TROPIC User Guide

1 Introduction

This is a guide on how to use TROPIC to calculate reduced transition probabilities. TROPIC (**TR**ansiti**O**n **P**robab**I**lity **C**alculator) is a program written in Python 3 with NumPy and SciPy. The latest version of each will suffice. The full package is maintained here and consists of the main script, example files, and this guide. The only components needed to run TROPIC are the main Python script and an input file. Details about the input file are discussed in Section 2.

2 Preparing the CSV File

TROPIC reads in all inputs from a comma separated value (CSV) file. Using a spreadsheet program (such as Excel) presents the data in clear format that can be easily edited. The list of required parameters is given in Table 1. An example of the input file displayed in Excel containing some transitions in the ^{172}Yb nucleus is shown in Figure 1 as calculated for Ref. [1].

Table 1: A list of each required parameter in the input file. If a parameter is not needed or unknown, the column should be left blank.

Parameter	Description	Units
A	Mass number	-
E_{lev}	Level energy	keV
τ	Lifetime	fs
$\Delta\tau^+$	Upper error on τ	fs
$\Delta\tau^-$	Lower error on τ	fs
E_γ	Energy of emitted γ ray	keV
ΔE_γ	Error on γ ray energy	keV
I	Intensity of emitted γ ray (or conversion electron)	-
ΔI	Error on γ ray intensity (or conversion electron)	-
α	Internal conversion coefficient	-
$\Delta\alpha$	Error on internal conversion coefficient	-
$\pi\lambda$	Multipolarity	-
δ	Multipole mixing fraction	-
$\Delta\delta^+$	Upper error on δ	-
$\Delta\delta^-$	Lower error on δ	-

When reading the input file, TROPIC skips the first row to allow the option of labeling the columns (as shown in Figure 1). Each row after the first corresponds to a transition to be calculated while each column contains a parameter required for the calculation. All columns after the last column ($\Delta\delta^-$) are also ignored, allowing the user to use that space to record notes, comments, or other information.

The Mass Number (A), level Energy (E_{lev}), and lifetime (τ) only need to be listed once for a given level. If a level has multiple transitions that are of interest, they should be listed in subsequent rows with those columns left blank. If a transition has a mixed multipolarity, it should be inputted as "$\pi\lambda/\pi(\lambda+1)$," with the lower multipolarity listed first (E.g. a M1+E2 mixed transition should

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	A	E_level_(keV)	tau_(fs)	tau_err_up (fs)	tau_err_down (fs)	E_g_(keV)	E_g_err_(keV)	I	I_err	alpha	alpha_err	multipolarity	delta	delta_err_up	delta_err_down	
2	172	78.7427	2380447	72135	72135	78.7426	0.0006	100		8.4		E2				
3	172	260.268	176009	11542	11542	181.528	0.004	100		0.376		E2				
4	172	539.977	23949	2164	2164	279.717	0.005	100		0.092		E2				
5	172	1042.914	4761	1298	1298	964.09	0.05	100				E2				
6								0.173	0.016							E0 transition
7	172	1117.874	5338	577	577	857.636	0.007	100	3			E2				
8						1039.15	0.01	100	3			M1/E2	2.3	0.5	0.3	
9						1117.94	0.03	36	3			E2				
10	172	1405.008	605932	86562	86562	250.035	0.007	6	0.4			E1				
11						287.139	0.003	100	14			E2				
12						1326.1	0.07	88	5			E2				
13								7.2	0.3							E0 transition
14								4.5	0.2							E0 transition
15	172	1476.784	69249	15870	15870	321.82	0.11	0.6	0.16	0.017		E1				
16						1397.92	0.05	100	3			M1/E2	0.8	0.5	0.5	
17								1.22	0.15	0.044						359 keV transition
18								12	2							1216 keV transition
19								36	1							1477 keV transition
20	172	1550.43	5.2E+09	144269504	144269504	174.7	1	100	4	0.079		E1				
21						197.6	0.3	7	1			M1/E2				delta unknown
22						1010.45	0.06	34.8	1.4			E1/M2	-0.38	0.05	0.05	

Figure 1: Example input file for TROPIC for some transitions in the ^{172}Yb nucleus displayed in Excel. All information was taken from [1]. The first row is used to label the columns. Each row after the first corresponds to a transition while each column lists a parameter of that transition. Details of each parameter are listed in Table 1. Columns after the last column (Column O or $\Delta\delta^-$) can be used to record notes as shown in the figure. Parameters that are not needed or unknown have been left blank. If the mixing ratio of a mixed transition is unknown (as noted for the 1550 keV level), each component is assumed to be pure. Transitions that are not of interest only require the inputs of the γ ray intensity, the internal conversion coefficient, and their respective errors. E0 transitions with known conversion electron intensities can also be included for accurate calculation of branching ratios. This is shown for the 1043, 1405, and 1477 keV levels in the figure.

be inputted as "M1/E2"). If a parameter is not needed or unknown for a transition (i.e. δ for pure transitions, an unknown α, or uncertainties), the column should be left blank. If the mixing ratio (δ) of a mixed transition is unknown, each component is assumed to be a pure transition and TROPIC calculates the $B(\pi\lambda)$ value for both.

TROPIC calculates the branching ratios, requiring the user to only provide the intensities and conversion coefficients in the input file. The only requirement for the format of the intensities is that they are accurately scaled with respect to each other. TROPIC also allows the user to obtain calculations for transitions of interest without the full investment of time and effort. After entering all the information on transitions that are of interest in the input file, the user only needs to list the other intensities and conversion coefficients in subsequent rows. If one of the transitions is a pure E0 transition with a known conversion electron intensity (i.e. a E0 transition from a 0^+ state to another 0^+ state), it can be also be included in a separate row by listing the intensity as usual and leaving the conversion coefficient column blank.

3 Execution

Before running, the Python script and the CSV file should be placed in the same directory. The program can be executed via the following command:

```
$ python3 TROPIC.py
```

A series of prompts will follow afterwards. These are in the following order: the input filename, the desired precision of the results, the desired method of error propagation (discussed in detail in Section 4), and the desired units (Weisskopf Units or $e^2b^\lambda/\mu_N^2 b^{\lambda-1}$). Figure 2 shows the prompts that are asked upon running TROPIC.

Once these inputs are provided, TROPIC automatically calculates the probabilities for all transitions of interest in the input file and provides the results in three ways simultaneously. The first way, presents the results in a text file in LaTeX syntax, which is presented as a table when compiled. The second way, gives the results as a CSV file, allowing them to be displayed in clear, readable format

```
Enter csv filename (LEAVE OUT file extension): example
Using the input parameters from: /path/to/directory/example.csv
Output files placed at: /path/to/directory/

Enter number of decimal places to report in results (Enter an integer): 2

Enter threshold for propagating errors by using Min/Max method (e.g. enter 0.1 for 10%, leave blank for standard error propagation): 0.1
Using Min/Max method when uncertainty is above 10.0%

Do you want to see the Weisskopf unit conversion? [Y/N]: y
```

Figure 2: Series of prompts that are asked when TROPIC is run.

with programs like Excel. The third way, displays the results on the terminal. Examples of the three output methods are shown in Table 2, Figure 3, and Figure 4.

Table 2: Results from TROPIC for transitions listed in the input file shown in Figure 1 displayed as a LaTeX table. All information needed for this output was taken from [1]. All B($\pi\lambda$) values are presented in Weisskopf Units.

A	E_{lev} (keV)	τ (fs)	E_γ (keV)	E_f (keV)	Intensity	α	$\pi\ell$	B($\pi\ell$)
172	78.7427	2380447(72135)	78.7426(5)	0.0	100	8.4	E2	$212.05^{+6.63}_{-6.24}$ W.u.
172	260.268	176009(11542)	181.528(4)	78.74	100	0.376	E2	$300.89^{+21.15}_{-18.55}$ W.u.
172	539.977	23949(2164)	279.717(5)	260.26	100	0.092	E2	$320.75^{+31.89}_{-26.61}$ W.u.
172	1042.914	4761(1298)	964.09(5)	78.82	100	0	E2	$3.62^{+1.36}_{-0.78}$ W.u.
172	1117.874	5338(577)	857.636(7)	260.24	100(3)	0	E2	$2.46^{+0.49}_{-0.39}$ W.u.
			1039.149(10)	78.73	100(3)	0	M1/E2	$3.57\text{e-}04^{+1.82e-04}_{-1.43e-04}$ W.u. (M1 component)
			1039.149(10)	78.73	100(3)	0	M1/E2	$0.79^{+0.21}_{-0.16}$ W.u. (E2 component)
			1117.94(3)	-0.07	36(3)	0	E2	$0.24^{+6.18e-02}_{-4.78e-02}$ W.u.
172	1405.008	605932(86562)	250.035(7)	1154.97	6.0(4)	0	E1	$9.71\text{e-}04^{+3.67e-04}_{-2.48e-04}$ mW.u.
			287.139(3)	1117.87	100(14)	0	E2	$5.9^{+2.79}_{-1.85}$ W.u.
			1326.10(7)	78.91	88(5)	0	E2	$2.47\text{e-}03^{+9.04e-04}_{-6.13e-04}$ W.u.
172	1476.784	69249(15870)	321.82(11)	1154.96	0.60(16)	0.017	E1	$5.47\text{e-}04^{+3.92e-04}_{-2.34e-04}$ mW.u.
			1397.92(5)	78.86	100(3)	0	M1/E2	$6.83\text{e-}05^{+7.51e-05}_{-3.68e-05}$ W.u. (M1 component)
			1397.92(5)	78.86	100(3)	0	M1/E2	$1.01\text{e-}02^{+1.26e-02}_{-8.50e-03}$ W.u. (E2 component)
172	1550.43	5193702147(144269504)	174.7(10)	1375.73	100(4)	0.079	E1	$7.61\text{e-}06^{+1.06e-06}_{-9.22e-07}$ mW.u.
			197.6(3)	1352.83	7(1)	0	M1/E2	$3.71\text{e-}08^{+8.76e-09}_{-7.62e-09}$ W.u. (assumed pure M1)
			197.6(3)	1352.83	7(1)	0	M1/E2	$4.29\text{e-}04^{+1.03e-04}_{-8.92e-05}$ W.u. (assumed pure E2)
			1010.45(6)	539.98	34.8(14)	0	E1/M2	$1.20\text{e-}08^{+1.87e-09}_{-1.64e-09}$ mW.u. (E1 component)
			1010.45(6)	539.98	34.8(14)	0	E1/M2	$7.75\text{e-}06^{+2.99e-06}_{-2.36e-06}$ W.u. (M2 component)

4 Error Propagation

TROPIC employs two methods to calculate the uncertainties of the calculated $B(\pi\lambda)$ values. The default method is by standard error propagation of all the known errors associated with the various input quantities. However, it might be the case that some parameters, usually the lifetimes, will have large uncertainties, sometimes greater than 100%. For those cases, it is more reasonable to use upper and lower bound values of each input parameter to obtain the highest and lowest possible $B(\pi\lambda)$ values and then subtract the upper and lower values from the nominal value to determine the uncertainties. TROPIC prompts the user at the beginning to provide a threshold for the errors in the parameters so that a choice is made on the method for error propagation. For example, if "0.1" is input, TROPIC will automatically switch to using the second "minimum/maximum value" method for error propagation for all transitions that contain a parameter with an uncertainty above 10%. If the user still wishes to use standard error propagation for all transitions, they can do so by submitting a blank input when prompted for the threshold.

References

[1] B. Singh. Nuclear Data Sheets for A = 172. *Nuclear Data Sheets*, 75(2):199–376, 1995.

	A	B	C	D	E	F	G	H	I	J	K	L
1	A	E_lev (keV)	tau (fs)	E_gamma (keV)	E_f (keV)	Intensity	ICC	Multipolarity	B(pi*l)	B(pi*l)_err_up	B(pi*l)_err_down	Unit
2	172	78.7427	2380447	78.7426	0	100	8.4	E2	212.05	6.63	6.24	W.u.
3	172	260.268	176009	181.528	78.74	100	0.376	E2	300.89	21.15	18.55	W.u.
4	172	539.977	23949	279.717	260.26	100	0.092	E2	320.75	31.89	26.61	W.u.
5	172	1042.914	4761	964.09	78.82	100	0	E2	3.62	1.36	0.78	W.u.
6	172	1117.874	5338	857.636	260.24	100	0	E2	2.46	0.49	0.39	W.u.
7				1039.149	78.73	100	0	M1/E2	3.57E-04	1.82E-04	1.43E-04	W.u. (M1 component)
8				1039.149	78.73	100	0	M1/E2	0.79	0.21	0.16	W.u. (E2 component)
9				1117.94	-0.07	36	0	E2	0.24	6.18E-02	4.78E-02	W.u.
10	172	1405.008	605932	250.035	1154.97	6	0	E1	9.71E-04	3.67E-04	2.48E-04	mW.u.
11				287.139	1117.87	100	0	E2	5.9	2.79	1.85	W.u.
12				1326.1	78.91	88	0	E2	2.47E-03	9.04E-04	6.13E-04	W.u.
13	172	1476.784	69249	321.82	1154.96	0.6	0.017	E1	5.47E-04	3.92E-04	2.34E-04	mW.u.
14				1397.92	78.86	100	0	M1/E2	6.83E-05	7.51E-05	3.68E-05	W.u. (M1 component)
15				1397.92	78.86	100	0	M1/E2	1.01E-02	1.26E-02	8.50E-03	W.u. (E2 component)
16	172	1550.43	5.2E+09	174.7	1375.73	100	0.079	E1	7.61E-06	1.06E-06	9.22E-07	mW.u.
17				197.6	1352.83	7	0	M1/E2	3.71E-08	8.76E-09	7.62E-09	W.u. (assumed pure M1)
18				197.6	1352.83	7	0	M1/E2	4.29E-04	1.03E-04	8.92E-05	W.u. (assumed pure E2)
19				1010.45	539.98	34.8	0	E1/M2	1.20E-08	1.87E-09	1.64E-09	mW.u. (E1 component)
20				1010.45	539.98	34.8	0	E1/M2	7.75E-06	2.99E-06	2.36E-06	W.u. (M2 component)

Figure 3: Results of calculations from TROPIC for transitions listed in the input file shown in Figure 1 displayed in Excel. All information needed for this output was taken from [1]. All B($\pi\lambda$) values are listed using Weisskopf Units.

```
Calculation Results:
------------------------------------------------------------------------
A: 172 | E_lev (keV): 78.7427 | tau (fs):  2380447.0

Transitions for this level:

E_gamma (keV) | E_f (kev) | Intensity | ICC | Multipolarity | B(pi*l)

78.7426(5) | 0.0 | 100 | 8.4 | E2 | 212.05 +/- (6.63, 6.24) W.u.

------------------------------------------------------------------------
A: 172 | E_lev (keV): 260.268 | tau (fs):  176009.0

Transitions for this level:

E_gamma (keV) | E_f (kev) | Intensity | ICC | Multipolarity | B(pi*l)

181.528(4) | 78.74 | 100 | 0.376 | E2 | 300.89 +/- (21.15, 18.55) W.u.

------------------------------------------------------------------------
A: 172 | E_lev (keV): 539.977 | tau (fs):  23949.0

Transitions for this level:

E_gamma (keV) | E_f (kev) | Intensity | ICC | Multipolarity | B(pi*l)

279.717(5) | 260.26 | 100 | 0.092 | E2 | 320.75 +/- (31.89, 26.61) W.u.

------------------------------------------------------------------------
A: 172 | E_lev (keV): 1042.914 | tau (fs):  4761.0

Transitions for this level:

E_gamma (keV) | E_f (kev) | Intensity | ICC | Multipolarity | B(pi*l)

964.09(5) | 78.82 | 100 | 0 | E2 | 3.62 +/- (1.36, 0.78) W.u.

------------------------------------------------------------------------
A: 172 | E_lev (keV): 1117.874 | tau (fs):  5338.0

Transitions for this level:

E_gamma (keV) | E_f (kev) | Intensity | ICC | Multipolarity | B(pi*l)

857.636(7) | 260.24 | 100(3) | 0 | E2 | 2.46 +/- (0.49, 0.39) W.u.

1039.149(10) | 78.73 | 100(3) | 0 | M1/E2 | 3.57e-04 +/- (1.82e-04, 1.43e-04) W.u. (M1 component)

1039.149(10) | 78.73 | 100(3) | 0 | M1/E2 | 0.79 +/- (0.21, 0.16) W.u. (E2 component)

1117.94(3) | -0.07 | 36(3) | 0 | E2 | 0.24 +/- (6.18e-02, 4.78e-02) W.u.
```

Figure 4: Results of calculations from TROPIC for transitions listed in the input file shown in Figure 1 displayed at the terminal. All information needed for this output was taken from [1]. All B($\pi\lambda$) values are listed using Weisskopf Units.