Chapter 8
Calculating in Mathcad

This chapter provides an overview of the calculation capabilities of Mathcad, focusing on defining and evaluating variables and functions. This chapter discusses only numerical equations. To learn how to use Mathcad's symbolic processing features, turn to Chapter 14, "Symbolic Calculation."

The following sections make up this chapter:

Defining and evaluating variables

How to define and evaluate variables, including range variables and built-in variables. How the relative placement of equations affects calculations. Global definitions.

Defining and evaluating functions

How to define and evaluate functions.

Units and dimensions

Mathcad's built-in unit capabilities.

Working with results

Result formatting, converting units in results, copying results.

Controlling calculation

How to suppress the way Mathcad automatically updates the worksheet.

Animation

How to create and play short animation clips by using the built-in variable FRAME.

Error messages

What to do when Mathcad displays an error message.

Defining and evaluating variables

When you type an expression into a worksheet, you are usually doing one of two things:

- You could be typing a variable or function name and assigning some value to it.
- You could be typing an equation and asking Mathcad to give you the answer.

We introduce these topics in this and the following section. See "Evaluating expressions numerically" on page 122 for details on numerical evaluation.

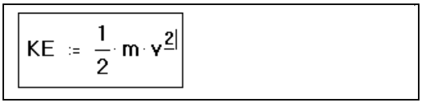
Defining a variable

A variable definition defines the value of a variable everywhere below and to the right of the definition. To define a variable, follow these three steps:

- Type the variable name to be defined. Chapter 4, "Working with Math," contains a description of valid variable names.

- Press the colon (**:**) key, or click **:=** on the Arithmetic toolbar. The definition symbol (**:=**) appears with a blank place-holder to the right.

- Type an expression to complete the definition. This expression can include numbers and any previously defined variables and functions.



The left-hand side of a "**:=**" can contain any of the following:

- A simple variable name like *x*.
- A subscripted variable name like v_i.
- A matrix whose elements are any of the above. For example, $\begin{bmatrix} x \\ y_1 \end{bmatrix}$. This technique allows you to define several variables at once: each element on the right-hand side is assigned simultaneously to the corresponding element on the left-hand side.
- A function name with an argument list of simple variable names. For example, $f(x, y, z)$. This is described further in the next section.
- A superscripted variable name like $\mathbf{M}^{\langle 1 \rangle}$.

Built-in variables

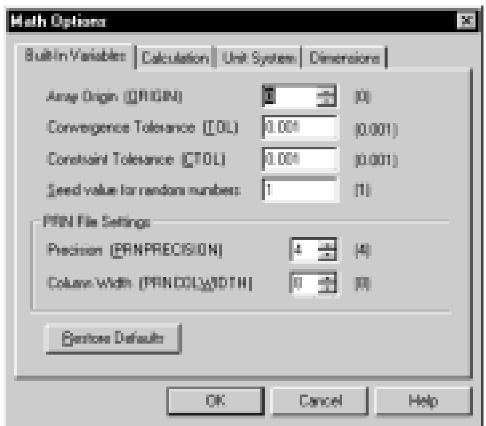
Mathcad includes several variables that are already defined when you start Mathcad. These variables are called *predefined* or *built-in variables*. Predefined variables either have a conventional value, like π and e, or are used as system variables to control how Mathcad works. See “Predefined variables” on page 347 in the Appendices for a list of built-in variables in Mathcad.

Note In addition to the built-in variables described here, Mathcad treats the names of all built-in *units* as predefined variables. See “Units and dimensions” on page 131.

Although Mathcad’s predefined variables already have values when you start Mathcad, you can still redefine them. For example, if you want to use a variable called e with a value other than the one Mathcad provides, enter a new definition, like $e := 2$. The variable e takes on the new value everywhere in the worksheet below and to the right of the new definition. Alternatively, create a global definition for the variable as described in “Global definitions” on page 123.

Note Mathcad’s predefined variables are defined for all fonts, sizes, and styles. This means that if you redefine e as described above, you can still use $\mathbf{e}$, for example, as the base for natural logarithms. Note, however, that Greek letters are not included.

You can modify many of Mathcad’s built-in variables without having to explicitly define them in your worksheet. To do so, choose **Options** from the **Math** menu, and click the Built-In Variables tab on the Math Options dialog box.



To set new starting values for any of these variables, enter a new value in the appropriate text box and click “OK.” Then choose **Calculate Worksheet** from the **Math** menu to ensure that all existing equations take the new values into account.

The numbers in brackets to the right of the variable names represent the default values for those variables. To restore these default values for the built-in variables listed in the dialog box, click “Restore Defaults” and then click “OK.”

Evaluating expressions numerically

To evaluate an expression numerically, follow these steps:

- Type an expression containing any valid combination of numbers, variables, and functions. Any variables or functions in this expression should be defined earlier in the worksheet.

$$\frac{1}{2} \cdot m \cdot v^2$$

- Press the "**=**" key, or click [=] on the Arithmetic toolbar. Mathcad computes the value of the expression and shows it after the equal sign.

$$\frac{1}{2} \cdot m \cdot v^2 = 567.108 \;\blacksquare$$

Figure 8-1 shows some results calculated from preceding variable definitions.

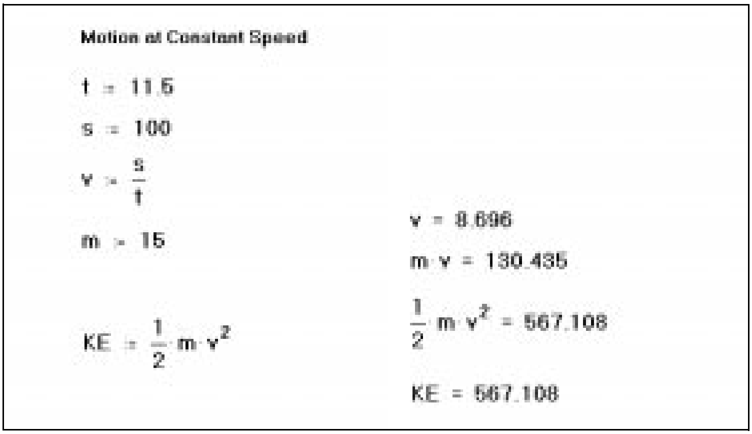


Figure 8-1: Calculations based on simple variable definitions.

Tip Whenever you evaluate an expression, Mathcad shows a final placeholder at the end of the equation. You can use this placeholder for unit conversions, as explained in "Working with results" on page 134. As soon as you click outside the region, Mathcad hides the placeholder.

How Mathcad scans a worksheet

Mathcad scans a worksheet the same way you read it: left to right and top to bottom. This means that a variable or function definition involving a "**:=**" affects everything below and to the right of it.

To see the placement of regions more clearly in your worksheet, choose **Regions** from the **View** menu. Mathcad displays blank space in gray and leaves regions in your background color.

Figure 8-2 shows examples of how placement of equations in a worksheet affects the evaluation of results. In the first evaluation, both *x* and *y* are highlighted (Mathcad shows them in red on screen) to indicate that they are undefined. This is because the definitions for *x* and *y* lie below where they are used. Because Mathcad scans from top to bottom, when it gets to the first equation, it has no idea what numbers to substitute in place of *x* and *y*.

The second evaluation, on the other hand, is below the definitions of *x* and *y*. By the time Mathcad gets to this equation, it has already assigned values to both *x* and *y*.

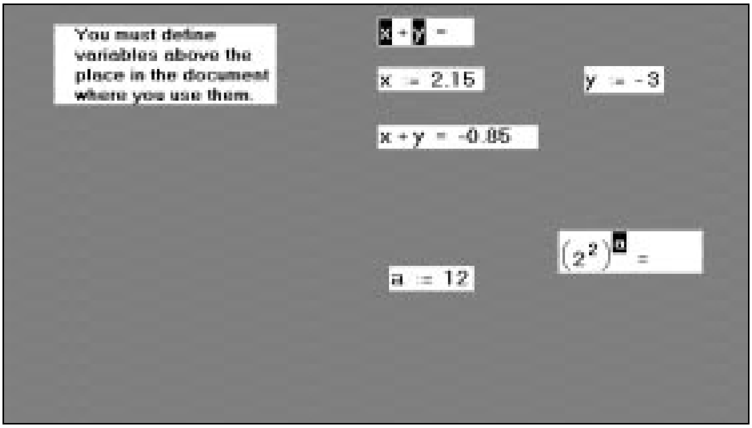


Figure 8-2: Mathcad evaluates equations from top to bottom in a worksheet. Undefined variables are highlighted.

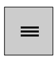
Note You can define a variable more than once in the same worksheet. Mathcad simply uses the first definition for all expressions below the first definition and above the second. For expressions below the second definition and above the third, Mathcad uses the second definition, and so on.

Global definitions

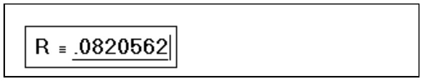
Global definitions are exactly like local definitions except that they are evaluated before any local definitions. If you define a variable or function with a global definition, that variable or function is available to all local definitions in your worksheet, regardless of whether the local definition appears above or below the global definition.

To type a global definition, follow these steps:

- Type a variable name or function to be defined.

- Press the tilde (**~**) key, or click  on the Evaluation toolbar. The global definition symbol appears.

- Type an expression. The expression can involve numbers or other globally defined variables and functions.



You can use global definitions for functions, subscripted variables, and anything else that normally uses the definition symbol “**:=**”.

This is the algorithm that Mathcad uses to evaluate all definitions, global and otherwise:

- First, Mathcad takes one pass through the entire worksheet from top to bottom. During this first pass, Mathcad evaluates global definitions only.
- Mathcad then makes a second pass through the worksheet from top to bottom. This time, Mathcad evaluates all definitions made with “**:=**” as well as all equations containing “=”.

Note A global definition of a variable can be overriden by a local definition of the same variable name with the definition symbol “:=”.

Figure 8-3 shows the results of a global definition for the variable *R* which appears at the bottom of the figure.

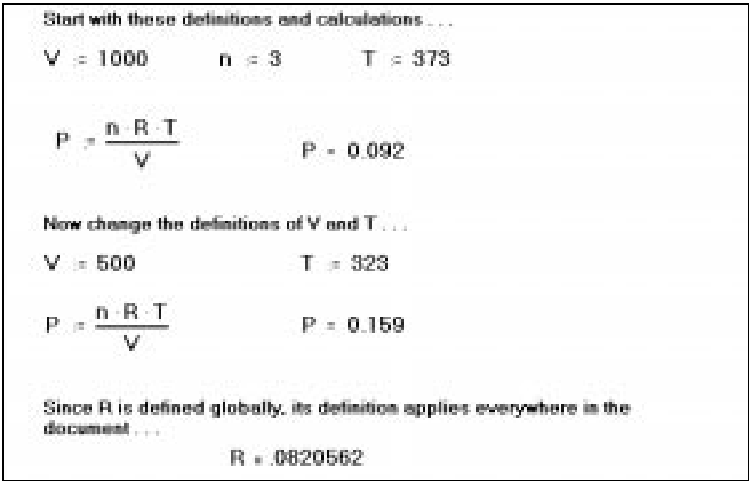


Figure 8-3: Using the global definition symbol.

Although global definitions are evaluated before any local definitions, Mathcad evaluates global definitions the same way it evaluates local definitions: top to bottom and left to right. This means that whenever you use a variable to the right of a “≡”:

- that variable must also have been defined with a “≡,” *and*
- the variable must have been defined *above* the place where you are trying to use it.

Otherwise, the variable is marked in red to indicate that it is undefined.

Tip It is good practice to allow only one definition for each global variable. Although you can do things like define a variable with two different global definitions or with one global and one local definition, this may make your worksheet difficult for others to understand.

Range variables

Iterative processes in Mathcad worksheets depend on *range variables*. Except for the way it is defined, a range variable looks just like a conventional variable. The difference is that a conventional variable takes on only one value. A range variable, on the other hand, takes on a range of values separated by uniform steps. For example, you could define a range variable to go from –4 through 4 in steps of 2. If you now use this range variable in an expression, Mathcad evaluates that expression five times, once for each value taken by the range variable.

Range variables are crucial to exploiting Mathcad's capabilities to their fullest. This section shows how to define and use range variables to perform iteration. For a description of more advanced iterative operations made possible by the programming operators in Mathcad Professional, turn to Chapter 15, "Programming."

Defining and using range variables

To define a range variable, type the variable name followed by a colon and a range of values. For example, here's how to define the variable *j* ranging from 0 to 15 in steps of 1:

- Type **j** and then press the colon key (**:**), or click [:=] on the Arithmetic toolbar. The empty placeholder indicates that Mathcad expects a definition for *j*. At this point, Mathcad does not know whether *j* is to be a conventional variable or a range variable.

- Type **0**. Then press the semicolon key (**;**), or click [m..n] on the Arithmetic toolbar. This tells Mathcad that you are defining a range variable. Mathcad shows the semicolon as two periods ".." to indicate a range. Complete the range variable definition by typing **15** in the remaining placeholder.

This definition indicates that *j* now takes on the values $0, 1, 2 \ldots 15$. To define a range variable that changes in steps other than 1, see the section "Types of ranges" on page 127.

Once you define a range variable, it takes on its complete range of values *every time you use it*. If you use a range variable in an equation, for example, Mathcad must evaluate that equation once for each value of the range variable.

You must define a range variable exactly as shown above. There must be:

- a variable name on the left,

- either a ":=" or a "≡" in the middle, and
- a valid range on the right.

Note You *cannot* define a variable in terms of a range variable. For example, if after having defined *j* as shown you now define $i := j + 1$, Mathcad assumes you are trying to set a scalar variable equal to a range variable and marks the equation with an appropriate error message.

One application of range variables is to fill up the elements of a vector or matrix. You can define vector elements by using a range variable as a subscript. For example, to define x_j for each value of *j*:

- Type **`x[j:j^2`**[**`Space`**]**`+1`**.

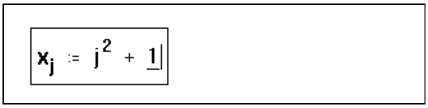


Figure 8-4 shows the vector of values computed by this equation. Since *j* is a range variable, the entire equation is evaluated once for each value of *j*. This defines x_j for each value of *j* from 0 to 15.

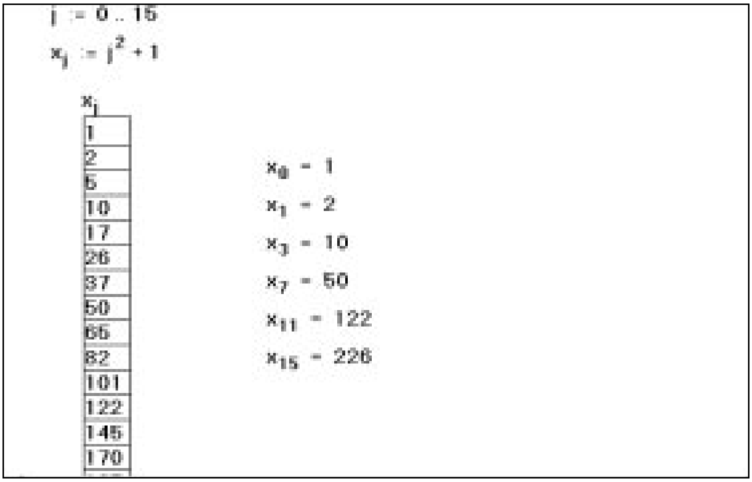


Figure 8-4: Using a range variable to define the values of a vector.

To understand how Mathcad computes with range variables, keep in mind this fundamental principle:

If you use a range variable in an expression, Mathcad evaluates the expression once for each value of the range variable.

If you use two or more range variables in an equation, Mathcad evaluates the equation once for each value of each range variable.

Tip Mathcad takes longer to compute equations with ranged expressions since there may be many computations for each equation. While Mathcad is computing, the mouse pointer changes its appearance. To learn how to interrupt a calculation in progress, see "Interrupting calculations" on page 144.

Types of ranges

The definition of *j* in the previous section, ranging from 0 to 15, is an example of the simplest type of range definition. But Mathcad permits range variables with values ranging from any value to any other value, using any constant increment or decrement.

To define an arbitrary range variable, type an equation of this form:

`k:1,1.1;2`

This appears in your document window as:

$$k := 1, 1.1 .. 2$$

In this range definition:

- The variable *k* is the name of the range variable itself. It must be a simple name. No subscripts or function definitions are allowed.
- The number 1 is the first value taken by the range variable *k*.
- The number 1.1 is the second value in the range. *Note that this is not the step size*. The step size in this example is 0.1, the difference between 1.1 and 1. If you omit the comma and the 1.1, Mathcad assumes a step size of one in whatever direction (up or down) is appropriate.
- The number 2 is the last value in the range. In this example, the range values are constantly increasing. If instead you had defined $k := 10 .. 1$, then *k* would count down from 10 to 1. Even if the third number in the range definition is not an even number of increments from the starting value, the range will not go beyond it. For example, if you define $k := 10, 20 .. 65$ then *k* takes values 10, 20, 30, . . ., 60.

Note You can use arbitrary scalar expressions in range definitions. However, these values must always be *real* numbers. Note also that if you use a fractional increment for a range variable, you will not be able to use that range variable as a subscript because subscripts must be integers.

Defining and evaluating functions

As described in Chapter 10, “Built-in Functions,” Mathcad has an extensive built-in function set. You can augment Mathcad’s built-in function set by defining your own functions.

You define a function in much the same way you define a variable. The name goes on the left, a definition symbol goes in the middle, and an expression goes on the right. The main difference is that the name includes an *argument list*. The example below shows how to define a function called *dist*(*x*, *y*) that returns the distance between the point (*x*, *y*) and the origin.

To type such a function definition:

- Type the function name.

$$\mathrm{dist}$$

- Type a left parenthesis followed by one or more names separated by commas. Complete this argument list by typing a right parenthesis.

$$\mathrm{dist}(x, y)$$

Note It makes no difference whether or not the names in the argument list have been defined or used elsewhere in the worksheet. What is important is that these arguments *must be names*. They cannot be more complicated expressions.

- Press the colon (**:**) key, or click **:=** on the Arithmetic toolbar. You see the definition symbol (**:=**).

$$\mathrm{dist}(x, y) := \blacksquare$$

- Type an expression to define the function. In this example, the expression involves only the names in the argument list. In general though, the expression can contain any previously defined functions and variables as well.

$$\mathrm{dist}(x, y) := \sqrt{x^2 + y^2}$$

Once you have defined a function, you can use it anywhere below and to the right of the definition, just as you would use a variable.

When you evaluate an expression containing a function, as shown in Figure 8-5, Mathcad:

- evaluates the arguments you place between the parentheses,
- replaces the dummy arguments in the function definition with the actual arguments you place between the parentheses,

- performs whatever arithmetic is specified by the function definition,
- returns the result as the value of the function.

Computing distances between points

$x1 := 0$ $\quad y1 := 1.5$

$x2 := 3$ $\quad y2 := 4$

$x3 := -1$ $\quad y3 := 1$ $\qquad dist(x, y) := \sqrt{x^2 + y^2}$

Compute distance from origin:

$dist(x1, y1) = 1.5$

$dist(x2, y2) = 5$

$dist(x3, y3) = 1.414$

Figure 8-5: A user-defined function to compute the distance to the origin.

The arguments of a user-defined function can represent scalars, vectors, or matrices. For example, you could define the distance function as $dist(v) := \sqrt{v_0^2 + v_1^2}$. This is an example of a function that accepts a vector as an argument and returns a scalar result. See Chapter 11, "Vectors, Matrices, and Data Arrays," for more information.

Note Function names are font sensitive. The function **f**(*x*) is different from the function f(*x*). Mathcad's built-in functions, however, are defined for all fonts (except the Symbol font), sizes, and styles. This means that **sin**(*x*), *sin*(*x*), and `sin`(*x*) all refer to the same function.

Variables in user-defined functions

When you define a function, you don't have to define any of the names in the argument list since you are telling Mathcad *what to do* with the arguments, not what they are. When you define a function, Mathcad doesn't even have to know the types of the arguments—whether the arguments are scalars, vectors, matrices, and so on. It is only when Mathcad *evaluates* a function that it needs to know what the argument types.

However, if in defining a function you use a variable name that *is not* in the argument list, you must define that variable name above the function definition. The value of that variable at the time you make the function definition then becomes a permanent part of the function. This is illustrated in Figure 8-6.

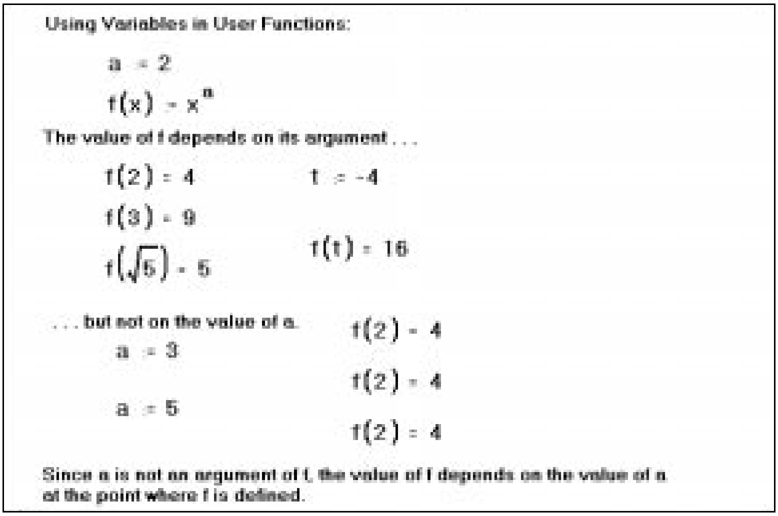


Figure 8-6: The value of a user function depends on its arguments.

If you want a function to depend on the value of a variable, you must include that variable as an argument. If not, Mathcad just uses that variable's fixed value at the point in the worksheet where the function is defined.

Recursive function definitions

Mathcad supports *recursive* function definitions—you may define the value of a function in terms of a previous value of the function. As shown in Figure 8-7, recursive functions are useful for defining arbitrary periodic functions, as well as elegantly implementing numerical functions like the factorial function.

Note that a recursive function definition should always have at least two parts:

- An initial condition that prevents the recursion from going forever.
- A definition of the function in terms of some previous value(s) of the function.

Note If you do not specify an initial condition that stops the recursion, Mathcad generates a "stack overflow" error message when you try to evaluate the function.

Pro The programming operators in Mathcad Professional also support recursion. See the section "Programs within programs" in Chapter 15 for examples.

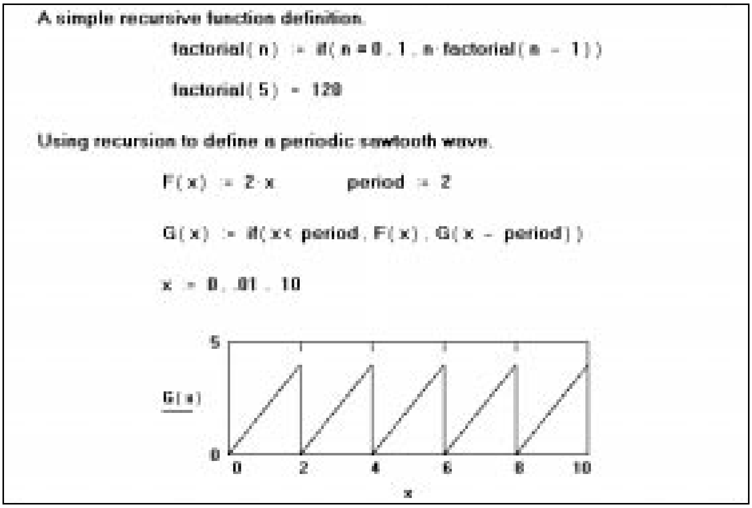


Figure 8-7: Mathcad allows recursive function definitions.

Units and dimensions

When you first start Mathcad, a complete set of units is available for your calculations. You can treat these units just like built-in variables. To assign units to a number or expression, just multiply it by the name of the unit.

Mathcad recognizes most units by their common abbreviations. Lists of all of Mathcad's built-in units in several systems of units are in the Appendices. By default Mathcad uses units from the SI unit system (also known as the International System of Units) in the *results* of any calculations, but you may use any supported units you wish in creating your expressions. See "Displaying units of results" on page 138 for more information about selecting a unit system for results.

For example, type expressions like the following:

```
mass:75*kg
acc:100*m/s^2
acc_g:9.8*m/s^2
F:mass*(acc + acc_g)
```

Figure 8-8 shows how these equations appear in a worksheet.

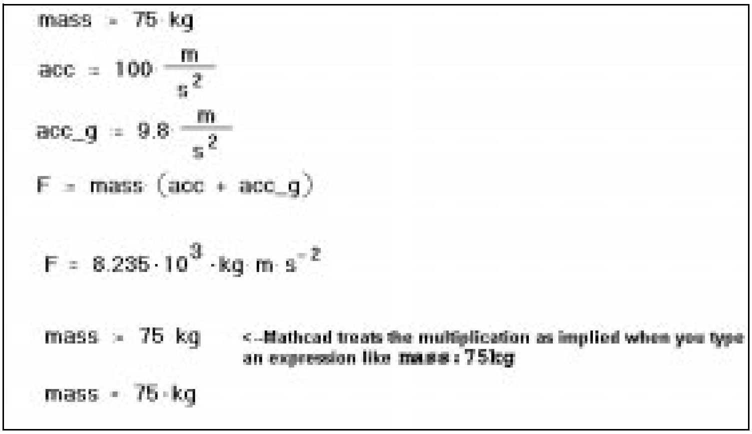


Figure 8-8: Equations using units.

Tip If you define a variable which consists of a number followed immediately by a unit name, you can omit the multiplication symbol; Mathcad inserts a space and treats the multiplication as implied. See the definition of mass at the bottom of Figure 8-8.

You can also use the Insert Unit dialog box to insert one of Mathcad's built-in units into any placeholder. To use the Insert Unit dialog box:

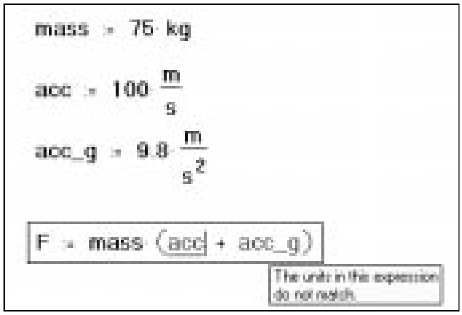
- Click in the empty placeholder and choose **Unit** from the **Insert** menu, or click  on the Standard toolbar. Mathcad opens the Insert Unit dialog box.

- The list at the bottom shows built-in units, along with their Mathcad names, corresponding to whatever physical quantity is selected in the top scrolling list. When "Dimensionless" is selected at the top, a list of all available built-in units shows on the bottom.
- If necessary, use the top scrolling list to display only those units corresponding to a particular physical quantity. This makes it easier to find a particular unit or to see what choices are appropriate.
- In the bottom list, double-click the unit you want to insert, or click the unit you want and then click "Insert." Mathcad inserts that unit into the empty placeholder.

Note Mathcad performs some dimensional analysis by trying to match the dimensions of your selected result with one of the common physical quantities in the top scrolling list. If it finds a match, you'll see all the built-in units corresponding to the highlighted physical quantity in the bottom scrolling list. If nothing matches, Mathcad simply lists all available built-in units on the bottom.

Dimensional checking

Whenever you enter an expression involving units, Mathcad checks it for dimensional consistency. If you add or subtract values with incompatible units, or violate other principles of dimensional analysis, Mathcad displays an appropriate error message.



For example, suppose you had defined *acc* as $100 \cdot m/s$ instead of $100 \cdot m/s^2$ as shown at right. Since *acc* is in units of velocity and *acc_g* is in units of acceleration, it is inappropriate to add them together. When you attempt to do so, Mathcad displays an error message.

Other unit errors are usually caused by one of the following:

- An incorrect unit conversion.
- A variable with the wrong units.
- Units in exponents or subscripts (for example $v_{3 \cdot acre}$ or $2^{3 \cdot ft}$).
- Units as arguments to inappropriate functions (for example, $\sin(0 \cdot henry)$).

Defining your own units

Although Mathcad recognizes many common units, you may need to define your own unit if that unit isn't one of Mathcad's built-in units or if you prefer to use your own abbreviation instead of Mathcad's abbreviation.

Note Although absolute temperature units are built into Mathcad, the Fahrenheit and Celsius temperature units are not. See the QuickSheet "Temperature Conversions" in the Resource Center for examples of how to define these temperature scales and to convert between them.

You define your own units in terms of existing units in exactly the same way you would define a variable in terms of an existing variable. Figure 8-9 shows how to define new units as well as how to redefine existing units.

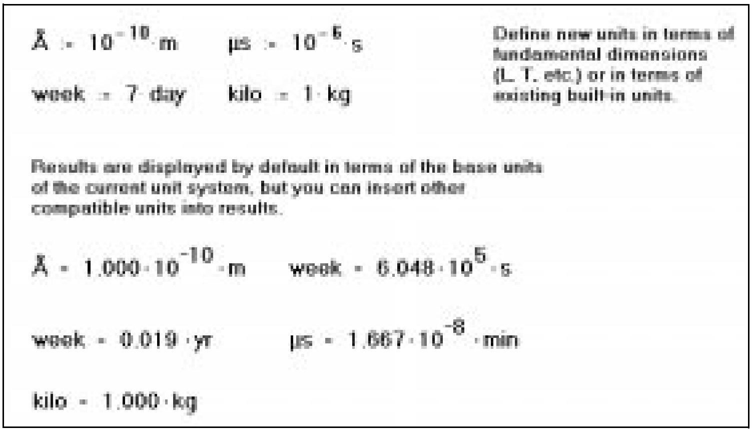


Figure 8-9: Defining your own units.

Note Since units behave just like variables, you may run into unexpected conflicts. For example, if you define the variable *m* in your worksheet, you won't be able to use the built-in unit *m* for meters anywhere below that definition. However, Mathcad automatically displays the unit *m* in any results involving meters, as described in "Displaying units of results" on page 138.

Working with results

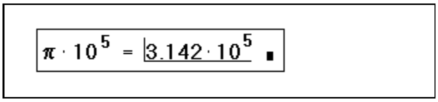
Formatting results

The way that Mathcad displays numbers (the number of decimal places, whether to use *i* or *j* for imaginary numbers, and so on) is called the *result format*. You can set the result format for a single calculated result or for an entire worksheet.

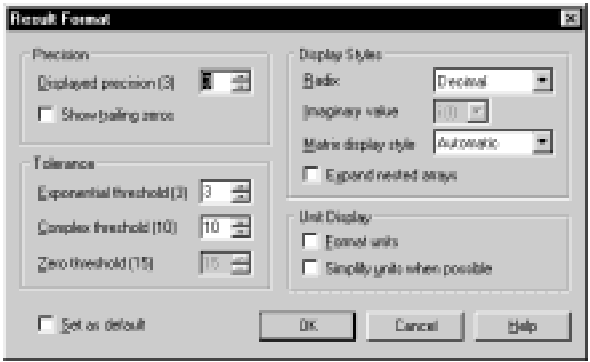
Setting the format of a single result

When you evaluate expressions numerically in Mathcad, results are formatted in the worksheet according to the worksheet default result format. You can modify the format for a single result as follows:

- Click anywhere in the equation whose result you want to format.



- Choose **Result** from the **Format** menu. Alternatively, double-click the equation itself. The Result Format dialog box appears.



- Change the desired settings. See below to learn about the various settings and their allowed values. To display the six decimal places shown below, you would increase “Displayed precision” from 3 to 6. Settings that are grayed can only be changed for the entire worksheet, as described in“Setting worksheet default format” on page 137.

- Click “OK.” Mathcad redisplays the result using the new format.

$$\pi \cdot 10^5 = 3.141593 \cdot 10^5$$

To redisplay a result using the worksheet default result format settings, click on the result to enclose the result between the editing lines, delete the equal sign, and press **=** to replace the equal sign. The result is now restored to the default worksheet settings.

Note When the format of a result is changed, only the *appearance* of the result changes in the worksheet. Mathcad continues to maintain full precision internally for that result. To see a number as it is stored internally, click on the result, press [**Ctrl**][**Shift**]**N**, and look on the message line at the bottom of the Mathcad window. If you copy a result, however, Mathcad copies the number only to the precision displayed.

This is the meaning of each of the settings in the Result Format dialog box:

Displayed precision

Enter an integer between 0 and 15. The default is 3. This controls the number of displayed digits to the right of the decimal point, equalling the lesser of Displayed Precision and (16 – the number of digits to the left of the decimal point). Mathcad maintains 16 digits of precision internally.

Show trailing zeros

Check this box to make all displayed results have as many digits to the right of the decimal point as required by the current choice of Displayed Precision. For example, with Displayed Precision set to 3, Mathcad displays 5 as 5.000.

Exponential threshold

Enter an integer n between 0 and 15. Mathcad shows computed results of magnitude greater than 10^n or smaller than 10^{-n} in exponential notation. When the threshold is 3, numbers like 30,000 are displayed as $3 \cdot 10^4$ instead of 30,000. The default is 3.

Complex threshold

Enter an integer *n* between 0 and 63. If the ratio between the real and imaginary part of a complex number is less than 10^n or greater than 10^{-n}, then the smaller part is not shown. The default setting is 10. This means that numbers like $1 + 10^{-12}i$ appear simply as 1.

Zero threshold

Enter an integer *n* between 0 and 307. Numbers less than 10^n are shown as zero. The default setting is 15. This means numbers of magnitude less than 10^{-15} appear as zero. This value can only be set for the entire worksheet.

Radix

Set the radix (base) in which results are displayed. The default is decimal. Hexadecimal results are indicated by the letter "**h**" after the number, octal results by the letter "**o**," and binary results by the letter "**b**." Mathcad does not reliably show hexadecimal, octal, or binary numbers of magnitude greater than 2^{31}.

Imaginary value

Select either *i* or *j* from the drop-down list to indicate an imaginary result. The default is *i*. You can use either *i* or *j* in equations you create—Mathcad always understands both. The selection you make here tells Mathcad which one to use when it gives you a complex answer. See "Inserting math" on page 46 for more information on how to enter complex numbers. This value can only be set for the entire worksheet.

Matrix display style

Choose Matrix here to display a result array in traditional matrix style, with brackets surrounding the elements. Choose Table to display a result array in a resizable scrolling output table, similar to a spreadsheet. Choose Automatic, the default, to have Mathcad choose a matrix display for result arrays having fewer than nine rows or columns, and an output table display for larger arrays. See "Displaying arrays" on page 226 for more information on output tables.

Expand nested arrays

Check this box to see nonscalar array elements displayed in expanded form. Nested arrays (see "Nested arrays" on page 233) may only be expanded if the result is displayed as a matrix. If a nested array is displayed as a table, you can temporarily expand an element by choosing **Down One Level** from the pop-up menu.

Format units

Check this box to see units in a result formatted wherever possible as a built-up fraction containing units with positive exponents only rather than as a product of units with positive and negative exponents (e.g., $m \cdot s^{-2}$). See "Displaying units of results" on page 138 for more information about units in results.

Simplify units when possible

Check this box to see units in a result expressed wherever possible in derived units (e.g., *N*) rather than in fundamental units (e.g., $kg \cdot m \cdot s^{-2}$).

Figure 8-10 shows the same number formatted several different ways.

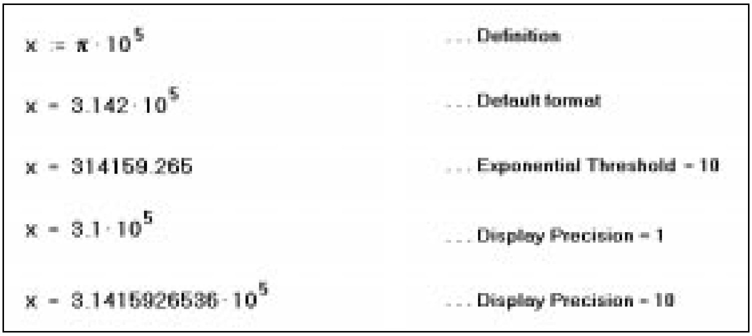


Figure 8-10: Several ways to format the same number.

Setting worksheet default format

To change the default display of numerical results in your worksheet:

- Click on a particular numerical result as described above.
- Choose **Result** from the **Format** menu. Check "Set as default" if it is not already checked.
- Change the desired settings in the Result Format dialog box.
- Click "OK."

Mathcad changes the display of all results whose formats have not been explicitly specified.

Tip Changing the worksheet default result format affects only the worksheet you are working in when you make the change. Any other worksheets open at the time retain their own default result formats. If you want to re-use your default result formats in other Mathcad worksheets, save your worksheet as a template as described in Chapter 7, "Worksheet Management."

Complex results

Complex numbers can arise in results if you enter an expression that contains a complex number. Even a Mathcad expression that involves only real numbers can have a complex value. For example, if you evaluate $\sqrt{-1}$, Mathcad returns i. See Figure 8-11 for examples.

Note When complex numbers are available, many functions and operators we think of as returning unique results become multivalued. In general, when a function or operator is multivalued, Mathcad returns the *principal value:* the value making the smallest positive angle relative to the positive real axis in the complex plane. For example, when it evaluates $(-1)^{1/3}$, Mathcad returns $.5 + .866i$ despite the fact that we commonly think of the cube root of –1 as being –1.

This is because the number $.5 + .866i$ makes an angle of only 60 degrees from the positive real axis. The number –1, on the other hand, is 180 degrees from the positive real axis. Mathcad's *n*th root operator returns –1 in this case, however.

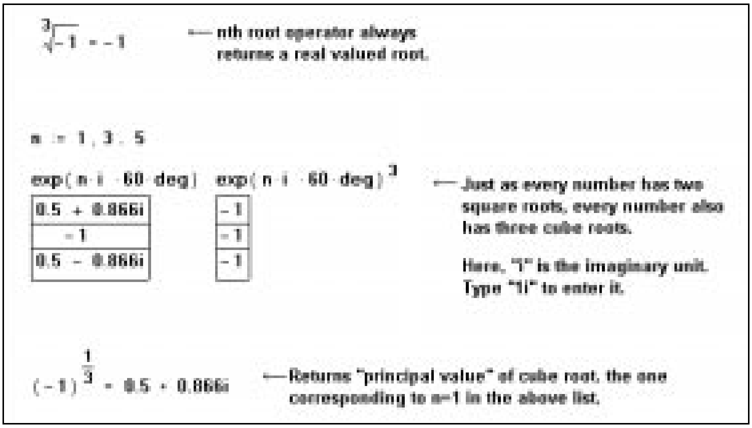


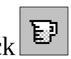
Figure 8-11: Examples of complex results.

Displaying units of results

Mathcad by default displays results in terms of the fundamental units of the unit system you're working with. Mathcad offers the following unit system choices: SI, CGS, MKS, U.S. customary units, or no unit system (see below).

Tip Check "Simplify units when possible" in the Result Format dialog box (see page 134)to see units in a result expressed in terms of derived units rather than in base units. Check "Format units" to see units in a result displayed as a built-up fraction containing terms with positive exponents only rather than as a product of units with positive and negative exponents.

You can have Mathcad redisplay a particular result in terms of any of Mathcad's built-in units. To do so:

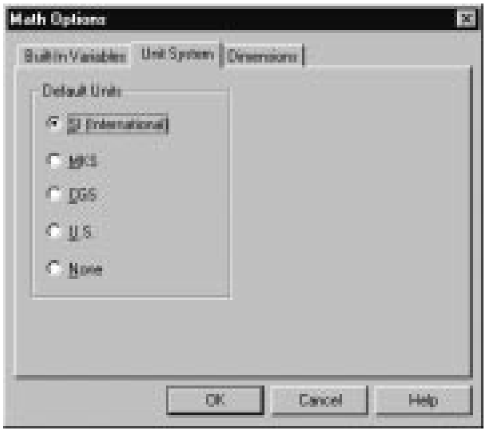
- Click in the result. You'll see an empty placeholder to its right. This is the *units placeholder*.
- Click the units placeholder and choose **Unit** from the **Insert** menu, or click  on the Standard toolbar. Mathcad opens the Insert Unit dialog box. This is described in "Units and dimensions" on page 131.
- Double-click the unit in which you want to display the result. Mathcad inserts this unit in the units placeholder.

Note For some engineering units—such as *hp*, *cal*, *BTU*, and *Hz*—Mathcad adopts one common definition for the unit name but allows you to insert one of several alternative unit names, corresponding to alternative definitions of that unit, in your results. In the case of horsepower, for example, Mathcad uses the U.K. definition of the unit *hp* but gives you several variants, such as water horsepower, metric horsepower, boiler horsepower, and electric horsepower.

Another way to insert a unit is to type its name directly into the units placeholder. This method is more general since it works not only for built-in units but for units you've defined yourself and for combinations of units.

Unit systems

When you start Mathcad, the SI system of units is loaded by default. This means that when you use the equal sign to display a result having units, Mathcad automatically displays the units in the result in terms of base or derived SI units.



You can have Mathcad display results in terms of the units of any of the other built-in unit systems in Mathcad: CGS, US customary, MKS, or no unit system at all. To do so, choose **Options** from the **Math** menu and click the Unit System tab. You will see a dialog box like the one shown at right.

Select the default unit system in which you want to display results. The SI unit system, widely used by scientists and engineers in many countries, provides two additional base units over the other systems, one for luminosity (*candela*) and one for substance (*mole*), and the base SI electrical unit (*ampere*) differs from the base electrical unit in the other systems (*coulomb*).

The following table summarizes the base units available in Mathcad's unit systems:

Unit System	Base Units
SI	*m*, *kg*, *s*, *A*, *K*, *cd*, and *mole*
MKS	*m*, *kg*, *sec*, *coul*, and *K*
CGS	*cm*, *gm*, *sec*, *coul*, and *K*
U.S.	*ft*, *lb*, *sec*, *coul*, and *K*
None	Displays results in terms of fundamental dimensions of length, mass, time, charge, and absolute temperature. All built-in units are disabled.

The standard SI unit names—such as *A* for *ampere*, *L* for *liter*, *s* for *second*, and *S* for *siemens*—are generally available only in the SI unit system. Many other unit names are available in all the available systems of units. For a listing of which units are available in each system, see the Appendices. Mathcad includes most units common to scientific and engineering practice. Where conventional unit prefixes such as *m-* for *milli-*, *n-* for *nano-*, etc. are not understood by Mathcad, you can easily define custom units such as μm as described in "Defining your own units" on page 133.

Tip For examples of units with prefixes not already built into Mathcad, see the QuickSheets in the on-line Resource Center.

If you click "None" in the Unit System tab of the Math Options dialog box, Mathcad doesn't understand any built-in units, and displays answers in terms of the fundamental dimensions of *length*, *mass*, *time*, *charge*, and *temperature*. However, even if you are working in one of Mathcad's built-in unit systems, you can always choose to see results in your worksheet displayed in terms of fundamental dimension names rather than the base units of the unit system. To do so:

- Choose **Options** from the **Math** menu.
- Click the Dimensions tab.
- Check "Display dimensions."
- Click "OK."

Unit conversions

There are two ways to convert from one set of units to another:

- By using the Insert Unit dialog box, or
- By typing the new units in the units placeholder itself.

To convert units using the Insert Unit dialog box:

- Click the unit you want to replace.
- Choose **Unit** from the **Insert** menu, or click  on the Standard toolbar.
- In the scrolling list of units, double-click the unit in which you want to display the result.

As a quick shortcut, or if you want to display the result in terms of a unit not available through the Insert Unit dialog box—for example, a unit you defined yourself or an algebraic combination of units—you can edit the units placeholder directly.

Figure 8-12 shows *F* displayed both in terms of fundamental SI units and in terms of several combinations of units.

When you enter an inappropriate unit in the units placeholder, Mathcad inserts a combination of base units that generate the correct units for the displayed result. For example, in the last equation in Figure 8-12, $kW \cdot s$ is not a unit of force. Mathcad therefore inserts m^{-1} to cancel the extra length dimension.

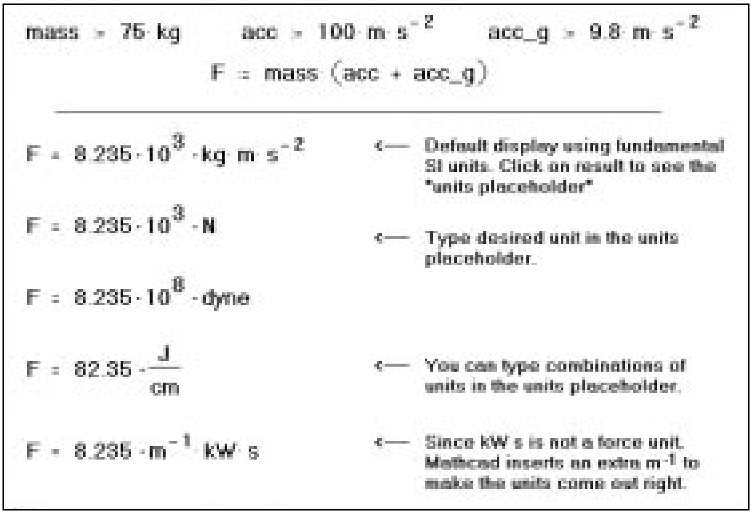


Figure 8-12: A calculated result displayed with different units.

Whenever you enter units in the units placeholder, Mathcad divides the value to be displayed by whatever you enter in the units placeholder. This ensures that the complete displayed result—the number *times* the expression you entered for the placeholder—is a correct value for the equation.

Note Conversions involving an offset in addition to a multiplication, for example gauge pressure to absolute pressure, or degrees Fahrenheit to Celsius, cannot be performed directly with Mathcad's unit conversion mechanism. You can, however, perform conversions of this type by defining suitable functions. See the QuickSheet "Temperature Conversions" in the Resource Center for examples of temperature conversion functions.

You can enter *any* variable, constant, or expression in a units placeholder. Mathcad then redisplays the result in terms of the value contained in the units placeholder. For example, you can use the units placeholder to display a result as a multiple of π or in engineering notation (as a multiple of 10^3, 10^6, etc.).

Tip You can also use the units placeholder for dimensionless units like degrees and radians. Mathcad treats the unit *rad* as a constant equal to 1, so if you have a number or an expression in radians, you can type *deg* into the units placeholder to convert the result from radians to degrees.

Copying and pasting numerical results

You can copy a numerical result and paste it either elsewhere in your worksheet or into a new application. See "Displaying arrays" on page 226 for information on copying and pasting arrays.

To copy a single number appearing to the right of an equal sign:

- Click on the result to the right of the equal sign. This puts the result between the editing lines.
- Choose **Copy** from the **Edit** menu, or click  on the Standard toolbar. This places the result on the Clipboard.
- Click wherever you want to paste the result. If you're pasting into another application, choose **Paste** from that application's **Edit** menu. If you're pasting into a Mathcad worksheet, choose **Paste** from Mathcad's **Edit** menu or click  on the Standard toolbar.

When you paste a numerical result into a Mathcad worksheet, it appears as:

- A math region consisting of a number if you paste it into empty space.
- A number if you paste it into a placeholder in a math region.
- A number if you paste it directly into text or into a placeholder in text created using the **Math Region** command on the **Insert** menu.

Note The **Copy** command copies the numerical result only to the precision displayed. To copy the result in greater precision, double-click it and increase "Displayed Precision" on the Result Format dialog box. **Copy** does not copy units and dimensions from a numerical result.

Controlling calculation

When you start Mathcad, you are in *automatic mode*. This means that Mathcad updates results in the worksheet window automatically. You can tell you're in automatic mode because the word "Auto" appears in the message line.

If you don't want to wait for Mathcad to make computations as you edit, you can disable automatic mode by choosing **Automatic Calculation** from the **Math** menu. The word "Auto" disappears from the message line and the check beside **Automatic Calculation** disappears to indicate that automatic mode is now off. You are now in *manual mode.*

Tip The calculation mode—either manual or automatic—is a property saved in your Mathcad worksheet. As described in Chapter 7, "Worksheet Management," the calculation mode is also a property saved in Mathcad template (MCT) files.

Calculating in automatic mode

Here is how Mathcad works in automatic mode:

- As soon as you press the equal sign, Mathcad displays a result.
- As soon as you click outside of an equation having a "**:=**" or a "≡," Mathcad performs all calculations necessary to make the assignment statement.

When you process a definition in automatic mode by clicking outside the equation region, this is what happens:

- Mathcad evaluates the expression on the right side of the definition and assigns it to the name on the left.
- Mathcad then takes note of all other equations in the worksheet that are in any way affected by the definition you just made.
- Finally, Mathcad updates any of the affected equations that are currently visible in the worksheet window.

Note Although the equation you altered may affect equations throughout your worksheet, Mathcad performs only those calculations necessary to guarantee that whatever you can see in the window is up-to-date. This optimization ensures you don't have to wait for Mathcad to evaluate expressions that are not visible. If you print or move to the end of the worksheet, however, Mathcad automatically updates the whole worksheet.

Whenever Mathcad needs time to complete computations, the mouse pointer changes its appearance and the word "WAIT" appears on the message line. This can occur when you enter or calculate an equation, when you scroll, during printing, or when you enlarge a window to reveal additional equations. In all these cases, Mathcad evaluates pending calculations from earlier changes.

As Mathcad evaluates an expression, it surrounds it with a green rectangle. This makes it easy to follow the progress of a calculation.

To force Mathcad to recalculate all equations throughout the worksheet, choose **Calculate Worksheet** from the **Math** menu.

Calculating in manual mode

In manual mode, Mathcad does not compute equations or display results until you specifically request it to recalculate. This means that you don't have to wait for Mathcad to calculate as you enter equations or scroll around a worksheet.

Mathcad keeps track of pending computations while you're in manual mode. As soon as you make a change that requires computation, the word “Calc” appears on the message line. This is to remind you that the results you see in the window are not up-to-date and that you must recalculate them before you can be sure they are updated.

You can update the screen by choosing **Calculate** from the **Math** menu or clicking  on the Standard toolbar. Mathcad performs whatever computations are necessary to update all results visible in the worksheet window. When you move down to see more of the worksheet, the word “Calc” reappears on the message line to indicate that you must recalculate to see up-to-date results.

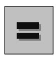
To process the whole worksheet, including those portions not visible in the worksheet window, choose **Calculate Worksheet** from the **Math** menu.

Note When you print a worksheet in manual calculation mode, the results on the printout are not necessarily up-to-date. In this case, make sure to choose **Calculate Worksheet** from the **Math** menu before you print.

Interrupting calculations

To interrupt a computation in progress:

- Press [**`Esc`**]. The dialog box shown at right appears.
- Click “OK” to stop the calculations or “Cancel” to resume calculations.

If you click “OK,” the equation that was being processed when you pressed [**`Esc`**] is marked with an error message (see “Error messages” on page 147) indicating that calculation has been interrupted. To resume an interrupted calculation, first click in the equation having the error message, then choose **Calculate** from the **Math** menu or click  on the Standard toolbar.

Tip If you find yourself frequently interrupting calculations to avoid having to wait for Mathcad to recalculate as you edit your worksheet, you can switch to manual mode as described above.

Disabling equations

You can *disable* a single equation so that it no longer calculates along with other regions in your worksheet. Disabling an equation does not affect Mathcad's equation editing, formatting, and display capabilities.

To disable calculation for a single equation in your worksheet, follow these steps:

- Click on the equation you want to disable.

- Choose **Properties** from the **Format** menu, and click the Calculation tab.
- Under "Calculation Options" check "Disable Evaluation."
- Mathcad shows a small rectangle after the equation to indicate that it is disabled. An example is shown at right.

$$KE := \frac{1}{2} \cdot m \cdot v^2 \ \blacksquare$$

Tip An easy shortcut for disabling evaluation is to click with the right mouse button on an equation and select **Disable Evaluation** from the pop-up menu.

To re-enable calculation for a disabled equation:

- Click on the equation to select it.
- Choose **Properties** from the **Format** menu, and click the Calculation tab.
- Remove the check from "Disable Evaluation."

Mathcad removes the small rectangle beside the equation, and calculation is re-enabled.

Animation

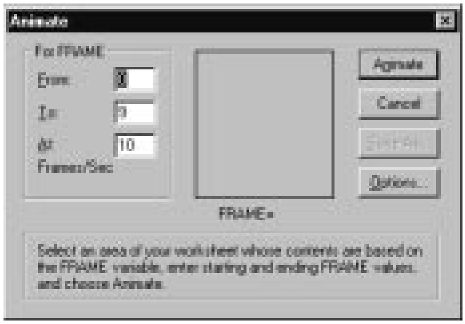
This section describes how to use Mathcad to create and play short animation clips by using the built-in variable FRAME. Anything that can be made to depend on this variable can be animated. This includes not only plots but numerical results as well. You can play back the animation clips at different speeds or save them for use by other applications.

Creating an animation clip

Mathcad comes with a predefined constant called FRAME whose sole purpose is to drive animations. The steps in creating any animation are as follows:

- Create an expression or plot, or a group of expressions, whose appearance ultimately depends on the value of FRAME. This expression need not be a graph. It can be anything at all.

- Choose **Animate** from the **View** menu to bring up the Animate dialog box.



- Drag-select the portion of your worksheet you want to animate as shown in Figure 8-13. Draw a rectangle around as many regions as you want to appear in the animation.
- Set the upper and lower limits for FRAME in the dialog box. When you record the animation, the FRAME variable increments by one as it proceeds from the lower limit to the upper limit.
- Enter the playback speed in the Frames/Sec. box.
- Click "Animate." You'll see a miniature rendition of your selection inside the dialog box. Mathcad redraws this once for each value of FRAME. This won't necessarily match the playback speed since at this point you're just *creating* the animation.

To save your animation clip as a Windows AVI file, suitable for viewing in other Windows applications, click "Save As" in the dialog box.

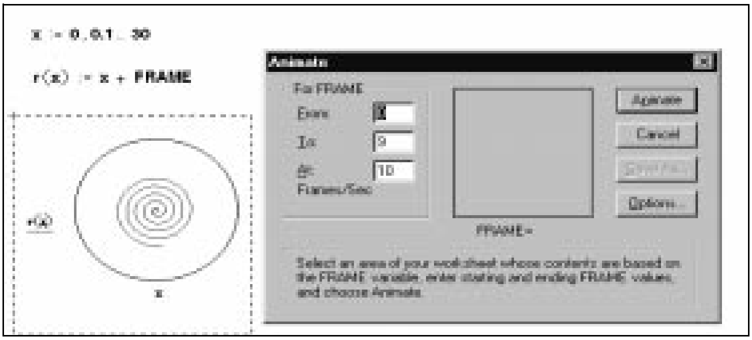


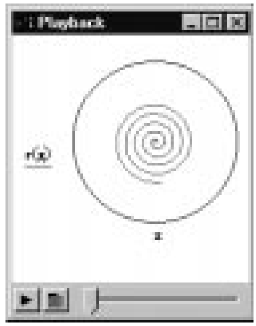
Figure 8-13: Selecting an area of a worksheet for animation.

Tip Since animation clips can take considerable disk space, Mathcad saves them in compressed format. Before creating the animation, you can choose what compression method to use or whether to compress at all. To do so, click "Options" in the Animate dialog box.

Playing an animation clip

As soon as you've created an animation clip as described in the previous section, Mathcad opens a Playback window:

The first frame of the animation clip you just created is already in the window. To play back the animation clip, click the arrow at the lower left corner of the window. You can also play back the animation clip on a frame by frame basis, either forward or backward. To do so, drag the slider below the animated picture to the left or right.



Tip You can control the playback speed by clicking the button to the right of the play button, which then opens a pop-up menu. Choose **Speed** from the menu and adjust the slider control.

Playing a previously saved animation

If you have an existing Windows AVI file on your disk, you can play it within Mathcad. To do so:

- Choose **Playback** from the **View** menu to bring up the Playback dialog box. The window is collapsed since no animation clip has been opened.

- Click on the button to the right of the play button and choose **Open** from the menu. Use the Open File dialog box to locate and open the AVI file you want to play.

Once you've loaded a Windows AVI file, proceed as described in the previous section.

Tip To launch an animation directly from your worksheet, you can insert a hyperlink to an AVI file by choosing **Hyperlink** from the **Insert** menu. You can also embed a shortcut to the AVI file in your worksheet by dragging the icon for the AVI file from the Windows Explorer and dropping it into your worksheet. Finally, you can embed or link an OLE animation object in your worksheet (see "Inserting objects" on page 95).

Error messages

If Mathcad encounters an error when evaluating an expression, it marks the expression with an error message and highlights the offending name or operator in red.

An error message is visible only when you *click on* the associated expression. Figure 8-14 shows how an error message looks when you click on an expression.

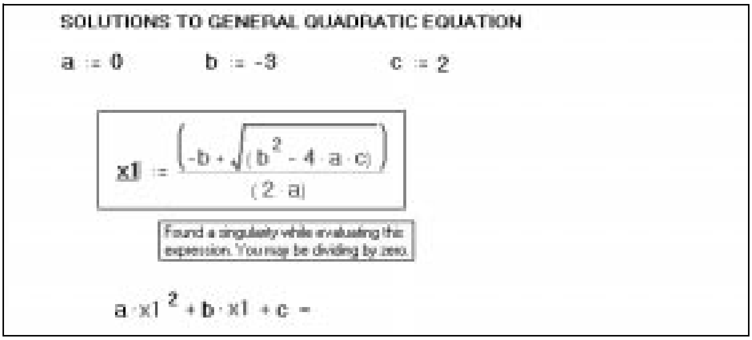


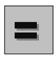
Figure 8-14: An error message and an undefined variable.

Tip You can get on-line help about any error message by clicking on it and pressing [**`F1`**].

Mathcad cannot process an expression containing an error. If the expression is a definition, the variable or function it is supposed to define remains undefined. This can cause any expressions that reference that variable to be undefined as well. In the example shown in Figure 8-14, an error in the definition of *x1* causes the expression following the definition to be undefined.

Fixing errors

If your worksheet contains several expressions with errors, this is what to do:

- Determine which expression with an error is closest to the *top* of the worksheet. This error is probably the cause of many of the other errors.
- If you anticipate time-consuming calculations, switch to manual mode as described in “Controlling calculation” on page 142. When you are ready to recalculate, choose **Calculate** from the **Math** menu or click  on the Standard toolbar turn. Alternatively, turn on automatic mode again.

Once you have determined which expression caused the error, edit that expression to fix the error or change the variable definitions that led to the error. When you click in the expression and begin editing, Mathcad removes the error message. When you click outside the equation (or in manual calculation mode, when you recalculate), Mathcad recomputes the expression. Once you have fixed the error, Mathcad then recomputes the other expressions affected by the expression you changed.

Note When you define a function, Mathcad does not try to evaluate it until you subsequently use it in the worksheet. If there is an error, the use of the function is marked in error, even though the real problem may lie in the definition of the function itself, possibly much earlier in the worksheet.
