

NuShellX@MSU

B. A. Brown

*Department of Physics and Astronomy
and National Superconducting Cyclotron Laboratory,
Michigan State University,
East Lansing, Michigan 48824-1321, USA*

W. D. M. Rae

Garsington, Oxfordshire, OX44, UK

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1 Introduction

This manual describes the version of NuShellX that can be used on Windows or Linux (64 bit).

NuShellX is set of programs for carrying out shell-model calculations with dimensions up to about 10,000,000. The main code NuShellX was written by W. D. M. Rae and is documented in the file NuShellX.pdf. NuShellX@MSU contains wrapper codes for input and output similar in style to the Oxbash code, and comes with a library of model spaces and interactions. Any paper that is written using the NuShellX@MSU code should contain a sentence of the type - “The calculations were carried out in the x model space with the y hamiltonian (give source reference for the interaction) using the code NuShellX@MSU [1]”. If the model space, model-space truncation or Hamiltonian is changed from the original reference it must be discussed and justified in the text.

Note that all calculations with NuShellX are in the proton-neutron formalism. When *.sp files and *.int files in isospin formalism are used, they are converted to proton-neutron formalism. Calculations in isospin formalism only can be carried out with the NuShell@MSU or Oxbash codes.

The complete listing of model spaces and hamiltonians is given in the text file label.dat in the sps folder. The folder sps contains some of the well established hamiltonians with references. The reference for the hamiltonians is usually given at the top of the *.int files. For most model spaces there are several hamiltonians (*.int files). In order to determine which one to use, start with those that have the most recent publications and read the discussion in these papers. A review for interactions in light nuclei is given in [2].

[1] The Shell-Model Code NuShellX@MSU, B. A. Brown and W. D. M. Rae, Nuclear Data Sheets 120, 115 (2014).

[2] The Nuclear Shell Model Towards the Drip Lines, B. A. Brown, Progress in Particle and Nuclear Physics 47, 517 (2001).

2 Installation

2.1 Windows setup

Unzip the folders to

```
c:\aaa\
```

so that the directory structure for nushellx is

```
c:\aaa\nushellx\windows\ (windows login, exe and bat files)
c:\aaa\nushellx\help\
c:\aaa\nushellx\sps\ (input files - same for windows and linux)
c:\aaa\nushellx\toi\ (table of isotopes data - same for windows and linux)
```

Go to the nushellx-login folder

```
c:\aaa\nushellx\windows\login
```

Edit the file login.bat (if needed).

You may edit the file ed.bat to point to your text editor.

Copy the nushellx-login shortcut file to the desktop. Right-click on the shortcut and then click on “properties.” Under the shortcut-tab in the line “start in” put the name of the aaa-nushellx-login folder on your computer. You may also want to change the font, layout and color options for the default screen.

This part only needs to be done once.

2.2 Linux setup

First you must install gfortran. Then unzip the folders to

```
...aaa/
```

so that the directory structure for nushellx is

```
...aaa/nushellx/linux/bin/ (linux executables)
...aaa/nushellx/help/
...aaa/nushellx/sps/ (input files - same for windows and linux)
...aaa/nushellx/toi/ (table of isotopes data - same for windows and linux)
```

2.3 Logging into nushellx with Windows

Left-click on the command-prompt (setup as above). This command goes to the nushellx-login folder and executes the login.bat command. Login.bat initializes the path so that the exe and bat files in the nushellx-windows folder can be used. Some special *.bat files in this nushellx-windows folder are listed below.

2.4 Logging into nushellx with Linux

You will need a

`.bash_profile`

file that contains (example given by my path names):

```
nuxhome=/mnt/home/brownbo
export PATH=$nuxhome/aaa/nushellx/linux/nushellx-gfortran-bin:$PATH
export nushellx_sps=$nuxhome/aaa/nushellx/sps/
export mass_data=$nuxhome/aaa/nushellx/toi/mass-data/
export toi_data=$nuxhome/aaa/nushellx/toi/toi-data/
```

There is a sample bash file in the linux folder. To make linux commands alias names for some common windows commands the followings can be defined in the bash file:

```
alias copy=cp
alias del=rm
alias q='qstat -u brownbo'
alias qall='checknode -v ifi-003'
alias sd='cd'
alias di='ls -g -l -a'
alias dis='ls -tr -l -g -a'
alias d='ls -l | egrep ^d'
alias ed='vi'
alias md='mkdir'
```

3 Using the batch file system

3.1 Some useful Windows commands

dir - make a listing of all files in the current folder

cd x - go to folder x, where x specifies a subfolder or the full directory structure.

cd .. - go to the parent folder

md x - make a subfolder with the name x

copy x y - will copy files from x to y, e.g.

3.2 Special commands (the *.bat files in nushellx-login)

sd x (Windows only) - if x is one of the following, the command prompt will move directly to one of the nushellx folders

login - login files

help - help files

sps - *.sp and *.int files and the label.dat file

rsh - c:\rsh-nushellx, the suggested scratch folder name

shell - runs the nushellx code for making the *.bat files for calculations

ed x - is **editor x** where x is the file name and **editor** is the name path specified in ed.bat in the login folder.

(Note - do not use **edit**. By Windows default this brings up a screen for an old and hard to use editor)

di - makes a listing of all files in the current folder. You can use x*y.z to get specific types of files.

dis - same as **di** but files are listed in order of data made with the latest being last.

d - list of directories.

save - copy all of the files to be kept to the subfolder save using the list from save.dat in the sps folder.

4 Basic input commands

4.1 Doing a shell-model calculation

After logging into nushellx type the following (replace x and y with your own names)

```
sd rsh    - goes to the rsh-nushellx folder (make the folder if it is not already made).
md x      - make the subfolder x (if it is not already made)
sd x      - goes to the subfolder x
shell     - answer the questions - call the batch file, for example, "test"
test     - runs the batch file made by shell
save     - (at the end) save the stuff to keep in the subfolder save
```

Once the subfolder is made, one can go to this folder and use it for any number of batch files. Shell makes unique names for all of the files (see below).

5 Input libraries

The folders sps contains previously made input files for the model space (*.sp) and hamiltonians (*.int). The file label.dat in the folder sps contains a list of available model space and hamiltonian combinations. The file label.dat is used to make names for the output files.

When shell is run with a given model space and interaction it looks for the input files (label.dat, *.sp and *.int) in the following folders

- 1) first in the current folder
- 2) next in the sps folder.

When the *.int files are modified it is best to first copy them from sps folder to the current working folder.

5.1 Sample inputs for shell

Answers to shell for the ^{20}Ne $J=0^+$ to $J=8^+$, wavefunctions in the sd shell.

```
ne20    - the batch file name
lpe     - the option to calculate wave functions (a)
sd      - model space name (b)
        - no restrictions (yes/no)
w       - interaction name
10      - number of protons
20      - number of nucleons
0.,8.   - min,max J
0       - parity
st      - stop
```

Notes:

A blank line can be used in place of **n** (no), **0.**, **0** or **st**

The energies for each state and some information on the wavefunctions are found in the *.lpe files. The energies for all levels in ^{20}Ne are found in the file ne200.lpt. The energies can be compared against those given at

<http://www.nsc1.msu.edu/~brown/resources/SDE.HTM>

a) The default value for the number of converged wavefunctions is 10. If you want a larger number modify the *.nieg file after running shell and before running the batch job.

b) The default label for the model space name is in the file label.dat. If you want to use another symbol type (in this example) sd,a where “a” will be the new symbol. In the model space and interaction are not in label.dat the “x” is used for the model space label and “y” is used for the interaction label.

Answers to shell for the ^{20}Ne $J=0^+$ and $J=2^+$ wavefunctions in the sd shell space followed by a calculation for the 0^+ to 2^+ and 2^+ to 2^+ one-body transition density for M1 and E2.

```
ne20t    - the batch file name
lpe      - the option to calculate wave functions
sd       - model space name
         - no restrictions (yes/no)
w        - interaction name
10       - number of protons
20       - number of nucleons
0.,2.,2. - min,max,delta J
0        - parity
----- (a)
den      - the option to calculate overlaps between two wavefunctions
t        - the one-body transition density overlap option
bw2400   - the name of the initial state (b)
1        - number of initial states
bw2400   - the name of the final state
5        - number of final states
0.,2.,2. - min,max,delta J for initial state
0.,2.,2. - min,max,delta J for final state
y        - restrict the tensor ranks for the one-body operator (c)
1.,2.    - min, max tensor-rank (for M1 and E2 in this case)
st       - stop
```

Notes:

a) If the wavefunctions have been calculated previously you may start here to make a batch file for the transition density. (It is recommended to give the wavefunction and one-body transition batch files difference names).

b) In the names bw2400 and bw2400 the last characters ("0" in this case) dummy letters that will be filled in after the min, max questions are answered.

c) If you want all possible tensor ranks type a blank line here and the next line will be skipped.

Answers to shell for the spectroscopic factor between ^{19}F $J=1/2^+$ and ^{20}Ne $J=0^+$ in the sd shell. The dashed lines separate different part of the input.

```

ne20s - the batch file name
-----
lpe    - the option to calculate wave functions
sd     - model space name
       - no restrictions (yes/no)
w      - interaction name
10     - number of protons
20     - number of nucleons
0.     - min,max J
0      - parity
-----
lpe    - the option to calculate wave functions (a)
9      - number of protons
19     - number of nucleons
0.5    - min,max J
0      - parity
-----
den    - the option to calculate overlaps between two wavefunctions
1      - the spectroscopic factor overlap option
bw1301 - the name of the initial (core) state
1      - number of initial states
bw2400 - the name of the final (overlap) state
5      - number of final states
0.5    - min,max J for initial state
0.     - min,max J for final state
       - restrict the tensor rank (no restrictions)
st     - stop

```

a) Note that when lpe is run the second time the information on model space, restrictions and interaction is not entered again.

5.2 Sample inputs for ^{22}Ne

The folder ne22 contains *.ans files for examples and for testing the code. ne22lpe.ans - is the input for wavefunctions and energy spectra for ^{22}Ne and surrounding nuclei. ne22den.ans - is the input for gamma decay in ^{22}Ne , Gamow-Teller charge exchange from ^{22}Ne , one nucleon spectroscopic factors from ^{22}Ne and two-nucleon transfer amplitudes from ^{22}Ne . The ne22den.ans file is also divided into separate inputs. The save folder contains the results of these calculations.

6 Model space truncations

In the examples given in the previous section the answer to the question for “any restrictions” was “n” (or blank) for “no”. If you want to put restrictions on partitions that are allowed answer “y” for “yes”. Shell will then ask for the type of restriction you want from the list of options

(s) subshell restrictions

When “s” is chosen, shell will ask for the minimum and maximum number of nucleons for each orbital. (NuShellX does not work for $\hbar\omega$ type truncations. For this you will need to use the code Oxbash or NuShell.)

7 The *.nux files

Files labeled *.nux are special control inputs.

iso.nux (before running shell): If this file exists we calculate the expectation value of T^2 . The output files are *.iso and *.lol.

fastin.nux (before running shell): A MPI type batch for the den(t) option was implemented for windows in Feb 2017. Inside shell, ifast = 1 uses the new batch system, ifast = 0 uses the old sequential system. The defaults are ifast = 1 for windows and ifast = 0 for linux. To override this default for windows make a file called fastin.nux and put 0 or 1 at the top.

maxj2.nux (before running shell): The default value for the maximum value for $2xJp$ and $2xJn$ in $(JpxJn)J$ are the maximum allowed in the model space. For example for $21Ne$ in the sd-shell the $2xJpmax=8$ and $2xJnmax=11$. To decrease these values make a file called maxj2.nux and put the new values for $2xJpmax$ and $2xJnmax$ in the first line.

nimin.nux: (nutra.f90) The default value for the minimum (min) value of the initial state index for transition matrix element is one (min=1). (The max value is entered in shell). To change the value make a file called ninim.nux and put the value for min in the first line.

maxdj.nux (nupom.f90). The default value is the maximum possible for the $a+(j1)a(j2)$ operator determined by the $j1$ and $j2$ values. To reduce this make a file called maxdj.nux and put the max value in the first line.

converge.nux (nucorex.f90, nulnz). Use this to change the converge criteria for the change in the eigenvalues from its default value of 0.0005 keV during the run. Make a file called converge.nux and put the new value in the first line.

iter.nux (nucorex.f90, nulnz). Use this to change the maximum number of iterations during the run. The default value depends on the case and is printed in the *.cpu file during the run. Make a file called iter.nux and put the new value in the first line.

8 Description of some other programs

shell makes a batch file **y.bat** that coordinates the program sequence and their inputs. The input is the answers to a series of questions. Alternatively, the input is from a **y.ans** file that has been made by a previous run of **shell** or by hand.

tbme generates a set of JT-coupled two-body matrix elements for a wide variety of two-body potential models.

dens calculates the radial wavefunctions for a given nucleus with oscillator, Woods-Saxon or Skyrme Hartree-Fock potentials and reads the *.obd from nushellx to calculate B(EL), B(ML) and B(GT) values. Sample inputs for **dens** are given in a separate section.

prs calculates values for Clebsch-Gordan, 3j, 6j and 9j coefficients.

9 Phase conventions

Phase conventions enter into the one-body transition densities. They are defined by the calculation of the Hamiltonian matrix elements. The radial wavefunction is positive at near $r = 0$. $|j\rangle = |[\ell \otimes s]^j\rangle$ The wavefunctions are real and do not contain any $(i)^\ell$ factor. The Edmonds reduced matrix element convention is used.

10 Conversion of isospin to proton-neutron two-body matrix elements

The conversion of normalized isospin wavefunctions to normalized proton-neutron (pn) wavefunctions is ($a \neq b$):

$$\begin{aligned}
 |aa, J \rangle_{pp} &= |aa, J = \text{even}, T = 1 \rangle \\
 |ab, J \rangle_{pp} &= |ab, J, T = 1 \rangle \\
 |aa, J = \text{even} \rangle_{pn} &= |aa, J = \text{even}, T = 1 \rangle \\
 |aa, J = \text{odd} \rangle_{pn} &= |aa, J = \text{odd}, T = 0 \rangle \\
 |ab, J \rangle_{pn} &= \sqrt{\frac{1}{2}} [|ab, J, T = 1 \rangle + |ab, J, T = 0 \rangle]
 \end{aligned}$$

Thus the normalized proton-proton (and neutron-neutron) matrix elements are just the $T = 1$ matrix elements, and the normalized proton-neutron matrix elements are ($a \neq b$ and $c \neq d$):

$$\begin{aligned}
 \langle aa, J | V | cc, J \rangle_{pn} &= \langle aa, J, T = 1 | V | cc, J, T = 1 \rangle + \langle aa, J, T = 0 | V | cc, J, T = 0 \rangle \\
 \langle ab, J | V | cc, J \rangle_{pn} &= \sqrt{\frac{1}{2}} [\langle ab, J, T = 1 | V | cc, J, T = 1 \rangle + \langle ab, J, T = 0 | V | cc, J, T = 0 \rangle] \\
 \langle aa, J | V | cd, J \rangle_{pn} &= \sqrt{\frac{1}{2}} [\langle aa, J, T = 1 | V | cd, J, T = 1 \rangle + \langle aa, J, T = 0 | V | cd, J, T = 0 \rangle] \\
 \langle ab, J | V | cd, J \rangle_{pn} &= \frac{1}{2} [\langle ab, J, T = 1 | V | cd, J, T = 1 \rangle + \langle ab, J, T = 0 | V | cd, J, T = 0 \rangle]
 \end{aligned}$$

In the first three of these equations one of the matrix elements on the right-hand side is zero.

Nushellx uses unnormalized proton-neutron matrix elements (upn) of the form

$$\begin{aligned}
 \langle aa, J | V | cc, J \rangle_{upn} &= [\langle aa, J, T = 1 | V | cc, J, T = 1 \rangle + \langle aa, J, T = 0 | V | cc, J, T = 0 \rangle] \\
 \langle ab, J | V | cc, J \rangle_{upn} &= [\langle ab, J, T = 1 | V | cc, J, T = 1 \rangle + \langle ab, J, T = 0 | V | cc, J, T = 0 \rangle] \\
 \langle aa, J | V | cd, J \rangle_{upn} &= [\langle aa, J, T = 1 | V | cd, J, T = 1 \rangle + \langle aa, J, T = 0 | V | cd, J, T = 0 \rangle] \\
 \langle ab, J | V | cd, J \rangle_{upn} &= [\langle ab, J, T = 1 | V | cd, J, T = 1 \rangle + \langle ab, J, T = 0 | V | cd, J, T = 0 \rangle]
 \end{aligned}$$

In the proton-neutron interaction (*.int) file there is a label T' . For the pp and nn matrix elements you must have $T' = 1$. If you are given a set of normalized proton-neutron matrix elements they must be converted into unnormalized matrix elements to use in nushell:

$$\begin{aligned}
 \langle aa, J, T' | V | cc, J, T' \rangle_{upn} &= \langle aa, J | V | cc, J \rangle_{pn} \quad (J + T' = \text{odd}) \\
 \langle ab, J, T' | V | cc, J, T' \rangle_{upn} &= \sqrt{2} \langle ab, J | V | cc, J \rangle_{pn} \quad (J + T' = \text{odd})
 \end{aligned}$$

$$\begin{aligned} \langle aa, J, T' | V | cd, J, T' \rangle_{upn} &= \sqrt{2} \langle aa, J | V | cd, J \rangle_{pn} \quad (J + T' = \text{odd}) \\ \langle ab, J, T' | V | cd, J, T' \rangle_{upn} &= 2 \langle ab, J | V | cd, J \rangle_{pn} \quad (T' = 0, 1) \end{aligned}$$

When the upn matrix elements are obtained from a set of good isospin matrix elements both matrix elements (with $T = 0$ and $T = 1$) can be used with $T' = T$. **When the upn matrix element is obtained from normalized pn matrix elements one must have $T=1$ for pp and nn and $J+T'=\text{odd}$ for pn except for the last line above where $T'=0$ can be used.**

11 File names

11.1 Files made by shell

y.bat - Windows batch file for program sequence

y.ans - a copy of the answers to the shell questions. If the *.ans file already exists it can be modified by notepad, and then used to answer the shell questions as follows:

```
shell
```

```
y.ans
```

For a series of calculations it may be efficient to generate the *.ans file (or files) with another program.

y.mit - a list of the hamiltonians and their normalizations. In some cases the hamiltonian may be broken into two or more parts. To change the details of the hamiltonian input copy the y.mit file to a file called “input.mit”, then edit this file. The values in “input.mit” will override the default values from shell.

11.2 Names for the wavefunction and overlap files

The first part of the file name for wavefunctions has the six letter form **abxypj** where:

a - symbol for the model space found in label.dat
 b - symbol for the interaction found in label.dat
 x - symbol for the number of valence protons
 y - symbol for the number of valence nucleons
 p - symbol for the parity (0 for + and 1 for -)
 j - symbol for two times the spin from the list below

The first part of the names for overlaps has the nine letter form **ABXYPJ_xypj** where **ABXYPJ** is the name of the initial state and **xypj** is part of the name of the final state.

If the model space and interaction name do not exist in label.dat they will be assigned the names **x** and **y**, respectively.

The symbols for J, T and N correspond to the following numbers

0 - 0	k - 20	f - 40	0 - 60	h - 80	f - 100	0 - 120
1 - 1	l - 21	g - 41	1 - 61	l - 81	g - 101	1 - 121
2 - 2	m - 22	h - 42	2 - 62	m - 82	h - 102	2 - 122
3 - 3	n - 23	i - 43	3 - 63	n - 83	i - 103	3 - 123
4 - 4	o - 24	j - 44	4 - 64	o - 84	j - 104	4 - 124
5 - 5	p - 25	k - 45	5 - 65	p - 85	k - 105	5 - 125
6 - 6	q - 26	l - 46	6 - 66	q - 86	l - 106	6 - 126
7 - 7	r - 27	m - 47	7 - 67	r - 87	m - 107	7 - 127
8 - 8	s - 28	n - 48	8 - 68	s - 88	n - 108	8 - 128
9 - 9	t - 29	o - 49	9 - 69	t - 89	o - 109	9 - 129
a - 10	u - 30	p - 50	a - 70	u - 90	p - 110	a - 130
b - 11	v - 31	q - 51	b - 71	v - 91	q - 111	
c - 12	w - 32	r - 52	c - 72	w - 92	r - 112	
d - 13	x - 33	s - 53	d - 73	x - 93	s - 113	
e - 14	y - 34	t - 54	e - 74	y - 94	t - 114	
f - 15	a - 35	u - 55	f - 75	a - 95	u - 115	
g - 16	b - 36	v - 56	g - 76	b - 96	v - 116	
h - 17	c - 37	w - 57	h - 77	c - 97	w - 117	
i - 18	d - 38	x - 58	i - 78	d - 98	x - 118	
j - 19	e - 39	y - 59	j - 79	e - 99	y - 119	

11.3 *.ext names for the outputs

The “save” command will copy all of these files to a subdirectory called save. The files saved (the list below) are in the save.dat file in the sps folder.

sps is the sps data folder, x is the nushellx program run in the batch
 from to

*.ab	x		tri-diagonal matrix
*.ans		shell	shell input file with answers to questions
*.bat	shell	x	shell output with scripts for running x
*.bei	dens	beta	made with *.ben file for GT
*.ben	shell	dens	input for GT beta decay matrix elements
*.beq	shell	beta	beta input for GT beta decay
*.beo	beta		beta output for GT beta decay
*.bgt	dens		made with *.ben file
*.bm1	gamma		list of B(M1) values, Ef-Ei, B, sum B, Ji, Jf
*.be2	gamma		list of B(E2) values, Ef-Ei, B, sum B, Ji, Jf
*.cpu	x		log of *.bat that contains cpu times
*.dei	dens	gamma	made with *.den file for M1 and E2
*.dai	sps	beta	xfg and fgtw input files for beta phase space
*.dat			input control files for shell and x
*.den	shell	dens	input for M1 and E2 matrix elements
*.deo	gamma		gamma decay scheme for M1 and E2
*.det	gamma		gamma decay half-lives
*.dim	shell		dimensions
*.eps	levp		postscript figure of energy levels, B(M1) and B(E2)
*.pdf	cps		pdf version of eps files
*.fid	shell		list of files to make accumulated *.lsf with nulsf
*.fil	shell		list of files to make *.lpt with nulev
*.int	sps		Hamiltonian files
*.iso	nuxpt		Information on isospin and isospin mixing (if iso.nux is present)
*.lev	nulev	levp	theory energies input to levp
*.lpe	x		list of eigenfunction properties
*.lpt	nulev		accumulated level scheme based on *.fil input
*.ls	x		Jp Jn decomposition of wf
*.lp	x		partition decomposition of wf
*.amp	x		amplitude decomposition of wf (made if amp.nux is present)
*.lsa	nulsf		spectroscopic amplitudes (with sign)
*.lsf	nulsf		spectroscopic factors
*.mit	shell		list of Hamiltonians to be added together
*.map	map		makes *.eps for B(M1) and B(E2)
*.npar	shell		list of neutron partitions
*.ppar	shell		list of proton partitions
*.nux			special condition files
*.plt	dens		data to plot with top(cps)

*.obd	nulsf	one-body transition densities
*.occ	x	accumulated levels with occupation numbers
*.ov	shellx2	expectation values of two-body scalar operators
*.sp	sps	model space information
*.tna	nulsf	two-nucleon amplitudes
*.top	levp	input to make the *.eps figures

12 Short history of NushellX

- 1976 Oxbash conception (W. D. M. Rae and C. H. Zimmerman).
- 1978 Working PDP10 version (N. S. Godwin and W. D. M. Rae).
- 1980 First VAX version with MACRO multiple-integer words, (A. Etchegoyen, B. A. Brown, W. A. Richter, N. S. Godwin and J. S. Winfield).
- 1982 General overall upgrade, multiple-integer words used for partitions (A. Etchegoyen and W. D. M. Rae).
- 1983 BASIS speeded up (J. S. Winfield). Documentation and general organization added (B. A. Brown).
- 1986 Upgrade to standard FORTRAN and preparation for use on the FPS-164 array processor (W. E. Ormand). (As of Nov 1988 the FPS versions are no longer being used.)
- 1988 Changes made to make OXBASH CRAY compatible (L. Zhao). General two-body interaction code added (B. A. Brown).
- 1994 Unix version and anonymous FTP (M. Horoi).
- 2004 Windows PC version (B. A. Brown).
- 2007 Nushell is a completely rewritten code in Fortran 95 by W. D. M. Rae. Nushell@MSU is the nushell core program with input and output formats in the Oxbash style.
- 2008 NuShellX is a completely new code written code in Fortran 95 by W. D. M. Rae. It starts with input from Nushell to create proton-neutron basis states. NuShellx@MSU is the NuShellx core program with input and output formats in the Oxbash style.
- 2009- many changes and additions to the code by Alex Brown

13 Sample formats for the *.sp and *.int files

13.1 General information on the *.sp and *.int files

The basic input files for oxbash are *.sp and *.int. The *.sp file specifies the single particle states. The *.int file specifies the hamiltonian. Sample files formats are given below.

The SPE are always read from the *.int file. Thus, if only the SPE are changed in the *.int file the *.op file does not have to be deleted.

13.2 Sample SP file in isospin formalism (p.sp)

```
t          t = isospin formalism
4 2       a and z of core
2         number of orbits
1 2       number of major shell and number of orbits in each
1 1 1 1   1st orbit n,l,2j
2 1 1 3
```

13.3 Sample SP file in proton/neutron formalism (ppn.sp)

```
pn          pn = proton-neutron formalism
4 2        a and z of core
4          number of orbits
2 2 2      2 major shell, number of proton orbits, number of neutron orbits
1 1 1 1    1st orbit n,l,2j
2 1 1 3
3 1 1 1
4 1 1 3
```

13.4 Sample INT file in isospin formalism (ckpot.int)

```
15      2.420  1.130
1  1  1  1      0  1      0.24
1  1  1  1      1  0     -4.29
2  1  1  1      1  0      1.20
2  1  2  1      1  0     -6.56
2  1  2  1      1  1      0.73
2  1  2  1      2  0     -4.06
2  1  2  1      2  1     -1.14
2  2  1  1      0  1     -5.05
2  2  1  1      1  0      1.77
2  2  2  1      1  0      3.21
2  2  2  1      2  1     -1.74
2  2  2  2      0  1     -3.33
2  2  2  2      1  0     -3.44
2  2  2  2      2  1      0.09
2  2  2  2      3  0     -7.27
```

The first line and any subsequent line with a “!” in front is header information not used by the programs. NMAT in the second line is the number of matrix elements. This number is not used but OPER will give a warning message if the number of inputs differs from NMAT. The remaining entries in the second line are the single-particle energies. Then comes a list of the matrix elements in the form I1,I2,I3,I4,J,T,tbme where I is the orbit index number. The input is always read in “free” format. Tbme is the value of the two body matrix element.

13.5 Sample INT file in proton/neutron formalism (ckpotpn.int)

```

! 1=P1P1/2 2=P1P3/2 3=N1P1/2 4=N1P3/2
 44  2.42000  1.13000  2.42000  1.13000
 1  1  1  1  0  1  0.24000
 2  1  2  1  1  1  0.73000
 2  1  2  1  2  1 -1.14000
 2  2  1  1  0  1 -5.05000
 2  2  2  1  2  1 -1.74000
 2  2  2  2  0  1 -3.33000
 2  2  2  2  2  1  0.09000
 3  3  3  3  0  1  0.24000
 4  3  4  3  1  1  0.73000
 4  3  4  3  2  1 -1.14000
 4  4  3  3  0  1 -5.05000
 4  4  4  3  2  1 -1.74000
 4  4  4  4  0  1 -3.33000
 4  4  4  4  2  1  0.09000
 1  3  1  3  0  1  0.24000
 1  3  1  3  1  0 -4.29000
 2  3  1  3  1  0  1.20000
 1  4  1  3  1  0 -1.20000
 2  3  2  3  1  0 -6.56000
 1  4  2  3  1  0  6.56000
 2  3  1  4  1  0  6.56000
 1  4  1  4  1  0 -6.56000
 2  3  2  3  1  1  0.73000
 1  4  2  3  1  1  0.73000
 2  3  1  4  1  1  0.73000
 1  4  1  4  1  1  0.73000

```

see ckpotpn.int for the rest of this input

The proton-proton and neutron-neutron matrix elements are just those for $T=1$ in the isospin formalism. **The proton-neutron matrix elements are not in the standard formalism, but must be converted from the isospin $T=0$ and $T=1$ matrix elements as in this example - compare with the ckpot.int matrix elements.**

14 Orbit labels

k	n	l	j	magic numbers	group names
1	0	s	1/2	2	
2	0	p	3/2		
3	0	p	1/2	8	p
4	0	d	5/2	14	
5	0	d	3/2		sd
6	1	s	1/2	20	
7	0	f	7/2	28	
8	0	f	5/2		fp (pf)
9	1	p	3/2		
10	1	p	1/2	40	j4
11	0	g	9/2	50	
12	0	g	7/2		
13	1	d	5/2		
14	1	d	3/2		j5
15	2	s	1/2		
16	0	h	11/2	82	
17	0	h	9/2		
18	1	f	7/2		
19	1	f	5/2		j6
20	2	p	3/2		
21	2	p	1/2		
22	0	i	13/2	126	
23	0	i	11/2		
24	1	g	9/2		
25	1	g	7/2		
26	2	d	5/2		j7
27	2	d	3/2		
28	3	s	1/2		
29	0	j	15/2	184	

15 Sample inputs for Dens

15.1 Ground state densities

To obtain the ground state density for ^{208}Pb with the SKX Skyrme hamiltonian:

```
dens
fn      - change filename for outoput (default=dens.dao)
pb208   filename
az      - to input A and Z values
208,82  the A and Z values
cp      - to setup the potential model (change potential)
sk20    the Skx Skyrme interaction
gd      - do the calculation for the Ground state Density
st      - stop
```

To find all of the potential model available type h after cp. In this list you will see that sk20 corresponds to Skx.

15.2 B(EL) and B(ML) values

(In many cases this will automatically be run to produce a gamma decay scheme.)

To calculate the B(M1) in ^{20}Ne between the first 2^+ state and the second 2^+ state

```
dens
az      - to input A and Z values
20,10   - the A and Z values
mh      - start the calculation for oscillator B value
M1,10   - 10 indicates the how the obd will be read
2.,2.   - J_i, J_f, T_i, T_f (if different from the defaults)
1,2,1,1,16,bw2404_2404 - n_i, n_f, p_i, p_f, A_c, name of OBD file
st      - stop
```

The n_i and the n_f is the state number, -n will loop from 1, to n. When n=-999 the loop if from 1 to all states in the obd file. p_i and p_f are the parities, 1 for + and -1 for -. A_c is the mass of core for the model space (^{16}O in this case).

To calculate the B(E2) in ^{20}Ne between the first 0^+ state (ground state) and the first 2^+ using the default oscillator value of $\hbar\omega = 45A^{-1/3}-25A^{-2/3}$:

```

dens
az
20,10
mh      - start the calculation for oscillator B value
E2,10  - 10 indicates the how the obd will be read
0.,2.  - J_i, J_f, T_i, T_f (if different from the defaults)
1,1,1,1,16,bw2400_2404  - n_i, n_f, p_i, p_f, A_c, name of OBD file
st      - stop

```

To use a b-value of 2.5 fm for the oscillator, do the following just before MH:

```

CP
H0,2.5

```

To use an $\hbar\omega$ -value of 14.0 MeV for the oscillator, do the following just before MH:

```

CP
H0,-14.0

```

To use another potential model such as SKX, do the following:

```

dens
az
20,10
cp
sk20
gd
td
E2,10
0.,2.  - J_i, J_f, T_i, T_f (if different from the defaults)
1,1,1,1,16,bw2400_2404
st

```

To calculate the electron scattering form factor for the ^{20}Ne transition with SKX:

```

DENS
az
20,10
cp
sk20
gd
ff      - start the form-factor calculation
E2,10
0.,2.
1,1,1,1,16,bw2400_2404
st

```

15.3 B(GT) values

(In many cases this will automatically be run.)

To calculate B(GT) values from state J_i to all states with J_f

```
dens
az
20,10,9      - the A, Z_i, Z_f values
gt
M1,10       - 10 indicates the how the obd will be read
2.,2.,0.,1. - J_i, J_f, T_i, T_f (if different from the defaults)
1,-999,1,1,16,bw2404_1404 - n_i, n_f, p_i, p_f, A_c, name of OBD file
st
```

15.4 Nested inputs for Dens, the *.den files

Any of the inputs given in the example above can be made in terms of a *.den file. For example, the ^{20}Ne electron scattering calculation can be done as

```
dens
ne
ne20ff
st
```

where ne20ff refers to another file called ne20ff.den that contains

```
az
20,10
cp
sk20
gd
ff      - start the form-factor calculation
E2,10
0.,2.
1,1,1,1,16,bw2400_2404
RE
```

The *.den file can end with “re” that means return to the main input stream or “st” that ends the calculation. These type of inputs can be nested to any level. They are convenient for defining files that define aspects of the calculation like the potential models and the effective operator parameters.

16 Gamma decay

(In many cases the following will automatically be run.)

Procedure for generating a gamma decay spectrum for nucleus x

1) Run shell with lpe and den(t) to obtain the *.obd files for all transitions

2) Edit the *.den file if needed.

3) Run dens by doing with the following input

```
dens  
ne  
x
```

7) Type

```
gamma x
```

8) Data output is in x.deo.