Analysis of Processes with Excel (*APEx*)

Version 1.01

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An Add-in for Microsoft Excel to accompany

***Elementary Principles of Chemical Processes*, 4th Edition**

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Contents

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Analysis of Processes with Excel *(APEx)*

Release Notes

APEx is an Excel add-in designed to accompany the fourth edition of *Elementary Principles of Chemical Processes,* a textbook for the introductory chemical engineering course on material and energy balances. It enables users to easily perform routine time-consuming tasks that often occur in the text's chapter-end problems—specifically, looking up values of physical properties of elements and compounds at specified temperatures and pressures, inserting the values into balance equations, and solving the equations. While the add-in greatly streamlines calculations, however, it does not eliminate the need for students to understand the principles and methods involved in identifying the required physical properties, deriving the equations, and interpreting the results.

APEx runs in all versions of Excel supporting Visual Basic for Applications. At time of publication, this includes Excel 2010 and 2013 for Microsoft Windows, and Excel 2011 for MacOS. Permission to run macros is required to run APEx, and the Excel add-in Solver must be installed and enabled prior to installation of APEx in order to run the Equation-Solving Wizard.

Acknowledgements

The ***APEx*** author would like to thank University of Kentucky chemical engineering graduates Rachel Brashear Draffen and Kandace Ramey Parker for their efforts in digitizing the data required to implement this add-in, and for implementing early versions of some the algorithms employed in this add-in.

The Equation Solving Wizard uses clsMathParser by Leonardo Volpi under freeware open license. Some code structures were adapted from those in the public domain and from "Professional Excel Development" by Rob Bovey, Dennis Wallentin, Stephen Bullen, and John Green.

APEx Installation Instructions

To use *APEx,* download the file APEx.xlam from the textbook website to your hard drive, flash drive, or network folder. If you are prompted for a location to which to save your download, take note of where it is saved. If you do not specify a location it will normally go to your **Downloads** folder. After downloading, you may move the file to any folder you choose prior to installation.

In Excel 2010/2013 for Windows

1. Click on the **File** tab, click **Options** (Figure 1), and then click the **Add-Ins** category (Figure 2).

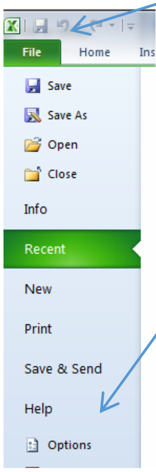


Figure 1

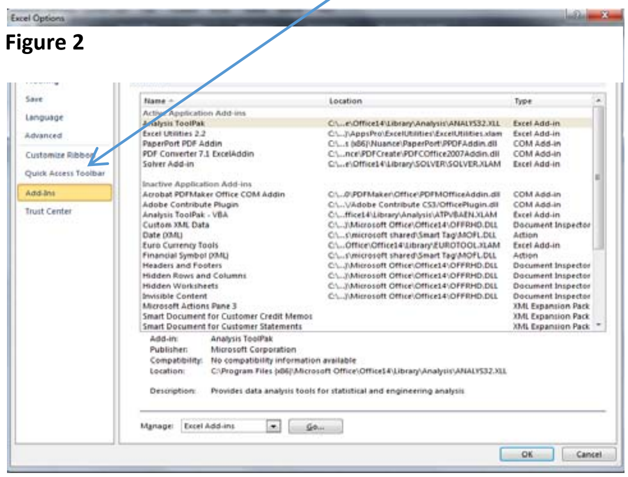


Figure 2

2. In the **Manage** box toward the bottom, select **Excel Add-ins**, and then click **Go**. The Add-Ins dialog box appears (Figure 3).

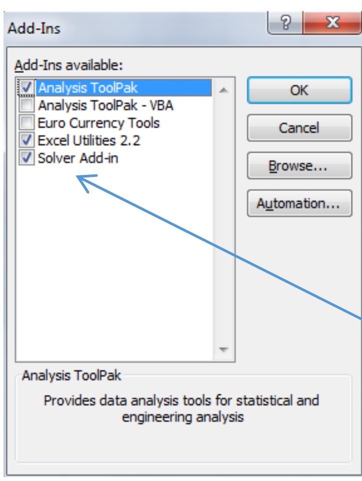


Figure 3

3. In the **Add-Ins available** box, if the check box next to **Solver** is not checked, click the box so that it is checked. Click **OK,** close Excel, start Excel, and restart the process from Step 1 (Figure

3). If the box is already checked, proceed to the next step.

If Solver is not installed prior to installing APEx, you will need to click through an error message (click **OK**) and a password request (click **Cancel**). The Equation Solving Wizard will not function until the Solver Add-in is installed. Always uninstall APEx and restart Excel prior to installing the Solver Add-in.

4. Click **Browse**. Navigate to the location to which you downloaded the add-in and select the **APEx.xlam** file (Figure 4). Click **OK**. The default location is the Downloads folder.

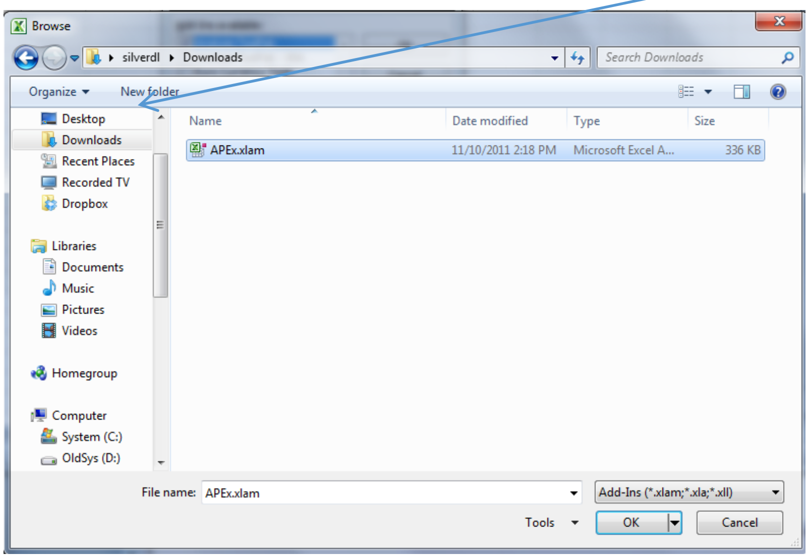


Figure 4

5. If not already selected, select the check box next to **APEx** (Figure 5). Click **OK**. Restart Excel.

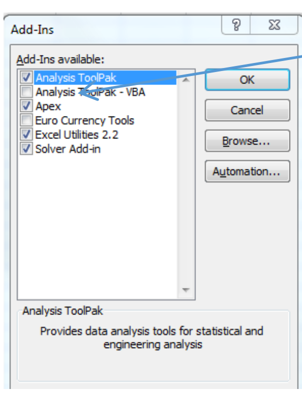


Figure 5

In Excel 2007

1. Click the **Microsoft Office Button** , and then click **Excel Options** (Figure 6).

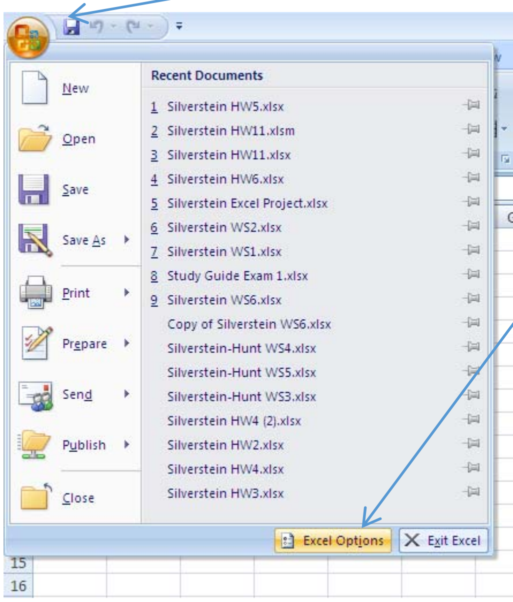


Figure 6

2. Click the **Add-Ins** category (Figure 7).

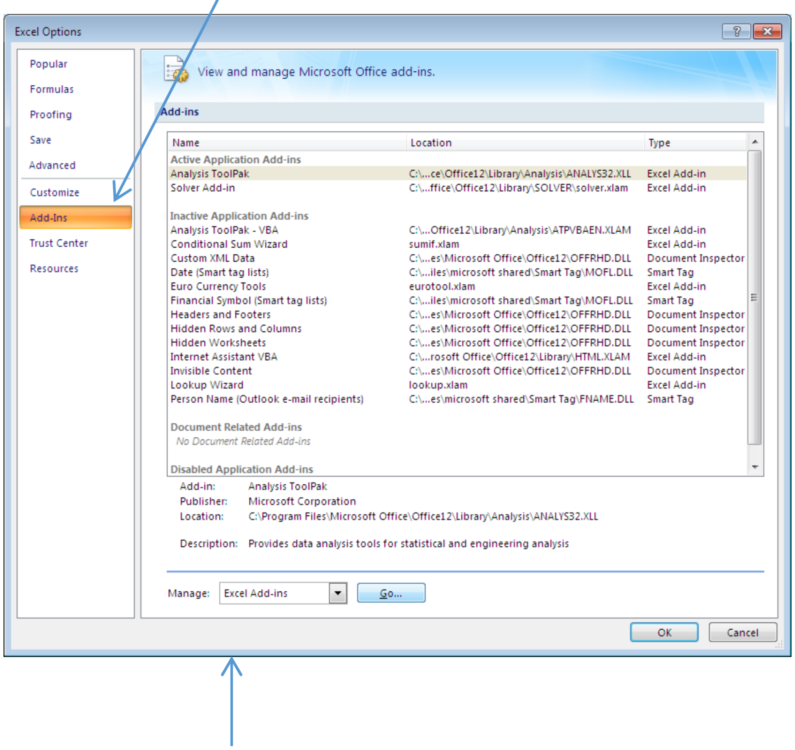


Figure 7

3. In the **Manage** box, **click Excel Add-ins**, and then click **Go** (Figure 7).

4. In the **Add-Ins available** box, if the check box next to **Solver** is not checked, click the box so that it is checked. Click OK and restart the process from Step 1 (Figure 8). If the box is already checked, proceed to the next step.

   If Solver is not installed prior to installing APEx, you will need to click through an error message (click **OK**) and a password request (click **Cancel**). The Equation Solving Wizard will not function until the Solver Add-in is installed. Always uninstall APEx and restart Excel prior to installing the Solver Add-in.

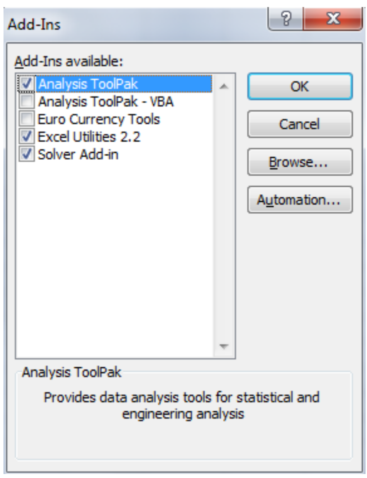


Figure 8

5. Click **Browse**. Navigate to the location to which you downloaded the add-in and select the **APEx.xlam** file. Click **OK**. The default location is the **Downloads** folder (Figure 9).

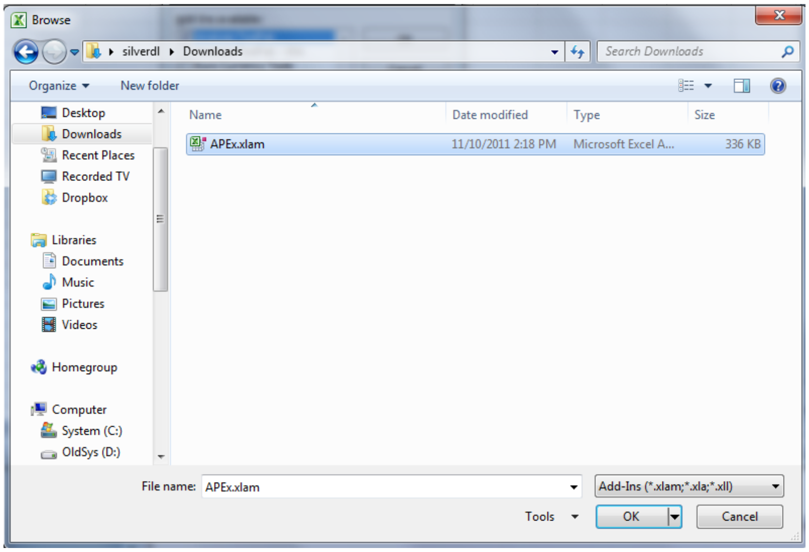


Figure 9

6. If not already selected, select the check box next to **APEx**. Click **OK** (Figure 10).

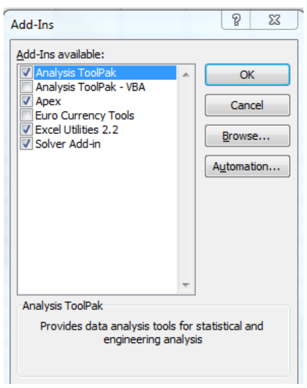


Figure 10

In Excel 2011 for Apple OS X

1. In the menu bar, click **Tools** and select **Add-Ins** (Figure 11). Activate Solver by clicking the checkbox to the right of **Solver.Xlam**, then click OK (Figure 12). Close and restart Excel.

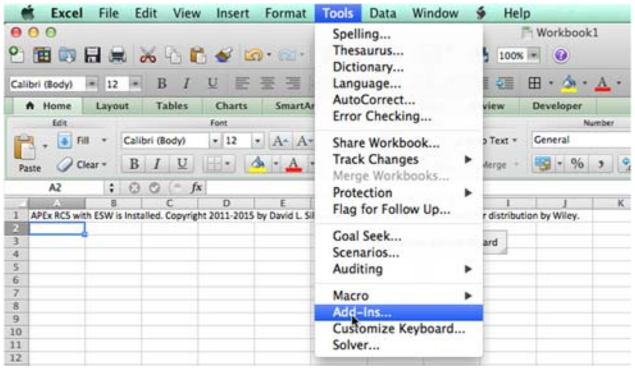


Figure 11

Figure 12

2. When Excel has restarted, click Tools and select Add-Ins again. This time, click **Select** and navigate to the location where you have placed the Add-In. Select the **APEx.xlam** file and click **Open** (Figure 13).

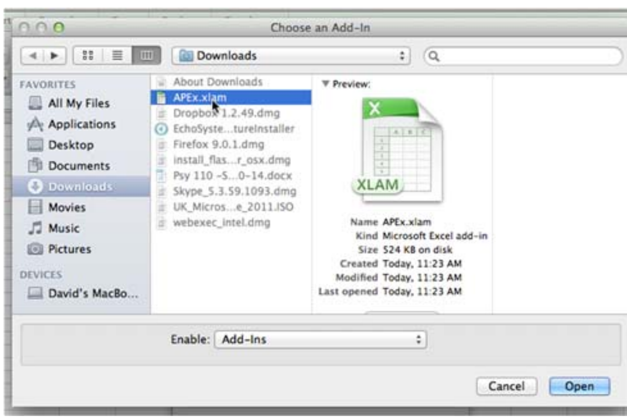


Figure 13

3. Select the **Apex.Xlam** Add-In from the list of Add-Ins Available and click OK. Restart Excel.

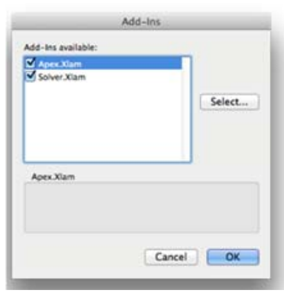


Figure 14

After Installation

The APEx.xlam file must remain accessible from the same location for the add-in to continue to function. If the add-in is moved, repeat the installation process with the new location.

To verify that the add-in is functioning, enter the formula **=AboutAPEx()** into a cell. If no error is returned, the add-in is available.

If you see an error message like the one on the left, click “Enable Macros” to enable the add-in.

Figure 15

Sometimes when opening a workbook using APEx functions you will receive a message like the one below. Click “Update” to continue your work.

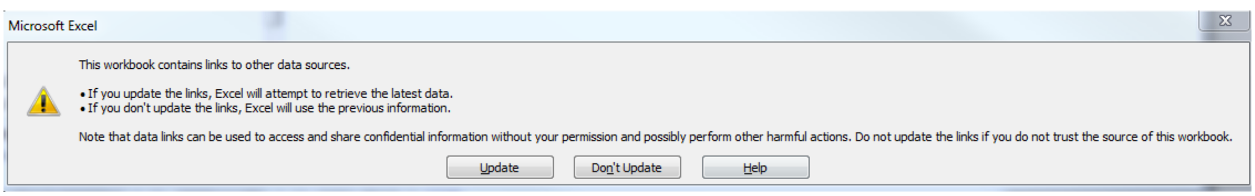


Figure 16

For More information on Excel Add-in Management

The instructions presented here are based on Microsoft documentation at the web pages below. See these pages for more information on managing Excel add-ins.

For Excel 2007:
http://office.microsoft.com/en-us/excel-help/load-or-unload-add-in-programs-HP010096834.aspx

For Excel 2010:
http://office.microsoft.com/en-us/excel-help/add-or-remove-add-ins-HP010342658.aspx

For Excel 2013:
http://office.microsoft.com/en-us/excel-help/add-or-remove-add-ins-HA102749008.aspx

For Excel for Mac 2011:
http://support.microsoft.com/kb/2431349/en-us

Fixes for Common Excel Add-in Issues:

Operation of the Equation Solving Wizard requires the Solver Add-in in Excel. If the POLYMATH ODE Solver add-in is installed and active on the system, Solver may not work as expected. To work around this issue, deactivate the Polymath ODE solver add-in when not in use.

If the add-in is moved, deleted, not available, or if a workbook is opened which was created using a different installation of APEx, error messages like the ones below will result. Selecting **Enable Content** (Figure 17) and **Edit Links…** (Figure 18) will allow you to update the location of the Add-in file.

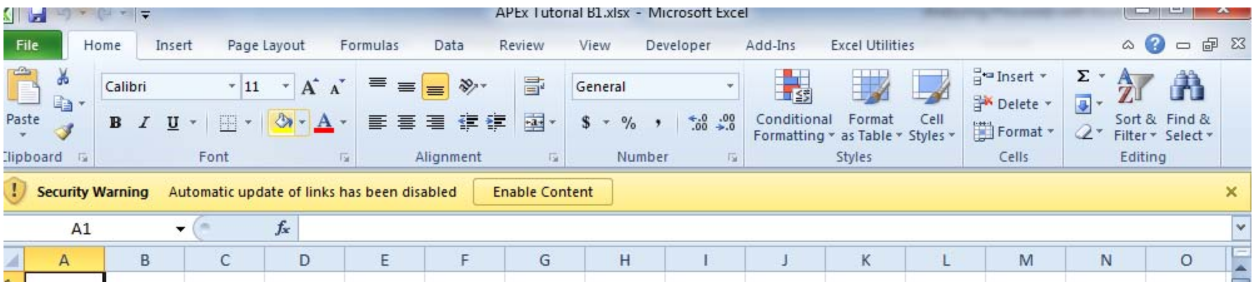


Figure 17

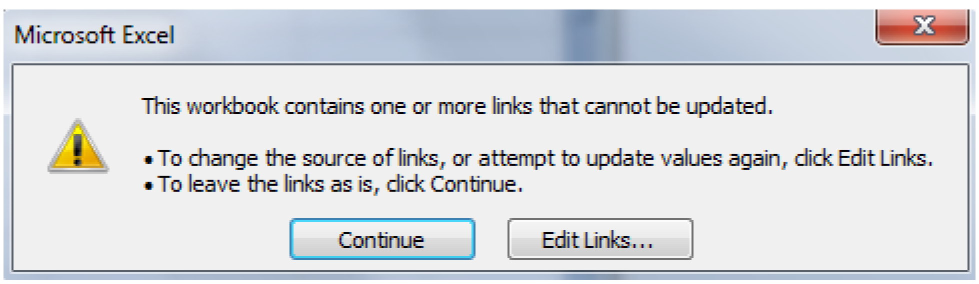
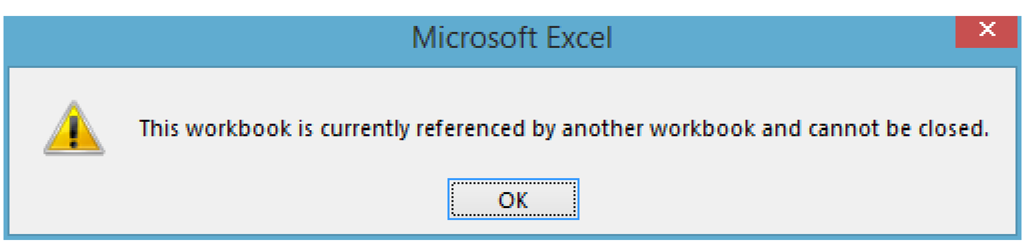


Figure 18

If a workbook using APEx is opened before APEx is correctly installed, results may need to be updated (#VALUE errors returned) after installing APEx. In Windows, CTRL+SHIFT+ALT+F9 will force a recalculation of all open worksheets. On a Mac, fn-F9 will have the same effect on the current worksheet.

When APEx is installed before Solver, ESW will not function until the Solver Add-in is installed. However, due to the order of installation, when Excel is later started, the following error message may be given:



To fix this error, unselect APEx in the Add-ins dialog, then restart Excel. Return to the Add-ins dialog and select APEx (ensuring Solver is still selected).

APEx Known Issues

The font used in ESW in Microsoft Office 2011 for Mac may be small.

Some text boxes in the tutorial workbook may not resize for non-default system font density

APEx Functions Overview

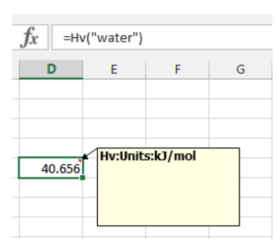
APEx functions exist to retrieve values of physical properties tabulated in the appendices of the textbook, calculate vapor pressures and boiling point temperatures using Antoine's equation, and calculate sensible heats by integrating tabulated heat capacities from one temperature to another. Like all Excel functions, an APEx function is entered into a spreadsheet cell as an equal sign followed by the function name. Neither the name of the function nor the arguments are case-sensitive. APEx ignores spaces in functions. Words that do not refer to Excel functions or cell names that can be translated into values (like names of species and symbols for phases) must be enclosed in quotation marks.

In all ***APEx*** functions, *compound* refers to the name of a chemical species as presented in the text tables. **Only those compounds and properties listed in the text tables are available**. For many compounds, you may also use alternative or common names, CAS number, or molecular formula. In all cases, the user must be aware of alternative interpretations of a species name (i.e. phosphorous could refer to red or white, and xylene could refer to any of 3 isomers). For cases where there is uncertainty regarding the appropriate name, use the name given in the textbook. For all lookup functions, if the compound is not available, the function returns #CNA. If the property of an available compound is not available, the function returns #PNA.

The units of a function are returned as a comment for each function. If multiple functions are called in a single formula, only the last function called will return units.

For example, **HV(*compound*)** is an APEx function that returns the heat of vaporization at 1 atm of a specified compound. If you enter any of the following expressions into a cell of an Excel spreadsheet with APEx installed, the value of the heat of vaporization of water in kJ/mol (40.656) will be returned:

= Hv("Water")
= HV ("water")
= hv("H2O")



A small red triangle will appear in the upper right corner of the cell, indicating the presence of a comment. If you place the mouse pointer over the cell, the function (Hv) and the units of the returned value (kJ/mol) will appear.

Functions are available from the Insert Function dialog within Excel, accessed from the  button adjacent to the formula bar. In Excel 2007 and Excel 2011, the functions are in the "User Defined" category and require the entire function name to be entered or for the function to be selected from the dialog to work. For Excel 2010 and 2013, there is an APEx category at the bottom of the list, and functions will be recognized while they are being entered.

APEx Functions by Textbook Table Reference

Examples appear below the list for each Table.

Table B.1: Property Lookup Functions (See examples below the list)

MW(*compound*) returns the molecular weight.

MWCalc(*elements, counts*) returns the molecular weight of a compound with a known chemical formula. The arguments are a vector of elements in the compound (a set of element symbols enclosed by curly braces { }, with each symbol enclosed in quotation marks and commas separating the symbols), a corresponding vector of atomic counts (how many atoms of each element are in a molecule of the compound). An example for the compound C_2H_6O is given below this list.

SG(*compound*) returns the specific gravity. Reference temperatures are returned as comments.

Tm(*compound*) returns the normal (1 atm) melting point temperature in °C

Hm(*compound*) returns the specific molar enthalpy change (heat) of melting at 1 atm in kJ/mol.

Tb(*compound*) returns the normal (1 atm) boiling point temperature in °C

Decomp(*compound*) returns the decomposition temperature at 1 atm in °C

Sublim(*compound*) returns the sublimation temperature at 1 atm in °C.

Ignite(*compound*) returns the ignition temperature at 1 atm in °C.

Hv(*compound*) returns the specific molar enthalpy change (heat) of vaporization at 1 atm in kJ/mol.

Tcrit(*compound*) returns the critical temperature in K

Pcrit(*compound*) returns the critical pressure in atm

DeltaHfg(*compound*) returns the specific heat of formation at 1 atm of the compound in the gaseous state in kJ/mol

DeltaHfl(*compound*) returns the specific heat of formation at 1 atm of the compound in the liquid state in kJ/mol

DeltaHfaq(*compound*) returns the specific heat of formation at 1 atm of the compound in aqueous solution in kJ/mol

DeltaHfc(*compound*) returns the specific heat of formation at 1 atm of the compound in the crystalline (solid) state in kJ/mol

DeltaHcg(*compound*) returns the specific heat of combustion at 1 atm of the compound in the gaseous state in kJ/mol

DeltaHcl(*compound*) returns the specific heat of combustion at 1 atm of the compound in the liquid state in kJ/mol

DeltaHcc(*compound*) returns the specific heat of combustion at 1 atm of the compound in the crystalline (solid) state in kJ/mol

DeltaHcs(*compound*) returns the specific heat of combustion at 1 atm of the compound in the solid state in kJ/mol

Examples

Function call	Value returned
=MW("Acetone")	58.08
=mwcalc({"C","H","O"},{2,6,1})	46.06952
=SG("acetone")	0.791

If you place the mouse pointer over the cell containing 0.791, a comment will appear indicating that the specific gravity is for the compound at 20°C relative to water at 4°C.

Table B.2: Calculation of specific heat

Enthalpy(*compound, T1, T2, [temperature units],[state]*) returns the integral of the constant pressure heat capacity correlations in Table B.2 for a temperature change from T1 to T2. The returned value is in kJ/mol.

If a temperature unit ("K", "R", "F") is not specified, °C is assumed. If state ("l", "g", "c" or "s") is not specified, the first entry in Table B.2 is used. If the heat capacity correlation for a compound is only given for one state in Table B.2, the [state] argument may be omitted. If that argument is included and you wish to omit the [temperature units] argument (defaulting to °C), you must insert two commas where that argument goes. (See example below.)

Function call	Value returned
=Enthalpy("ethanol",150, 250,,"g")	8.937605

If either T1 or T2 is outside of the range of validity of the correlation, a comment is placed in the cell indicating "Out of Range." If multiple coefficient sets are available for a given species and state, coefficients for the narrowest range containing T1 and T2 are used.

Table B.3: Vapor pressure of water

VPWater(*temperature,[temperature units]*) returns the vapor pressure of water in mm Hg for a given temperature.

If a temperature unit ("K", "R", "F") is not specified, °C is assumed. For values not explicitly included on the table, the function will linearly interpolate using table entries on the appropriate row. If a temperature beyond the limits of the table (<-14.9 °C or >101.9 °C) is entered, a #RANGE error is returned.

Function call	Value returned
=VPWater(50)	92.51

Table B.4: Antoine equation calculations of vapor pressures and boiling points

AntoineP(*compound, temperature, [temperature units]*) returns the vapor pressure in mm Hg at a given temperature.

If temperature units are not specified ("K", "R", "F"), °C is assumed. If the given temperature is outside of the correlation range, a comment "Out of Range" is placed in the calling cell. If multiple correlations are available, the one with the narrowest range including the desired temperature is used.

AntoineT(*compound, pressure*) returns the boiling point temperature in °C for a given pressure in mm Hg. (The returned value is also the temperature at which the compound has the specified vapor pressure,)

Function call	Value returned
=AntoineP("decane", 100)	71.72963
=AntoineT("decane",71.72963)	100

Tables B.5-B.7: Steam Tables

SteamSatT(*value*, *typegiven*, *typetoreturn*, *[phase]*) For the given value of the variable “typegiven”, returns the value of the variable “typetoreturn” from the saturated steam temperature table. Valid entries for parameters 2 and 3 are “T”, “P”, “V”, “U”, and “H”. Phase must be specified when returning V, U, and H. Valid phases are “L”, “E” (for evaporation), and “V”.

SteamSatP(*value,typegiven, typetoreturn, [phase], [root]*) For given value of the variable “typegiven”, returns the value of the variable “typetoreturn” from the saturated steam pressure table. Valid entries for Parameters 2 and 3 are “T”, “P”, “V”, “U”, and “H”. Phase must be specified when returning V, U, and H. Valid phases are “L”, “E”, and “V”. For some “typegiven” quantities (U and H for vapor), multiple solutions are possible. The last optional parameter “root” can be specified as requesting the lower pressure root (“L”) or the upper pressure root (“U”). The default is “L” if this parameter is omitted.

SteamSH(*value1, value2, typegiven1, typegiven2, typetoreturn, [phase]*) For the “value1” of variable “typegiven1” and “value2” of variable “typegiven2”, returns the value of variable “typetoreturn”. Valid entries for value1 are “T” and “P”; variables “typegiven2” and “typetoreturn” may be “T”, “P”, “V”, “U”, or “H”. Phase is assumed vapor (“V”) unless otherwise specified as “L”. (Notice that “V” may stand for volume or vapor, depending on where it occurs in the argument list.)

Function call	Value returned
=SteamSatT(56,"T","P")	0.1651
=SteamSatT(56,"T","H","L")	234.4
=SteamSatP(0.1651,"P","T")	55.963
=SteamSH(150,1.5,"T","P","V")	1.6975

Table B.10: Estimating heat capacities using Kopp's rule

Kopps(*elements*, *number_atoms*, [*phase*]) Returns an estimate of the constant pressure heat capacity in J/(mol-°C) of a compound with a known chemical formula using Kopp's rule. The arguments are a vector of elements in the compound (a set of element symbols enclosed by curly braces { }, with each symbol enclosed in quotation marks and commas separating the symbols), and a corresponding vector of atomic counts (how many atoms of each element are in a molecule of the compound). If phase is not specified ("s", "l"), a liquid is assumed. An example for the liquid compound $C_6H_{14}O$ is given below.

Function call	Value returned
=Kopps({"C","H","O"},{6,14,1})	349

Table B.11: Integral heats of solution

HsHCl(*r*) Returns the integral heat of solution at 25°C in kJ/mol for HCl(g) at a given value of *r*(mol H_2O/mol HCl). If the value of *r* requires extrapolation in Table B.11, a comment to that effect is added to the cell. The heat of solution at infinite dilution is returned by entering *r* as "inf".

HsNaOH(*r*) Returns the integral heat of solution at 25°C in kJ/mol for NaOH(s) at a given value of *r*(mol H_2O/mol NaOH). If the value of *r* requires extrapolation in Table B.11, a comment to that effect is added to the cell. The heat of solution at infinite dilution is returned by entering *r* as "inf".

HmH2SO4(*r*) Returns the integral heat of mixing at 25°C in kJ/mol for H_2SO_4(l) at a given value of *r*(mol H_2O/mol H_2SO_4). If the value of *r* requires extrapolation in Table B.11, a comment to that effect is added to the cell. The heat of mixing at infinite dilution is returned by entering *r* as "inf".

Function call	Value returned
=HsHCl(500)	-74.52
=HsNaOH("inf")	-42.89
=HmH2SO4(0.7)	-20.666

Linear Regression and Interpolation

Slope1(*y_values, x_values*) Fit a straight line through the origin ($y = ax$) to a set of data for y vs. x by the method of least squares (linear regression). The arguments are a vector of y values (a set of numbers separated by commas and enclosed by curly braces { }) and a vector of the corresponding x values. Returns the value of the slope (a).

Slope(*y_values, x_values*), **Intercept**(*y_values, x_values*) Fit a straight line ($y = ax + b$) to a set of data for y vs. x by the method of least squares (linear regression). The arguments are a vector of y values (a set of numbers separated by commas and enclosed by curly braces { }) and a vector of the corresponding x values. **Slope** returns the value of the slope (a), and **Intercept** returns the value of the intercept (b). **Slope** and **Intercept** are Excel functions, not parts of APEx.

Linterp(*x_values, y_values, xgiven*) Returns a "*y*" value at a given "*x*" value (the third argument of the function) determined by linear interpolation between tabulated values of x and corresponding values of y. The first and second arguments are a vector of x values (a set of numbers separated by commas and enclosed by curly braces { }) and a vector of the corresponding y values. If the given value of x is outside the range of tabulated values, a comment to that effect is placed in the cell. Note the order of input arguments is different than in the regression functions.

Function call	Value returned
= slope1({0.5, 6.5, 12.5}, {0, 1, 2})	6.3
= slope({0.5, 6.5, 12.5}, {0, 1, 2})	6.0
= intercept({0.5, 6.5, 12.5}, {0, 1, 2})	0.5
= linterp({0, 1, 2}, {0.5, 6.5, 12.5}, 1.5)	9.5

APEx Alphabetical List of Available Functions

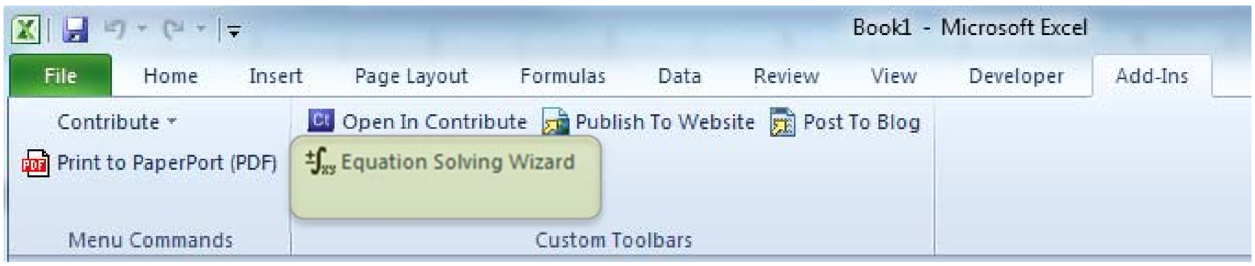
APEx Function	Textbook Table Reference
AntoineP(*compound, temperature, [temperature units]*)	Table B.4: Antoine equation calculations of vapor pressures and boiling points
AntoineT(*compound, pressure*)	Table B.4: Antoine equation calculations of vapor pressures and boiling points
Decomp(*compound*)	Table B.1: Property lookup functions
DeltaHcc(*compound*)	Table B.1: Property lookup functions
DeltaHcg(*compound*)	Table B.1: Property lookup functions
DeltaHcl(*compound*)	Table B.1: Property lookup functions
DeltaHcs(*compound*)	Table B.1: Property lookup functions
DeltaHfaq(*compound*)	Table B.1: Property lookup functions
DeltaHfc(*compound*)	Table B.1: Property lookup functions
DeltaHfg(*compound*)	Table B.1: Property lookup functions
DeltaHfl(*compound*)	Table B.1: Property lookup functions
Enthalpy(*compound, T1, T2, [temperature units],[state]*)	Table B.2: Calculation of specific heat
Hm(*compound*)	Table B.1: Property lookup functions
HmH2SO4(*r*)	Table B.11: Integral heats of solution
HsHCl(*r*)	Table B.11: Integral heats of solution
HsNaOH(*r*)	Table B.11: Integral heats of solution
Hv(*compound*)	Table B.1: Property lookup functions
Ignite(*compound*)	Table B.1: Property lookup functions
Kopps(*elements*, *number_atoms*, [*phase*])	Table B.10: Estimating heat capacities using Kopp's rule
Linterp(*x_values, y_values, x*)	Linear Regression and Interpolation
MW(*compound*)	Table B.1: Property lookup functions
MWCalc(*elements, counts*)	Table B.1: Property lookup functions
Pcrit(*compound*)	Table B.1: Property lookup functions
SG(*compound*)	Table B.1: Property lookup functions
Slope1(*y_values, x_values*)	Linear Regression and Interpolation
SteamSatP(*value*,*typegiven*, *typetoreturn*, [*phase*], [*root*])	Tables B.5-B.7: Steam Tables
SteamSatT(*value*,*typegiven*, *typetoreturn*, [*phase]*)	Tables B.5-B.7: Steam Tables
SteamSH(*value1*, *value2*, *typegiven1*, *typegiven2*, *typetoreturn*, [*phase*])	Tables B.5-B.7: Steam Tables
Sublim(*compound*)	Table B.1: Property lookup functions

Tb(*compound*)	Table B.1: Property lookup functions
Tcrit(*compound*)	Table B.1: Property lookup functions
Tm(*compound*)	Table B.1: Property lookup functions
VPWater(*temperature,[temperature units]*)	Table B.3: Vapor pressure of water

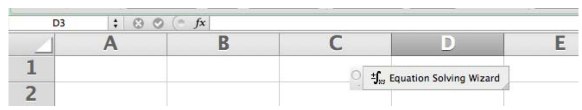
APEx Equation Solving Wizard

When ***APEx*** is properly installed, a new button will appear enable access to the Equation Solving Wizard (**ESW**), a way of automating the setup of the solution of a system of algebraic equations by use of the method of least squares and Excel's Solver.

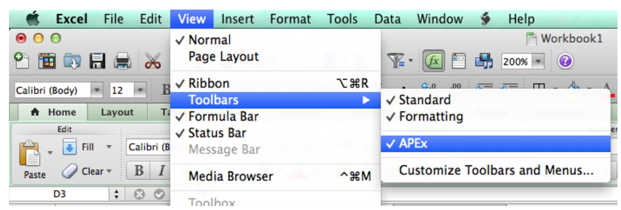
In Windows, the button will appear in the Add-ins tab of the Excel Ribbon as illustrated below.



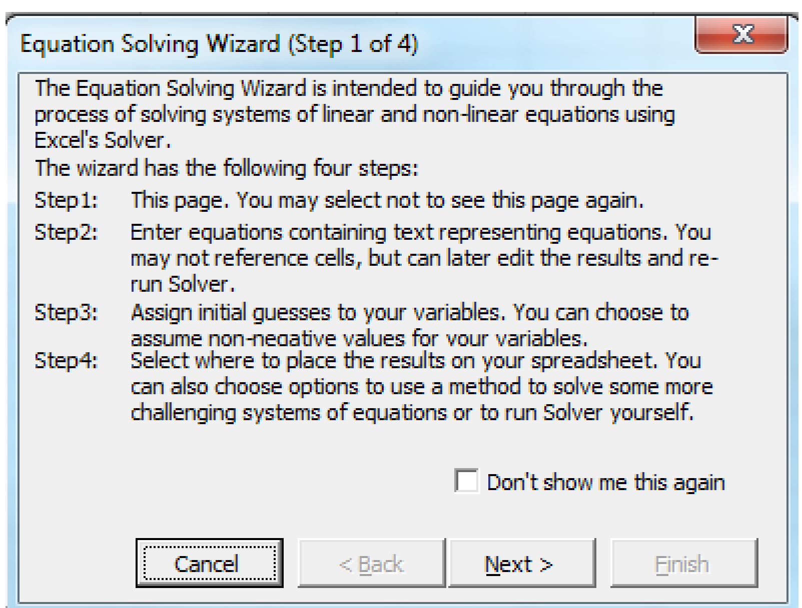
On a Mac, the button appears as a floating toolbar as shown at right. The toolbar may be relocated by clicking and dragging on the tab to the left of the button.



If the toolbar on a Mac is closed, it can be accessed by using the menu bar and clicking **View** followed by **Toolbars**, then selecting **APEx** as shown.



On either platform, clicking on the Equation Solving Wizard button brings up the dialog box shown explaining the operation of the Wizard. You may select the checkbox left of "Don't show me this again" to suppress this explanation when starting the **ESW** on the same computer.



The steps in the process are:

1. Enter your equations as text on the worksheet, then copy and paste into ESW
2. Specify initial values for your variables
3. Specify where the solution should be placed on your worksheet and options to enhance the solution process
4. Run Solver
5. Check the solution for convergence

Step 1. Entering equations.

Type or paste from the clipboard text containing the algebraic equations you wish to solve. You must be explicit with your arithmetic operations (i.e. 3(x+1) should be entered as 3*(x+1), and 3x as 3*x). Excel and ***APEx*** functions may be included.

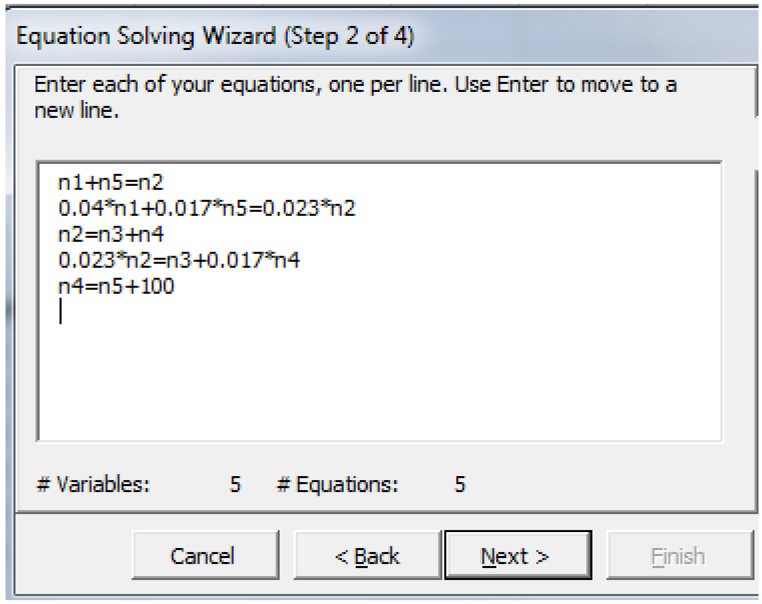
Each equation should be on a separate line. Use the enter key to create a new line. Variables must start with a letter and should only contain letters and numbers. If necessary, rewrite your equations to avoid possible division by zero during the solution search process.

For example, to complete Example 4.5-1 in the text, you have the following equations to solve:

$n_1 + n_5 = n_2$
$0.04n_1 + 0.017n_5 = 0.023n_2$
$n_2 = n_3 + n_4$
$0.023n_2 = n_3 + 0.017*n_4$
$n_4 = n_5 + 100$

To enter these into the **ESW**, you would recast these equations in a form without formatting and without implicit multiplication. The result would look like this:

n1 + n5 = n2
0.04*n1 + 0.017*n5 = 0.023*n2
n2 = n3 + n4
0.023*n2 = n3 + 0.017*n4
n4 = n5 + 100



Type these lines on the spreadsheet (one equation per cell) and copy and paste them into the **ESW** as shown.

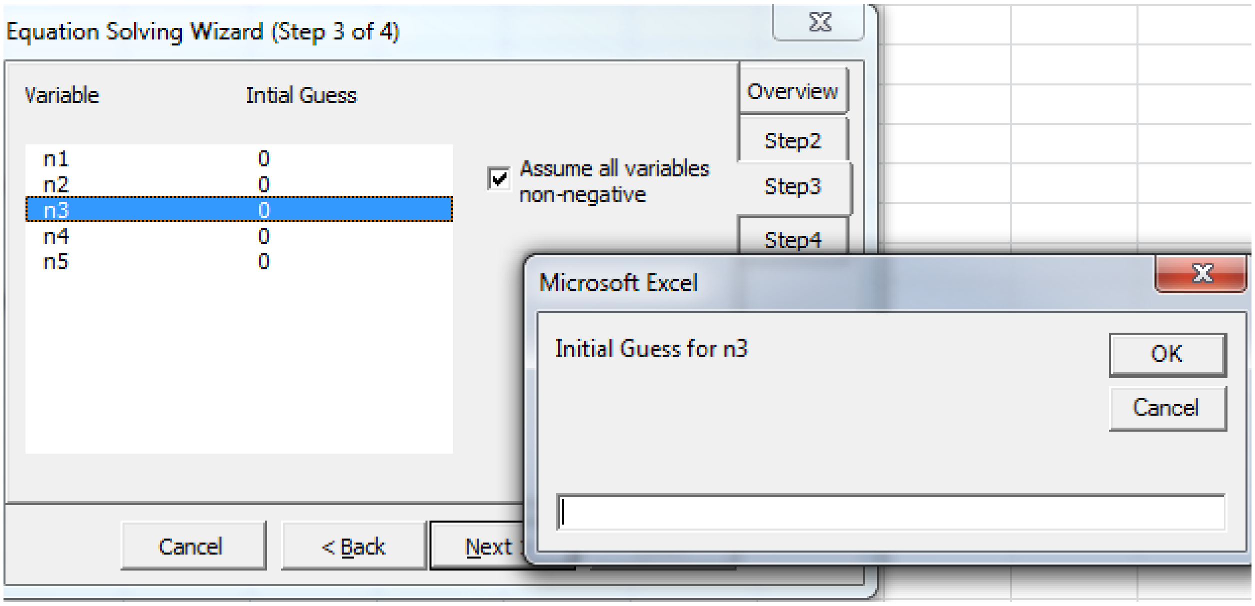
The ***APEx* ESW** maintains a count of variables and equations while you are entering your equations. If the degrees of freedom for the system are not satisfied, the **ESW** will not allow you to move to the next step.

Step 2. Initial values for variables

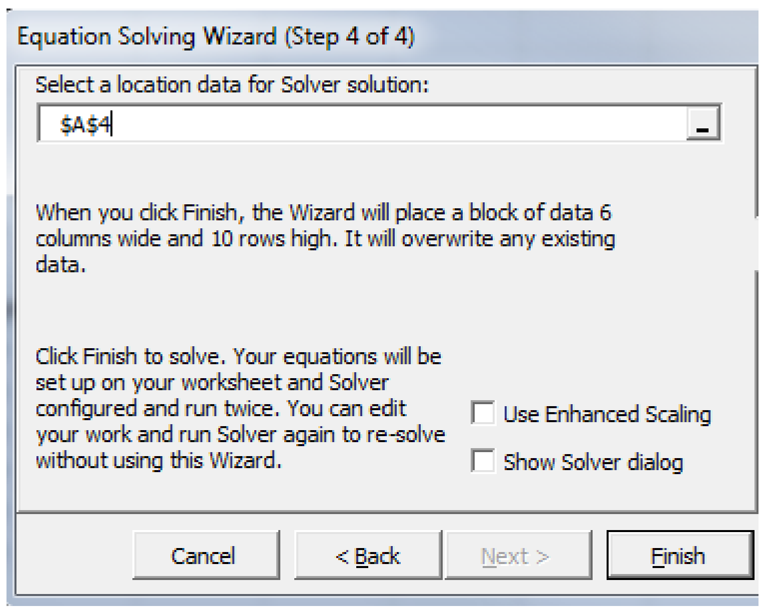
Click **Next** to review the variable list. By default, all variables are initialized with a guess of 0. To change the initial guess for a variable, click the appropriate line and enter the new value in the dialog box as shown below. It is important that values of variables be selected such that the arguments of logarithms are positive and no division by zero will occur in the initial evaluation of your equations.

You may also select the checkbox indicating that all variables may be assumed non-negative when optimizing the solution. This is appropriate when all variables are flow rates and compositions, for example. If any variable may be negative, you should not check this button. Additional constraints to the solution (such as that some of the variables must be non-negative) may be added after using the **ESW** by invoking the Solver dialog.

For our example, accept the default guesses of 0 as shown below, and select **Assume all variables non-negative** since these flow rates must all be positive values.



Step 3. Place the solution on the spreadsheet and select options

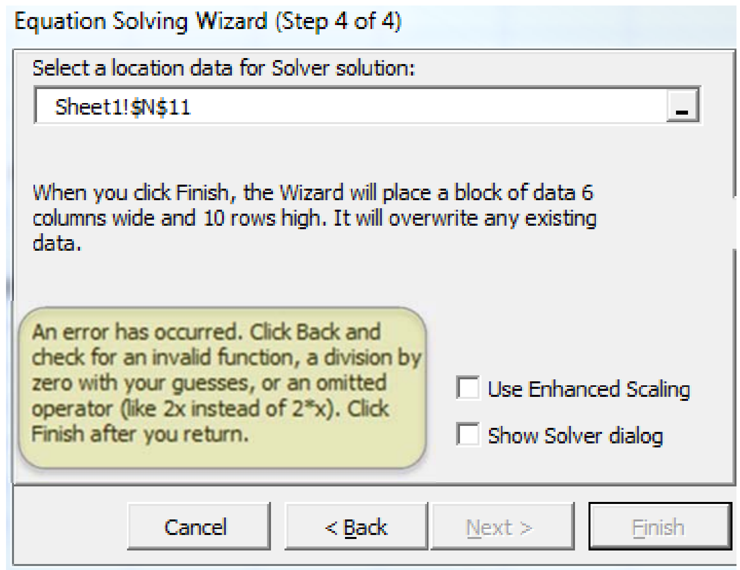


Once the equations and initial variable values have been specified, click **Next** to specify the region of the spreadsheet on which to place the equations and solutions. You need only specify the upper left cell of the region. You may type the cell address (e.g., C17) in the space provided, or click on the button at the right of the space to select the cell from your workbook. The dialog box contains information on the space required for your output, so take care to select a location such that the ESW output does not overwrite anything important.

You may also select from two other options which may help if you have trouble solving a particular system of equations. The first, "Use Enhanced Scaling", examines the equations with your initial guesses and identifies any equations whose values differ from the others by more than three orders of magnitude, then multiplies both sides of the largest equation by a factor to bring it in line with the order of magnitude of the rest of the equations. This can occur in problems involving both material and energy balances or in problems involving phase equilibrium. First try solving your equations without this option, and if the solution does not converge and you see equations with left-hand side or right-hand side values orders of magnitude different from those for other equations, try this scaling feature.

The second option is to bring up the Solver dialog so that you can add constraints and change various Solver parameters before starting the search for the solution, See an Excel textbook for more information on using Solver.

Step 4. Run Solver



Click Finish to instruct ESW to implement the equation solution setup on the spreadsheet and to run Solver. If any errors are encountered, a message like the one in the figure to the right will appear on the **ESW** box advising you to go back and adjust your input. Common causes of this error include an invalid specified location for the solution, invalid equations, implicit multiplication ('3x' instead of '3*x'), invalid mathematical expressions or function names, divisions by zero, or attempts to calculate logarithms of non-positive values.

After Solver completes its search for the solution, the region of the spreadsheet designated for the output will look like the figure below.

Variable	n1	n2	n3	n4	n5
Value	102.3958	392.5174	2.395833	390.1215	290.1215
Equation	**LHS**	**RHS**	**(LHS-RHS)^2**		
n1+n5=n2	392.5174	392.5174	8.89E-19		
0.04*n1+0.017*n5=0.023*n2	9.027899	9.027899	4.52E-16		
n2=n3+n4	392.5174	392.5174	1.03E-18		
0.023*n2=n3+0.017*n4	9.027899	9.027899	1.38E-19		
n4=n5+100	390.1215	390.1215	2E-18		
		SUM	4.56E-16		

Here are the elements of the output:

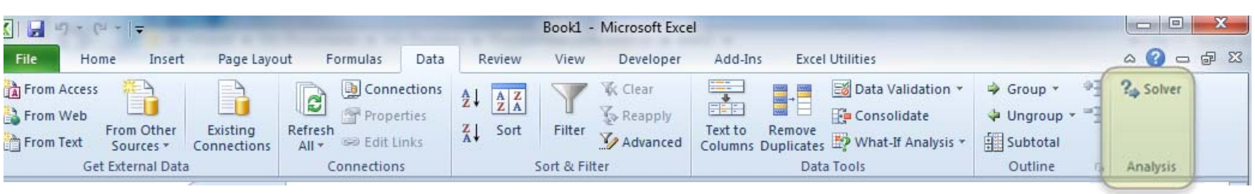
- The row labeled **Variable** contains the names of the system variables as you entered them in your equations, and the **Value** row contains the values returned by Solver. Those values would constitute the final solution of the equations if the solution process converged.
- Under the **Equation** label are the equations as you entered them in **ESW**. The **LHS** and **RHS** columns contain Excel formulas for the left-hand and right-hand sides of the equations, with the variables replaced by the corresponding cell addresses in the **Values** row. When variable values change, the **LHS** and **RHS** values change correspondingly.
- The **(LHS-RHS)^2** column contains the squares of the values of (LHS–RHS) for each equation, and the sum of those values appears in the cell to the right of the **SUM** label. The closer **SUM** is to zero, the more likely the variable values are is to be the correct solution of the equations.

Solver uses a sophisticated non-linear optimization algorithm to search for the variable values that minimize **SUM.** The closer **SUM** is to zero, the more likely it is that Solver converged to the correct solution of your equations. In the case of the previous figure, **SUM** is 4.56×10^{-16}, which for all practical purposes equals zero. You would stop at that point, and copy your solutions from the **Values** row.

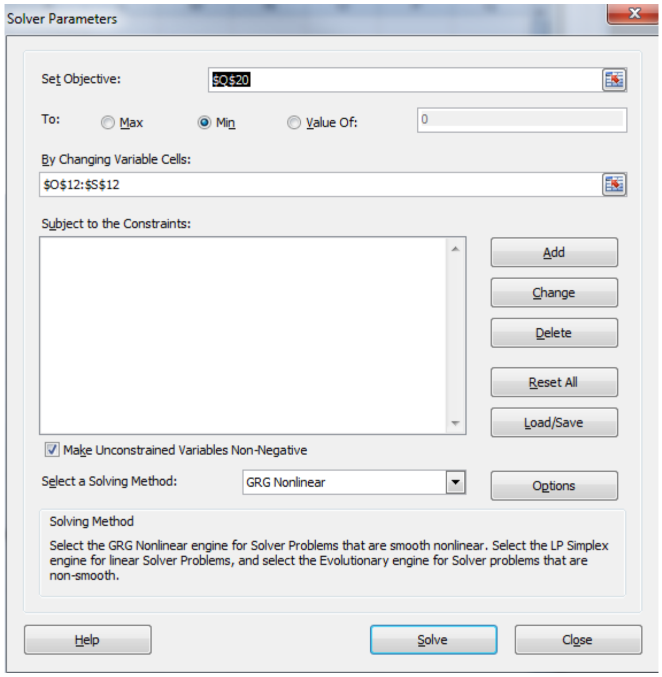
Step 5. Check the solution, and if the value of SUM **is not extremely small, initiate another Solver search**

If you run **ESW** or Solver and the returned value of **SUM** is not close to zero (say, if it is greater than 10^{-6}), first double-check your equations on the spreadsheet to make sure they have all been entered (and translated by ESW) correctly. Sometimes you will make a syntax error that Solver catches, and it will give you an error message and maybe a hint about what the error is. At other times you may enter an equation that is legal but wrong, like typing a times symbol (*) when you meant to add (+). Solver will run, but the solution it generates could be nonsense.

You can try different initial guesses (by changing the variable values on the spreadsheet), modify your equations to take advantage of ***APEx*** functions (by editing the LHS and RHS formulas), or correct any errors you might have made. When you bring up Solver (from the **Data** tab, **Analysis** section in the ribbon in Windows or Mac, also on under the Tools menu on Mac), all of the **ESW** settings will still be there so you can click **Solve** to try a solution with your new data.



A typical Solver configuration screen in Excel is shown below. More information on using Solver can be found in any Excel textbook written for engineering students.



Troubleshooting Solver and ESW

(a) See if your equations are poorly scaled. **If they are, use the Enhanced Scaling option in ESW. If that doesn't work, move on to** (b)**.**

Examine the values of **(LHS–RHS)**^{2} to see if one or more are much greater (by a factor of 10^3 or more) than the others. If they are, re-run ESW using the Enhanced Scaling option if you didn't use that option the first time. This option will multiply the LHS and RHS formulas by the same constant to bring the order of magnitudes of all of the equations closer. This helps Solver make changes to the variables that move the solution closer to one that satisfied all of the equations.

(b) See if your equations are all linear. If they are, follow the instructions below. If they're not, move on to (c).

A set of *n* linear equations (which have the form $ax_1 + bx_2 + cx_3 + \ldots = K$) in *n* unknowns $(x_1, x_2, \ldots, x_n)$ has a unique solution. In many of the problems at the end of the textbook chapters, your equations will all be linear, and ESW-Solver should converge to that solution with a value of **SUM** close to zero the first time you enter the equations correctly and run the program. If you don't get that result, examine your equations closely, correct any errors, and then bring up the Solver dialog window again and click Solve as described above.

If you still haven't converged, get help—you've almost certainly done something wrong. If your equations are not all linear, move on.

(c) Try try again—with different guesses for your variables.

Sets of equations that are not all linear are much more complex. They may have one solution (like linear equations), multiple solutions (like one quadratic equation in one unknown, which has two solutions), or no solutions (like sin $x = 2$). If you are trying to solve a text problem involving at least one nonlinear equation and **SUM** is not close to zero the first time you run Solver (say, if it is greater than 10^{-6}), rerun Solver starting with the variable values returned in the previous run. If that doesn't work, find ways of approximating the values of the unknown variables instead of just assuming they're zero, make the approximate values your initial guesses, and run Solver again. If that doesn't work, get help.

Other ESW hints:

When using ESW in Excel for Mac, “ghost” windows sometimes appear when switching from ESW to Solver causing Excel to appear to freeze. Pressing the “ESC” key can clear those “ghosts”.

ESW is a tool to help you set up solutions for systems of non-linear equations in Excel—eventually, you’ll find it quicker to skip the ESW step and just develop solution spreadsheets directly!