<u>Documentation for WSAW/FOLD/DWHI package.</u>

This package is meant to calculate charge-exchange cross sections for composite probes (i.e. A(^{3}He,t) or A(^{7}Li,^{7}Be) reactions. When using this code for material that is published, you must use the following reference:

J. Cook and J.A. Carr, computer program FOLD, Florida State University (unpublished), based on F. Petrovich and D. Stanley, Nucl. Phys. A275, 487 (1977), modified as described in J. Cook et al, Phys. Rev. C 30, 1538 (1984) and R.G.T. Zegers, S. Fracasso and G. Colò (2006), unpublished.

The interaction that is used (and for which an interaction file is oncluded (love_140) should be referenced as follows:

W.G. Love and M. A. Franey, Phys. Rev. C 24, 1073 (1984).

M.A. Franey and W.G. Love, Phys. Rev. C 31, 488 (1985).

If one uses the radial wave functions for ^{3}He and ^{3}H delivered with the code (HE3H3: i.e. for these no WSAW input is needed; this is strongly recommended if one calculated the (^{3}He,t) or (t,^{3}He) reaction), one needs to use the following reference:

S.C. Pieper and R.B. Wiringa, Annu. Rev. Nucl. Part. Sci. 51, 53 (2001) and R.G.T. Zegers, Phys.Rev. C 74, 024309 (2006).

Of course any other paper used to obtain optical potentials or microscopic input must be referenced as well.

The whole package consist of 3 parts, described in more detail below. There are two versions:

1) For linux (in the tar. File). Unpack the whole structure and then make the executable in each of the directories. You might have to adjust the makefiles, depending on the fortran compiler used. To run the code xxxx (xxxx=wsaw,fold,dwhi) type xxxx < inputfile > outputfile.
2) DOS/WINDOWS: No longer supported.

   Here is a VERY brief description for the example calculation, included in the package: ^{12}C(^{3}He,t)^{12}N(g.s.).
1) Start in the directory WSAW. Run:
    a. wsaw < wsaw12c12n.inp > wsaw12c12n.out
    b. Besides the .out file, which you don't really need for further calculations, it produces C12N12 (C12N12_test is included in the package for comparison). This file must be copied to the FOLD directory, where it will be used in the calculations. The example calculation is for (^{3}He,t), so for the projectile-ejectile system no radial wavefunctions have to be created (HE3H3 file is used for that; see above). In general, one has to create radial wavefunctions for the projectile-ejectile system.

2) Go to the FOLD directory and run:
   a. fold < 12cgs.inp > 12cgs.out
   b. It makes two output files (12cgs.out [can compare with
      12cgs.out_test] which is just for check (very useful though)) and
      FOLDCGS (FOLDCGS_example is the check file), which must be copied
      to the DWHI directory for further calculations. Fold uses C12N12
      and HE3H3 (for the case of (^{3}He,t): already in the directory) and
      love_140 (Love-Franey interaction at 140 MeV; must be changed at
      different energies).
3) Go to the DWHI directory and run:
   a. dwhi < 12cgs.inp > 12cgs.out
   b. It produces 12cgs.out (12cgs_test.out is included as reference)
      and a .plot file, which also has the result in a convenient
      output for plotting.

Any usage of the code or sample inputs comes with no guarantee. For
questions/comments, you can contact Remco Zegers (zegers@nscl.msu.edu).

Documentation for December 2009 version of WSAW at MSU NSCL

This program produces a file containing Woods-Saxon radial functions
where each is prefaced by a header that can be interpreted by FOLD.
Based on a program written by Petrovich in the good old days. This version
is made by R. Zegers, December 2009.

Note: for the binding energies, it is convenient to use a code like OXBASH or
NUSHELL(X)

Input structure:

Most input formats are I5 and F10

1) RMESH=0.1, RMAX=20., NPUNCH=1, NBPUNCH=150, IDBUG=0

2) FILENAM

3) TMC, TIZC, V0, A, R0, RC, VSO

TMC = core mass

TIZC = core charge

V0 = starting value for volume potential depth (will be fit)

A = diffuseness for this potential

R0 = radius parameter for this potential

RC = coulomb radius parameter

VSO = spin-orbit potential strength to us

4) EBIND, TMP, TL, TNODE, TIZP, XJ, XS

EBIND = binding energy of particle

TMP = mass of particle

TL = orbital angular momentum (L) of particle orbit

TNODE = number of interior nodes (starts at zero)

TIZP = charge of particle

XJ = total angular momentum (J) of particle orbit

XS = spin (S) of particle

arbitrary number of card 3+4 sets terminated by TMC = -1

Documentation for August 1989 version of FOLD at MSU NSCL

  This program produces direct and exchange double-folded potentials
  based on the Petrovich, Philpott, Carpenter and Carr formalism with
  central and tensor forces only. [see NP A425 (1984) 609]

  The original model for the program is the Petrovich and Stanley
  folding code which was also a model for ALLWRLD, but they have
  diverged in general structure and detail. This version handles
  complex t-matrices and the simple Golin Fermi-motion correction
  to SNKE in the AEA. The option to use EXCHNG to actually execute
  this correction exactly via Moshinsky transforms and the like is
  untested and has not been converted to use the complex t-matrices;
  it should not be used.

  May 2005 - updates by R.G.T. Zegers NSCL
  The correction factors for the strengths were taken out (still listed in
  output but not used in calculation. The Z coefficients should be input
  like in DW81, i.e. the OBTD's from OXBASH multiplied by the common scale
  factors
  The SKNE approximation was updated: the kA parameter (see Love and Franey
  1985) is input as FNRM2. The difference is large for light target nuclei.
  FNRM1 is a common scale factor for the transformation of tNN to tNA. At 420
  MeV the correction is about 10% in cross section.

  Input structure:

     Most everything is read in I5 or F10 formats.

  1) KEXCHG, KPUNCH=1, FILNAM(char*8)

     KEXCHG =0(direct), =1(ZREA for C), =2(EXCHNG -- do not use!)

  2) NR, H, ELAB, APROJ, IPRTR, IPRTQ, IPRTF

  3a) FJF, PARF, FJI, PARI   ---   for the PROJECTILE   ----

  3b) TF, TFM, TI, TIM

  3c) NTYPF, KOPTN, ALPHA

     NTYPF =1(static), =2(inelastic), =3(charge exchange)

     KOPTN =1(S[T]), =2(S[pn]), =3(Z[T]), =4(Z[pn]) =5(Wildenthal trans amp)

  3d) IDF, IDI, JX, Z1, Z2   (terminated by -1,-1)

       the Z's are the Raynal/ALLWRLD definition for MT=0
       conversion to actual MT can be wrong for special cases
       IDI corresponds to OXBASH's "created", IDF to "destroyed"

  3e) FILEN   (read and used if ALPHA=0)

  4a) FJF, PARF, FJI, PARI   ---   for the TARGET   ----

4b) TF, TFM, TI, TIM

     4c) NTYPF, KOPTN, ALPHA

     4d) IDF, IDI, JX, Z1, Z2   (terminated by -1,-1)

     4e) FILEN   (read and used if ALPHA=0)

     5) FNRM1, FNRM2, FNRM3, FRCEFILE(char*48)
FNRM1: scale factor for transformation of tNN to tAA. See the 1981 and 1985
Love & Franey papers. Note that the description in L&F is only for tNN->tNA.
FNRM2: kA-> momentum for short-range exchange approximation. Calculated based
on Love & Franey (1981 & 1985) but realize that there equations are only for
tNN->tNA.

     6) NFORM   (number of SETS of cards 7 and 8)

     7) JR, JP, JT, KFORCE
          KFORCE = -1 for Central + Tensor
                    0 for Central only
                    1 for LS (spin-orbit)
                    2 for Tensor only

     8) DNORM(1), ..., DNORM(7)   --- card for each T, proj and targ

        these scale rho-m; rho-s for L=J-1,J,J+1; rho-l for L=J-1,J,J+1

Some additional notes on the MSU NSCL version of FOLD

Explanation of those input parameters which are not explained in
DOC_FOLD.LIS and are obvious:

Card 2) NR   : number of integration steps
        H   : step size (fm)
        ELAB : bombarding energy in MeV } These two parameters only used
        APROJ : projectile mass   } for SNKE wavenumber determination
        IPRTR : set to 1 for printout of r-space densities
        IPRTQ : set to 1 for printout of q-space densities
        IPRTF : set to 1 for printout of formfactors

Card 3a) For the projectile...
        FJF   : spin of final particle
        PARF : parity of final particle (+, -)
        FJI   : spin of initial particle
        PARI : parity of initial particle (+, -)

Card 3b) Projectile (contd.)
        TF   : Isospin of the final particle
        TFM   : Isospin projection of the final particle (+ve = neutron excess)
        TI   : Isospin of the initial particle
        TIM   : Isospin projection of the initial particle

Card 3c) Projectile (contd.)
        NTYPF : see DOC_FOLD
        KOPTN : see DOC_FOLD. The Z-coeff definition used by FOLD is

             dJ,DT   CG(Ti Tim dT dTm | Tf Tfm) HAT(dT)
             Z   = --------------------------------- * BHW
              j,j'   HAT(Ji) * HAT(Tf)

            where,
                  HAT(j) = SQRT (2j + 1)

            and BHW is the Wildenthal transition amplitude (as output
            by OXBASH, for example):

                                + ~   dJ,dT
                     < Wf ||| (aj x aj') ||| Wi>
                BHW = -----------------------------
                            HAT(dJ) * HAT (dT)

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Card 3d) Projectile (contd.)
      IDF   : sub-orbital ID number for the final (destroyed) particle or
hole
      IDI   : sub-orbital ID number for the initial (created) particle or
hole


       1 = 0s1/2         16 = 2p1/2        31 = 2f5/2
       2 = 0p1/2         17 = 2p3/2        32 = 2f7/2
       3 = 0p3/2         18 = 1f5/2        33 = 1h9/2
       4 = 1s1/2         19 = 1f7/2        34 = 1h11/2
       5 = 0d3/2         20 = 0h9/2        35 = 0j13/2
       6 = 0d5/2         21 = 0h11/2       36 = 0j15/2
       7 = 1p1/2         22 = 3s1/2        37 = 4s1/2
       8 = 1p3/2         23 = 2d3/2        38 = 3d3/2
       9 = 0f5/2         24 = 2d5/2        39 = 3d5/2
      10 = 0f7/2         25 = 1g7/2        40 = 2g7/2
      11 = 2s1/2         26 = 1g9/2        41 = 2g9/2
      12 = 1d3/2         27 = 0i11/2       42 = 1i11/2
      13 = 1d5/2         28 = 0i13/2       43 = 1i13/2
      14 = 0g7/2         29 = 3p1/2        44 = 0k15/2
      15 = 0g9/2         30 = 3p3/2        45 = 0k17/2


Cards 4a-d) As per cards 3a-d, but for target system.

OLD CARD 5
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Card 5) FNRM1 : Normalization of SNKE Yukawa of 1st range given in force file
        FNRM2 :       "          "   "   "   "   "   2   "   "   "   "
        FNRM2 :       "          "   "   "   "   "   3   "   "   "   "
        FRCEFILE : name of file containing n-n force parameters
        For a list of available force files, see [DWBA.SCRI.FORCEFILES]
NEW CARD 5
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R.G.T. Zegers Card 5) has been replaced:
        FNRM1 : normalization of SNKE Yukawas (all ranges) for transformation
                from tNN to tNA
        FNRM2 : kA (momentum of projectile in NA frame) instead of lab
momentum
                Especially important for very light (A<10) target nuclei.
        FNRM3:  not used


Card 7) JR    : "relative" spin transfer (known in DWHI as LTRT)
        JP    : spin transfer in the projectile system (2*JP = ISTRT in DWHI)
        JT    : spin transfer in the target system (2*JT = JTRT in DWHI)
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Documentation for December 2009 version of DWHI at MSU NSCL

This program performs the DWBA calculation using the double-folded scattering
potentials produced by FOLD. It is patterned after DWUCK with the addition
of better coulomb routines for the heavy ion case by Julian Cook. It produces
plot files suitable for PLOTIT.
In the WINDOWS/DOS version of the code, the 'EQUIVALENCE' command does not
work (input.for) and has been replaced.
Note that the PLOTFILE must be removed before running the code (else the code
will stop). Also, if the program fails to run properly, one has to remove by
hand the files *.SCR before running again. Else the code will stop.

  Input structure:

     Most everything is read in I3 and F7 formats, see example below.
     Definitions generally follow the DWUCK code this was originally
     based upon, with a few variations. Check code when in doubt.

  1) ICON(1), ..., ICON(20), TITLE

     ICON(1)=1 to use the kind of ANGLE input shown for card 2

     ICON(2)=2 to use a microscopic form factor

     ICON(3)=1 to use incoherent sum of the different LTR cases

     ICON(4)=0 to print form factor used, non-zero to suppress this

     ICON(5)=2 to print complex T-L, complex S-L, and S-L magnitude
            =1 to print no elastic scattering info
            =0 to print complex T-L only

     ICON(9)=4 to always produce a 4-cycle semi-log graph

     ICON(10)=0 to use non-relativistic kinematics

  1a) FILNAM(char*8)   -- read if ICON(2) is not 1, contains form factor

  2) ANGLE(1), ANGLE(2), ANGLE(3)

     ANGLE(1) = number of angles

     ANGLE(2) = initial angle

     ANGLE(3) = angle step size

  3) L, NFF, ISA, ISB, JA, JB

     L = number of partial waves for elastic

     NFF = number of form factors to expect -- must match number
           produced by FOLD; must also be used in correct order.

ISA,ISB = 2 * projectile spin in initial (A) and final (B) channel

    JA,JB = 2 * target spin in initial (A) and final (B) channel

4) DR, NNR, KRCO   --   must match corresponding card in FOLD. The parameter
KRCO was added by R. Zegers. If set to a value larger than 1, then the
formfactor will be cut from the inside: i.e. the program will run from step
KRCO to NNR (in steps of DR) instead of from 1 to NNR (in steps of DR). This
feature is for checks only. It allows one to study the surface nature of a
certain probe. Leave KRCO open or set to 1 for a normal calculation.

5a) E, FM, Z, FMA, ZA, RY, FS, QCD   --- incoming channel

    E = lab energy

    FM,Z = projectile mass and Z

    FMA,ZA = target mass and Z

    RY = coulomb radius (multiplies TARGET mass to 1/3)

    FS = 0

    QCD = 0

5b) FZ, VR, RY, AR, VSOR, VI, RZ, AI, VSOI, PWR (until FZ=0)

    FZ = potential option (1=WS, 2=surface WS, 3=second derivative)

    VR,RY,AR,VSOR = real volume, radius, diffuseness, and LS values

    VI,RZ,AI,VSOI = imaginary volume, radius, diffuseness, and LS

    PWR = 0 for cases we use

6a) E, FM, Z, FMA, ZA, RY, FS, QCD   --- outgoing channel

    E = Q-value here

6b) FZ, VR, RY, AR, VSOR, VI, RZ, AI, VSOI, PWR (until FZ=0)

7) LTRT, ISTRT, JTRT   (there are NFF pairs of 7 and 8)

    LTRT = JR, ISTRT = 2*JP, JTRT = 2*JT

8) BETAR=0, BETAI=0, BETAC=0, FNORM=1

9) PLOTFILE(char*16)