

**Jacek Kobus**

**2 Dimensional Finite Difference  
Hartree-Fock Program**

User's Guide

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# 1 Description of the command structure

The input command file consists of separate lines each containing

- a label
- a label followed by a character, integer(s) and/or real number(s)
- a character, integer(s) and/or real number(s)

Real numbers can be written in a fix point or scientific notation. Note that

- labels can be in upper or lower case,
- compulsory labels, i.e. these that must be included in the input command file, are marked “●” and the optional ones “○”,
- the compulsory labels must follow the order given below; the optional ones can be inserted anywhere between **title** and **stop** labels,
- optional parameters are enclosed in square brackets,
- $r$  denotes a real number,  $i$  – an integer,  $c$  – a string of characters,
- an exclamation mark or a hash placed anywhere in an input line starts a comment; what follows “!” or “#” is ignored.

The following labels can be used:

- **TITLE**

**Format:** title

$c$

$c$  is any string of up to 80 characters describing the current case. This string is added as a header to a text file with extension `dat` that contains basic data identifying a given case, i.e. atomic numbers of nuclei, grid size and the number of electrons and orbital and exchange functions.

- **METHOD**

**Format:** method  $c$

Select the type of calculation.

$c$ : HF – Hartree-Fock method

$c$ : HFS – Hartree-Fock-Slater method

$c$ : OED – One Electron Diatomic states

- **NUCLEI**

**Format:** `nuclei  $Z_A$   $Z_B$   $R$  [ $c$ ]`

Set the nuclei charges and the bond length.

$Z_A$ : nuclear charge of centre A (integer)

$Z_B$ : nuclear charge of centre B (integer)

$R$ : bond length (real)

$c$ : *angstrom* – the internuclear separation can be given in angstrom units if this string is included (the conversion factor 0.529177249 is used)

If  $|Z_A - Z_B| < 10^{-6}$  then the molecule is considered to be a homonuclear one (this threshold can be changed by redefining HOMOLEVL variable in blk\_data.inc.raw).

- **HOMO**

**Format:** `homo`

This label is used to impose explicitly  $D_{\infty h}$  symmetry upon orbitals of homonuclear molecules in order to improve scf/sor convergence.

- **BREAK**

**Format:** `break`

When this label is present homonuclear molecules are calculated in  $C_{\infty v}$  symmetry and the  $D_{\infty h}$  symmetry labels ( $u$  or  $g$ ) are superfluous (see below).

- **CONFIG**

**Format:** `config  $i$`

$i$ : the total charge of a system

The following cards define molecular orbitals and their occupation. **Note that the last orbital description card must contain an extra label *end*.**

The possible formats are:

**Format:**  `$i$   $c$`

$i$ : number of fully occupied orbitals of a given irreducible representation (irrep) of the  $C_{\infty v}$  group; 2 electrons make  $\sigma$  orbitals fully occupied and 4 electrons are needed for filling the orbitals belonging to the other irreps

$c$ : symbol of the  $C_{\infty v}$  irrep to which the orbitals belong (*sigma*, *pi*, *delta* or *phi*)

**Format:**  $i \ c_1 \ c_2$

$i$ : number of fully occupied orbitals of a given irrep of the  $D_{\infty h}$  group

$c_1$ : symbol of the  $C_{\infty v}$  irrep to which the orbitals belong (*sigma*, *pi*, *delta* or *phi*)

$c_2$ : symbol for the inversion symmetry of the  $D_{\infty h}$  irreps (*u* or *g*)

Use this format for a homonuclear molecule unless **break** command is included.

**Format:**  $i \ c_1 \ c_2 \ [c_3 \ [c_4 \ [c_5]]]$

$i$ : number of orbitals of a given irrep of the  $C_{\infty v}$  group

$c_1$ : symbol for the  $C_{\infty v}$  irreps to which the orbitals belong (*sigma*, *pi*, *delta*, *phi*)

$c_2$ - $c_5$ : +, - or . (a dot); +/- denotes spin up/down electron and . denotes an unoccupied spin orbital

**Format:**  $i \ c_1 \ c_2 \ c_3 \ [c_4 \ [c_5 \ [c_6]]]$

$i$ : number of orbitals of a given irrep of the  $D_{\infty h}$  group

$c_1$ : symbol for the  $C_{\infty v}$  irrep to which the orbitals belong (*sigma*, *pi*, *delta*, *phi*)

$c_2$ : symbol for the inversion symmetry of the  $D_{\infty h}$  irrep (*u* or *g*)

$c_3$ - $c_6$ : +, - or . (a dot); +/- denotes spin up/down electron and . denotes an unoccupied spin orbital

## • GRID

Two possible formats are (the second one is retained for the backward compatibility):

**Format:** **grid**  $n_\nu \ R_\infty$

An integer and a real define a single 2d grid.

$n_\nu$ : the number of grid points in  $\nu$  variable

$R_\infty$ : the practical infinity

$n_\mu$  is calculated so as to make the step size in  $\mu$  variable equal to the stepsize in  $\nu$  variable.  $n_\nu$  and  $n_\mu$  have to meet special conditions. If the conditions are not fulfilled the nearest (but smaller) appropriate values are used.

**Format: grid**  $n_\nu$   $n_\mu$   $R_\infty$

Two integers and one real define a single 2d grid.

$n_\nu$ : the number of grid points in  $\nu$  variable

$n_\mu$ : the number of grid points in  $\mu$  variable

$R_\infty$ : the practical infinity

$n_\nu$  and  $n_\mu$  have to meet special conditions. If the conditions are not fulfilled the nearest (but smaller) appropriate values are used.

- **INTERP**

**Format: interp**

Use this label to change the grid between separate runs of the program. The restriction is that only a number of grid points in one of the variables or  $R_\infty$  can be changed at a time.

- **INOUT**

**Format: inout**  $c1$   $c2$

The x2dhf program can be compiled to support calculation using three different combinations of integer/real data types: i32 (4-byte integers, 8-byte reals), i64 (8-byte integers, 8-byte reals) and r128 (8-byte integers, 16-byte reals); see Makefile for details. Strings  $c1$  and  $c2$  determine the combination appropriate for the format of input and output data, respectively, and each string can be i32, i64 or r128.

In order to facilitate exchange of binary data generated on machines of different architectures or using different compilers additional formats are available, namely i32f, i64f or r128f which allow to export/import data written in formatted instead of unformatted form.

- **INITIAL**

**Format: initial**  $i_1$  [  $i_2$  [  $i_3$  ] ]

$i_1$ : determine the initial source of orbitals and potentials:

- \*  $i_1 = 1$  – molecular orbitals are formed as a linear combination of hydrogenic functions on centres  $A$  and  $B$ ; in the case of HF or HFS calculations Coulomb (exchange) potentials are approximated as a linear combination of Thomas-Fermi ( $1/r$ ) potentials at the two centres; if method OED is chosen the potential function is approximated as a linear combination of  $Z_A/r_1$  and  $Z_B/r_2$  terms and the exchange potentials are set to zero

- \*  $i_1 = 2$  – GAUSSIAN94 output is used to retrieve exponents and expansion coefficients of (uncontracted) molecular orbitals (it is assumed that the output is contained in gauss94.out and gauss94.pun files) and Coulomb and exchange potentials are initialized as in  $i_1 = 1$  case; see routine PREPG94 for more details
  - \*  $i_1 = 3$  – GAUSSIAN94 modified output is used to retrieve exponents and expansion coefficients of molecular orbitals (it is assumed that the output is contained in gauss94l.out file) and Coulomb and exchange potentials are initialized as in  $i_1 = 1$  case; see routine PREPG94L for details
  - \*  $i_1 = 5$  – initial orbitals, Coulomb and exchange potentials are retrieved from disk files (2dhf\_input.orb, 2dhf\_input.coul and 2dhf\_input.exch, respectively) created in a previous run. Data defining the case are retrieved from a 2dhf\_input.dat textfile.
  - \*  $i_1 = 6$  – orbitals and Coulomb potentials are retrieved from disk files and exchange potentials are initialized as in  $i_1 = 1$  case (convenient when going from HFS to HF calculations)
  - \*  $i_1 = 55$  – initial orbitals and potentials are retrieved from disk files but the content of a 2dhf\_input.dat file is retrieved from a 2dhf\_input.orb (binary) file. Use this value when reading binary data generated by older versions of the program.
- $i_2$ : specifies how exchange potentials are to be read/written and manipulated (stored in memory). The program always keeps all orbitals and Coulomb potentials in core. The exchange potentials can also be all kept in core (if there is enough memory). However, during a relaxation of a particular orbital only a fraction of them is in fact needed. Thus all exchange potentials can be kept on disk as separate files (named fort.31, fort.32, ... during a run) and only relevant ones are being retrieved when necessary.<sup>1</sup>
- \*  $i_2 = 0$  – read exchange potentials as separate files and write them back as separate files

---

<sup>1</sup>A note of warning for the users of the g77 compiler. You might encounter an I/O error when trying to run cases requiring more than 70 exchange potentials. By default g77 accepts file unit numbers in the range 0-99. If you need more files to be opened you have to edit f/runtime/libI77/fio.h in the g77 source tree, changing the line: #define MXUNIT 100. Change the line so that the value of MXUNIT is defined to be at least one greater than the maximum unit number needed.

- \*  $i_2 = 1$  – read all exchange potentials in a file but write them out as separate files
  - \*  $i_2 = 2$  – read all exchange potentials separately but write them out as a single file
  - \*  $i_2 = 3$  – read and write exchange potentials in the form of a single file (default)
- $i_3$ : if  $i_1 = 1$  then this parameter must be set to 1 or 2 (if omitted it is set to 1). In such a case the initialization of each of the orbitals has to be defined in terms of the linear combination of atom centered hydrogen-like functions. For each orbital include a card of the following format (the order of orbitals should match the order specified under the **config** label):

**Format:**  $c_A \ n_A \ l_A \ \zeta_A \ c_B \ n_B \ l_B \ \zeta_B \ i_1 \ [ \ i_2 \ ]$

where

$c_A$  – mixing coefficient for a hydrogenic orbital on the  $Z_A$  centre (real),

$n_A$  – its principle quantum number (integer)

$l_A$  – its orbital quantum number (integer)

$\zeta_A$  – the effective nuclear charge if  $i_3 = 1$  or a screening parameter if  $i_3 = 2$  (real)

$c_B$  – mixing coefficient for a hydrogenic orbital on the  $Z_B$  centre (real),

$n_B$  – its principle quantum number (integer)

$l_B$  – its orbital quantum number (integer)

$\zeta_B$  – the effective nuclear charge if  $i_3 = 1$  or a screening parameter if  $i_3 = 2$  (real)

$i_1$  – set to 1 to freeze the orbital during scf; otherwise set to 0 (integer)

$i_2$  – a number of successive over-relaxations for a given orbital (integer); if omitted is set to 10

#### ◦ **FEFIELD**

**Format:** **ffield**  $r$

$r$ : a strength of an external static electric field directed along the internuclear axis (in atomic units)

#### ◦ **MULTIPOL**

**Format:** **multipol**  $r$

$r$ : if  $r > 0$  multipole moment expansion coefficients are recalculated when the maximum error in orbital energy is reduced by  $r$  (the default value is 1.15). To suppress recalculation of the coefficients set  $r$  to a negative real number. This is useful when generating potentials from a set of fixed orbitals, e.g from GAUSSIAN94 orbitals.

## ◦ SCF

**Format:** `scf [  $i_1$  [  $i_2$  [  $i_3$  [  $i_4$  [  $i_5$  ] ] ] ] ]`

$i_1$ : maximum number of scf iterations (default 1000); to skip the scf step set  $i_1$  to a negative integer,

$i_2$ : every  $i_2$  scf iterations orbitals and potentials are saved on disk (default 100). If  $i_2 = 0$  functions are saved on disk upon completion of the scf process. If  $i_2 < 0$  functions are never written to disk,

$i_3$ : if the maximum error in orbital energy is less than  $10^{-i_3}$  than the scf process is terminated (the default value is 10),

$i_4$ : if the maximum error in orbital norm is less than  $10^{-i_4}$  than scf process is terminated (the default is 10),

$i_5$ : the level of output during scf process

\*  $i_5 = 1$  – the orbital convergence rate, orbital energy and normalization of every orbital is printed in every scf iteration

\*  $i_5 = 2$  – the orbital convergence rate, orbital energy and normalization of the worst converged orbital is printed in every scf iteration (default)

\*  $i_5 = 3$  – the orbital convergence rate, orbital energy and normalization of the worst converged orbital is printed every  $i_2$  iterations. Printing of “... multipole moment expansion coefficients (re)calculated ...” communicate is suppressed

Total energy is printed every  $i_2$  iterations.

## ◦ FIX

**Format:** `fix [  $i_1$  [  $i_2$  [  $i_3$  ] ] ]`

If  $i_1$ ,  $i_2$  or  $i_3$  are set to 1 then orbitals, Coulomb potentials or exchange potentials, respectively, are kept frozen during the scf/sor process (the respective default values are 0, 0 and 2). If  $i_3 = 2$  then exchange potentials are relaxed only once during an scf cycle.  $i_2$  and  $i_3$  cannot be set to 1 if hydrogenic orbitals are used to initiate the orbitals.

- **CONV**

**Format:** `conv [ i1 [ i2 [ i3 ] ] ]`

Sometimes the convergence threshold (for energy and/or normalization) is set too low and cannot be satisfied on a given grid and as a result the SCF/SOR process continues in vain. The iterations are stopped if orbital energies or orbital norms display no improvement over a given number of  $i_2$  and  $i_3$  most recent iterations, respectively (the default values are set to 20). The monitoring begins after  $i_1$  initial iterations (default 250).

- **XALPHA**

**Format:** `xalpha alpha`

If this label is present and the method chosen is HFS then DFT energy functionals are used with the given value of  $\alpha$  parameter.

FIXME  $V_x = -3\alpha(\frac{3}{4\pi}\rho)^{1/3}$ , is used and the parameter  $\alpha$  can be modified. This approximation is useful to quickly improve the initial HF orbitals.  $\alpha$  is a real number and 2/3 is its default value.

- **DFTEX**

**Format:** `xalpha idftex`

- **DFTCORR**

**Format:** `dftcorr idftcorr`

dftcorr 2 full LYP formula

dftcorr 12 a simplified LYP formula (only 10% faster)

FIXME

- **SCMS**

**Format:** `scms`

- **LAGRA** ???????????

**Format:** `lagra sflagra dflagra`

If this label is present the Slater exchange approximation, i.e.  $V_x = -\frac{3}{2}\alpha(\frac{3}{\pi}\rho)^{1/3}$ , is used and the parameter  $\alpha$  can be modified. This approximation is useful to quickly improve the initial HF orbitals.  $\alpha$  is a real number and 0.7 is its default value.

- **SOR**

**Format:** `sor [  $i_1$  [  $i_2$  [  $i_3$  ] ] ]`

Change default values of sor parameters.

$i_1$ : the number of (MC)SOR iterations for a given function being relaxed in a single SCF cycle (the default value is 10)

$i_2$ : a scaling factor used to change  $i_1$  when relaxing potentials (see RELCOUL1/2 and RELEXCH1/2). The new value of (MC)SOR iterations is calculated as  $i_1/i_2$ ; the default value of  $i_2$  is 1.

$i_3$ : if  $i_1 = 1(2)$  SOR (MCSOR) method is used to solve Poisson equations for orbitals and potentials (the default value is 1); if  $i_1 = 3$  SOR method is used to solve Poisson equations for orbitals and MCSOR – for potentials

- **OMEGA**

**Format:** `omega  $\omega_{orb}$   $\omega_{pot}$`  Two real numbers setting over-relaxation parameters for relaxation of orbitals and potentials. Note that a semiempirical formula can be used to calculate a near-optimal value of  $\omega_{pot}$  by specifying this parameter as a negative real number.

For backward compatibility the following format is also supported:

**Format:** `omega`

$\omega_{orb}$

$\omega_{pot}$

- **ORDER**

**Format:** `order [  $i_1$  [  $i_2$  [  $i_3$  ] ] ]`

Up to three integers defining the ordering of mesh points on subgrids.

$i_k = 1$ : natural ordering

$i_k = 2$ : 'middle' type of sweep (the default)

- **FERMI**

**Format:** `fermi  $r_A$   $r_B$`

When this label is present, the Fermi nuclear charge distribution is used. Optional parameters  $r_A$  and  $r_B$  define the atomic masses (in amu) of nuclei A and B. If omitted the corresponding values from the table of atomic masses are taken (see `blk.data`).

- **GAUSS**

**Format:** `gauss`  $r_A$   $r_B$

When this label is present, the Gauss nuclear charge distribution is used. Optional parameters  $r_A$  and  $r_B$  define the atomic masses (in amu) of nuclei A and B. If omitted the corresponding values from the table of atomic masses are taken (see `blk.data`).

- **DEBUG**

**Format:** `debug`  $i_1 \dots i_{20}$

Up to 20 different debug flags can be set at a time. If the integer  $i_k$  is encountered the debug flag  $i_k$  is set, i.e.  $\text{idbg}(i_k) = 1$  ( $1 \leq i_k < 600$ ).

- **STOP**

**Format:** `stop`

This label indicates the end of input data.

## 2 Examples of input command cards

1.  $^2S$  ground state of the  $\text{Th}^{+89}$  one-electron system.

```
TITLE
      Th+89  point/finite  nucleus R = 2.5
METHOD OED
NUCLEI  90.0 0.0  2.0
CONFIG 89
      1 sigma +  end
GRID 169 193  2.5
INITIAL  1 3 1
      1.0 1 0 90.0  0.0  1 0  1.0  0
SCF  30 10 8
omega
      1.80
      1.80
! fermi 232.0 0.0
STOP
```

2. First excited  $^2S$  state of the  $\text{Th}^{+89}$  one-electron system.

```
TITLE
      Th+89  point/finite  nucleus R = 2.5
METHOD OED
NUCLEI  90.0 0.0  2.0
CONFIG 88
      1 sigma +
      1 sigma +  end
GRID 169 193  2.5
INITIAL  5 3 1
      1.0 2 0 90.0  0.0  1 0  1.0  0
      1.0 1 0 90.0  0.0  1 0  1.0  1 ! 1s orbital must be kept frozen
SCF  30 10 8
omega
      1.80
      1.80
!fermi 232.0 0.0
STOP
```

3. Hartree-Fock ground state of the beryllium atom.

```

TITLE
    Be R_inf=35.0 bohr  R = 2.3860 bohr
METHOD  hf ! or METHOD HFS
NUCLEI  4.0  0.0  2.386
CONFIG  0
        2 sigma  end
GRID    91 35.0
grid 169 35.0
INITIAL  1 3 1
    1.0   2 0 4.0       0.0   1 0 9.0   0
    1.0   1 0 4.0       0.0   1 0 9.0   0
SCF 3000 10 12 12 1
! note that omega for potentials is set automatically
conv 150 150
omega
    1.92
    -1.87
stop

```

4. Hartree-Fock ground state energy of the hydrogen molecule.

```

title
    H2: [169x193;35]  R = 1.4au
method hf
!nuclei  1.0 1.0  1.4
nuclei  1.0 1.0  2.0
!homo
!break
config 0
    1 sigma g end
!grid 169 193  35.0
grid 169  40.0
initial  1 3 1
    1.0 1 0 1.0   1.0   1 0  1.0   0
scf 1000 10 16 16
omega
    1.95
    -1.87
stop

```

5. Hartree-Fock ground state of the BF molecule.

```

TITLE
    BF: R = 2.386 bohr
METHOD HF
NUCLEI 5.0 9.0 2.386
CONFIG 0
    1 pi
    5 sigma      end
! initial orbitals are taken from GAUSSIAN94 output (see bf.inp)
! bf_g94.out and bf_g94.pun files must be copied into a working
! directory as gauss94.out and gauss94.pun files, respectively
INITIAL 2 3
GRID 169 35.0
SCF 200 20 8
omega
    1.85
    1.97
multipol -1
fix 1 0 2          ! orbitals are not relaxed
STOP

```

6. HF calculations for the lowest  $^3P$  state of the carbon atom.

```

TITLE
    3P C    R = 2.386
METHOD HF
NUCLEI 6.0 0.0 2.386
CONFIG 0
    1 pi  + . +
    1 sigma
    1 sigma      end
GRID 169 30.0
INITIAL 1 3 1
    1.0  2 1 5.0      0.0  1 0 9.0  0
    1.0  2 0 6.0      0.0  1 0 9.0  0
    1.0  1 0 6.0      0.0  1 0 9.0  0
SCF 400 20 12 12
omega
    1.80
    1.87
STOP

```

7. HF calculations for the lowest  $^2P$  state of the  $C^+$  ion.

```

TITLE
  1P C+   R = 2.386
METHOD HF
NUCLEI  6.0  0.0  2.386
CONFIG  1
  1 pi   +
  1 sigma
  1 sigma end
GRID  169 30.0
INITIAL  1 3 1 ! or INITIAL  5 3 1 and using 3P results
  1.0   2 1 5.0      0.0   1 0 9.0   0
  1.0   2 0 6.0      0.0   1 0 9.0   0
  1.0   1 0 6.0      0.0   1 0 9.0   0
SCF 500 20 7
omega
  1.82
  1.87
STOP

```

8. HF calculations for the lowest state of the  $C_2$  molecule.

```

TITLE
  C2      R = 2.358
METHOD HF
NUCLEI  6.0 6.0 2.358
homo
!break
CONFIG  0
  1 pi   u
  1 sigma u
  1 sigma g
  1 sigma u
  1 sigma g end
GRID  169 193 40.0
INITIAL  2 3 0
! just a couple of dozen iterations to start with
SCF 50 10 10 10 1
! note the small value of overrelaxation parameter for orbitals
! often initial scf/sor iterations have to be require slower
! convergence rates
omega
  1.25

```

```
1.85
STOP
```

```
TITLE
  C2      R = 2.358
METHOD HF
NUCLEI 6.0 6.0 2.358
homo
!break
CONFIG 0
  1 pi    u
  1 sigma u
  1 sigma g
  1 sigma u
  1 sigma g end
GRID 169 193 40.0
INITIAL 5 3 0
SCF 500 10 10 10 1
! the overrelaxation parameter for potentials is at its more or less
! optimal value
omega
  1.75
  1.85
STOP
```

9. HF calculations for the lowest state of the  $N_2$  molecule.

```
TITLE
  N2      R = 2.068
METHOD HF
NUCLEI 7.0 7.0 2.068
homo
CONFIG 0
  1 pi    u
  1 sigma g
  1 sigma u
  2 sigma g
  1 sigma u end
GRID 169 193 40.0
INITIAL 1 3 1
```

```

0.5   2 1 5.0   0.5   2 1 5.0   0
1.5   2 1 5.0   0.0   2 1 5.0   0
0.5   2 0 7.0  -0.5   2 0 7.0   0
0.5   2 0 7.0   0.5   2 0 7.0   0
0.5   1 0 7.0   0.5   1 0 7.0   0
0.5   1 0 7.0  -0.5   1 0 7.0   0
SCF 2000 10 10 10 2
omega
1.65
1.85
STOP

```

10. HF calculations for the lowest state of the  $F_2$  molecule.

```

TITLE
F2      R = 2.668  (1.4118449A)
METHOD HF
NUCLEI  7.0 7.0 2.668
homo
!break
CONFIG  0
1 pi    u
1 sigma g
1 sigma u
1 sigma g
1 sigma u
1 sigma g end
GRID 169 193 40.0
INITIAL  2 3
SCF 100 10 10 10
omega
1.75
1.75
STOP

```

### 3 Description of the data file structure of the program

There are several standard names used by the program to keep track of its input and output disk files. Normally the program writes out the data in the course of computations and upon the completion into the following disk files:

**2dhf\_output.orb** containing molecular orbitals (in the order specified by the input data following **config** label) followed by their normalization factors, orbital energies, Lagrange multipliers and multipole moment expansion coefficients (see WTDISK for more details),

**2dhf\_output.coul** containing corresponding Coulomb potentials and

**2dhf\_output.exch** containing all exchange potentials if  $i_2$  parameter on **initial** card is 2 or 3 or

**fort.31**, **fort.32**, ... if  $i_2$  is 0 or 1 where each file contains the exchange potential for a particular pair of orbitals.

If  $i_1$  parameter on **initial** card is 5 the orbitals are retrieved from **2dhf\_input.orb** file, Coulomb potentials from **2dhf\_input.coul** and exchange potentials from **2dhf\_input.exch** file (or **fort.31**, **fort 32**, ... files). Note that there is only one set of **fort.i** files.

## 4 How to run the program?

In order to simplify the usage of the program, the xhf script is provided which facilitates handling of the disk files. The command xhf requires one, two or three parameters:

`./xhf  $c_1$  [  $c_2$  [  $c_3$  ] ]`

where

- $c_1$  is either
  - the prefix of a command data file which name is of the form  $c_1$ .data,
  - *rename* to change the names of temporary files with 2dhf\_input/2dhf\_output prefixes into the corresponding names with prefixes specified by  $c_2$  and/or  $c_3$  strings. This is useful when the command xhf is aborted and files with 2dhf\_input/2dhf\_output prefixes are left. It is thus recommended that the process x2dhf itself should be killed, if necessary, not xhf itself.
  - *remove* to remove all temporary files.
- $c_2$  is either
  - the prefix of names of output files produced by the program if  $c_2$  is the last command argument, i.e. the output files 2dhf\_output.orb, 2dhf\_output.coul and 2dhf\_output.exch (fort.31, ...) are renamed as  $c_2$ .orb,  $c_2$ .coul,  $c_2$ .exch ( $c_2$ .fort.31, ...), respectively,

- the prefix of names of input files required by the program to continue calculations, i.e. the input files `c2.orb`, `c2.coul`, `c2.exch` (`c2.fort.31`, ...) are moved into `2dhf.input.orb`, `2dhf.input.coul`, and `2dhf.input.exch` (`fort.31`, ...).

- `c3` is the prefix of names of output files generated by the program.

If, for example, `be.data` file contains input data cards for the beryllium atom (see Example 3) then

```
./xhf be be-1
```

starts and performs the first 300 scf iterations. Type

```
./xhf be be-1 be-2
```

to continue calculations. In order to converge the scf process increase the maximum value of the scf iterations and use the following command

```
./xhf be be-2 be-1
```

## 5 How to stop the program?

How to abort the program during a lengthy calculation without killing the process and interrupting the disk read/write operations which can well happen when separate files for the exchange potentials are being used? All you have to do is to create a (zero length) file named **stop\_x2dhf** in a working directory (`./xhf stop` make the file or you can use the Unix **touch** command to this end). The program aborts gracefully whenever this file is detected upon the completion of a current orbital/potential relaxation.

## 6 Useful hints

- The program should be easy to use provided you can start a calculation for a specific system. You should not encounter any serious problems when the system contains atoms from the first two rows of the Periodic Table. Then even the rough hydrogenic estimates of the orbitals should prove adequate and after the initial couple of dozen of iterations a smooth convergence should set in.

If, however, a system contains more than 15-20 electrons the initial estimates of the orbitals have to be good enough to avoid divergences. Then, you have to choose the parameters of the hydrogenic orbitals carefully or perform the finite basis set calculations using the Gaussian94 to provide the initialization data for orbitals.

- Do not start calculations on too dense a grid. For example, the  $61 \times 61$  grid is sufficient to check the quality of the initial data for the  $Ne_2$  system.
- At the very beginning set the maximum number of scf iterations to something between 20 and 50 and/or impose crude convergence criteria for the orbital energy and normalization.
- Choose small values of the relaxation parameters ( $1 < \omega < 1.2$ ) to avoid divergence in the first few dozens of iterations. Later on the parameters should be increased to a desired (optimum) values (see the  $Ne_2$  example).

The dependence of the optimum value of the relaxation parameter  $\omega_{pot}$  on the grid size is illustrated by the following table:

$n_\nu \times n_\mu$	$\omega_{pot}$
$50 \times 50$	1.89
$100 \times 100$	1.94
$159 \times 100$	1.96
$300 \times 300$	1.98

Now it is possible to set  $\omega_{pot}$  to its near-optimal value by using a semiempirical formula (B.Sobczak MSc Thesis, Torun 2002); see the description of the *OMEGA* label above.

Optimum values of the orbital relaxation parameter are somewhat smaller and are not directly related to the grid size. In most cases choosing  $1.75 \leq \omega_{orb} \leq 1.85$  should lead to fairly good convergence rates.