugging.

HLPINP The Vax version of this routine calls LBR$OUTPUT_HELP. The versions for other machines read a packed help file called HELP$GARFIELD, GARFIELD PACKHELP or similar which is prepared by HLPPAC.

HLPINQ Determines whether some topic exists on the help file or not.

HLPPAC Reads the raw help file HELP_RAW$GARFIELD, GARFIELD RAWHELP or similar, which is in the Vax .HLP input format, and transforms it into a direct access file (packed file) called HELP$GARFIELD, GARFIELD PACKHELP or similar. The direct access file consists of blocks of text each preceded by a link record that contains the record numbers

of the link records of all its subtopics, in addition to its own topic string and the number of records of the topic itself. The root record is located at record 1.

HLPPRT Prints a topic.

HLPSUB Prints the list of subtopics associated with a given topic.

DATASET Some routines manipulating datasets for input and output.

DSNCMP Compares the member creation date with the date of the latest format modification. Used to ensure that cell and gas datasets can be read successfully.

DSNFMT The Vax version of this routine resolves wildcard characters in the file specification, if any, and substitutes user supplied defaults for file name components, calling LIB$FIND_FILE. The routine has an entry DSNFMD for setting the default file name.

DSNINP Interprets dataset instructions (lines starting on %). If the first command is only a % sign, the routine will loop until it finds EXIT, no further % signs being needed.

DSNLOC Scans through the dataset currently open on unit 12, looking for the member name specified in its calling sequence.

DSNLOG Writes an entry in a log for dataset usage (cells, gas, SCEPTRE). The routine has an entry DSNPRT to print out the log records.

DSNOPN The VM/CMS version of this routine works via an exec written to disk and executed via DSNVMX. The exec replaces = signs in the file specification by the corresponding defaults then lists all files matching the specification and then eliminates files that have improper format and files that can not be written to if such access is requested. If output has to be written to a library, the file is either requested to exist on a disk to which the user has write access or not to exist, explicitly specified and to be located on a disk to which the user has write access. A file is only opened for reading if the file exists. If more than one file satisfies all requirements, the first file as listed by LISTFILE will be accessed. If the disk on which the file is (to be) located has been modified since the last ACCESS, the disk is ACCESSed again. No access if granted to a file that is currently accessed by another user, if the program can determine such access is indeed taking place. This routine has an entry DSNFMD for setting a default file.

The version of this routine for other machines carries out similar checks but from Fortran. Wildcards are only allowed on Vax computers, where they are resolved by DSNFMT.

DSNVMX Writes a REXX exec to disk, executes it and returns the return code to the calling routine.

ALGEBRA The routines in this patch handle formulae. More detailed descriptions of some of them are in Section 4.5 on page 116.

ALGCAL Takes care of procedure calls from instruction lists.

ALGCLR Marks an entry point for deletion. The instruction sublist and the memory associated with it can later on be freed by ALGGBC.

ALGEDT Is a very modest editor for instruction lists, mainly used for debugging ALGPRE and ALGEXE.

ALGERR Prints the number of arithmetic errors counted by ALGEXE/ALGEX2 since the last call to ALGERR.

ALGEXE Executes a set of instructions from the selected sub-list. The routine checks to some extent whether the entry point information for the requested sub-list is consistent with the input parameters.

ALGEX2 Performs the calculations on numbers for ALGEXE, only one instruction is processed at a time. This routine is also called from ALGPRE to evaluate constant subexpressions.

ALGEX3 Performs the calculations on logicals for ALGEXE, only one instruction is processed at a time. This routine is also called from ALGPRE to evaluate constant subexpressions.

ALGEXE Performs the calculations on strings for ALGEXE, only one instruction is processed at a time. This routine is also called from ALGPRE to evaluate constant subexpressions.

ALGGBC Garbage collect of the algebra storage: instruction list, registers and entry point table.

ALGINT Initialisation routine called from INIT.

ALGPRE The heart of this section, converts a formula to a set of instructions. It has an entry ALGSIM to simplify an instruction list.

ALGPRT Prints (part of) the instruction list in a, hopefully, more or less readable format.

GRAPHICS The plotting calls in the program are those suitable for a GKS compilation. The routines in this patch take also care of the graphics initialisation.

GERHND Catches the error messages produced by GKS. It writes its output to logical unit 10, like GKS itself, rather than to standard output. For a few frequently occurring errors, an explanatory note is added.

GPL2 Similar to GPL, but for double precision arguments.

GRACWK Activates a workstation.

GRADWK Defines a workstation.

GRCLWK Closes a workstation.

GRDAWK Deactivates a workstation.

GRDLWK Deletes a workstation.

GROPWK Opens a workstation.

GRAINP This routine reads the graphics (subsection) commands.

GRALOG Keeps a list of plots being made. This routine has an entry GRAPRT to print out the list.

GRALPH Switches the terminal to alphanumeric mode.

GRAPOL Draws a polar coordinate system, see also GRCART.

GRATTR Reads the representations of the various primitives.

GRATTS (Entry in GRATTR) Changes the attributes of GKS primitives according to the item to be plotted.

GRATTG (Entry in GRATTR) Reads a representation table.

GRATTW (Entry in GRATTR) Writes a representation table.

GRAXIS Calls either GRCART or GRAPOL, with labels for the axis.

GRCART Draws a neat set of Cartesian axis.

GRCBIS Is an auxiliary routine of GRCONT; searches via bisection for the point at which the contour crosses a grid segment.

GRCGRA Is an auxiliary routine of GRCTRA; returns the function gradient.

GRCLAB Is an auxiliary routine of GRCPLT; plots a piece of the contour, adding labels with function values if requested.

GRCMIN Is an auxiliary routine of GRCUPD; minimises the distance between a grid point and a contour segment.

GRCOLC Returns a flag indicating whether a given workstation has colours. Value 1 means no colours, 0 means colours, -1 means the output is going to WISS or MO for which there is no way to determine whether the final output device has colours or not.

GRCOLR Reads instructions defining new colours, also serves for inquiries.

GRCOLD (Entry in GRCOLR) Returns a short descriptive string used by GRATTQ. It returns either in RAW format or in FORMATTED format, in the latter INPFIX is called to remove the hashes and to change to lower case.

GRCOLQ (Entry in GRCOLR) Displays information about colours in full detail.

GRCOLG (Entry in GRCOLR) Reads a list of colours from dataset.

GRCOLW (Entry in GRCOLR) Writes a list of colours to dataset.

GRCOMM Plots a small comment line, like the cell id.

GRCONT Plots contours.

GRCPLT Buffers contour points and calls GRCLAB to plot when the buffer is full.

GRCTRA Auxiliary routine of GRCONT; follows a contour from the starting point found by GRCBIS. It sends the points to GRCPLT for plotting.

GRCUPD Auxiliary routine of GRCUPD; performs the grid updates while the contour is being traced.

GRGRAF Inquires whether the screen may be erased and used for graphics. When running with GTS-GRAL/GKS, the screen is switched to graphics mode as soon as the return key is hit.

GRGRPH Plots a graph, given a set of data-points.

GRGRP2 The same as GRGRPH but for double precision arguments.

GRHIST Plots a histogram.

GRINIT Initialises the graphics and opens graphics output and error logging files.

GRLINE Calls GPL after taking a base-10 log of the coordinates to be plotted on a logarithmic scale.

GRMARK Calls GPM after taking a base-10 log of the coordinates to be plotted on a logarithmic scale.

GRMENU Shows a menu of options for interactive graphics. Two versions exist: one for GTS-GRAL up to version 2.6 and one for other flavours of GKS and later versions of GTS-GRAL.

GRMETA Decodes the command line options concerning the metafile.

GRNEXT Clears the screen, it issues a clear workstation or TVNEXT command.

GRAOPT Decodes some options such as logarithmic/linear scales.

GRTERM Decodes the command line options concerning the terminal.

GRTEXT Plots text at a give position. It differs from the GKS routine GTX in that the text is always plotted in NT=0, so as to avoid distortion.

GRQWK Returns the workstation identifier when given the name.

ROUTINES Most general purpose routines are contained in this patch.

BOOK Allows several facilities to be booked, released etc so that they are not used in parallel by several routines.

BTEXT A routine sending the name of the step currently executed to the B-display of a CDC computer. It uses the COMPASS routine BDISP (contained in the same deck). This routine has been tested on the NIKHEF CYBER 173, which perished some time ago, only.

CFMCIR Transforms from Cartesian to internal coordinates.

CFMCIP Transforms polar to Cartesian coordinates.

CFMRIC Transforms from internal to Cartesian coordinates.

CFMRIP Transforms internal to polar coordinates.

CFMPTC Transforms polar to Cartesian coordinates.

CFMPTR Transforms polar to internal coordinates.

CF2RTC CFMRTC for double precision arguments.

CF2RTP CFMRTP for double precision arguments.

CLIP Clips a line segments to the size of a given box, for real arguments. It returns IFAIL=1 if the line segment has length 0 after clipping but it does not print an error message if this happens.

CLIP2 Identical to CLIP but for double precision arguments.

CROSS Determines whether two straight lines cross at an intermediate point for both lines.

DATIMH (Vax only) Returns the current date and time, both as character*8. On all other machines the CERN library routine DATIMH (Z007) is used.

F010 (NAG-numerical-routines compilation only.) Is a set of matrix routines replacing part of the CERN library F010 package. DEQINV inverts and solves a set of double precision equations, calling F01ACF and F01AAF. DEQN merely solves the set of equations, not setting a proper inverse. Its replacement uses F03AFF and F04AHF. REQN is similar to DEQN, the main difference being that the default accuracy parameter X02AAF is not used because the data are single precision.

KERNERR Interface to the KERNLIB error handling routines (N001).

INTERP Interpolates using the spline coefficients calculated by SPLINE. An IFAIL=1 error condition is set if the value for which the interpolation is to be carried out, is out of range.

INTER2 Identical to INTERP but for double precision arguments.

INVINT Finds the point at which the cumulative distribution of the input distribution reaches some threshold.

LSQFIT Performs a least squares fit of a one dimensional set of data to a general function.

NORRAN (NAG-numerical-routines compilation only.) Returns a normally distributed random number. It uses the NAG routine G05DDF and replaces the CERN library routine V101.

QUIFMT Formats numbers into text.

RNDEXP Generates random numbers according to a exponential distribution.

RNDM (NAG-numerical-routines compilation only.) Returns a uniformly distributed random number. It uses the NAG routine G05CAF and replaces the CERN library routine V104.

RNDNOR Generates normally distributed random numbers with a given mean and standard deviation. It uses the library routine NORRAN.

ROUND Rounds a range to some decent values, such that the interval is reasonable too.

SPLINE Prepares a cubic spline interpolation for a list of REALs. If the x-array is not in strictly increasing order an IFAIL=1 error condition is returned, the coefficients are not correct in this case.

SPLIN2 Identical to SPLINE but for double precision arguments.

STRBUF A dynamic string buffer.

TIMLOG Stores the string it is called with together with the amount of CPU time used since the previous call. It prints its data when called with an empty string. Use is made of the library routine TIMED. The VM/CMS vector compilation also calls assembler routines written by Michel Roethlisberger/IBM to obtain the fraction of time spent in the vector units.

VMCMS A skeleton to make a routine that passes commands to VM/CMS.

WILDCRD Determines whether a string matches a wildcard.

HISTOGRAM A set of routines for histogram handling.

HSADM Book-keeping of histograms.

HISENT Enters numbers into a histogram, performing automatic scaling if requested.

HISGET Reads a histogram from a dataset.

HISINT Initialisation of the histogram routines, called from INIT.

HISPRT Prints a histogram.

HISPLT Plots a histogram using GRHIST.

HISSCL Scales a histogram by a given factor.

HISWRT Writes a histogram to a dataset.

VAXAST A set of routines written by Carlo Mekenkamp (University of Leiden, Netherlands) handling control-C interrupts on a Vax.

See writeup Z037 of the CERN program library for information.

CELL This patch contains the routines defining the cell.

CELDEF Is called by TEST and its main task is to call the other routines in this patch. It returns to TEST as soon as one of them fails.

CELINP This routine reads all the cell description input and stores them in common CELDAT.

CELCHK Tries to make sure that the cell makes sense (it eliminates wires outside planes or wires too close to each other). The routine sets the default cell dimensions and stores the maximum and minimum voltages in the cell.

CELTYP Determines the potential to be used for the field calculations. It sets quasi-periodicities for the B and C type cells.

CELPRT Prints all available cell data.

CELPLT Prepares a frame in which a layout of the cell will be plotted.

CELLAY This routine does the actual plotting of the layout. It is called from many other routines as well.

CELWRT In a first stage this routine isolates a dataset name from its input string and stores it. In a second stage all available cell data are written.

CELGET Reads cell data from a dataset written by CELWRT.

WIRSEL Selects wires for special treatment.

MAGINP Reads magnetic field data and calculates the α coefficient (see Section 4.1.11 on page 105). It computes the cylindrical components of the magnetic field.

GAS The routines in this patch do the same job as the cell routines i.e. they read gas data, store it in a suitable format and provide the requested information to other sections.

GASDEF Calls the other routines in this patch during a gas section. It checks the IFAIL flag after each call and returns to the main program as soon as an error is found. GASDEF has an entry XXXGAS that loads CO2 in case gas data is needed but no gas has been entered.

GASINP Reads gas data from input file. This routine can, instead or reading data, call one of the routines filling the gas data common block directly.

GASCHK Checks the correctness of the gas data entered in GASINP and sets the GASOK bits accordingly.

GASMIX Computes the drift velocity and diffusion in a mixture of gasses.

FGAS1 Used to integrate F_0.

FGAS2D Used to calculate the diffusion.

FGAS2N Used to normalise F_0.

FGAS2V Used to calculate the drift velocity.

GASMB Returns information on the gas data, such as a list of break points, the name, the ionisation potential.

GASMD Returns the cross section, mean free path and average energy loss per collision.

GASMG1 Used to calculate integrals.

GASMG2 Used to calculate integrals.

GASPRE Prepares the interpolation of the drift-velocity, the diffusion and the Townsend coefficient. It also sets the coefficients for the extrapolations.

A20E80 Transfers a mixture of 20 % argon and 80 % ethane to /GASDAT/.

A50E50 Transfers a mixture of 50 % argon and 50 % ethane to /GASDAT/.

A80E20 Transfers a mixture of 80 % argon and 20 % ethane to /GASDAT/.

A73M10 Transfers a mixture of 73 % argon, 20 % methane and 7 % propanol to /GASDAT/.

CO2 Transfers the CO_2 data to the /GASDAT/ common block.

C80E20 Transfers a mixture of 80 % CO_2 and 20 % ethane to /GASDAT/.

C90E10 Transfers a mixture of 90 % CO_2 and 10 % ethane to /GASDAT/.

C90I10 Transfers a mixture of 90 % CO_2 and 10 % isobutane to /GASDAT/.

ETHANE Transfers the ethane data to the /GASDAT/ common block.

ISOBUT Transfers the isobutane data to the /GASDAT/ common block.

METHAN Transfers the methane data to the /GASDAT/ common block.

GASPRT Prints tables of the diffusion and drift-velocity and lists the other relevant gas quantities (such as A, Z, ρ etc.).

GASPLT Makes logarithmic plots of the diffusion coefficient and of the drift-velocity and a histogram of the cluster-size distribution.

GASWRT In a first stage a dataset name is extracted from command line. In the second stage all gas data (including the spline coefficients and the cluster-size histogram) are written to this dataset.

GASGET Retrieves the gas data written by GASWRT.

DRIFTV Returns the magnitude of the drift-velocity for electrons given the electric field-strength. It interpolates the tables.

DIFFC Similar to DRIFTV but for the diffusion coefficient.

GASTWN Returns the Townsend coefficient for a given field-strength.

OPTIMISE

OPTADD Adds elements to the cell.

OPTCHV Changes the potential of a selected group of wires and then recalculates the charges.

OPTDEL Deletes elements from the cell.

OPTFAC Splits the field and the potential into pieces proportional to the wire potentials and a constant part.

OPTINP Reads optimisation instructions and calls the other routines in this patch when needed.

OPTSET Attempts to make a given field-function as equal to a given target-function as possible by playing with the potentials.

OPTFUN Used by OPTSET in the minimising cycles.

OPTXYA Selects the points at which the field-function and the target-function are to be evaluated. It also sets the initial values of the parameters.

OPTAVE Computes the average of the field-function.

OPTIDSN Saves and restores sets of potentials.

FIELDPLOT A patch consisting of set of routines producing the plots and tables of the potential, the electric field and the magnetic field.

FLDINP Reads the plot parameters from standard input and calls the other routines in this patch when some action is required.

FLDPLT Makes the plots specified in the command line.

FCONT A subroutine called by the NAG graphical supplement library routines returning a field function to be used by the contour plotting subroutine.

FLDPRT Prints the field quantities listed in the input string.

FLDCHK This routine is useful for the debugging of the field routines as it allows checking of the potentials on the wires and the planes, of the consistency between the potential and the electric field, of the charge on the wires and of the Maxwell relations $\nabla E = 0$ (outside the wires) and $\nabla B = 0$ (if there is a magnetic field).

ZERO Routines locating the zeros of the field.

ZROARG Returns the argument of the field at some point on the boundary of the current search area.

ZROCONT Counts the number of zeros in the current search area, using the change in argument.

ZROFIND Controls the other routines. It builds a stack of search areas which are divided into two at each iteration.

ZROLOC Attempts a precise localisation of the zero within the current search area.

ZROTST Debugging routine for zero finding.

FIELDCAL Responsible for electric fields and potentials and magnetic fields.

SETUP Calls one of the more specific SET... routines:

SETNEW Calculates the charges for a new set of voltages, without recalculating the capacitance matrix.

SETA00 for non-periodic cells,

EFQA00 for non-periodic cells with dielectrica,

SETB1X for x-periodic cells and at most one plane at constant x,

SETB1Y for y-periodic cells and at most one plane at constant y,

SETB2X for cells with (the equivalent of) 2 planes at constant x,

SETB2Y for cells with (the equivalent of) 2 planes at constant y,

SETC10 for cells periodic in x and in y without planes,

SETC2X for y periodic cells with (the equivalent of) 2 planes at constant x,

SETC2Y for x-periodic cells with (the equivalent of) 2 planes at constant y,

SETC30 for cells with (the equivalent of) 2 planes at constant x and 2 planes at constant y.

'the equivalent of' is to be interpreted as having 2 planes or having one plane and being periodic in the sense orthogonal to the plane. These routines fill a capacitance matrix stored in common /CAPAC/ later to be accessed by:

CHARGE Inverts the capacitance matrix and determines the charges on the wires. If no equipotential planes are present, the net charge on the wires will be 0. This may imply that the reference voltage is different from 0.

When all this has been done the electric field may be calculated:

EFIELD Checks that the point at which the electric field is to be evaluated is not located inside a wire or outside a plane (after reduction to the elementary cell) and calls one of the field routines EFC...:

EFCA00 (scalar and IBM vectorisable version available) for non-periodic cells,

EFDA00 for non-periodic cells with dielectrica,

EFCB1X (scalar and IBM vectorisable version available) for x-periodic cells and at most one plane at constant x,

EFCB1Y (scalar and IBM vectorisable version available) for y-periodic cells and at most one plane at constant y,

EFCB2X (this routine is IBM vectorisable) for cells with (the equivalent of) 2 planes at constant x,

EFCB2Y (this routine is IBM vectorisable) for cells with (the equivalent of) 2 planes at constant y,

EFCC10 (only available in scalar form) for x- and y-periodic cells without planes,

EFCC2X (only available in scalar form) for y periodic cells with (the equivalent of) 2 planes at constant x,

EFCC2Y (only available in scalar form) for x periodic cells with (the equivalent of) 2 planes at constant y,

EFCC30 (only available in scalar form) for cells with (the equivalent of) 2 planes at constant x and 2 planes at constant y.

PH2 (Written by G.A. Erskine, somewhat modified.) Computes essentially the logarithm of the ϑ function. This routine is used only for the potential calculations in C type cells. It has an entry PH2LIM for the diagonal terms.

E2SUM (Written by GA Erskine, substantially modified.) Computes the logarithmic contribution to the electrostatic field. This routine is used only for the field calculations in C1 type cells.

Some routines needed later on for dielectrics and multipole terms are already to be found in this patch:

EFCMAT Computes correction factors for the field.

EFMWIR Decomposes the field around a wire in a multipole series.

EFDFUN Function used by EFDWIR, returns a sum of Legendre polynomials.

Magnetic fields are calculated by:

BFIELD Its only task is calling one of the 4 following routines:

MAGO0 magnetic field calculation for non-periodic cells,

MAGX0 magnetic field calculation for x-periodic cells,

MAGO0Y magnetic field calculation for y-periodic cells,

MAGXY magnetic field calculation for x- and y-periodic cells.

DRIFT The routines in this patch plot drift-and equal arrival time lines.

DRFARR Calculates arrival time distributions.

DRFDRF Calls DRFEDG, DRFTRA, DRFWIR or DRFZRO when drift line plots have to be made.

DRFEDG Does the same as DRFWIR but now the drift-lines start at the edges of the drift-area.

DRFEQT The routine DRFEQT accumulates equal time data on the current drift-line. Doing so, it counts the number of errors and memory overflow. The entry DRFEQP outputs the data stored so far, plotting separate sets of contours for each wire, checking that equal time contours do not cross drift-lines. The second entry DRFEQR resets the number of contours to 0. The third entry DRFEQE prints the number of errors found by DRFEQT.

DRFGRA Executes drift section commands selected via a graphics menu.

DRFINP Reads instructions from input file and calls one of the other routines when some action is required.

DRFPLT This routine examines the DRIFT instruction and calls either DRFEDG or DRFTRA, DRFWIR or DRFZRO as appropriate providing them with arguments.

DRFSIN Plots and prints information on individual drift lines.

DRFTRA Does the same as DRFWIR but now the drift-lines start on a track.

DRFTR2 Plots the graphs for which DRFTRA has accumulated the data.

DRFTAB Makes a drift-time table, printing the output or plotting it in the form of a rough contour diagram (using NAG routines).

DRFWIR This routines has DLCALC calculate drift-lines starting near the surface of the sense wires and plots them. It calls DRFEQT to store points on equal arrival time contours.

DRFXTP Produces a so-called x(t)-plot, see Section 4.3.3 on page 112. It has two auxiliary routines:

DRFXT1 Calculates the point at which the current drift-line crosses a straight line with given parameters. It uses a simple linear interpolation, which was found to be more accurate than a third order fitting.

DRFXT2 Returns the minimum of a parabola passing through three given points. It gives an indication whether the parabola is degenerate and whether the 'minimum' is in reality a maximum.

DRFZRO Plots drift-lines from the zeros of the field.

DRIFTCALC This is the core of all routines needing drift-lines.

DLCALC This very important routine calculates a drift-line and stores it in the common /DRIFTL/. How the drift-line is calculated is described in detail in Section 4.3 on page 110 of this writeup. After each integration step DLCSTA is called and the status code returned by this routine is examined and appropriate action is taken. During each step, both DLCALC and DLCSTA can call the auxiliary routines DLCWIR, DLCPLA and DLCMIN.

DLCSTA This routine checks the status of the drift-line after each integration step. Each step, a probable target wire is selected which DLCALC will use during the next step to see whether a wire has been crossed. The ISTAT code has the following meaning: 0: calculation in progress, -1: left drift-area, -2: maximum number of steps (MXLIST) reached, -3: abnormal end or particle stopped, -4: particle hit a plane, $0 < \text{ISTAT} \leq \text{MXWIRE}$: particle hit wire ISTAT, $\text{ISTAT} > \text{MXWIRE}$: particle hit a periodic replica of wire ISTAT-MXWIRE. A non-zero code normally means that some last step has to be performed by this routine (or DLCWIR or DLCPLA) and that DLCALC will stop. The routines called by instructions mentioned in Chapter 2.0 on page 3 will interpret the status codes but the debugging routines/options usually print the raw results.

DLCWIR Terminates the drift-line by stepping towards the target wire by means of the dedicated wire algorithm described in the paragraph on drift-line integration (see Section 4.3.2 on page 111).

DLCMIN Determines the minimum distance between the target wire during the step.

DLCPLA Terminates the drift-line by stepping towards a plane.

DLCPRO Projects 3-dimensional drift lines onto a specified 2-dimensional plane.

DLCVEL Calls EFIELD to find the electric field-strength at a given position and then calls DRIFTV to find the drift-velocity for this field-strength. The magnetic field routines are also called in case a magnetic field has to be taken into account. High B field corrections, such as those described in [1] may have to be introduced in this routine.

DLCDIF A service routine which returns a fairly accurate estimate of the integrated diffusion coefficient over the present drift-line.

DLCTWV A service routine which returns a fairly accurate estimate of the integrated electron multiplication factor over the present drift-line.

DLCTRP Calculates drift-lines from a track, storing the data in a format suitable for interpolation.

DLCTRI Interpolates the track-data prepared by DLCTRP.

DLCTRW Writes the data prepared by DLCTRP to a file.

DLCTRG Retrieves the interpolation-data from a file written by DLCTRW.

SIGNAL The signal simulation patch

SIGINP This routine controls the other routines in this patch. It interprets the instructions and as soon as simulation is requested, the routine SIGGEN will be called. It tells SIGGEN whether the signal matrices and the ion-tails may be reused or not.

SIGGEN Controls the signal simulation.

SIGIPR Stores the signal matrices, Fourier transforms them, inverts them and transforms them back to the original domain.

IPRA00 Signal matrix calculation for cells with reduced cell type A.

IPRB2X Signal matrix calculation for cells with reduced cell type B2X.

IPRB2Y Signal matrix calculation for cells with reduced cell type B2Y.

IPRC30 Signal matrix calculation for cells with reduced cell type C3.

IONBGN Opens the scratch file used for signal matrices and determines the most efficient format, given the maximum record length allowed by the disks MXRECL and the maximum number of records (1000).

IONIO Performs the actual I/O operations for SIGIPR. It shares a common block with IONBGN telling it how to read/write the matrices. The routine reads/writes only those sections of each matrix that will be/have been modified by SIGIPR.

SIGCLS Generates positions and energies for clusters along the track. It also calculates the arrival times for each of the primary electron ion pairs and their charge after avalanche.

SIGAVA Does the avalanche calculation for SIGCLS.

EPULSE Adds a spike to the signal.

SIGION Adds an ion-tail to the signal, it keeps the signals it has calculated unless changes occur. It needs (amongst others) SIGFLD.

SIGFLD Calculates the electric field in the non-periodic cell via one of the more specific routines:

IONA00 for cells with reduced periodicity A,

IONB2X for cells with reduced periodicity B2X,

IONB2Y for cells with reduced periodicity B2Y,

IONC30 for cells with reduced periodicity C3.

SIGPLT Plots the pure and cross-induced signals obtained.

SIGWRT Outputs the signals to a file of which the name was established in a first call from SIGINP.

SIGCHK Runs a couple of checks on signal related calculations.

SIGTHR Computes arrival time distributions. The routine has a series of auxiliary routines.

6.4 Programhistory

1/9/84 (At CERN) First version, written in Siemens Fortran 77, ready for use with MVS. It contained the basic features of the present program but was far less elaborate.

1/2/85 (At NIKHEF-H) A program which could be run on Apollo and CDC too, was sent to CERN. By then, the language had become standard Fortran 77. Use in an interactive environment has been supported from then on. The field calculations in C cells was improved.

15/5/85 (At CERN) An entirely new, much expanded signal section was introduced. The drift-line calculation routines were replaced by more stable ones. New were magnetic field, sense wire selection and the CHECK instruction.

15/2/86 (At CERN, Leiden) Because of the introduction of VM/CMS at CERN, the GD3 plotting calls were replaced by their GKS equivalents, adding interface routines for both miniGD3 and GD3. The rather strange "features" of VM/CMS called for many changes in file handling. In this version free format input, algebraic formula handling, cylindrical symmetry, 3 new standard gasses and the APOLLO command were added. Field calculation was speeded up by 10 to 40 %.

7/7/86 (At CERN, Leiden) The x(t) routine was replaced by a much more accurate one. The formula used so far for calculating the drift-velocity if magnetic fields are present turned out to be inadequate and was hence replaced. File handling and cylindrical symmetry routines were improved. New was the FACTOR instruction.

26/6/87 (In Padova) Numerous corrections are applied in the cylindrical symmetry parts. An instruction to create a drift-time table has been introduced in the drift section. The program can now also be compiled on a Vax. The use of the NAG graphics supplement routines has been extended, they can now be used for field contour plotting, plotting of contours in a drift-time table and for surface plotting.

1/12/87 (at CERN) Major revision of the program because the original construction of the program could no longer be maintained given its growth. Many routines have been renamed as a consequence. Most modifications should however be transparent to the users. Additions include: dataset access and inquiry, calculation of arrival time distributions, checks on the signal calculation, Townsend coefficients. Replaced are: the x(t) routines, equal time contour routines, the field calculation in C type cells and the drift-line termination routines. Several hooks for future options have been put into the program. The abbreviation convention has been changed. This writeup has been converted from Cernpaper to SGML (mixed with Script commands).

1/5/88 (at CERN) Several parts of the program have been refined but no major changes have occurred. The routines for finding and interpreting the zeros of the field, which have been present since about a year, have been made operational. The same applies to the optimisation section. Various graphics settings are under user control from this version onwards.

1/1/89 (at CERN) The use of Vax features has been extended: on-line help is provided, a template file linked with the help file has been written and the program is started via CDU. The latter feature allows the specification of the terminal type at start-up time. The control-C interrupt, present already for a long time, has been further improved by Carlo Mekenkamp. A help facility similar to that on Vax and using the same input files is available for use on other machines. The program runs successfully on the Cray. Various features such as drift-line calculation under graphics input control have been added.

15/6/89 (at CERN) Dielectrica are being introduced on a test basis. The compilation options GD3, miniGD3 and CDC have been removed. At the same time the use of GKS features has been increased, allowing for instance user control on the appearance of every part of a plot.

1/9/89 (at CERN) On the occasion of its 5th anniversary, Garfield is introduced in the CERN Program Library. Vectorisable versions for some CPU intensive routines are provided.

1/5/90 (at CERN) The use of NAG contour routines is being reduced because of insufficient availability and their rather poor quality. The field contours are now being plotted by the programs own routines; drift-time table contours will follow. An instruction to do calibrations with cluster counting (ARRIVAL) has been added. The program now also runs on Sun computers. Loops and conditionally executed pieces of input have been added.

1/10/92 (AT CERN) Gas mixing routines have been introduced. Global variables now have a type associated with them, random number generators have been made available.

7. 0 Acknowledgments

Garfield has greatly benefitted from the help of many people. In particular the following persons should be mentioned. Diego Bettoni, for a long time the primary user of the program, carried out a great deal of testing. Karl Dederichs provided the CO_2 gas data and gave a lot of practical advice. G. A. Erskine did virtually all the work on doubly periodic potentials and gave valuable advice with respect to the signal calculations. Chris Fabjan, my supervisor during my stay at CERN as a summer-student in '84, introduced me to drift-chambers. Matthias Grosse Perdekamp has provided descriptions of argon-ethane and argon-methane gas mixtures. He also compared calculated and measured signals. Ingo Herbst has pointed out how the magnetic field description could be improved and provided the descriptions of methane and ethane. Discussions with Iouri Ivaniouchenkov were very valuable when writing the arrival time distribution routines. Carlo Mekenkamp gave highly useful programming advice, wrote some of the input and all of the AST routines for control-C interception on the Vax. François Piuz teached me most of what I now know about energy loss in gasses. Alan Rudge explained some of the electronics used in the read-out to me.

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