

POLYMATH

VERSION 4.02

USER-FRIENDLY NUMERICAL ANALYSIS PROGRAMS

- SIMULTANEOUS DIFFERENTIAL EQUATIONS
- SIMULTANEOUS ALGEBRAIC EQUATIONS
- SIMULTANEOUS LINEAR EQUATIONS
- POLYNOMIAL, MULTIPLE LINEAR AND
NONLINEAR REGRESSION

for IBM and Compatible Personal Computers

THIS MANUAL AND SOFTWARE ARE TO ACCOMPANY
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POLYMATH Internet Site
<http://www.polymath-software.com>

Users are encouraged to obtain the latest general information on POLYMATH and its use from the above Internet site. This will include updates on this version and availability of future versions.

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HARDWARE REQUIREMENTS

POLYMATH runs on the IBM Personal Computer and most compatibles. A floating-point processor is required. Most graphics boards are automatically supported. The minimum desirable application memory is 450 Kb plus extended memory for large applications. POLYMATH works with PC and MS DOS 3.0 and above. It can also execute as a DOS application under Windows 3.1, Windows 95, and Windows NT. It is important to give POLYMATH as much of the basic 640 Kb memory as possible and up to 1024 Kb of extended memory during installation. A variety of drivers are provided for most printers and plotters. Additionally some standard graphics file formats are supported.

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INTRODUCTION

POLYMATH OVERVIEW

POLYMATH is an effective yet easy to use computational system which has been specifically created for professional or educational use. The various programs in the POLYMATH series allow the user to apply effective numerical analysis techniques during interactive problem solving on a personal computer. Whether you are student, engineer, mathematician, scientist, or anyone with a need to solve problems, you will appreciate the ease in which POLYMATH allows you to obtain solutions. Chances are very good that you will seldom need to refer to this manual beyond an initial reading because POLYMATH is so easy to use.

With POLYMATH, you are able to focus your attention on the problem at hand rather than spending your valuable time in learning how to use or reuse the program. You are encouraged to become familiar with the mathematical concepts being utilized in POLYMATH. These are discussed in most textbooks concerned with numerical analysis.

The available programs in POLYMATH include:

- ***SIMULTANEOUS DIFFERENTIAL EQUATION SOLVER***
- ***SIMULTANEOUS ALGEBRAIC EQUATION SOLVER***
- ***SIMULTANEOUS LINEAR EQUATION SOLVER***
- ***POLYNOMIAL, MULTIPLE LINEAR AND NONLINEAR REGRESSION***

Whether you are a novice computer user or one with considerable computer experience, you will be able to make full use of the programs in POLYMATH which allow numerical problems to be solved conveniently and interactively.

If you have limited computer experience, it will be helpful for you to read through this manual and try many of the QUICK TOUR problems. If you have considerable personal computer experience, you may only need to read the chapters at the back of this manual on the individual programs and try some of the QUICK TOUR problems.

This manual will be a convenient reference guide when using POLYMATH.

MANUAL OVERVIEW

This manual first provides general information on features which are common to all of the POLYMATH programs. Particular details of individual programs are then presented. Major chapter topics are outlined below:

INTRODUCTION

The introduction gives an overview of the POLYMATH computational system and gives general instructions for procedures to follow when using individual POLYMATH programs.

GETTING STARTED

This chapter prepares you for executing POLYMATH the first time, with information about turning on the computer, loading POLYMATH, and making choices from the various menu and option screens.

HELP

On-line access to a general help section is discussed.

UTILITIES

This chapter discusses features that all programs have available. These include a scientific calculator and a convenient conversion for units and dimensions. This chapter discusses saving individual problems, data and/or result files on a floppy or hard disk. It also describes the use of the problem library for storing, retrieving and modifying problems on a disk. Options for the printing and plotting of results are explained.

The remaining chapters of the manual present a QUICK TOUR of each individual POLYMATH program and are organized according to the following subsections:

1. PROGRAM OVERVIEW

This subsection gives general details of the particular program.

2. QUICK TOUR

You can use this subsection to see how easy it is to enter and solve a problem with a particular POLYMATH program.

APPENDIX

Detailed installation instructions and additional output options are presented for advanced users.

DISPLAY PRESENTATION

Throughout this manual, a full screen is indicated by a total enclosure:



An upper part of screen is contained within a partial enclosure:



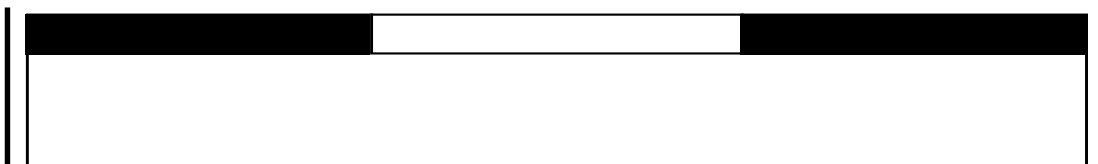
A lower part of screen is shown by a partial enclosure:



An intermediate part of a screen is given between vertical lines:

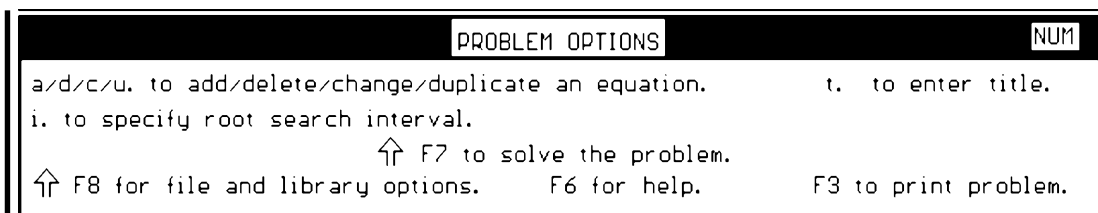


The option box is given by:



KEYBOARD INFORMATION

When using POLYMATH, it is not necessary to remember a complex series of keystrokes to respond to the menus, options, or prompts. The commands available to you are clearly labeled for easy use on each display. Normally the keystrokes which are available are given on the display as indicated on the PROBLEM OPTIONS display shown below.



USING THE ↵ KEY

In this manual as in POLYMATH, the ↵ symbol is used to indicate the carriage return key which is also called the enter key. Usually when you are responding to a menu option, the enter key is not required. However, when data or mathematical functions are being entered, the enter key is used to indicate that the entry is complete.

SHIFTED KEYPRESSES

Some options require that several keys be pressed at the same time. This is indicated in POLYMATH and in this manual by a dash between the keys such as a ↑ F8 which means to press and hold the ↑ or "shift" key, then press the F8 function key and finally release both keys.

THE EDITING KEYS

Use the left and right arrow keys to bring the cursor to the desired position, while editing an expression. Use the Del key to delete the character above the cursor or the ← (Back Space) key to delete the first character to the left of the cursor. Typed in characters will be added to the existing expression in the first position left to the cursor.

BACKING UP KEYS

Press either the F8 or the Esc key to have POLYMATH back up one program step.

ENTERING VARIABLE NAMES

A variable may be called by any alphanumeric combination of characters, and the variable name **MUST** start with a lower or upper case letter. Blanks, punctuation marks and mathematical operators are not allowed in variable names.

Note that POLYMATH distinguishes between lower and upper case letters, so the variables 'MyVar2' and 'myVar2' are not the same.

ENTERING NUMBERS

All numbers should be entered with the upper row on the key board or with the numerical keypad activated. Remember that zero is a number from the top row and not the letter key from the second row. The number 1 is from the top row while letter l is from the third row.

The results of the internal calculations made by POLYMATH have at least a precision of eight digits of significance. Results are presented with at least four significant digits such as xxx.x or x.xxx . All mathematical operations are performed as floating point calculations, so it is not necessary to enter decimal points for real numbers.

MATHEMATICAL SYMBOLS

You can use familiar notation when indicating standard mathematical operations.

Operator	Meaning	Symbol	Entry
+	addition	+	+
-	subtraction	-	-
x	multiplication	*	*
÷	division	/	/
	power of 10	x.x10 ^a	x.xea x.xEa
	(x.x is numerical with a decimal and a is an integer) exponentiation	r ^s	r**s or r^s

MATHEMATICAL FUNCTIONS

Useful functions will be recognized by POLYMATH when entered as part of an expression. The arguments must be enclosed in parentheses:

ln (base e)	exp2(2^x)
abs (absolute value)	round (rounds value)
sin	sec
arcsin	arcsec
sinh	arcsinh
log (base 10)	exp10 (10^x)
int (integer part)	sign (+1/0/-1)
cos	csc
arccos	arccsc
cosh	arccosh
exp	sqrt (square root)
frac (fractional part)	cbt (cube root)
tan	cot
arctan	arccot
tanh	arctanh

LOGICAL EXPRESSIONS

An "if" function is available during equation entry with the following syntax: if (condition) then (expression) else (expression). The parentheses are required, but spaces are optional. The condition may include the following operators:

>	greater than
<	less than
>=	greater than or equal
<=	less than or equal
==	equals
<>	does not equal
	or
&	and

The expressions may be any formula, including another "if" statement. For example:

a=if(x>0) then(log(x)) else(0)

b=if (T<minT) then(minT) else (if (T>maxT) then (maxT) else (T))

POLYMATH MESSAGES

There are many POLYMATH messages which may provide assistance during problem solving. These messages will tell you what is incorrect and how to correct it. All user inputs, equations and data, are checked for format and syntax upon entry, and feedback is immediate. Correct input is required before proceeding to a problem solution.

HARD COPY

If there is a printer connected to the computer, hard copy of the problem statements, tabular and graphical results etc. can be made by pressing F3 key wherever this option is indicated on the screen. Complete screen copies can also be made if the DOS graphics command is used before entering POLYMATH and your printer accepts this graphics mode.

Problem statements and results can be also printed by saving them on a file and printing this file after leaving POLYMATH.

GRAPHICS

POLYMATH gives convenient displays during problem entry, modification and solution. Your computer will always operate in a graphics mode while you are executing POLYMATH.

GETTING STARTED

This chapter provides information on the hardware requirements and discusses the installation of POLYMATH.

HARDWARE REQUIREMENTS

POLYMATH runs on IBM compatible personal computers from the original IBM PC XT to the latest models with Pentium chips. Most graphics boards are automatically supported. The minimum application memory requirement is 560Kb, and a new feature uses extended memory when it is available. POLYMATH works with PC and MS DOS 3.0 and above. POLYMATH can be a DOS application under Windows 3.1 and Windows 95. Calculations are very fast since the floating point processor is used when it is available.

POLYMATH SOFTWARE

The complete set of POLYMATH application programs with a general selection menu is available on a single 3-1/2 inch 1.44 Mb floppy in compressed form. It is recommended that a backup disk be made before attempting to install POLYMATH onto a hard disk. Installation is available via an install program which is executed from any drive.

INSTALLATION TO INDIVIDUAL COMPUTERS AND NETWORKS

POLYMATH executes best when the software is installed on a hard disk or a network. There is a utility on the POLYMATH distribution disk which is called "install". **Detailed installation instructions are found in the Appendix of this manual.** Experienced users need to simply put the disk in the floppy drive, typically A or B. Type "install" **at the prompt of your floppy drive**, and press return. Follow the instructions on the screen to install POLYMATH on the particular drive and directory that you desire. Note that the default drive is "C:" and the default directory is called "POLYMAT4". Network installation will require responses to additional questions during installation. Latest detailed information can be found on the INSTALL.TXT and README.TXT files found on the installation disk.

The PRINTSET program which can be used to change the printer specifications without completely reinstalling POLYMATH is discussed in the Appendix.

FIRST TIME EXECUTION OF POLYMATH

The execution of POLYMATH is started by first having your current directory set to the subdirectory of the hard disk where POLYMATH version 4.0 is stored. This is assumed to be C:\POLYMAT4

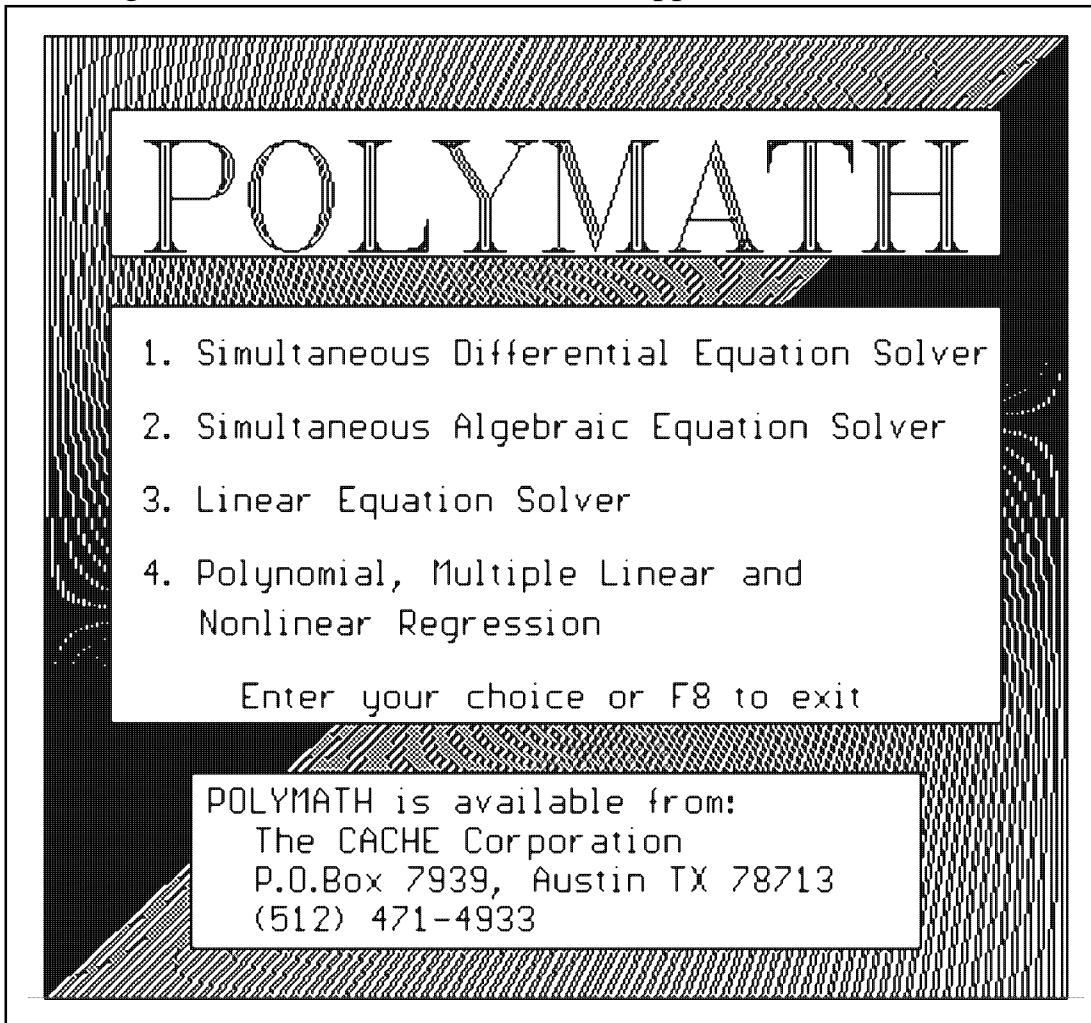
```
C:\POLYMAT4 >
```

Execution is started by entering "polymath" at the cursor

```
C:\POLYMAT4 > polymath
```

and then press the Return (↵) key.

The Program Selection Menu should then appear:



The desired POLYMATH program is then selected by entering the appropriate letter. You will then taken to the Main Program Menu of that particular program. Individual programs are discussed in later chapters of this manual.

EXITING POLYMATH PROGRAM

The best way to exit POLYMATH is to follow the instructions on the program display. However, a Shift F10 keypress (↑F10) will stop the execution of POLYMATH at any point in a program and will return the user to the Polymath Program Selection Menu. *THIS ACTION WILL DELETE THE EXISTING PROBLEM* so be sure to store your problem as an individual file or in the library before exiting the program in this manner. A query is made to determine if the user really wants to end the program in this manner while losing the current problem.

This ↑ F10 keypress is one of the few POLYMATH commands which is not always indicated in the various Display Menus. It is worth remembering.

HELP

MAIN HELP MENU

Each individual POLYMATH program has a detailed help section which is available from many points in the program by pressing F6 when indicated. The Help Menu allows the selection of the topic area for specific help as shown below for the Differential Equation Solver:

SOLUTION OF ORDINARY DIFFERENTIAL EQUATIONS
(Explanations and examples)

HELP MENU

Select a topic to study from the list below

- a. Entering the equations.
- b. Integration algorithms.
- c. Results storage algorithm.
- d. Troubleshooting.

F8 to return

For example, pressing "a" gives a discussion on entering the equations.

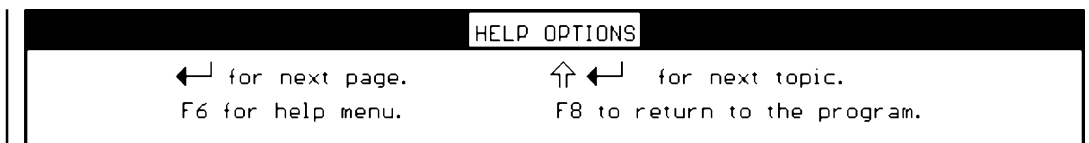
ENTERING THE EQUATIONS INTO THE PROGRAM (page 1 of 6)

The purpose of this program is to help you solve systems of first-order ordinary differential equations. The system may contain up to 31 differential and supporting explicit algebraic equations.

The differential equations should be entered in the following form:

$d(x)/d(t) = \text{an expression}$
or $d(x) = \text{an expression.}$

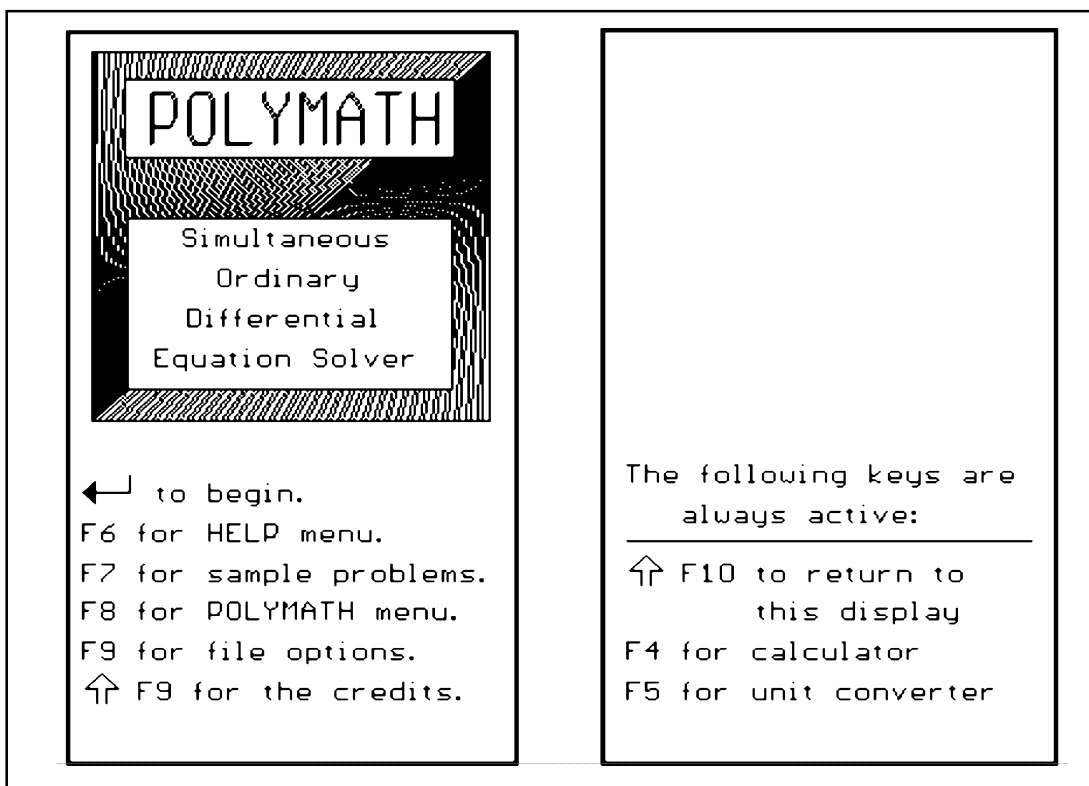
Once the current topic is completed, the Help Options Menu provides for additional options as shown below:



The \uparrow - F8 option to return to the program will take you to the display where you originally requested HELP

ACCESSING HELP BEFORE PROBLEM ENTRY

The Main Help Menu is reached during the startup of your POLYMATH program from the Main Menu as shown below and from the Problem Options Menu by pressing F6.



ACCESSING HELP DURING PROBLEM ENTRY

When you are entering a problem, the HELP MENU is available from the Problem Options Menu. This will allow you to obtain the necessary help and return to the same point where the HELP MENU was originally requested. As an example, this access point is shown in the Problem Options Menu shown on the next page.

```
PROBLEM OPTIONS NUM
a/d/c/u. to add/delete/change/duplicate an equation.      t. to change title.
i/f. to specify initial/final values.                    ↑,↓, PgUp, PgDn to move pointer.
                ↑ F7 to solve the problem.
↑ F8 for file and library options.      F6 for help.      F3 to print problem.
```

CALCULATOR HELP

A detailed discussion of the POLYMATH Calculator is given in Chapter 4 of this manual. The Calculator can be accessed from by pressing F4 from any point in a POLYMATH program.

```
» _
CALCULATOR: Enter an expression and press <ENTER> to evaluate it.
  Press <ESC> to leave or press F6 for information.
```

An F6 keypress brings up the same page help which provides a brief instruction inside the Calculator window.

UNIT CONVERSION HELP

The Unit Conversion Utility is discussed in Chapter 4 of this manual. There is no on-line help for this utility.

UTILITIES

CALCULATOR

A sophisticated calculator is always available for use in a POLY-MATH program. This calculator is accessed by pressing the F4 key . At this time a window will be open in the option box area which will give you access to the calculator.



CALCULATOR: Enter an expression and press <ENTER> to evaluate it.
Press <ESC> to leave or press F6 for information

The POLYMATH calculator allows you to enter an expression to be evaluated. After the expression is complete, press \leftarrow to have it calculated. You may then press \leftarrow again to clear the expression, or you may edit your expression using the standard editing functions. When you wish to leave the calculator, just press the F8 or Esc key.

CALCULATOR EXPONENTIATION

Numbers may also be entered in scientific notation. The calculator will recognize E or e as being equivalent to the notation *10**. Either ** or ^ indicates general exponentiation. For example, the following three expressions are equivalent for a particular value of A:

$$4.71*10**A = 4.71eA = 4.71*10^A$$

AVAILABLE FUNCTIONS

A number of standard functions are available for use in the calculator. The underlined portion of the following functions is all that is required provided that all arguments are enclosed in parentheses. The arguments may themselves be expressions or other functions. The nesting of function is allowed.

ln () or alog () = natural logarithm to the base e

log () or alog10 () = logarithm to the base 10

exp () = exponential (e^x)

exp2 () = exponential of 2 (2^x)

exp10 () = exponential of 10 (10^x)

sqrt () = square root

abs () = absolute value

int () or ip () = integer part
frac () = or fp () = fractional part
round () = rounded value
sign () = returns + 1 or 0 or -1
N! = factorial of integer part of number N (this only operates on a number)
sin () = trigonometric sine with argument in radians
cos () = trigonometric cosine with argument in radians
tan () = trigonometric tangent with argument in radians
sec () = trigonometric secant with argument in radians
csc () = trigonometric cosecant with argument in radians
cot () = trigonometric cotangent with argument in radians
arcsin () = trigonometric inverse sine with result in radians, alternates arsin () and asin ()
arccos () = trigonometric inverse cosine with result in radians, alternates arcos () and acos ()
arctan () = trigonometric inverse tangent with result in radians, alternate atan ()
arcsec () = trigonometric inverse secant with result in radians
arccsc () = trigonometric inverse cosecant with result in radians
arccot () = trigonometric inverse cotangent with result in radians
sinh () = hyperbolic sine
cosh () = hyperbolic cosine
tanh () = hyperbolic tangent
arcsinh () = inverse hyperbolic sine
arccosh () = inverse hyperbolic cosine
arctanh () = inverse hyperbolic tangent

You should note that the functions require that their arguments be enclosed in parentheses, but that the arguments do not have to be simple numbers. You may have a complicated expression as the argument for a function, and you may even nest the functions, using one function (or an expression including one or more functions) as the argument for another.

ASSIGNMENT FUNCTIONS

The assignment function is a way of storing your results. You may specify a variable name in which to store the results of a computation by first typing in the variable name, then an equals sign, then the expression you wish to store. For example, if you wish to store the value of $\sin(4/3)^2$ in variable 'a', you would enter:

$$a = \sin(4/3)**2$$

Variable names must start with a letter, and can contain letters and digits. There is no limit on the length of the variable names, or on the number of variables you can use. You can then use the variable 'a' in other calculations. **These variables are stored only as long as you remain in the current POLYMATH program. Please note that all stored values are lost when the particular program is exited. Calculator information is not retained during problem storage.**

CALCULATOR EXAMPLES

Example 1. In this example the vapor pressure of water at temperatures of 50, 60 and 70 °C has to be calculated using the equation:

$$\log_{10} P = 8.10765 - \frac{1750.29}{235.0 + T}$$

For $T = 50$ the following expression should be typed into the calculator:

➤ 10^(8.10675 - 1750.29 / (235+50))

CALCULATOR: Enter an expression and press <ENTER> to evaluate it.
Press <ESC> to leave or press F6 for information.

Pressing ← brings up the desired answer which is 92.3382371 mm Hg at 50 °C. To change the temperature use the left arrow to bring the cursor just right to the zero of the number 50, use the ← (BkSp or delete) key to erase this number and type in the new temperature value.

Example 2. In this example the pressure of carbon dioxide at temperature of $T = 400$ K and molal volume of $\widehat{V} = 0.8$ liter is calculated using the following equations:

$$P = \frac{RT}{\widehat{V} - b} - \frac{a}{\widehat{V}^2}$$

Where $a = \frac{27}{64} \left(\frac{R^2 T_c^2}{P_c} \right)$ $b = \frac{RT_c}{8 P_c}$

$$R = 0.08206, T_c = 304.2 \text{ and } P_c = 72.9.$$

One way to carry out this calculation is to store the numerical values in the named variables. First you can type in $P_c = 72.9$ and press \leftarrow to store this value as shown below.

```

>> Pc=72.9
CALCULATOR: Enter an expression and press <ENTER> to evaluate it.
=72.9
    
```

After that you can type in $T_c = 304.2$ and $R = 0.08206$. To calculate b , you must type in the complete expression as follows:

```

>> b=R*Tc/(8*Pc)
CALCULATOR: Enter an expression and press <ENTER> to evaluate it.
=0.0428029012
    
```

The value of a is calculated in the same manner yielding a value of 3.60609951. Finally P can be calculated as shown:

```

>> P=R*400/(0.8-b)-a/(0.8*0.8)
CALCULATOR: Enter an expression and press <ENTER> to evaluate it.
=37.7148168
    
```

UNIT CONVERSION

A utility for unit conversion is always available for use within a POLYMATH program. Unit Conversion is accessed by pressing F5 wherever you desire. This will result in the following window in the option box area:

Type the letter of the physical quantity for conversion. a) Energy b) Force c) Length d) Mass e) Power f) Pressure g) Volume h) Temperature F8 or ESC to exit
--

The above listing indicates the various classes of Unit Conversion which are available in POLYMATH. A listing of the various units in each class is given below:

ENERGY UNITS: joule, erg, cal, Btu, hp hr, ft lb_f, (liter)(atm), kwh

FORCE UNITS: newton, dyne, kg, lb, poundal

LENGTH UNITS: meter, inch, foot, mile, angstrom, micron, yard

MASS UNITS: kilogram, pound, ton (metric)

POWER UNITS: watts, hp (metric), hp (British), cal/sec, Btu/sec, ft lb_f/sec

PRESSURE UNITS: pascal, atm, bar, mm Hg (torr), in Hg, psi [lb_f/sq in]

VOLUME UNITS: cu. meter, liter, cu. feet, Imperial gal, gal (U.S.), barrel (oil), cu. centimeter

TEMPERATURE UNITS: Celsius, Fahrenheit, Kelvin, Rankine

PREFIXES FOR UNITS

It is convenient to also specify prefixes for any units involved in a Unit Conversion. This feature provides the following prefixes:

deci 10 ⁻¹	centi 10 ⁻²	milli 10 ⁻³	micro 10 ⁻⁶	deka 10
hecto 10 ²	kilo 10 ³	mega 10 ⁶	giga 10 ⁹	

UNIT CONVERSION EXAMPLE

Suppose you want to convert 100 BTU's to kilo-calories. First you should access the Unit Conversion Utility by pressing F5. This will bring up the following options

Type the letter of the physical quantity for conversion. a) Energy b) Force c) Length d) Mass e) Power f) Pressure g) Volume h) Temperature F8 or ESC to exit
--

Press "a" to specify an Energy conversion:

From units: Type in a letter (F9 to set a prefix first) a. joule b. erg c. cal d. Btu e. hp hr f. ft lb _f g. (liter)(atm) h. kwh

Type a "d" to specify Btu:

From units : Btu To units: (F9 for a prefix) a. joule b. erg c. cal d. Btu e. hp hr f. ft lb, g. (liter)(atm) h. kwm
--

Use F9 to indicate a Prefix:

Press the number of the needed prefix or F9 for none. 1) deci 10 ⁻¹ 2) centi 10 ⁻² 3) milli 10 ⁻³ 4) micro 10 ⁻⁶ 5) deka 10 6) hecto 10 ² 7) kilo 10 ³ 8) mega 10 ⁶ 9) giga 10 ⁹

Please indicate kilo by pressing the number 7.

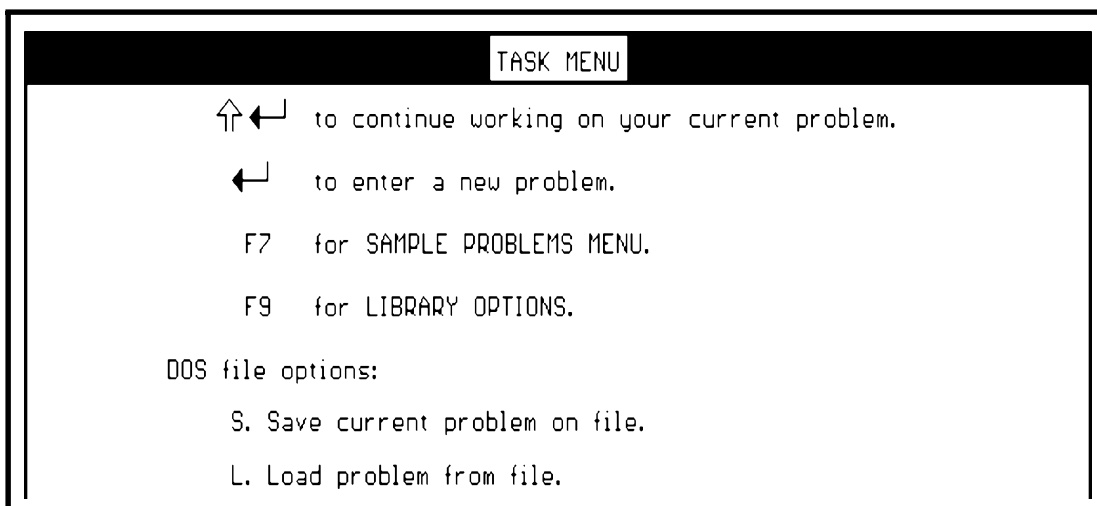
From units: Btu To units: kilo - a. joule b. erg c. cal d. Btu e. hp hr f. ft lb _f g. (liter)(atm) h. kwh
--

Complete the units by pressing "c" for calories. Indicate the numerical value to be 100 and press enter:

From units: Btu To units: kilo-cal Numerical value: 100 100.00 Btu = 25.216 kilo-cal

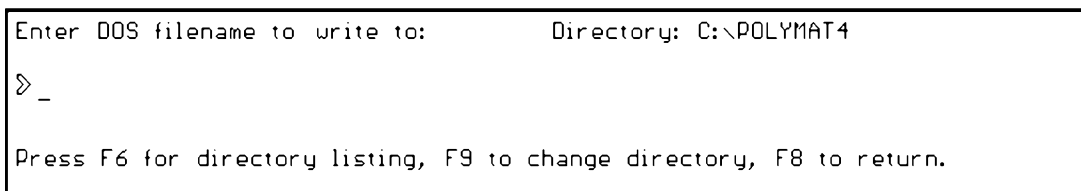
PROBLEM STORAGE

POLYMATH programs can be stored for future use as either DOS files or in a "Library" of problems. The Library has the advantage that the titles are displayed for only the problems for the particular POLYMATH program which is in use. Both the DOS files and the Library can be placed in any desired subdirectory or floppy disk. In both cases, only the problem and **not** the solution is stored. The storage options are available from the Task Menu which is available from POLYMATH programs by pressing either F9 from the Main Menu or ↑ F8 from the Problem Options Menu.



FILE OPERATIONS

A current problem can be saved to a DOS file by selecting "S" from the Task Menu. The desired directory and DOS file name can be specified from the window given below:



Note that the path to the desired directory can also be entered along with the file name as in "A:\MYFILE.POL" which would place the DOS file on the Drive A.

A previously stored problem in a DOS file can be loaded into POLYMATH from the Task Menu by selecting "L". A window similar to the one above will allow you to load the problem from any subdirectory or floppy disk. An F6 keypress gives the contents of the current directory for help in identifying the file name for the desired problem.

LIBRARY OPERATIONS

The Library is **highly recommended for storing problems** as the titles of the problems are retained and displayed which is a considerable convenience. Also, only the problems for the particular POLYMATH program in current use are displayed. The Library is accessed from the Task Menu by pressing F9 as shown below:

Regression Library directory: C:\POLYMAT4		
	File name	Problem title
→ 1)	REG01 .POL	Sample Problem 1
2)	REG02 .POL	Sample Problem 2
3)	REG03 .POL	Sample Problem 3
4)	REG04 .POL	Sample Problem 4

LIBRARY OPTIONS		
S.	Store current problem.	C. Change library directory
or: Use ↑ or ↓ to move problem pointer and press:		
L.	Load problem.	D. Delete problem. F8 to return

If there is no current Library on the desired subdirectory or floppy disk, then a Library is created.

LIBRARY STORAGE

The Library Options menu allows the current POLYMATH problem to be stored by simply entering "S". The title as currently defined in the active problem will be displayed. The user must choose a file name for this particular problem; however, it will then be displayed along with the Problem title as shown above.

LIBRARY RETRIEVAL

The Library Options window allows the current POLYMATH problem to be recalled by first using the cursor keys to direct the arrow to the problem of interest and then entering "L". A window will confirm the library retrieval as shown below:

```
Reading problem from file REG04.POL...

Load done, press F8 to remain in library
          any other key for problem options
```

Problems may be deleted from the Library by using the arrow to identify the problem, and then selecting "D" from the Library Options menu. Users are prompted to verify problem deletion.

PROBLEM OUTPUT AS PRINTED GRAPHICS

One of the most useful features of POLYMATH is the ability to create graphical plots of the results of the numerical calculations. The command to print graphical output is F3. The first step in printing graphical output is to display the desired output variables. The POLYMATH programs allow the user to make plots of up to four variables versus another variable.

An example which will be used to demonstrate plotting is the Quick Tour Problem 1 from the next chapter. Here the POLYMATH Differential Equation Solver has produced a numerical solution to three simultaneous ordinary differential equations. The calculations are summarized on a Partial Results display which has the following Display Options Menu:

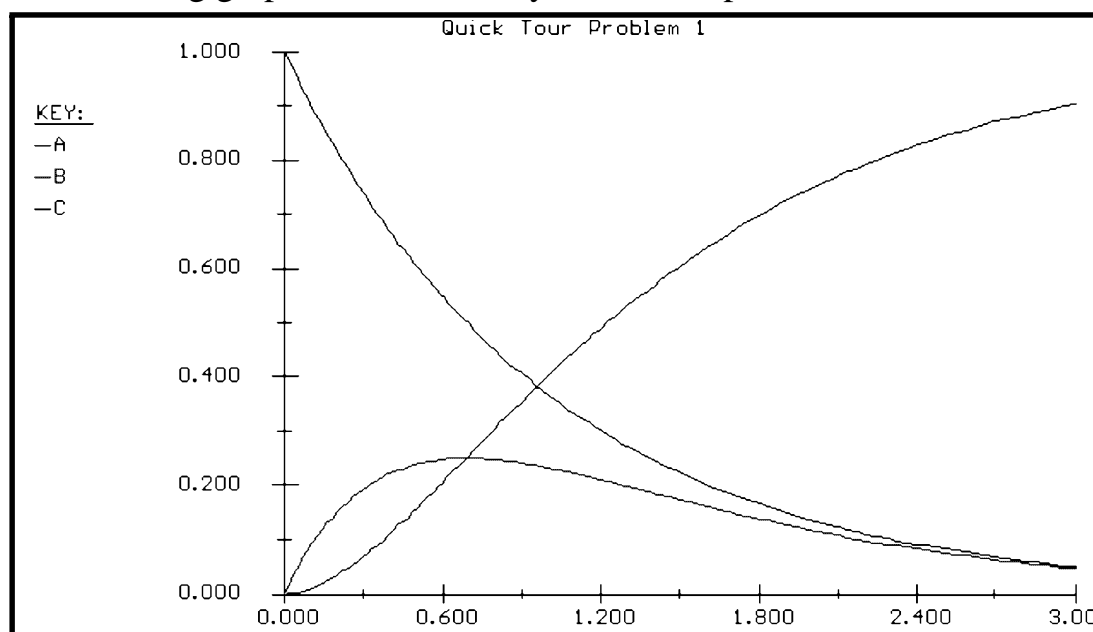
DISPLAY OPTIONS		NUM
g. Other variables in GRAPH form.	t. Same variables in TABULAR form.	
d. Write results to file.	s. Summary table.	F3 to prepare to print graph.
↑ F8 for new problem or library.		↑ ← to make changes.

SIMPLE SCREEN PLOT

The selection of "g" from the Display Options Menu allows the user to select desired variables for plotting. A plot of variables A, B, and C versus the independent variable t can be obtained by entering "A,B,C" at the cursor and pressing the Return key (←).

```
Type in the names of up to four (4) variables separated by commas (,)
and optionally one independent variable preceded by a slash (/).
For example,      myvar1,myvar2/timevar
> A,B,C_
```

The resulting graph is automatically scaled and presented on the screen.

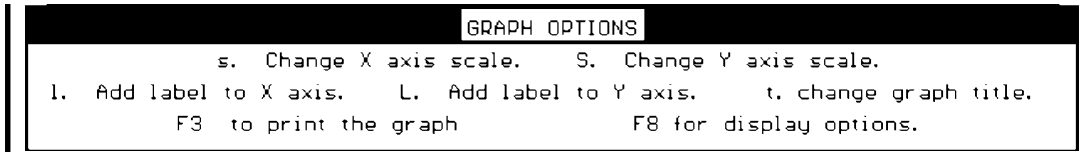


OPTIONAL SCREEN PLOT

The selection of "g" from the Display Options Menu with the entry of "B/A" results in B plotted versus A. This demonstrates that dependent variables can be plotted against each other.

PRESENTATION PLOT

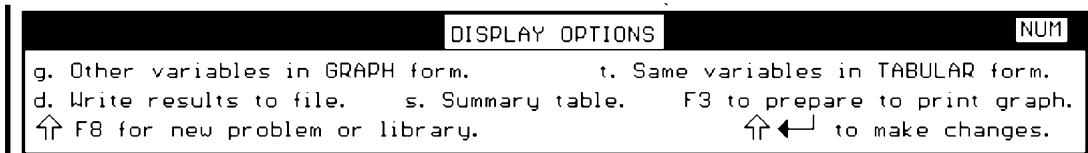
A simple plot can be printed directly or it can be modified before printing by using options from the Graph Option Menu shown below:



This menu allow the user to modify the plot before printing as desired to obtain a final presentation graphic with specified scaling and labels.

PROBLEM OUTPUT TO SCREEN AND AS PRINTED TABLES

The Display Options Menu also allows the user to select tabular output from the Partial Results Display by pressing "t":



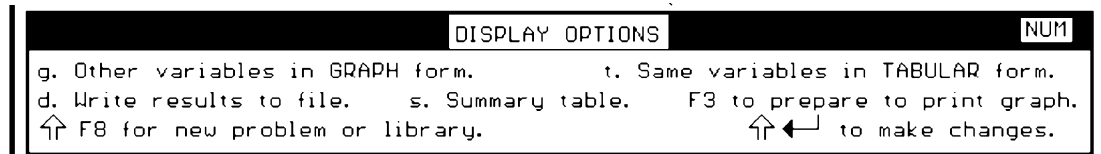
This is shown below for the same entry of "A, B, C" for the Quick Tour Problem 1 from the next chapter on differential equations.

t	A	B	C
0	1	0	0
0.3	0.74081822	0.19200658	0.067175195
0.6	0.54881164	0.24761742	0.20357094
0.9	0.40656966	0.24127077	0.35215957
1.2	0.30119421	0.21047626	0.48832953
1.5	0.22313016	0.17334309	0.60352675
1.8	0.16529889	0.13797517	0.69672595
2.1	0.12245643	0.10746085	0.77008272
2.4	0.090717953	0.082488206	0.82679384
2.7	0.067205513	0.062688932	0.87010556
3	0.049787068	0.047308316	0.90290462

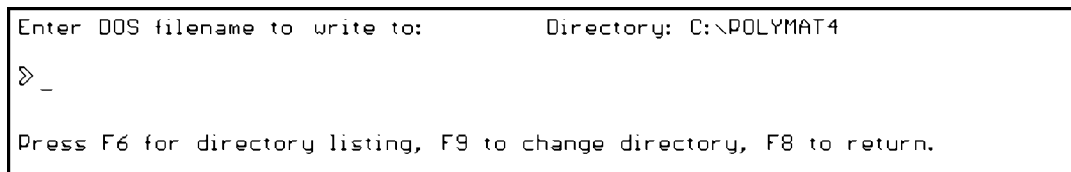
The output shown above gives variable values for the integration interval at selected intervals. The maximum number of points is determined by the numerical integration algorithm. Output variable values for a smaller number of points are determined by interpolation. A Screen Table can be printed by using F3.

PROBLEM OUTPUT AS DOS FILES

The output from many of the POLYMATH programs can also be stored for future use as DOS files for use in taking results to spreadsheets and more sophisticated graphics programs. Typically this is done after the output has been sent to the screen. This is again accomplished with option "d" from the Display Options Menu.



This option take the user to a display where the name and location of the DOS data file is entered:



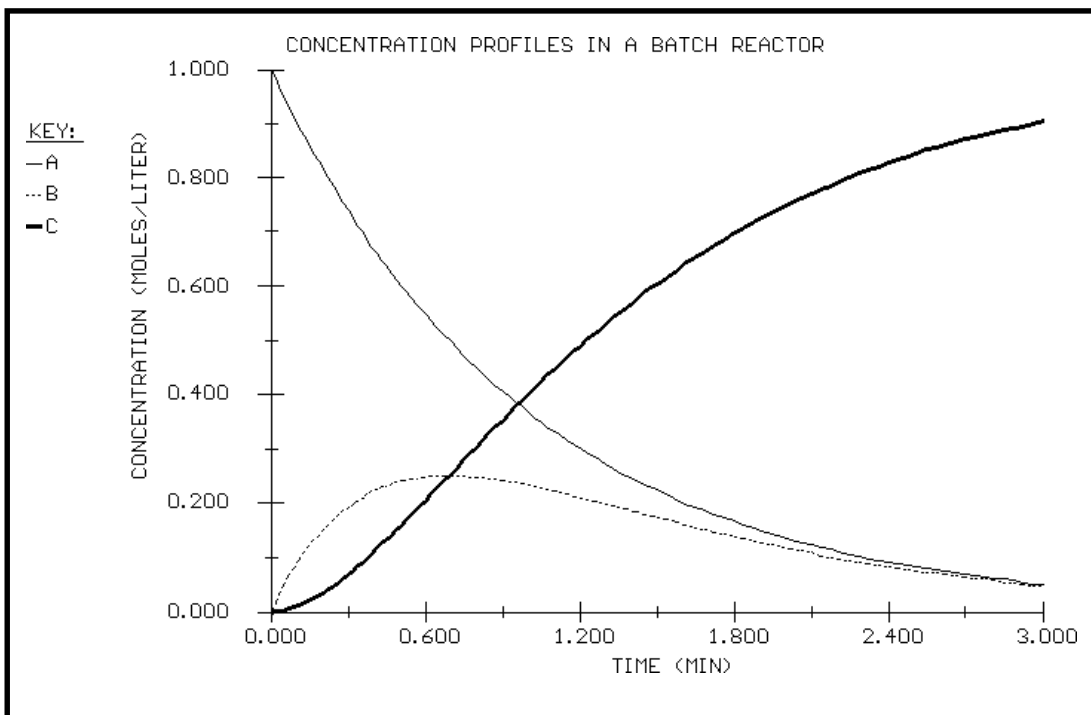
Please note that the user can change the drive and the directory to an desired location. One the location is indicated and the file name is entered, the desired variable names must be provided and the number of data points to be saved. The file shown below was created as shown for the request of "A,B,C" and 10 data points for Quick Tour Problem 1 from the next chapter:

t	A	B	C
0	1	0	0
0.3	0.74081822	0.19200658	0.067175195
0.6	0.54881164	0.24761742	0.20357094
0.9	0.40656966	0.24127077	0.35215957
1.2	0.30119421	0.21047626	0.48832953
1.5	0.22313016	0.17334309	0.60352675
1.8	0.16529889	0.13797517	0.69672595
2.1	0.12245643	0.10746085	0.77008272
2.4	0.090717953	0.082488206	0.82679384
2.7	0.067205513	0.062688932	0.87010556
3	0.049787068	0.047308316	0.90290462

Note that the separate columns of data in this DOS output file are separated by tabs which is suitable format for input to various spreadsheet or graphics programs.

PROBLEM OUTPUT AS GRAPHICS FILES

Advanced POLYMATH users can direct their printed output to many standard graphics files for direct use in word processing, desktop publishing, etc. This is accomplished through special polymath.bat files which **direct any printer output to specified graphics files with user-defined file names**. Details of this option are found in Chapter 9 of this manual. A typical example would be to create the following output in a TIFF file for inclusion in a written reporting using word processing or desktop publishing. The problem is again the for Quick Tour Problem 1 from the next chapter. Note that the figure below has utilized the title and axis definition options.



The modified bat file which lead to the above TIFF image was

```
ECHO OFF
SET BGIPATH=C:\POLYMAT4\BGI
SET PM_WORKPATH=C:\POLYMAT4
SET PM_PRINTER=_TIF,0,FILE:E:\PMOUT+++.TIF
POLYMENU
CLS
```

and the first tiff image was stored as PMOUT001.TIF in C:\POLYMAT4 directory. See Chapter 9 for more information.

DIFFERENTIAL EQUATION SOLVER

QUICK TOUR

This section is intended to give you a very quick indication of the operation of the POLYMATH Differential Equation Solver Program.

DIFFERENTIAL EQUATION SOLVER

The program allows the numerical integration of up to 31 simultaneous nonlinear ordinary differential equations and explicit algebraic expressions. All equations are checked for syntax upon entry. Equations are easily modified. Undefined variables are identified. The integration method and stepsize are automatically selected; however, a stiff algorithm may be specified if desired. Graphical output of problem variables is easily obtained with automatic scaling.

STARTING POLYMATH

To begin, please have POLYMATH loaded into your computer as detailed in Chapter 2. Here it is assumed that your computer is set to the hard disk subdirectory or floppy drive containing the POLYMATH package. At the prompt (assumed C:\POLYMAT4 here), you should enter "polymath"

```
C:\POLYMATH4 > polymath
```

then press the Return (↵) key. The Program Selection Menu should then appear, and you should enter "1" to select the Simultaneous Differential Equation Solver. This should bring up the Main Program Menu:

<div style="border: 1px solid black; padding: 5px; text-align: center; margin-bottom: 10px;">POLYMATH</div> <div style="border: 1px solid black; padding: 5px; text-align: center; margin-bottom: 10px;">Simultaneous Ordinary Differential Equation Solver</div> <p>←↵ to begin. F6 for HELP menu. F7 for sample problems. F8 for POLYMATH menu. F9 for file options. ⇧ F9 for the credits.</p>	<p>The following keys are always active:</p> <hr style="width: 50%; margin: 5px auto;"/> <p>⇧ F10 to return to this display F4 for calculator F5 for unit converter</p>
---	---

Now that POLYMATH is loaded, please press F6 and then the letter "a" to get information on "Entering the equations". The first page of the Help Section should be on your screen as shown here:

ENTERING THE EQUATIONS INTO THE PROGRAM (page 1 of 6)

The purpose of this program is to help you solve systems of first-order ordinary differential equations. The system may contain up to 31 differential and supporting explicit algebraic equations.

The differential equations should be entered in the following form:

$d(x)/d(t) = \text{an expression}$
or $d(x) = \text{an expression.}$

Here t is the independent variable and x is a dependent variable. Variable names must begin with an alphabetic character, and can contain an unlimited number of alphabetic and numeric characters. Variable names are case-sensitive, meaning 't' and 'T' are two different variables.

Auxiliary algebraic equations may be entered in the form:

$x = \text{an expression}$

where the same naming rules apply.

HELP OPTIONS

<p>← for next page. F6 for help menu.</p>	<p>↑ ← for next topic. F8 to return to the program.</p>
---	---

Please press F8 to return from the Help to the program, and then press the Enter key (↵) to continue this Quick Tour example.

SOLVING A SYSTEM OF DIFFERENTIAL EQUATIONS

Let us now enter and solve a system of three simultaneous differential equations:

$$\begin{aligned} d(A) / d(t) &= -k_A (A) \\ d(B) / d(t) &= k_A (A) - k_B (B) \\ d(C) / d(t) &= k_B (B) \end{aligned}$$

In these equations, the parameter k_A is to be constant at a value of 1.0 and the parameter k_B is to be constant at the value of 2.0. The initial condition for dependent variable "A" is to be 1.0 when the initial value of the independent variable "t" is zero. The initial conditions for dependent variables "B" and "C" are both zero. The solution for the three differential equations is desired for the independent variable "t" between zero and 3.0. Thus this problem will be entered by using the three differential equations as given above along with two expressions for the values for k_A and k_B given by:

$$k_A = 1.0; \quad k_B = 2.0$$

ENTERING THE EQUATIONS

The equations are entered into POLYMATH by first pressing the "a" option from the Problem Options Menu. The following display gives the first equation as it should be entered at the arrow. (Use the Backspace key, to correct entry errors after using arrow keys to position cursor.) Press the Return key (\leftarrow) to indicate that the equation is to be entered. Don't worry if you have entered an incorrect equation, as there will soon be an opportunity to make any needed corrections.

Differential Equations: 0	Auxiliary Equations: 0
\gg d(A)/d(t)=-ka*A_	

The above differential equation is entered according to required format which is given by:

$$d(x)/d(t)=\text{an expression}$$

where the dependent variable name "x" and the independent variable name "t" must begin with an alphabetic character and can contain any number of alphabetic and numerical characters. In this Quick Tour problem, the dependent variables are A, B and C for the differential equations, and the independent variable is t. Note that POLYMATH variables are case sensitive. The constants k_A and k_B are considered to be variables which can be defined by explicit algebraic equations given by the format:

$$x=\text{an expression}$$

In this problem, the variables for k_A and k_B will have constant values. Note that the subscripts are not available in POLYMATH, and in this problem the variable names of ka and kb will be used.

Please continue to enter the equations until your set of equations corresponds to the following:

Equations: → d(A)/d(t)=-ka*A d(B)/d(t)=ka*A-kb*B d(C)/d(t)=kb*B ka=1 kb=2
--

As you enter the equations, note that syntax errors are checked prior to being accepted, and various messages are provided to help to identify input errors. Undefined variables are also identified by name during equation entry.

ALTERING THE EQUATIONS

After you have entered the equations, please press ← with no equation at the arrow to go to the Problem Options display which will allow needed corrections:

Equations	
→	$d(A)/d(t) = -k_a * A$
	$d(B)/d(t) = k_a * A - k_b * B$
	$d(C)/d(t) = k_b * B$
	$k_a = 1$
	$k_b = 2$
Differential Equations: 3 Auxiliary Equations: 2	
PROBLEM OPTIONS NUM	
a/d/c/u. to add/delete/change/duplicate an equation. t. to enter title.	
i/f. to specify initial/final values. ↑, ↓, PgUp, PgDn to move pointer.	
↑ F7 to solve the problem.	
↑ F8 for file and library options. F6 for help. F3 to print problem.	

The Problem Options Menu allows you to make a number of alterations on the equations which have been entered. Please make sure that your equations all have been entered as shown above. Remember to first indicate the equation that needs altering by using the arrow keys. When all equations are correct, press ↑ F7 (keep pressing shift while pressing F7) to continue with the problem solution.

ENTERING THE BOUNDARY CONDITIONS

At this point you will be asked to provide the initial values for the independent variable and each of the dependent variables defined by the differential equations.

Enter initial value for t
➤ _

Please indicate this value to be the number "0" and press Return.

The next initial value request is for variable "A". Please this value as the value "1."

Enter initial value for A
➤ 1 _

The initial values for B and C will be requested if they have not been previously entered. Please enter the number "0" for each of these variables.

Next the final value for t, the independent variable, will be requested. Set this parameter at "3":

Enter final value for t
 >> 3 _

As soon as the problem is completely specified, then the solution will be generated. However, if you corrected some of your entries, then you may need to press \uparrow F7 again to request the solution. Note that a title such as "Quick Tour Problem 1" could have been entered from the Problem Option Menu.

SOLVING THE PROBLEM

The numerical solution is usually very fast. For slower computers, an arrow will indicate the progress in the independent variable during the integration. Usually the solution will be almost instantaneous. The screen display after the solution is given below:

Quick Tour Problem 1

Equations	Initial values
→ $d(A)/d(t) = -k_a * A$	1
$d(B)/d(t) = k_a * A - k_b * B$	0
$d(C)/d(t) = k_b * B$	0
$k_a = 1$	
$k_b = 2$	
$t_0 = 0, \quad t_f = 3$	

Solution process complete.

Press any key to display results.

Differential Equations: 3 Auxiliary Equations: 2

Solution progress - independent variable value

Another Return keypress gives the partial Results Table which summarizes the variables of the problem as shown below:

Quick Tour Problem 1				
<u>Variable</u>	<u>Initial value</u>	<u>Maximum value</u>	<u>Minimum value</u>	<u>Final value</u>
t	0	3	0	3
A	1	1	0.0497871	0.0497871
B	0	0.249993	0	0.0473083
C	0	0.902905	0	0.902905
ka	1	1	1	1
kb	2	2	2	2

DISPLAY OPTIONS		NUM
t. Results in TABULAR form.	g. Results in GRAPHICAL form.	
d. Output results to DOS file.	F3 to print this summary table.	
↑ F8 for new problem or library.	↑ ← to make changes.	

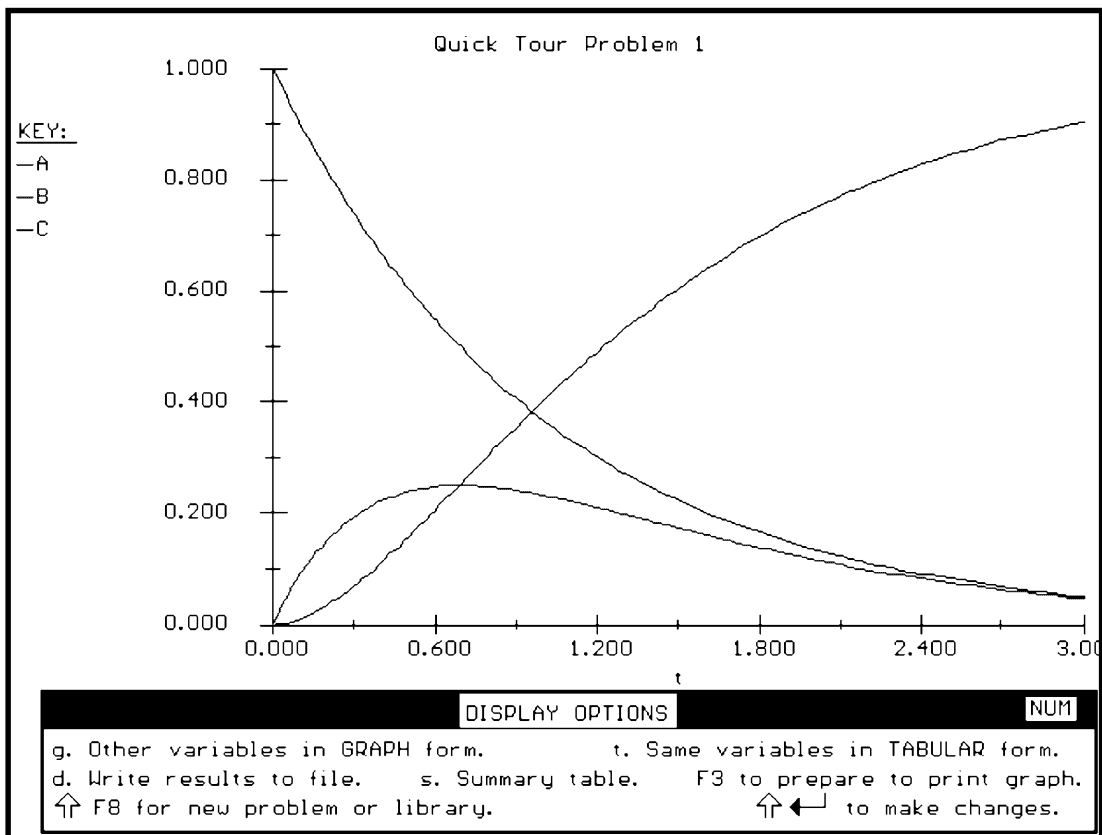
The Partial Results Table shown above provides a summary of the numerical simulation. To display or store the results you can enter "t" (tabular display), "g" (graphical display), or "d" (storing the results on a DOS file). This Table may be printed with the function key F3.

PLOTTING THE RESULTS

Let us now plot the variable from this Problem 1 by entering "g" for a graphical presentation. When asked to type in the variable for plotting, please enter the input indicated below at the arrow:

<p>Type in the names of up to four (4) variables separated by commas (,) and optionally one 'independent' variable preceded by a slash(/). For example, myvar1, myvar2/timevar</p> <p>➤ A, B, C _</p>

A Return keypress (←) will indicate the end of the variables and should generate the graphical plot on the next page of the specified variables A, B, and C versus t, the independent variable, for this example.



Suppose that you want to plot variable B versus variable A. Select the option "g" from the Display Options Menu and enter B/A when asked for the variable names.

Type in the names of up to four (4) variables separated by commas (,) and optionally one 'independent' variable preceded by a slash(/).
 For example, myvar1, myvar2/timevar

➤ B/A

This will result in a scaled plot for variable B versus variable A.

This concludes the Quick Tour problem using the Differential Equation Solver. If you wish to stop working on POLYMATH, please follow the exiting instructions given below.

EXITING OR RESTARTING POLYMATH

A ↑ - F10 keypress will always stop the operation of POLYMATH and return you to the Program Selection Menu. **THIS ACTION WILL DELETE THE EXISTING PROBLEM.** The program can be exited or restarted from the Program Selection Menu.

INTEGRATION ALGORITHMS

The program will first attempt to integrate the system of differential equations using the Runge-Kutta-Fehlberg (RKF) algorithm. A detailed discussion of this algorithm is given by Forsythe et al.* This algorithm monitors the estimate of the integration error and alters the step size of the integration in order to keep the error below a specified threshold. The default values for both relative and absolute (maximal) errors are less than 10^{-10} . If this cannot be attained, then the absolute and relative errors are set as necessary to 10^{-7} and then to 10^{-4} .

If it is not possible to achieve errors of 10^{-4} , then the integration is stopped, and the user is given a choice to continue or to try an alternate integration algorithm for stiff systems of differential equations. Under these circumstances, the system of equations is likely to be "stiff" where dependent variables may change in widely varying time scales, and the user is able to initiate the solution from the beginning with an alternate "stiff" integration algorithm. The algorithm used is the semi-implicit extrapolation method of Bader-Deuflhard**, and the maximal errors are again started at 10^{-10} .

When the integration is very slow, the F10 keypress will allow the selection of the stiff algorithm, and the problem will be solved from the beginning.

* Forsythe, B. E., M. A. Malcolm, and C. B. Moler, **Computer Methods for Mathematical Computation**, Prentice-Hall, Englewood Cliffs, NJ, 1977.

** Press, W. H., P. B. Flannery, S. A. Teukolsky, and W. T. Vetterling, **Numerical Recipes**, 2nd Ed., Cambridge University Press, 1992, pp. 735-739.

TROUBLE SHOOTING

SPECIFIC ERROR MESSAGES

Most error messages given by POLYMATH are self-explanatory, and they suggest the type of action which should be taken to correct the difficulty.

NONSPECIFIC ERROR MESSAGES

"Circular dependency detected."

This message appears during the inputting of equations when the equations are not all explicit. For example, an attempt to define $y=z/x$ when z has been previously defined will cause this error message to appear. This version of POLYMATH Differential Equations Solver can only solve variables which can be explicitly expressed as a function of other variables.

"The expression ... is undefined at the starting point."

This common problem can be solved by starting the integration from $t=\text{eps}$ where eps is a very small number and t represents the independent problem variable.

"Solution process halted due to a lack of memory."

This message may result when the default Runge-Kutta-Fehlberg algorithm is used for a stiff system of differential equations, and thus very small step sizes are taken. Consequently, a large number of data points for possible plotting of the results. **Use the F10 to stop the integration and switch to the stiff algorithm.** If the message persists, then take the following steps to resolve the difficulty:

- (1) If you are running under Windows, make sure the PIF for POLYMATH specifies 640K of conventional memory and 1024K or more of XMS (but see item (3) below).
- (2) Remove other memory-resident programs from your computer.
- (3) Reduce the number of equations. This is most easily accomplished by introducing the numerical values of the constants into the equations, instead of defining them separately. Due to a limitation of some versions of HIMEM, POLYMATH may not be able to access most of the XMS in the number of equations exceeds approximately 24. (The exact number depends on the computer's configuration.)
- (4) Reduce the integration interval.

"Solution process halted because it was not going anywhere."

This message usually appears when the problem is very stiff, and the default RKF algorithm is used for integration. The stiff algorithm should be used, or the interval of integration should be reduced. If the error message persists, there are probably errors in the problem setup or input. Please check for errors in the basic equation set, the POLYMATH equation entry, and the numerical values and the units of the variables.

ALGEBRAIC EQUATION SOLVER

QUICK TOUR

This chapter is intended to give a very brief discussion of the operation of the POLYMATH Nonlinear Algebraic Equation Solver.


NONLINEAR ALGEBRAIC EQUATION SOLVER

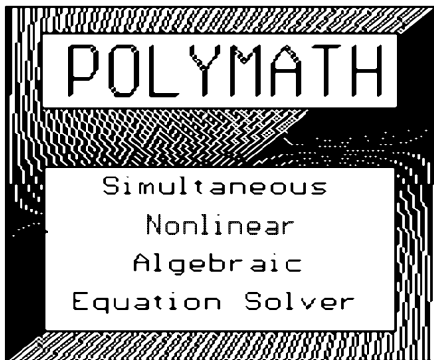



The user can solve up to a combination of 32 simultaneous nonlinear equations and explicit algebraic expressions. Only real (non-complex) roots are found. All equations are checked for correct syntax and other errors upon entry. Equations can be easily be modified, added or deleted. Multiple roots are given for a single equation.

STARTING POLYMATH

To begin, please have POLYMATH loaded into your computer as detailed in Chapter 2. Here it is assumed that your computer is set to the hard disk subdirectory or floppy drive containing the POLYMATH package. At the prompt (assumed C:\POLYMAT4 here), you should enter "polymath"

```
C:\POLYMAT4>polymath
```

then press the Return () key. The Main Program Menu should then appear: The Program Selection Menu should then appear, and you should enter "2" to select the Simultaneous Algebraic Equation Solver.

 <p> to begin. F6 for HELP menu. F7 for sample problems. F8 for POLYMATH menu. F9 for file options.  F9 for the credits.</p>	<p>The following keys are always active:</p> <hr/> <p> F10 to return to this display F4 for calculator F5 for unit converter</p>
---	---

Once that POLYMATH is loaded, please utilize the Help Menu by pressing F6 and then the letter "a" to obtain details on in order to learn how to input the equations. The first page of this Help Section is given below:

ENTERING THE EQUATIONS INTO THE PROGRAM (page 1 of 5)

The purpose of this program is to help you to solve systems of nonlinear algebraic equations. The system may contain up to 32 nonlinear simultaneous and supporting auxiliary equations. Only real roots (non-complex) can be found.

Variable names must begin with an alphabetic character and can contain alphabetic and numeric characters. Variable names are case-sensitive, meaning 't' and 'T' are two different variables.

Nonlinear equations requiring simultaneous solution (implicit equations) may be entered in the following form:

f(x)= an expression.

where 'x' is named according to the rules given above, and f(x) is an expression to have the value of zero.

In addition to the implicit equations, auxiliary equations can be defined. The auxiliary equations are solved sequentially. They are of the form:

x= an expression

where 'x' is any variable name.

HELP OPTIONS

← for next page. F6 for help menu.	↑ ← for next topic. F8 to return to the program.
---------------------------------------	---

This Help Section gives detailed information for entering the nonlinear and auxiliary equations. Press F8 to return from the Help Section to the program, and then press the Enter key (↵) to enter an equation for the first Quick Tour example. The Problem Options Menu at the bottom of your display allows entry of equations with the keypress of "a". Now you are ready for the first problem.

Nonlinear Equations: 0	Auxiliary Equations: 0
------------------------	------------------------

PROBLEM OPTIONS

a. to add an equation. ↑ F8 for file and library options.	t. to enter title. ↑ F7 to solve the problem. F6 for helpful information.
--	---

SOLVING ONE NONLINEAR EQUATION

The first nonlinear equation to be solved as Quick Tour Problem 1 is:

$$x^2 - 5x + 6 = 0$$

The solution is to be obtained over the range of x between 1 and 4. This equation is entered into POLYMATH using the equation entry guidelines where the equation is to be zero at the solution. The following display gives the equation as it should be entered at the arrow: (Use the ← or the delete key to erase entered characters. Standard DOS editing is available at the cursor.)

Nonlinear Equations: 1	Auxiliary Equations: 0
▷ f(x)=x^2-5*x+6_	

The format for the above equation for $f(x)$ is that the left side of the equation will be equal to zero when the solution has been obtained. The variable which is to be determined is set as an argument within the parentheses for the function $f()$.

Thus in this case, the variable is x and the function to be solved as being zero is x^2-5x+6 . Also note that in POLYMATH one way of entering x^2 is x^2 . An alternative entry is $x**2$.

After you have correctly typed the equation at the arrow, please press ← once to enter it and then ← **again** to end equation entry. This should result in the Problem Options Menu at the bottom of the display and the equation at the top:

Equations	
→ f(x)=x^2-5*x+6	
Nonlinear Equations: 1	Auxiliary Equations: 0
PROBLEM OPTIONS NUM1	
a/d/c/u. to add/delete/change/duplicate an equation.	t. to enter title.
i. to specify initial values.	
↑ F7 to solve the problem.	
↑ F8 for file and library options.	F6 for help. F3 to print problem.

The Problem Options Menu indicates which options are now available for you to carry out a number of tasks. In this case, the problem should be complete, and these options for the equation at the arrow will not be needed. If an equation needed to be changed, then you would enter a "c" at the above display. (The arrow is moved by the arrow keys on the keyboard.)

Once you have the equation entered properly, please press $\uparrow F7$ to solve the problem. You will then be asked to provide the interval over which you wish to find solutions for the equation. This interval is only requested during the solution of a single nonlinear equation.

```
Enter minimal value for x
> _
```

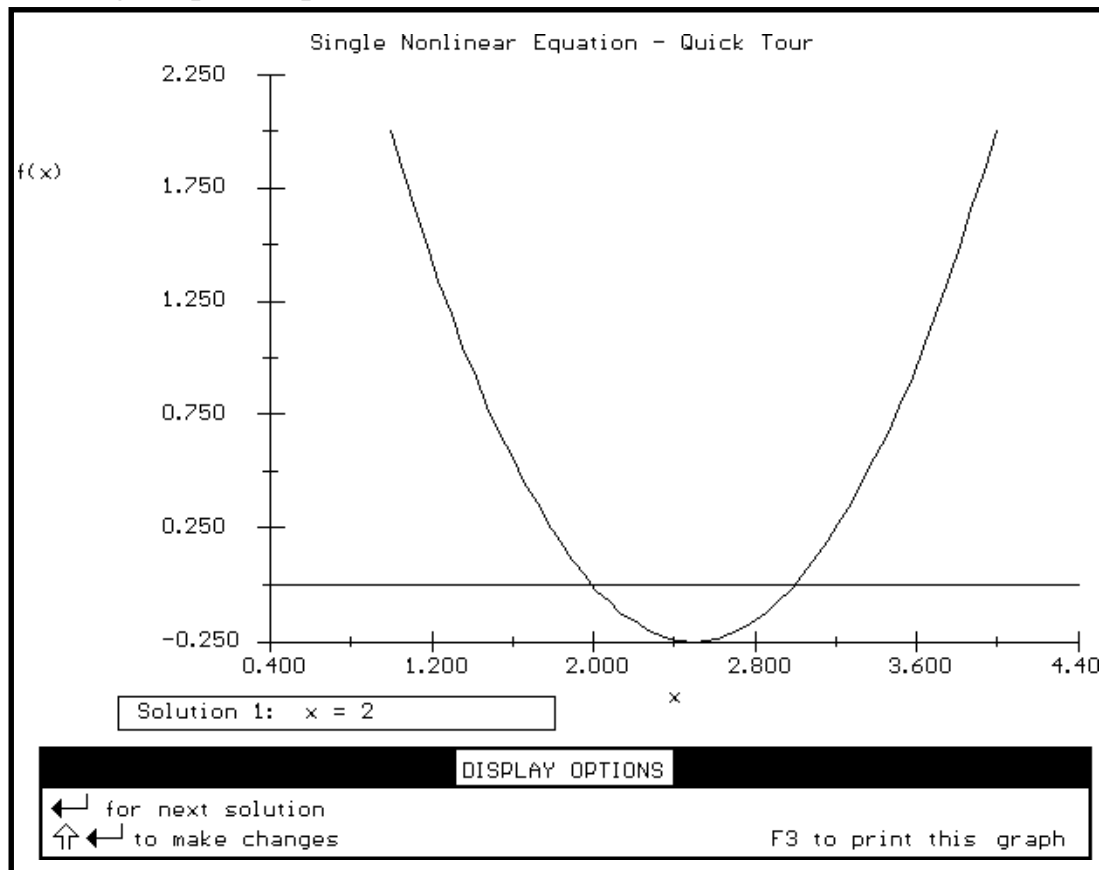
Please indicate the x_{\min} to be 1 and press (\leftarrow). Then indicate x_{\max} to be 4 and press (\leftarrow).

```
Enter maximal value for x
> 4 _
```

The entire problem is then display above the Problem Options Menu:

```
Equations
→ f(x)=x^2-5*x+6
  x_min = 1,  x_max = 4
```

For this single equation, the solution is presented graphically over the search range which you indicated. The solution is where the function $f(x)$ is equal to zero. POLYMATH has the ability to determine multiple solutions to a single equation problem, and the first of two solutions is shown below:



Press enter (\leftarrow) for the second solution.

Solution 2: $x = 3$

A shift-return ($\uparrow \leftarrow$) will return you to the Problem Options Display.

SOLVING A SYSTEM OF NONLINEAR EQUATIONS

Next, you will solve two nonlinear equations with two unknowns. To enter this new set of equation press \uparrow F8 for a new problem, then press \leftarrow followed by "y" to enter a new problem.

The equations that will be solved are:

$$k C_{A1}^2 = \frac{v (C_{Af} - C_{A1})}{V} \quad \text{and} \quad k C_{A2}^2 = \frac{v (C_{A1} - C_{A2})}{V}$$

where $k = 0.075$; $v = 30$; $C_{Af} = 1.6$; $C_{A2} = 0.2C_{Af}$.

Thus there are two unknowns: C_{A1} and V .

To solve this system of equations, each nonlinear equation must be rewritten in the form $f(x) =$ (an expression that is to have the value of zero at the solution). The appropriate forms for these equations are:

$$f(C_{A1}) = kC_{A1}^2 - \frac{v(C_{Af} - C_{A1})}{V}$$

and

$$f(V) = kC_{A2}^2 - \frac{v(C_{A1} - C_{A2})}{V}$$

All equations can be entered into POLYMATH as shown below. Note that each of the problem unknowns (C_{A1} and V) should appear once and only once inside the brackets in the left of the equal sign. The unknown variable may not be in that particular equation. POLYMATH just needs to know the variable names that you are using in your problem. The explicit algebraic equations may be entered directly. Please enter the equations as given below. The order of the equation is not important as POLYMATH will order the equations during problem solution.

Equations

$$f(Ca1)=k*Ca1^2-v*(Caf-Ca1)/V$$

$$f(V)=k*Ca2^2-v*(Ca1-Ca2)/V$$

$$k=0.075$$

$$Caf=1.6$$

$$v=30$$

$$Ca2=0.2*Caf$$

Press \uparrow F7 to solve this system of equations.

For two or more nonlinear equations, POLYMATH requires an initial estimate to be specified for each unknown.

```
Enter initial value for Ca1
> _
```

While the solution method used is very robust, it often will not be able to find the solution if unreasonable initial estimated are entered. In this example, physical considerations dictate that C_{A1} must be smaller than C_{A0} and larger than C_{A2} . So please enter initial estimate of Ca1 as 1.0. As for V, any positive value up to about $V=3900$ can be a reasonable estimate. Please use the initial value of 300 for V in this Quick Tour example.

After entering the initial values, this example problem should be:

Equations	Initial values
→ $f(Ca1)=k*Ca1^2-v*(Caf-Ca1)/U$	1
$f(U)=k*Ca2^2-v*(Ca1-Ca2)/U$	300
$k=0.075$	
$v=30$	
$Caf=1.6$	
$Ca2=0.2*Caf$	

Please press \uparrow -F7 to solve the problem. The solution process will start and its progress will be indicated on the screen by an arrow moving along a ruler scale. For most computers, the solution is so fast that the display of the iterations in the numerical solution to a converged solution will not be seen. When visible, the arrow indicates how far from zero the function values are at a particular stage of the solution on a logarithmic scale. Details are given in the Help Section by pressing F6.

The results are given after any keypress as shown below:

Variable	Solution	
	Value	f()
Ca1	0.601997	-2.04e-15
U	1101.55	-6.739e-16
k	0.075	
v	30	
Caf	1.6	
Ca2	0.32	

Please note that the values of the various nonlinear equation functions (nearly zero) are given along the with values of all the problem variables.

This concludes the Quick Tour problem using the Simultaneous Nonlinear Algebraic Equation Solver. If you wish to stop working on POLYMATH, please follow the exiting instructions given below.

EXITING OR RESTARTING POLYMATH

A \uparrow - F10 keypress will always stop the operation of POLYMATH and return you to the Program Selection Menu. **THIS ACTION WILL DELETE THE EXISTING PROBLEM.** The program can be exited or restarted from the Program Selection Menu.

SELECTION OF INITIAL ESTIMATES FOR THE UNKNOWNNS

The solution algorithm requires specification of initial estimates for all the unknowns. Generally speaking, closer initial estimates have a better chance of converging to the correct solution.

If you wish to solve only a single nonlinear equation, the program will plot the equation so that the location of the roots (if any) can be seen. The program will then show the roots. If no roots exist in the chosen range, the plot will indicate what range should be explored to have the nonlinear function $f()$ cross zero.

When several equations are to be solved, the selection of the initial values is more complicated. First, the user should try to find the limiting values for the variables using physical considerations. (For example: The mole or mass fraction of a component can neither be negative nor greater than 1; the temperature of cooling water can be neither below freezing nor above boiling; etc.) Typical initial estimates are taken to be mid range.

Users should be particularly careful not to select initial estimates where some of the functions may be undefined. (For example, $f(xa)=1/(xa-xb)+...$ is undefined whenever $xa=xb$; $f(xb)=\log(1-xb)$ is undefined whenever $xb \geq 1$; etc.) The selection of such initial estimates will stop the POLYMATH solution, and an error message will be displayed.

METHOD OF SOLUTION

For a single nonlinear equation, the user must specify an interval in which the real root(s) can be found. The program will first attempt to locate points or regions where the function is undefined inside this interval*. If the equations are too complicated for determination of discontinuity points, a warning message is issued.

*For details of the method, see Shacham, O. and Shacham, M., Acm. Trans. Math. Softw., **16** (3), 258-268 (1990).

The function is plotted and smaller intervals in which root(s) are located by a sign change of the function. The Improved Memory Method*, which employs a combination of polynomial interpolation and bisection, is used to converge to the exact solution inside those intervals. Iterations are stopped when the relative error is $<10^{-10}$. Numerical perturbation is used to calculate needed derivatives.

For solving a system equations, the bounded Newton-Raphson (NR) method is used. The NR direction is initially used, but the distance is limited by the possible discontinuities **. The progress in iteration will be either the full NR step or close to the first point of discontinuity in that direction. The logarithm of the Euclidean norm of the function residuals is displayed during solution. Norm values below 10^{-5} are not shown. Iterations end when the norm of the relative error is $< 10^{-10}$.

TROUBLE SHOOTING

Most error messages are self-explanatory and suggest needed action. Other less obvious error messages and suggested actions are given below:

"Circular dependency detected."

This message appears while inputting equations when an attempt is made to define a variable as a function of another variable that was already defined as a function of the new variable. For example, attempting to define $y=z/x$, when z is already defined as a function of y , will cause this error. This can be prevented by writing the equation in a implicit form: $f(y)=y-z/x$.

"Solution process halted because ..."

This message for simultaneous nonlinear equations suggests that:

1. The system contains equations which are very nonlinear.
2. The initial estimates are too far from the solution.

or 3. **The problem has no solution.**

Equations can be made less nonlinear by eliminating division by unknowns (multiplying both sides of the equation by the expression that contains the unknowns). Often, substitution and reordering can bring the system of equations to a form that only one equation is implicit. Realistic initial estimates can often help achieve a solution. Finally, nonconvergence may indicate that the set of equations set has no solution. Check the problem setup in this case and pay particular attention to the units.

*For details of this method, see Shacham, M., Computers & Chem. Engng., 14 (6), 621-629 (1990)

**For details of the method, see Shacham, O. and Shacham, M., Acm. Trans. Math. Softw., 16 (3), 258-268 (1990).

LINEAR EQUATION SOLVER

QUICK TOUR

This chapter is intended to give a very brief discussion of the operation of the POLYMATH Linear Equation Solver.


LINEAR EQUATION SOLVER

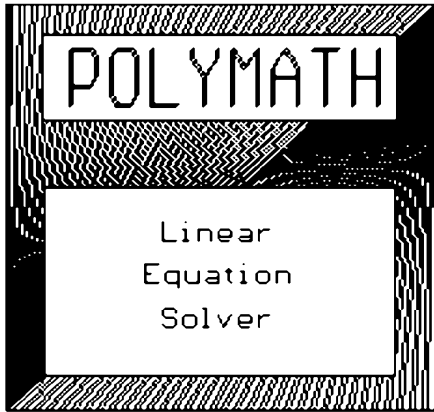



The user can solve up to a combination of 32 simultaneous linear equations. The equations are entered in matrix form.

STARTING POLYMATH

To begin, please have POLYMATH loaded into your computer as detailed in Chapter 2. Here it is assumed that your computer is set to the hard disk subdirectory containing the POLYMATH package. At the prompt (assumed C:\POLYMAT4 here), you should enter "polymath"

```
C:\POLYMAT4>polymath
```

then press the Return () key. The Main Program Menu should then appear: The Program Selection Menu should then appear, and you should enter "3" on the keyboard to select the Linear Equation Solver.

 <p> to begin. F6 for HELP menu. F7 for sample problems. F8 for POLYMATH menu. F9 for file options.  F9 for the credits.</p>	<p>The following keys are always active:</p> <hr/> <p> F10 to return to this display F4 for calculator F5 for unit converter</p>
---	---

Once that POLYMATH is loaded, please utilize the Help Menu by pressing F6 for information regarding the use of the Linear Equation Solver. This Help Section is given below:

ENTERING DATA INTO THE LINEAR EQUATION SOLVER

The purpose of this program is to solve systems of up to 32 linear equations, where the coefficients and constants are entered in matrix form.

On the main data screen, the matrix of coefficients (up to 6 columns and 18 rows of it) and the vector of coefficients (up to 18 rows of it) are displayed. Each equation (row) is indicated by a number, and each column by a variable name (x1, x2, ..., xn, b).

At any given time, one of the boxes is highlighted. This is the current box. You can move the highlight by using the arrow keys (↑,↓,→,←) and the Home, End, PageUp and PageDown keys (if you use the numeric keypad keys, make sure NumLock is off). The Home and End keys function as Page Left and Page Right, respectively.

To enter or modify a value in a data cell, move the highlight to the appropriate box and either start typing in a number, or press <Enter> to edit the value already in the box. When you are done typing in the number, you may press the <Tab> key to move to the next box in the current row, the ↑ or ↓ key to move to the box above or below the current one, or <Enter> to move to the first box in the next row. Note that if you started editing by pressing <Enter>, pressing <Enter> when done will not move the highlight.

Column names may not be changed.

This Help Section gives detailed information for entering a system of linear equations. Press any key to return from the Help Section to the program, and your display should be at the Main Menu for the Linear Equation Solver. (An alternate command to reach the Main Menu is the ↑F10 keypress.)

To begin the first Quick Tour example, please press the Return key (↵) from the Main Menu. This will give the Task Menu as shown below:

TASK MENU

↵ to enter a new problem.
F7 for SAMPLE PROBLEMS MENU.
F9 for LIBRARY OPTIONS.

DOS file options:
S. Save current problem on file.
L. Load problem from file.

↑ F10 for the MAIN MENU

SOLVING FIVE SIMULTANEOUS LINEAR EQUATIONS

A typical problem for simultaneous linear equations is given below for the variables x1 through x5:

$$\begin{aligned} x_1 + 0.5 x_2 + 0.333333 x_3 + 0.25 x_4 + 0.2 x_5 &= 0.0 \\ 0.5 x_1 + 0.333333 x_2 + 0.25 x_3 + 0.2 x_4 + 0.166667 x_5 &= 1.0 \\ 0.333333 x_1 + 0.25 x_2 + 0.2 x_3 + 0.166667 x_4 + 0.142857 x_5 &= 0.0 \\ 0.25 x_1 + 0.2 x_2 + 0.166667 x_3 + 0.142857 x_4 + 0.125 x_5 &= 0.0 \\ 0.2 x_1 + 0.166667 x_2 + 0.142857 x_3 + 0.125 x_4 + 0.111111 x_5 &= 0.0 \end{aligned}$$

The above problem is stored as a Sample Problem in POLYMATH. To recall the above problem, press F7 from the Task Menu of the Linear Equation Solver. Then select problem number "2" to obtain the Problem Options Menu shown below:

Sample Problem 2						
Name	x1	x2	x3	x4	x5	b
1	1	0.5	0.333333	0.25	0.2	0
2	0.5	0.333333	0.25	0.2	0.166667	1
3	0.333333	0.25	0.2	0.166667	0.142857	0
4	0.25	0.2	0.166667	0.142857	0.125	0
5	0.2	0.166667	0.142857	0.125	0.111111	0

PROBLEM OPTIONS	
← to edit current box.	↑, ↓, →, ←, PgUp, PgDn, Home, End to move pointer.
	T. to enter title
⇧ F7 to solve this problem.	F6 for helpful information.
⇧ F8 for file and library options.	F3 to print problem.

Solve this system of equations by pressing ⇧F7 which should yield the results and the Display Options Menu on the next page. Remember that this keypress combination is accomplished by pressing and holding the Shift key and then pressing the F7 function key.

Sample Problem 2	
Solution	
Variable	Value
x1	-300
x2	4800
x3	-18900
x4	26880
x5	-12600

DISPLAY OPTIONS	
d. Output results to DOS file.	F3 to print results.
⇧ F8 for new problem or library	⇧ ← to make changes.

Lets explore making changes to this system of equations. This is accomplished by first pressing $\uparrow \leftarrow$ to "make changes" to the problem. Use the arrow keys to take the highlighted box to the top of the "b" of constants for the equation. Please delete the 0 and enter 1.0 in this box which corresponds to changing the first linear equation to:

$$x_1 + 0.5 x_2 + 0.333333 x_3 + 0.25 x_4 + 0.2 x_5 = 1.0$$

This involves using the arrow key and pressing the return key (\leftarrow) when the highlighted box is in the desired location as shown.

b	
0	
1	
0	
0	
0	

Then enter the new value at the cursor:

$\> 1 _$ Tab: next column

Please solve the problem by pressing $\uparrow F7$. The results are shown below:

Sample Problem 2	
Variable	<u>Solution</u> Value
x1	-275
x2	4500
x3	-17850
x4	25480
x5	-11970

This concludes the Quick Tour Problem for Simultaneous Linear Equations. When you are ready to leave this program and return to the Program Selection Menu, use the $\uparrow F10$ keypress which is discussed below.

EXITING OR RESTARTING POLYMATH

A $\uparrow F10$ keypress will always stop the operation of POLYMATH and return you to the Program Selection Menu. **THIS ACTION WILL DELETE THE EXISTING PROBLEM.** The program can be exited or restarted from the Program Selection Menu.

REGRESSION

QUICK TOUR

This chapter is intended to give a very brief overview of the operation of the POLYMATH Polynomial, Multiple Linear and Nonlinear Regression program.

REGRESSION PROGRAM

This program allows you to input numerical data into up to 30 columns, with up to 100 data points in each column. The data can be manipulated by defining expressions containing the names of previously defined columns. Relationships between different variables (columns of data) can be found using polynomial, multiple linear and nonlinear regression as well as cubic spline interpolation. Fitted curves can be interpolated, differentiated and integrated. Graphical output of the fitted curves and expressions is presented, and a statistical analysis of the parameters found during the regressions is given.

STARTING POLYMATH

To begin, please have POLYMATH loaded into your computer as detailed in Chapter 2. Here it is assumed that your computer is set to the hard disk subdirectory or floppy drive containing the POLYMATH package. At the prompt (assumed C:\POLYMAT4 here), you should enter "polymath"

```
C:\POLYMAT4 > polymath
```

then press the Enter (↵) key. The Program Selection Menu should then appear, and you should enter "4" on the keyboard to select the Polynomial, Multiple Linear and Nonlinear Regression program. This should bring up the Main Program Menu as given in the next page.

In order to save time in entering data points during this quick tour, we will use sample problems which have been stored in POLYMATH. Press F7 to access the Sample Problems Menu from the Main Program Menu.

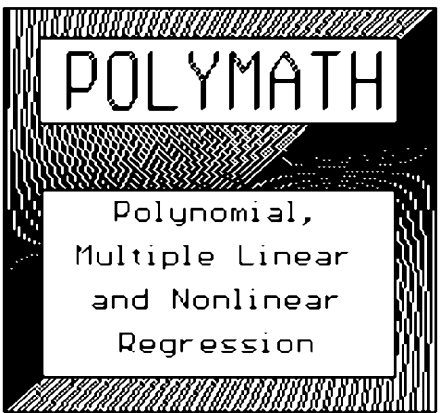
QUICK TOUR PROBLEM 1

Let us consider a fairly typical application of the Regression Program in which some data are available. When these data are fitted to a polynomial

within POLYMATH, the polynomial expression has the form:

$$P(x) = a_0 + a_1x + a_2x^2 + \dots + a_nx^n$$

where y is the dependent variable, x is the independent variable, and the parameters are $a_0 \dots a_n$. Variable "n" here represents the degree of the polynomial. In POLYMATH, the maximum degree which is shown is 5. The above polynomial expression gives a relationship between the dependent variable and the independent variable which is obtained by determining the parameters according to a least squares objective function. Data points are usually available which give x and y values from which the parameters $a_0 \dots a_n$ can be determined.

 <p>← to begin. F6 for HELP menu. F7 for sample problems. F8 for POLYMATH menu. F9 for file options. ↑ F9 for the credits.</p>	<p>The following keys are always active:</p> <hr/> <p>↑ F10 to return to this display F4 for calculator F5 for unit converter</p>
--	---

RECALLING SAMPLE PROBLEM 3

After pressing F7 at the Main Program Menu, the Sample Problems Menu should appear on your screen as shown on the next page.. The sample problem to be discussed should be retrieved by pressing "3" on the keyboard. This will result in the Problem Options Display which includes 10 data points of x and y as shown on the next page.

SAMPLE PROBLEMS MENU

- 1 One independent variable fitted to an equation of the form

$$Y = a_0 X^{a_1} \quad \text{linearized to:}$$

$$\ln Y = a_0 + a_1 \ln X$$

- 2 One independent variable fitted to a nonlinear equation:

$$Y = 10 \{ a_0 + a_1 / (X+z) \}$$

- 3 One independent variable fitted to a polynomial.

- 4 Two independent variables fitted to a linear equation:

$$Y = a_0 + a_1 X_1 + a_2 X_2$$

- 5 Two independent variables fitted to an equation of the form:

$$Y = a_0 X_1^{a_1} X_2^{a_2} \quad \text{linearized and regressed as:}$$

$$\ln Y = a_0 + a_1 \ln X_1 + a_2 \ln X_2$$

- 6 Three independent variables fitted to an equation of the form:

$$Y = 1000 X_1 / (a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3)$$

linearized to:

$$1000/Y = a_1 + a_0*(1/X_1) + a_2*(X_2/X_1) + a_3*(X_3/X_1)$$

regressed as:

$$y = a_1 + a_0*x_1 + a_2*x_2 + a_3*x_3$$

F8 to return

Sample Problem 3

Name	X	Y					
1	0.23	5.64					
2	1.01	7.83					
3	2.29	17.04					
4	2.87	21.38					
5	4.15	24.56					
6	5.36	16.21					
7	5.51	14.57					
8	6.36	0.78					
9	6.84	-7.64					
10	7	-12.52					
11							
12							
13							
14							
15							
16							
17							
18							

PROBLEM OPTIONS

NUM

- ← to edit current box. ↑, ↓, →, ←, PgUp, PgDn, Home, End to move pointer.
- ↑ ← for row/column options. T. to change title.
- ↑ F7 to fit a curve or do regression. F6 for helpful information.
- ↑ F8 for file and library options. F3 to print problem.

FITTING A POLYNOMIAL

The Problem Options Menu includes problem editing, library, printing, help and solution options. To fit a polynomial to the data of Y versus X you should select the "↑ F7 to fit a curve or do regression" option. After pressing ↑ F7 the following "Solution Options" menu appears:

SOLUTION OPTIONS	
l. Do linear regression.	L. Linear regression without free parameter.
p. Fit a polynomial.	P. Polynomial passing through origin.
s. Fit a cubic spline.	R. Do nonlinear regression.
↑ ← or F8 for problem options	

After pressing "p" (lower case), you should be asked for the name of the independent variable's column, as shown below:

Enter independent column name (← to cancel): > _
--

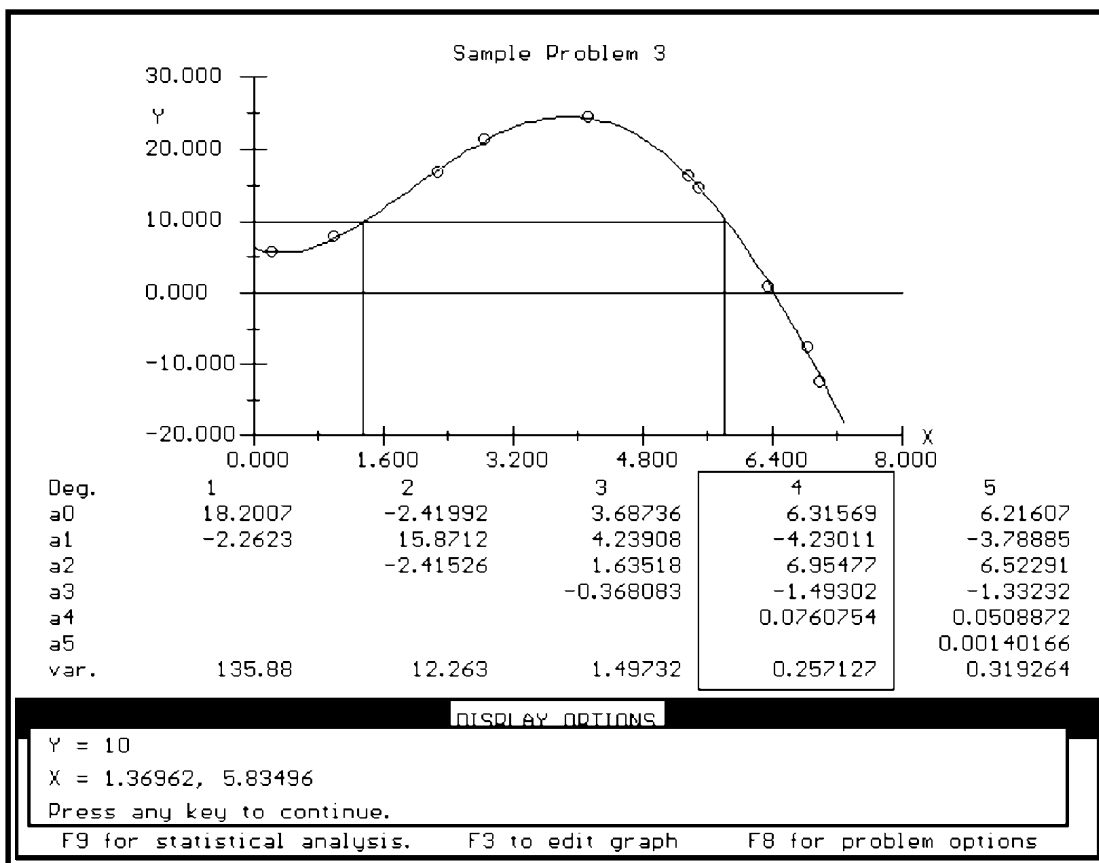
You should enter a capital "X" (upper case) as name of the independent variable and press ←. The same question regarding the dependent variable will be presented. Please enter a capital "Y" (upper case) at the arrow. The following display should appear:

Sample Problem 3

Deg.	1	2	3	4	5
a0	18.2007	-2.41992	3.68736	6.31569	6.21607
a1	-2.2623	15.8712	4.23908	-4.23011	-3.78885
a2		-2.41526	1.63518	6.95477	6.52291
a3			-0.368083	-1.49302	-1.33232
a4				0.0760754	0.0508872
a5					0.00140166
var.	135.88	12.263	1.49732	0.257127	0.319264

DISPLAY OPTIONS		
1, 2, 3, 4, 5 to choose a polynomial	r. Residuals plot	s. save results
x. Y value for specific X	y. X value for specific Y	
i. Integrate polynomial	d. differentiate polynomial	
F9 for statistical analysis.	F3 to edit graph	F8 for problem options

On this display the coefficients of the polynomial $P(x)$, up to the fifth order are shown together with the value of the variance. One of the polynomials is highlighted by having a box around it. This is the lowest order polynomial, such that higher order polynomial does not give significantly better fit. The same polynomial is also plotted versus the experimental data. Other polynomials can be highlighted and plotted by pressing a number between 1 and 5. There are many additional calculations and other operations that can be carried out using the selected polynomial. Please make sure the highlighted box is on the 4th degree polynomial. Let us find the value of X for $Y = 10$. To do that you should press "y" and enter after the prompt regarding the value of Y : "10". The following display results:



The resultant X values are shown both graphically and numerically. For $Y = 10$ there are two X values, $X = 1.36962$ and $X = 5.83496$.

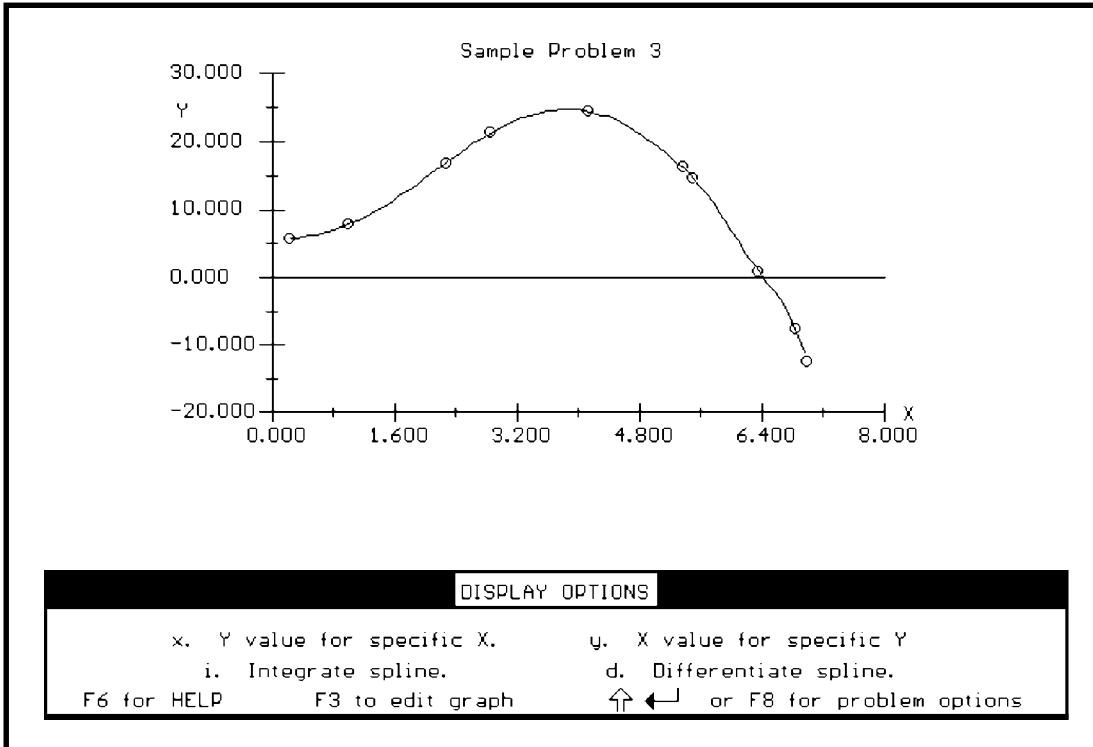
FITTING A CUBIC SPLINE

We will now fit a cubic spline to these data of Sample Problem 3. Please press F8 two times to return to the Problems Options Menu. Then press \uparrow F7 to "fit a curve or do regression". The Solutions Options Menu should appear.

SOLUTION OPTIONS

- l. Do linear regression.
 - p. Fit a polynomial.
 - s. Fit a cubic spline.
 - L. Linear regression without free parameter.
 - P. Polynomial passing through origin.
 - R. Do nonlinear regression.
- ↑ ← or F8 for problem options

Enter "s" (lower case) for a cubic spline followed by "X" and then "Y".
The following display should present the results:



EVALUATION OF AN INTEGRAL WITH THE CUBIC SPLINE

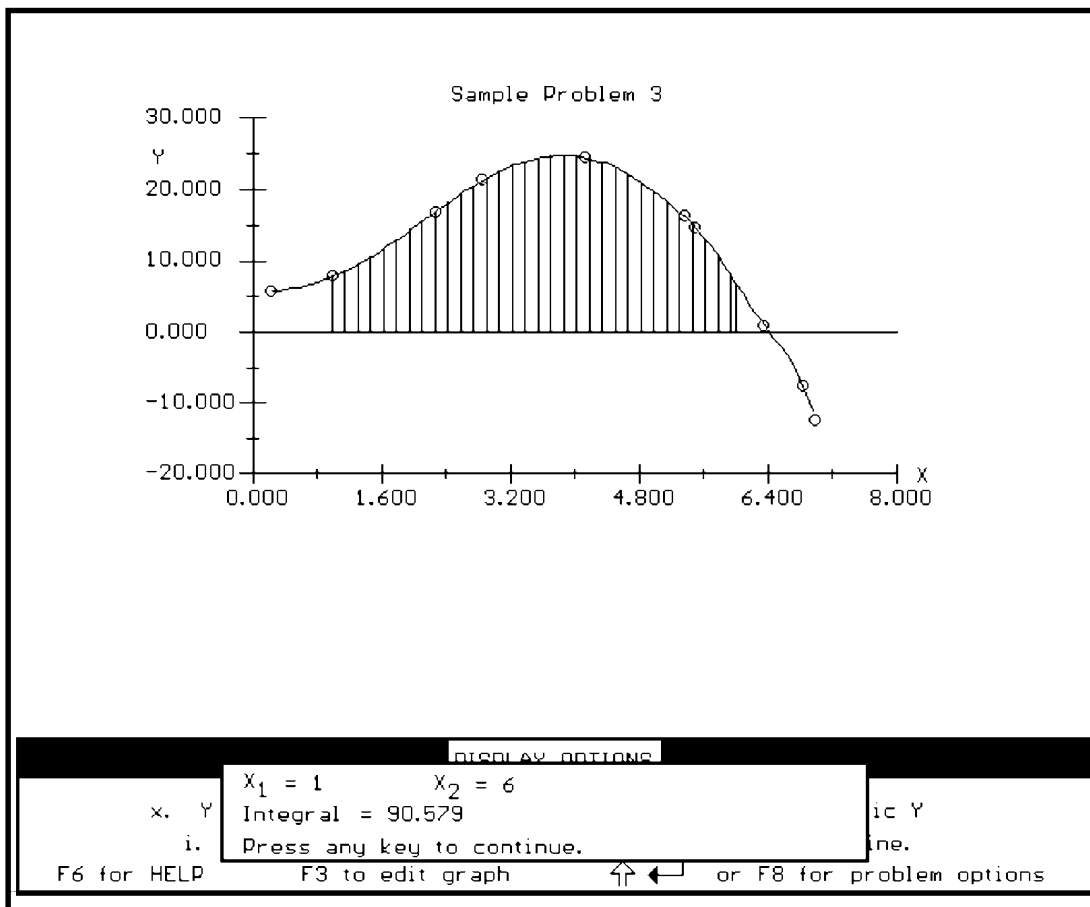
Please take options "i" and request the initial value for the integration to be "1" at the arrow:

Enter first value for X :>> 1 _

Press ← and then enter "6" at the arrow for the find value of the integration.

Enter second value for X :>> 6 _

Press ← to have the resulting integration shown on the next display with both graphical and numerical results:



Please press any key to end this Sample Problem 3.

MULTIPLE LINEAR REGRESSION

It will often be useful to fit a linear function of the form:

$$y(\underline{x}) = a_0 + a_1 x_1 + a_2 x_2 + \dots + a_n x_n$$

where x_1, x_2, \dots, x_n are n independent variables and y is the dependent variable, to a set of N tabulated values of $x_{1,i}, x_{2,i}, \dots$ and $y(x_i)$. We will examine this option using Sample Problem 4.

RECALLING SAMPLE PROBLEM 4

First exit to the main title page by pressing \uparrow F10. Press F7 to access the Sample Problems Menu, and select problem number 4 by pressing "4". (The problem display is shown on the next page).

Sample Problem 4						
Name	X1	X2	Y			
1	78	1	1.5			
2	113.5	3.2	6			
3	130	4.8	10			
4	154	8.4	20			
5	169	12	30			
6	187	18.5	50			
7	206	27.5	80			
8	214	32	100			
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						

PROBLEM OPTIONS **NUM**

← to edit current box. ↑, ↓, →, ←, PgUp, PgDn, Home, End to move pointer.
 ↑ ← for row/column options. T. to change title.
 ↑ F7 to fit a curve or do regression. F6 for helpful information.
 ↑ F8 for file and library options. F3 to print problem.

SOLVING SAMPLE PROBLEM 4

After you press ↑ F7 "to fit a curve or do regression", the following Solution Options Menu should appear:

SOLUTION OPTIONS	
l. Do linear regression.	L. Linear regression without free parameter.
p. Fit a polynomial.	P. Polynomial passing through origin.
s. Fit a cubic spline.	R. Do nonlinear regression.
	↑ ← or F8 for problem options

This time press "l" (lower case letter "l") to do "linear regression". You will be prompted for the first independent variable (column) name.

SOLUTION OPTIONS	
l. Enter 1st independent column name (← to end):	er.
p. > X1 _	
s.	
	↑ ← or F8 for problem options

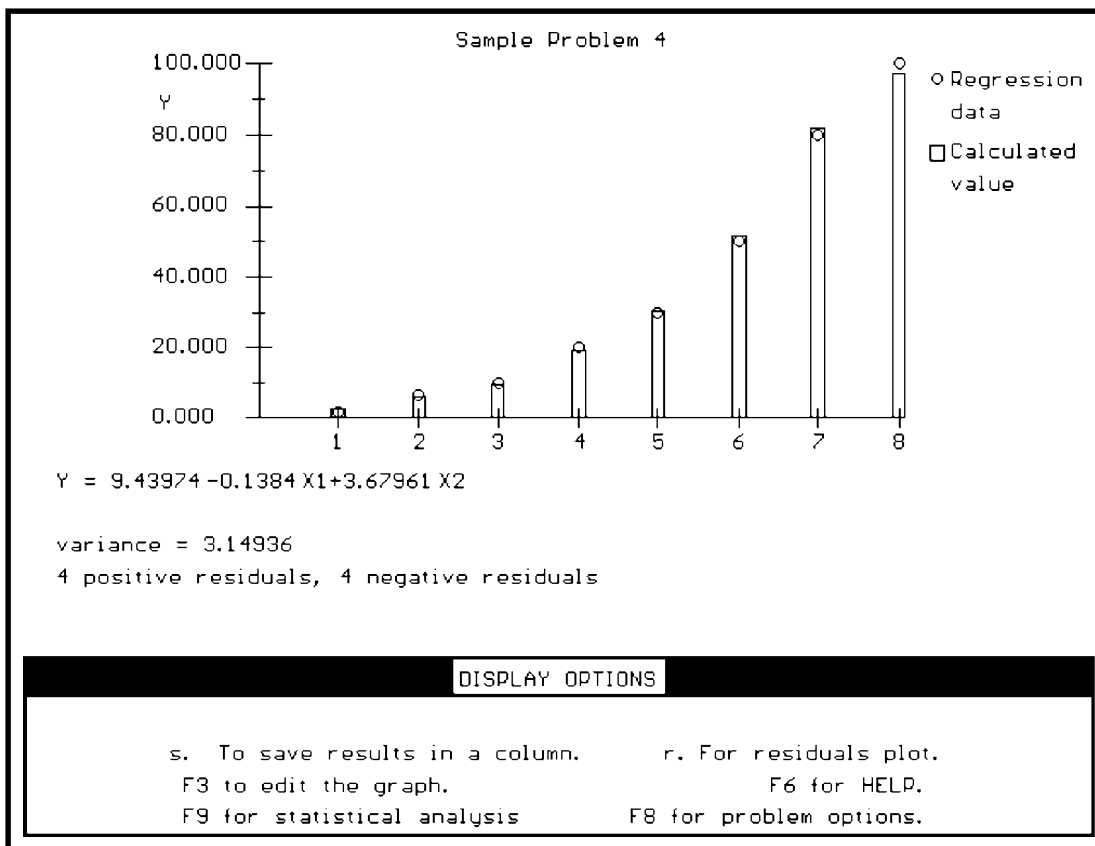
Please type in "X1" at the arrow and press ←. You will be prompted for the 2nd independent variable. Enter "X2" as the second independent variable name and press ← once again. A prompt for the 3rd independent variable will appear. You should press ← here without typing in anything else, since there are no additional independent variables.

At the prompt for the dependent variable (column) name shown below you should type "Y" and press \leftarrow .

```

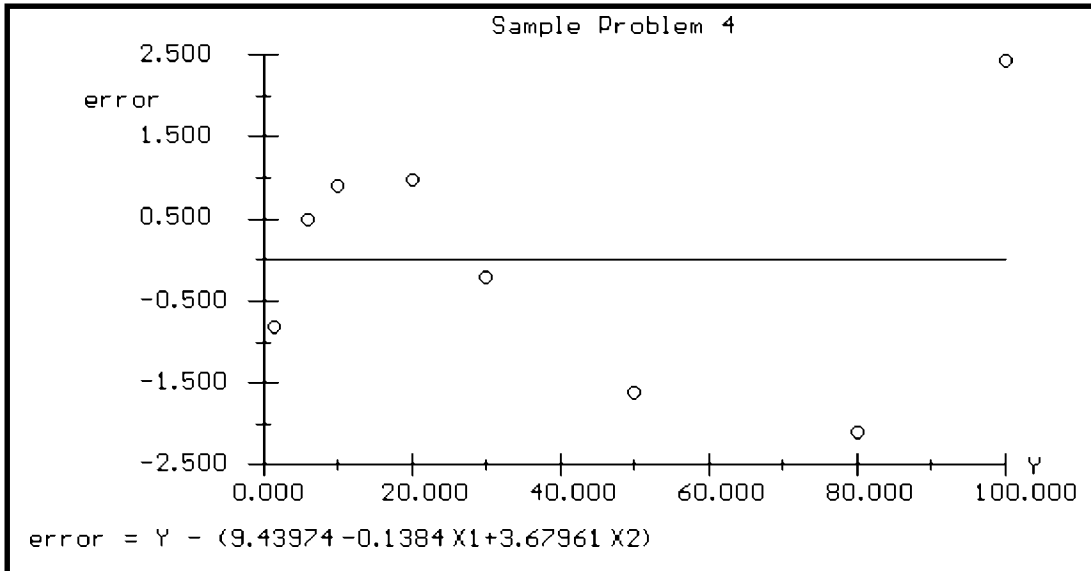
SOLUTION OPTIONS
1. Enter dependent column name (  $\leftarrow$  to cancel):
p. >> Y_
s.
F10  $\leftarrow$  or F8 for problem options
  
```

Once the calculations are completed, the linear regression (or correlation) is presented in numerical and graphical form.



Please note that the correlation the equation for variable "Y" has the form of the linear expression: $Y = a_0 + a_1 X_1 + a_2 X_2$ where $a_0 = 9.43974$, $a_1 = -0.1384$ and $a_2 = 3.67961$. This graphical display of Sample Problem 4 presents the regression data versus the calculated values from the linear regression. The numerical value of the variance and the number of the positive and negative residuals give an indication regarding the validity of the assumption that Y can be represented as linear function of X1 and X2. The results in this case indicate a good fit between the observed data and the correlation function.

The Display Options Menu allows the user to use an "s" keypress "to save results in a column". This refers to saving the calculated value of Y from the linear regression to the Problems Options Display under a column name provided by the user. The "r" keypress from the Display Options Menu give a statistical residual plot as shown below:



The "F9" keypress from the Display Options Menu give a statistical summary:

Sample Problem 4

Matrix of correlation coefficients for the linear correlation equation

	1	2	3
1	1	-0.973045	0.8467
2	-0.973045	1	-0.935468
3	0.8467	-0.935468	1

Param.	Value	0.95 conf. interval	lower limit	upper limit
1	9.43974	11.1725	-1.73278	20.6123
2	-0.1384	0.103488	-0.241888	-0.0349122
3	3.67961	0.423457	3.25615	4.10307

The confidence intervals given in the statistical summary are very useful in interpreting the validity of the linear regression of data.

This concludes Sample Problem 4 which illustrated multiple linear regression.

TRANSFORMATION OF VARIABLES

A nonlinear correlation equation can be often brought into a linear form by a transformation of the data. For example, the nonlinear equation:

$$Y = a_0 X_1^{a_1} X_2^{a_2}$$

can be linearized by taking logarithm of both sides of the equation:

$$\ln Y = \ln a_0 + a_1 \ln X_1 + a_2 \ln X_2.$$

To demonstrate this option please recall Sample Problem 5. To do this, please press \uparrow F10 to get to the Main Program Menu, F7 to access the Sample Problems Menu and select Sample Problem number 5. This should result in the Problem Option Display below:

Sample Problem 5							
Name	X1	X2	Y	lnX1	lnX2	lnY	
1	0.475	0.475	1.063	-0.74444	-0.74444	0.0610951	
2	0.465	0.465	1.05	-0.765718	-0.765718	0.0487902	
3	0.421	0.42	1.2	-0.865122	-0.867501	0.182322	
4	0.32	0.52	0.6	-1.13943	-0.653926	-0.510826	
5	0.54	0.54	0.9375	-0.616186	-0.616186	-0.06454	
6	0.57	0.37	2.063	-0.562119	-0.994252	0.724161	
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							

PROBLEM OPTIONS	
\leftarrow	to edit current box. $\uparrow, \downarrow, \rightarrow, \leftarrow, \text{PgUp}, \text{PgDn}, \text{Home}, \text{End}$ to move pointer.
$\uparrow \leftarrow$	for row/column options. T. to change title.
\uparrow F7	to fit a curve or do regression. F6 for helpful information.
\uparrow F8	for file and library options. F3 to print problem.

In this display X1, X2 and Y represent the original data, the variables (columns) lnX1, lnX2 and lnY represent the transformed data. You can see the definition of ln X1 , for example, by moving the cursor (the highlighted box), which located in row number 1 of the first column, into the box containing "lnX1" (using the arrow keys) and press \leftarrow .

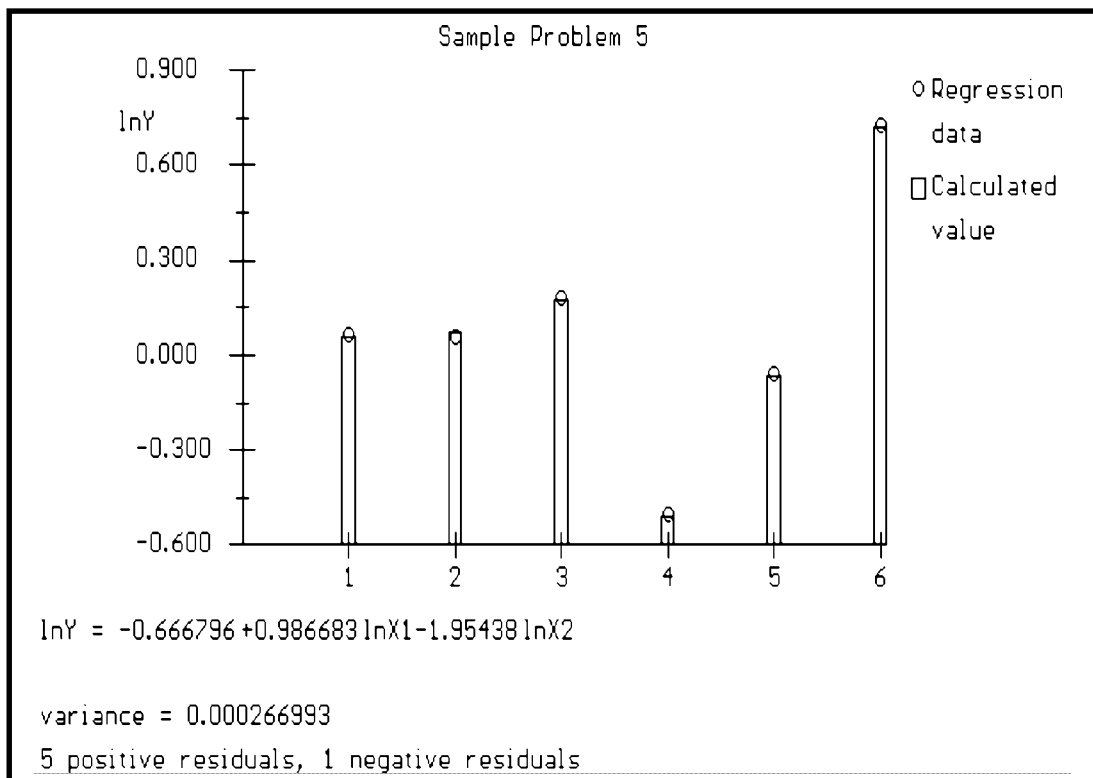
The following window is brought up:

Enter column definition:

➤ $\ln X1 = \ln(X1)$ _

Note that the expression in the right hand side of the column definition equation must be a valid algebraic expression, and any function arguments used in the expression should be enclosed within parentheses.

Since we do not want to change this expression, please press \leftarrow to close the window. Now press \uparrow F7 to do regression, then "l" to do linear regression. Type in "lnX1" as the name of the first independent variable, "lnX2" as the name of the second independent variable and "lnY" as the name of the dependent variable. The results should be displayed as shown below:



All of the statistical analyses are available for the transformed variable.

Please note that the results indicate that the equation for variable "Y" can be written as: $Y = a_0 X_1^{a_1} X_2^{a_2}$ where $a_0 = \exp(-0.666796) = 0.5133$, $a_1 = 0.986683$ and $a_2 = -1.95438$.

This concludes the transformation of variable and the multiple linear regression for Sample Problem 5.

NONLINEAR REGRESSION

It is often desirable to fit a general nonlinear function model to the independent variables as indicated below:

$$y(\underline{x}) = f(x_1, x_2, \dots, x_n; a_0, a_1, \dots, a_m)$$

In the above expression, x_1, x_2, \dots, x_n are n independent variables, y is the dependent variable, and a_0, a_1, \dots, a_m are the model parameters. The data are represented by a set of N tabulated values of $x_{1,i}, x_{2,i}, \dots$ and $y(\underline{x}_i)$. The regression adjusts the values of the model parameters to minimize the sum of squares of the deviations between the calculated $y(\underline{x})$ and the data $y(\underline{x}_i)$.

The nonlinear regression capability of POLYMATH allows a general nonlinear function to be treated directly without any transformation. Lets return to Sample Problem 5 and this time treat the model for Y directly where

$$Y = a_0 X_1^{a_1} X_2^{a_2} .$$

Please recall Sample Problem 5. From the Problem Options Display press \uparrow F7 and then enter "R" (upper case R) to "Do nonlinear regression." The user is then prompted to:

```
| Enter the model equation (  $\leftarrow$  to cancel) :  
|  $\gg$  _
```

The user can then enter the model equation using any of the variables from the columns of the Problem Options Display and any unknown parameters (maximum of five) which are needed. For this example, please enter

```
| Enter the model equation (  $\leftarrow$  to cancel) :  
|  $\gg$  Y=k*X1^alpha*X2^beta_
```

Thus in this problem, the unknown parameters are k , α , and β . The next query for the user is to supply initial estimates for each of the unknown parameter in turn:

```
| Enter initial guess for k :  
|  $\gg$  _
```

It is good practice to provide good initial parameter estimates from either reasonable physical/chemical model values or from a linearized treatment of the nonlinear model. In this example however, please set all initial guesses for the parameters as unity, "1.0". Then POLYMATH will provide a summary of the problem on the Regression Option Display as shown on the next page.

```

Sample Problem 5

Nonlinear regression model equation:
Y=k*X1^alpha*X2^beta

Initial estimates:
k = 1
alpha = 1
beta = 1

REGRESSION OPTIONS
e. Change the model equation.
i. Change the initial guesses.
  ↑ F7 to solve.
  F8 for the problem options.

```

The Regression Options Menu gives several useful options for model changes and alterations to initial parameter guesses; however, please press \uparrow F7 to solve this problem. The program search is shown to the user and the converged solution is indicated below:

```

Sample Problem 5

Nonlinear regression model equation:
Y=k*X1^alpha*X2^beta

Initial estimates:                Current values:
k = 1                             k = 0.509711
alpha = 1                         alpha = 0.987817
beta = 1                          beta = -1.96425

Log of sum of squares:
-3
-4
Sum of squares = 0.000903922

Solution process complete.
Press any key to see the graph of the results.

```

There are a number of options from the Display Options Menu (not shown here). Perhaps the most useful is the "statistical analysis" which is given on the next page.

$$\mathbf{X}^T \mathbf{X} \mathbf{A} = \mathbf{X}^T \mathbf{Y}$$

where

$$\mathbf{Y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix} \quad \mathbf{A} = \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_n \end{bmatrix} \quad \mathbf{X} = \begin{bmatrix} x_1^0 & x_1^1 & \cdot & \cdot & \cdot & x_1^n \\ x_2^0 & x_2^1 & \cdot & \cdot & \cdot & x_2^n \\ \vdots & \vdots & \cdot & \cdot & \cdot & \vdots \\ x_N^0 & x_N^1 & \cdot & \cdot & \cdot & x_N^n \end{bmatrix}$$

and where $y_1, y_2 \dots y_N$ are N observed values of dependent variable, and $x_1, x_2 \dots x_N$ are N observed values of the independent variable.

Multiple linear regression can also be expressed in the same form except that the matrix \mathbf{X} is redefined as follows:

$$\mathbf{X} = \begin{bmatrix} 1 & x_{1,1} & x_{2,1} & \cdot & \cdot & \cdot & x_{n,1} \\ 1 & x_{1,2} & x_{2,2} & \cdot & \cdot & \cdot & x_{n,2} \\ \vdots & \vdots & \vdots & \cdot & \cdot & \cdot & \vdots \\ 1 & x_{1,N} & x_{2,N} & \cdot & \cdot & \cdot & x_{n,N} \end{bmatrix}$$

where $x_{i,j}$ is the j -th observed value of the i -th independent variable.

When polynomial or multiple linear regression are carried out without the free parameter (a_0), the first element in vector \mathbf{A} and the first column in matrix \mathbf{X} must be removed.

In POLYMATH the normal equations are solved using the Gauss-Jordan elimination. It is indicated in the literature that direct solution of normal equations is rather susceptible to round off errors. Practical experience has shown this method to be sufficiently accurate for most practical problems.

The nonlinear regression problems in POLYMATH are solved using the Levenberg-Marquardt method. A detailed description of this method can be found, for example, in the book by Press et al.*

*Press, W. H., P. B. Flannery, S. A. Teukolsky, and W. T. Vetterling, **Numerical Recipes**, 2nd Ed., Cambridge University Press, 1992, pp. 678-683.

APPENDIX

INSTALLATION FROM THE CRE-99 CD-ROM ACCOMPANYING "ELEMENTS OF CHEMICAL REACTION ENGINEERING" AND EXECUTION INSTRUCTIONS FOR VARIOUS OPERATING SYSTEMS

This Appendix provides complete instructions for the installation and execution of POLYMATH for the DOS, Windows 3.1 and Windows 95 operating systems. Detailed information is provided for advanced options. Latest updates are on the README.TXT and INSTALL.TXT files.

DOS INSTALLATION

Place the CD-ROM in an appropriate drive. This is usually drive D. First set your current directory to that of the CD-ROM and indicate the location of the POLYMATH installation software. For example, if the drive to be used is D, then insert "D:" at the cursor and press Enter. Then enter "cd\html\toolbox\polymath\files". At the cursor enter "dir" to verify that you have the following POLYMATH installation files in that directory:

```
PMUNZIP.EXE
BGI.EXE
INSTALL.EXE
README.TXT
INSTALL.TXT
```

POLYMATH installation is initiated by typing "install" at the cursor the drive and subdirectory containing the above files. For a CD-ROM as drive D, this would be:

```
D:\html\toolbox\polymath\files>install
```

The installation program will ask a number of questions. These are listed later on this file. Please refer to the details of these questions as needed. Follow the instructions on the screen. Note that the initial recommendation for the Printer Output setting is option 1. Half Page, Low Resolution. When the installation is complete, press Enter.

DOS EXECUTION

1. Change your directory to the POLYMATH directory by entering "C:" and then "cd\polymath4" at the cursor. Substitute your specified location if you did not use the default directory location.
2. Enter "polymath" at the cursor.
3. Always end POLYMATH by exiting from the Program Selection Menu.

WINDOWS 3.1 INSTALLATION

1. Put the CD-ROM in the appropriate drive such as “D:”.
2. Double click on the Main icon in the Program Manager window.
3. Double click on the MS-DOS Prompt icon.
4. Change the directory to the CD-ROM drive to where POLYMATH is stored. For example, if the drive to be used is D, then insert “D:” at the cursor and press Enter. Then enter “cd\html\toolbox\polymath\files”.
5. At the D:\html\toolbox\polymath\files> prompt, enter “dir”.
6. The following five files should be listed: PMUNZIP.EXE, INSTALL.EXE, INSTALL.TXT, BGI.EXE, and README.TXT.
7. At the D:\html\toolbox\polymath\files> prompt, enter “install”
8. Follow the instructions on the screen. Please note that the initial recommended setting for Output is option 1. Half Page, Low Resolution.
9. At the DOS prompt enter “exit” to return to Windows

CONTINUE STEPS BELOW TO CREATE A PIF FILE FOR POLYMATH ONLY IF POLYMATH DOES NOT EXECUTE PROPERLY

10. From the Program Manager Window click on Main.
11. From the Main Window double click on PIF Editor.
12. Please enter the following in the PIF Editor:

Program Filename: POLYMATH.BAT
Window Title: POLYMATH 4.0
Startup Directory: C:\POLYMAT4
Video Memory: Low Graphics
Memory Requirements: -1 -1
EMS Memory: 0 1024
XMS Memory: 1024 1024
Display Usage: Full Screen

13. From File use Save As “POLYMAT4.PIF”.

WINDOWS 3.1 EXECUTION*

1. From the File options in the Program Manager Window, select Run.
2. The Command Line for your POLYMATH location should be entered such as “c:\polymat4\polymath”.
3. Click on “OK”
4. If POLYMATH does not run properly, then create a PIF file starting with Step 10 as given above.
5. Always end POLYMATH by exiting from the Program Selection Menu.

* A Program Group and a Program Item can be created under Windows to allow POLYMATH to be executed conveniently from the desktop.

Windows 95 Installation

1. Put the installation disk in your floppy drive.
2. Click on the Start button.
3. Click on the My Computer icon.
4. Double click on the CD-ROM icon indicating cre-99. Then continue double clicking on html, toolbox, polymath, and files.
5. Double click on the Install.exe file
6. Follow the directions on the screen. Please note that the initial recommended setting for Output is option 1. Half Page, Low Resolution.
7. When installation is complete, press Enter.
8. Close the DOS window.

Windows 95 Execution*

1. Click on the Start button.
2. Click on the Run icon.
3. Enter "c:\polymat4\polymath"
4. Always end POLYMATH by exiting from the Program Selection Menu.

* A Program Group and a Program Item can be created under Windows 95 to allow POLYMATH to be executed conveniently from the desktop.

INSTALLATION QUESTIONS

1. Enter drive and directory for POLYMATH [C:\POLYMAT4] :
==>

The default response is indicated by the contents of the brackets [...] which is given by pressing Enter key. The full path (drive and directory) where you wish the POLYMATH program files to be stored must be provided here. If the directory does not exist, then the installation procedure will automatically create it.

NOTE: Network clients will need read and execute permission for this directory and its subdirectories. This procedure does not provide the needed permissions.

2. Is this a network installation? [N]

If you are installing POLYMATH on a stand-alone computer, take the default or enter "N" for no and **GO TO 5. on the next page of this manual.** If you are installing on any kind of network server, answer "Y" and continue with the installation.

3. What will network clients call <POLYdir> [POLYdir]?

====> _

This question will only appear if you answered "Y" to question 2 to indicate a Network installation. Here "POLYdir" is what was provided in question 1. On some networks, the clients "see" server directories under a different name, or as a different disk, than the way the server sees them. This question enables POLYMATH to print by indicating where the printer-driver files are located. They are always placed in subdirectory BGI of the POLYMATH directory by the installation procedure. During run time, they must be accessed by the client machines, thus POLYMATH must know what the client's name is for the directory.

4. Enter drive and directory for temporary print files [C:\TMP]:

====> _

This question will only appear if you answered "Y" to question 2 to indicate a Network installation. Depending on the amount of extended memory available, and the type of printer is use, POLYMATH may need disk workspace in order to print. Since client machines are not normally permitted to write on the server disk, you are requested to enter a directory where files may be written. The temporary print files are automatically deleted when a print is completed or cancelled.

5. The POLYMATH installation program now copies all of the needed files according to your previous instructions. This may take some time as the needed files are compressed on the installation diskette.

6. Please select the type of output device you prefer [1]: _

1. Printer
2. Plotter

====> _

Your answer here will take you to an appropriate selection menu.

7 A. POLYMATH INSTALLATION - printer selection

Please select the type of printer you have:

1. Canon Laser Printer
2. Canon BJ 200
3. Canon BJC 600
4. HP LaserJet II

5. HP LaserJet III
6. HP LaserJet IV
7. HP LaserJet III or IV (HPGL/2)
8. Epson 9-pin Dot Matrix Printer
9. Epson 24-pin Dot Matrix Printer
10. Epson 9-pin Dot Matrix Printer (color)
11. Epson 24-pin Dot Matrix Printer (color)
12. Epson Stylus
13. Epson Color Stylus
14. IBM Proprinter
15. IBM Proprinter X24
16. IBM Quietwriter
17. Kodak Diconix
18. OkiData Dot Matrix Printer (native mode)
19. PostScript printer
20. Toshiba 24-pin Dot Matrix Printer (native mode)
21. Xerox CP4045/50 Laser Printer (USA)
22. Xerox CP4045/50 Laser Printer (International)
23. HP DesignJet
24. HP DeskJet (Black & White)
25. HP DeskJet 500C (Color)
26. HP DeskJet 550C (Color)
27. HP DeskJet 1200C
28. HP PaintJet
29. HP PaintJet XL300
30. HP ThinkJet

====> _

Type in the number of your printer (or a type of printer that your printer can emulate) and press Enter.

7 B. POLYMATH INSTALLATION - plotter selection

Please select the type of plotter you have:

1. HP 7090 Plotter
2. HP 7470 Plotter
3. HP 7475 Plotter
4. HP 7550 Plotter
5. HP 7585 Plotter
6. HP 7595 Plotter
7. Houston Instruments DMP/L Plotters

====> _

Type in the number of your plotter (or a type of plotter that your plotter can emulate) and press Enter.

Once you have selected either a printer or a plotter, you will be asked to select the mode for your output.

8. POLYMATH INSTALLATION - printer/ plotter mode selection

Please select the mode you want output in [1]:

1. Half Page, Low Resolution
2. Half Page, Medium Resolution
3. Half Page, High Resolution
4. Landscape, Low Resolution
5. Landscape, Medium Resolution
6. Landscape, High Resolution
7. Portrait, Low Resolution
8. Portrait, Medium Resolution
9. Portrait, High Resolution

====> _

Generally, the fastest printing with adequate resolution is option (1), which is also the default. This choice is recommended. It is easy to change your printer/plotter selection and mode by using the PRINTSET program which is installed in the POLYMATH directory.

9. POLYMATH INSTALLATION - printer/ plotter port selection

Please select the port your printer/plotter is connected to [1] :

1. LPT1
2. LPT2
3. COM1
4. COM2
5. LPT3

====> _

The default port, LPT1, is the first parallel port on most personal computers and usually is connected to the printer. For network installations, these are usually "logical" printer names, but they work just as well. If your network uses other printer logical names, please read the Appendix section entitled "PRINTING FOR ADVANCED USERS" which starts on the next manual page.

10. POLYMATH Execution

The POLYMATH program can now be executed by first changing the directory of your personal computer to the one where the program has been installed. Then you should enter "polymath" at the cursor as shown below and press Enter:

```
C:\POLYMAT4> polymath_
```

Windows users must use POLYMATH as a DOS program. Advanced users may wish to place the polymath program in the "path" statement of the autoexec.bat file so that POLYMATH is more easily available from any cursor.

"OUT OF ENVIRONMENT SPACE" MESSAGE

If you receive this message or if you are having difficulty in printing from POLYMATH, then follow **ONE** of the following instruction set for your particular operating system.

Window 95, Windows 98, or Windows NT 4.0

1. Open a DOS prompt window (if yours opens full-screen, hit Alt+Enter to get a window).
2. Click on the "Properties" button at the top.
3. At the end of the Cmd line, add the text "/e:2048" (if you already have this, then change the existing number to a higher number in increments of 1024).

Windows 3.x and Windows 95

1. Open a DOS prompt window.
2. At the C:\ prompt type "CD/WINDOWS, and press Enter.
3. Type "EDIT SYSTEM.INI" and press Enter.
4. Locate a line that reads "[NonWindows App]".
5. Make sure that this section contains the following entry:
"CommandEnvSize=2048".
6. Save the modified file.
7. Reboot your computer.
8. Adjust the size upwards in increments of 1024 as necessary.

DOS or Windows 3.1

1. Open a DOS prompt window.
2. Type "SET" at the prompt.

3. Look for the the line that displays the value of the COMSPEC environment variable.

If COMSPEC is set to C:\COMMAND.COM then add the following line to the CONFIG.SYS file:

```
SHELL=C:\COMMAND.COM C:\ /E:2048 /P
```

If COMSPEC is set to C:\DOS\COMMAND.COM then add this line to the CONFIG.SYS file:

```
SHELL=C:\DOS\COMMAND.COM C:\DOS /E:2048 /P
```

4. Reboot your computer.

5. Adjust the size of E: in Step 3 upwards in increments of 1024 as necessary.

CHANGING PRINTER SELECTION

The printer selection may be changed without a complete reinstallation of POLYMATH by using the PRINTSET utility program which is stored on the directory containing POLYMATH. This program is executed by entering "printset" while in the POLYMATH directory. If there are several printers to be used with POLYMATH, then different POLYMATH.BAT files can be created for each printer. The batch file for printers is discussed in the following section.

PRINTING FOR ADVANCED USERS

POLYMATH printing is accomplished using GRAF/DRIVE PLUS which is a trademark for copyrighted software from Fleming Software. The printer setup is controlled by three environmental variables which are set in the POLYMATH.BAT file. This file is created by the INSTALL procedure, and it can be subsequently be modified by the PRINTSET utility or with an editor. CAUTION: This file should only be altered with an editor by advanced users.

A typical POLYMATH.BAT file is shown below:

```
ECHO OFF
SET BGIPATH=C:\POLYMAT4\BGI
SET PM_WORKPATH=C:\POLYMAT4
SET PM_PRINTER=_LJ3R,0,LPT1
POLYMENU
CLS
```

In this file, the three environmental variables are:

BGIPATH - This is the directory in which the printer driver "BGI" files for **POLYMATH** reside. It is usually the BGI subdirectory of the **POLYMATH** directory. This variable is not normally changed.

PM_WORKPATH - This is the directory in which temporary print files are stored.

PM_PRINTER - This variable has the following form:

<printer_type>,<page_format>,<printer_port>

This variable in the previous **POLYMATH.BAT** file is defined as:

PM_PRINTER=_LJ3R,0,LPT1

where **_LJ3R** indicates the **printer_type** as HP LaserJet III, 0 (the number zero) indicates the **page_format** as half page with low density print, and **LPT1** indicates the **printer_port** as LPT1.

PM_PRINTER Options for <printer_type> and <page_format>

A detailed listing of the <printer-type> and <page_format> options is given in Table 1 at the end of this Appendix.

PM_PRINTER Options for <printer_port>

The <printer_port> may be any of the following: LPT1, LPT2, LPT3, COM1, COM2 or other physical/logical device names.

PRINTING TO STANDARD GRAPHICS FILES

It is possible to have all output which is "printed" by **POLYMATH** to be saved as various graphics files for use in word processing, desktop publishing, etc. This involves specialized use of the **PM_PRINTER** variable which is not available during the **INSTALL** procedure or the **PRINTSET** program for printer modification. **All printing to graphics files requires the creation of a special batch file for this purpose.**

A typical file for this purpose which is arbitrarily called POLYGRAP.BAT is shown below:

```
ECHO OFF
SET BGIPATH=C:\POLYMAT4\BGI
SET PM_WORKPATH=C:\POLYMAT4
SET PM_PRINTER=_TIF,0,FILE:C:\GRAPHS\PMOUT+++.TIF
POLYMENU
CLS
```

In the above file, the PM_PRINTER variable _TIF indicates the **printer_type** as a Tagged Image Format (TIFF), 0 indicates low resolution with two colors, and FILE:C:\GRAPHS\PMOUT+++.TIF indicates the location and name of the resulting graphics file.

PM_PRINTER Options for <printer_type> and <page_format> for Graphics Files

A detailed listing of the <printer-type> and <page_format> options for graphics file output is given in Table 2 at the end of this Appendix.

PM_PRINTER Options for <printer_port> for Graphics Files

This variable can be defined as FILE:<filename> when the output is to be to a file and not a port. (Note that if <filename> is a logical device name, such as LPT3, the output will be printed.) <filename> may be a particular filename or a general template, including '+' signs where a sequence number is to be written. The above example will create a sequence of files named PMOUT001.TIF, PMOUT002.TIF, etc., stored in directory C:\GRAPHS .

Table 1.1 - PM_PRINTER OPTIONS

<printer_type>	<page_format>	Output Page /Resolution /Color	<page_format>	Output Page /Resolution /Color
Epson-compatible 9-pin Dot Matrix, and IBM Proprinter				
_FX	0	HalfLo	5	LandHi
	1	HalfMed	6	FullLo
	2	HalfHi	7	FullMed
	3	LandLo	8	FullHi
	4	LandMed		
Epson-compatible 24-pin Dot Matrix				
_LQ	0	HalfLo	5	LandHi
	1	HalfMed	6	FullLo
	2	HalfHi	7	FullMed
	3	LandLo	8	FullHi
	4	LandMed		
Epson-compatible 9-pin Dot Matrix Printer (color)				
_CFX	0	HalfLoC	3	LandMedC
	1	HalfMedC	4	FullLoC
	2	LandLoC	5	FullMedC
Epson-compatible 24-pin Dot Matrix Printer (color)				
_CLQ	0	HalfLoC	3	LandMedC
	1	HalfMedC	4	FullLoC
	2	LandLoC	5	FullMedC

Table 1.2 - PM_PRINTER OPTIONS

<printer_ type>	<page_ format>	Output Page /Resolution /Color	<page_ format>	Output Page /Resolution /Color
IBM Proprinter X24				
_PP24	0	HalfLo	5	LandHi
	1	HalfMed	6	FullLo
	2	HalfHi	7	FullMed
	3	LandLo	8	FullHi
	4	LandMed		
IBM Quietwriter				
_IBMQ	0	HalfLo	5	LandHi
	1	HalfMed	6	FullLo
	2	HalfHi	7	FullMed
	3	LandLo	8	FullHi
	4	LandMed		
OkiData Dot Matrix Printer (native mode)				
_OKI92	0	Half	2	Full
	1	Land		
Toshiba 24-pin Dot Matrix Printer (native mode)				
_TSH	0	Half	2	Full
	1	Land		

Table 1.3 - PM_PRINTER OPTIONS

<printer_type>	<page_format>	Output Page /Resolution /Color	<page_format>	Output Page /Resolution /Color
LaserJet II, LaserJet III, LaserJet IV, DeskJet (black cartridge), Canon laser				
_LJ _LJ3R	0	HalfLo	5	LandHi
_LJ4 _DJ	1	HalfMed	6	FullLo
_Canon	2	HalfHi	7	FullMed
	3	LandLo	8	FullHi
	4	LandMed		
DeskJet 500C (color cartridge), and DeskJet 550C				
_DJC _DJC550	0	HalfLoC8	5	LandHiC8
	1	HalfMedC8	6	FullLoC8
	2	HalfHiC8	7	FullMedC8
	3	LandLoC8	8	FullHiC8
	4	LandMedC8		
PaintJet				
_PJ	0	HalfLoC2	8	FullLoC8
	1	LandLoC2	9	HalfHiC8
	2	FullLoC2	10	LandHiC8
	3	HalfHiC2	11	FullHiC8
	4	LandHiC2	12	HalfLoC16
	5	FullHiC2	13	LandLoC16
	6	HalfLoC8	14	FullLoC16
	7	LandLoC8		

Table 1.4 - PM_PRINTER OPTIONS

<printer_type>	<page_format>	Output Page /Resolution /Color	<page_format>	Output Page /Resolution /Color
PostScript Printers				
_PS	0	Half	6	HalfC16
	1	Land	7	LandC16
	2	Full	8	FullC16
	3	HalfGR	9	HalfC256
	4	LandGR	10	LandC256
	5	FullGR	11	FullC256
Hewlett-Packard Plotters				
_HP7090	0	DraftPL	2	DraftPLB
	1	LQPL	3	LQPLB
_HP7470	0	DraftPL	1	LQPL
_HP7475 _HP7550	0	DraftPL	4	DraftPLr
	1	LQPL	5	LQPLr
	2	DraftPLB	6	DraftPLBr
	3	LQPLB	7	LQPLBr
_HP7585 _HP7595	0	DraftPL	5	LQPLC
	1	LQPL	6	DraftPLD
	2	DraftPLB	7	LQPLD
	3	LQPLB	8	DraftPLE
	4	DraftPLC	9	LQPLE

Table 1.5 - PM_PRINTER OPTIONS

<printer_type>	<page_format>	Output Page /Resolution /Color	<page_format>	Output Page /Resolution /Color
Canon BJ 200, and Epson Stylus				
_BJ200 _ESCP2	0	HalfLo	5	LandHi
	1	HalfMed	6	FullLo
	2	HalfHi	7	FullMed
	3	LandLo	8	FullHi
	4	LandMed		
Canon BJC600, and Epson Color Stylus				
_BJC600 _ESCP2C	0	HalfLoC8	5	LandHiC8
	1	HalfMedC8	6	FullLoC8
	2	HalfHiC8	7	FullMedC8
	3	LandLoC8	8	FullHiC8
	4	LandMedC8		
HPGL/2 (DeskJet 1200C, PaintJet XL300, and DesignJet)				
_HGL2	0	HalfC2	5	FullC8
	1	LandC2	6	HalfC256
	2	FullC2	7	LandC256
	3	HalfC8	8	FullC256
	4	LandC8		

Table 2.1 - PM_PRINTER OPTIONS

<printer_ type>	<page_ format>	Output Page /Resolution /Color	<page_ format>	Output Page /Resolution /Color
Zsoft PCX				
_PCX	0	LoResC16	3	LoResC2
	1	MedResC16	4	MedResC2
	2	HiResC16	5	HiResC2
Windows BMP				
_BMP	0	ColorMode	1	MonoMode
GEM IMG				
_IMG	0	LoResC2	2	HiResC2
	1	MedResC2		
Tagged Image Format (TIFF) compressed and uncompressed				
_TIF _UTIF	0	LoResC2	2	HiResC2
	1	MedResC2		
Computer Graphics Metafile (ANSI)				
_CGM	0	ColorMode	1	MonoMode
AutoCad DXF				
_DXF	0	ColorMode		
Video Show (ANSI NAPLPS)				
_VSHO	0	ColorMode		
Word Perfect Graphics				
_WPG	0	ColorMode	1	MonoMode

Table 2.2 - PM_PRINTER OPTIONS

<printer_type>	<page_format>	Output Page /Resolution /Color	<page_format>	Output Page /Resolution /Color
Windows Metafile				
_WMF	0	ColorMode	1	MonoMode
Adobe Illustrator PostScript				
_AI	0	ColorMode	1	MonoMode
Color QuickDraw (PICT)				
_PCT	0	ColorMode	1	MonoMode