Handout on Formatting of Figures for ME487 Laboratory Reports
taken from
Knisely, C. W. and Knisely, K. I., 2014, *Engineering Communication*, Cengage Learning: Stamford, CT, Chap. 6.

Figures

Figures include all elements that are not text or tables. Labels such as *Photograph 1, Sketch 3,* and *Drawing 5* are **not** used. In technical writing, all of these visual elements are called *figures.*

A few simple rules for figures are as follows:

- Simplicity is crucial. Restrict the scope of the figure to show exactly your intended message.
- Craft a figure title that concisely and accurately describes the data in the figure. The guidelines given in Table 6.7 apply equally to figure titles.
- Number figures independently of tables and in the order they are discussed in the text.
- Whenever possible, use technical charting software (SigmaPlot, Kaleidagraph, Delta- or MATLAB! graph) rather than business spreadsheet software such as Microsoft Excel.

TABLE 6.7 | Examples of faulty titles and how to correct them

Faulty Title	What's Wrong	Correction
Table 1.2 The Estimated Land Area And Subsurface Reservoir Volumes Needed For EGS Development.	Do not capitalize common nouns; do not start a title with the word "the"	Table 1.2 Estimated land area and subsurface reservoir volumes needed for EGS development
Table 1.2 Table of estimated land area and subsurface reservoir volumes needed for EGS development.	Do not start a title for a graphic with a description of the graphic	
Table 1.2 shows the estimated land area and subsurface reservoir volumes needed for EGS development.	Separate the table number and the title	
Table 1.2 Subsurface reservoir volumes	Do not write vague and undescriptive titles	
Table 1.2 Estimated land area and subsurface reservoir volumes needed for EGS development for 25, 50, 75, and 100 MW_e plants.	Do not make titles excessively detailed; avoid repeating column headings	

When preparing graphs:

- Use two-dimensional charts as a rule; three-dimensional charts add clutter and make it difficult to compare data sets; "pseudo-3D" effects are meaningless and may obscure other data.
- Use simple black and white format; eliminate gray-scale shading, patterning, text marking of data series, and other effects; use only those items that are essential to make your point.
- Use a line for continuous data (theory); plot individual data points as a scatterplot, a histogram, or a column chart.
- Vary line type for different sets of continuous data; do not rely on color differences.
- Plot no more than six data sets on a single graph (unless there is a good reason).
- Label each axis clearly and include the units in parentheses (or alternatively in square brackets).
- Include a legend (data set identification) if there are multiple data sets.
- Position the legend preferentially (1) on the plot area, (2) immediately beneath the graph, (3) as part of the caption, or (4) immediately above the graph.
- Give each graph a caption (positioned *below* the figure in a report) or a title (positioned *above* the figure in a presentation).
- Do not display gridlines, chart shading, and text callouts of data unless there is a good reason for doing so.
- Do not simply accept Excel defaults—the default format is not standard for technical reports.

We frequently refer to MS Excel in the following sections when we provide examples of different types of graphs. While Excel is not the only or the best software available for making graphs, it is a good plotting program for novices for the following reasons:

- Data input and subsequent plotting of these data is relatively straightforward in Excel.
- Excel is readily available and is included in the Microsoft Office suite of computer software.
- If your organization has Excel on its computers, you can probably get personal assistance from an information technology or computer support staff member.

You may eventually switch to a higher-powered plotting program such as SigmaPlot, Kaleidagraph, or Deltagraph, but the experience gained by working with Excel should make this transition easier. MATLAB is also excellent!

x–y Graphs

An *x–y* graph displays the relationship between *two or more quantitative parameters or variables*. The **independent variable** is the one that the engineer changes or manipulates. The **dependent variable** changes in response to changes in the independent variable. By convention, the independent variable is plotted on the horizontal or *x*-axis. The dependent variable is plotted on the vertical or *y*-axis. If there is not a causative relationship between the two parameters, then it does not matter which parameter is plotted on which axis.

Coordinate Axes The coordinate axes for *x–y* graphs are selected based on the patterns shown by the numerical data. Three common axes are

- Linear (also called rectangular or Cartesian)
- Logarithmic (also called log-log)
- Semi-logarithmic

Linear coordinates are the most frequently used grid (see Figure 6.3a). The *x*- and *y*-axes are both linear, and the intervals are uniform. In other words, the distance between major divisions on each axis is constant. For ease of reading, the increments of the major divisions are multiples of 1, 2, or 5.

Graphs with logarithmic coordinates have a logarithmic scale on both axes (see Figure 6.3b); semi-log plots have one logarithmic and one linear axis (see Figure 6.3c). On a log scale, the distance plotted between successively higher numbers becomes successively smaller. The advantage of using a logarithmic scale is that a wide range of values, whose smallest and largest values differ by several orders of magnitude (powers of 10), can be plotted without loss of resolution. Furthermore, data that appears as a power law ($y = ax^n$)

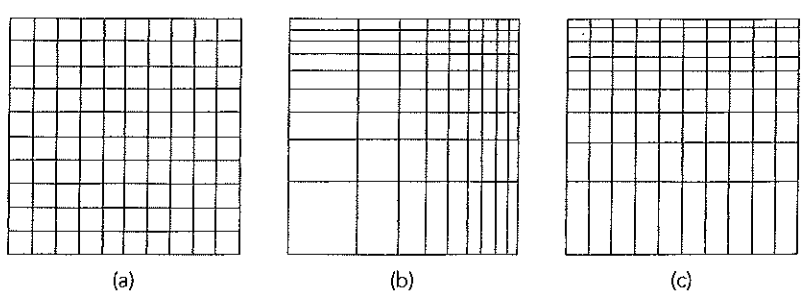

FIGURE 6.3 Coordinate grids found in engineering graphs: (a) Cartesian (linear), (b) log-log, (c) semi-log

when plotted on linear coordinates can be transformed to a linear form on log-log coordinates (see the section "Applying Graphical Analysis"). Similarly, exponential functions appear as straight lines on semi-logarithmic coordinates.

Data Points—Fit a Line to Them or Not? After having plotted data on an x–y graph with the appropriate coordinate grid, how do you decide whether to leave the points unconnected, add a line of best fit, or connect the points with straight or smoothed lines? The answer to this question depends on the purpose of your study and the nature of the data. Several engineering studies provide examples.

Points Left Unconnected An x–y graph in which the points are not connected is called a **scatterplot**. Quite often a scatterplot represents a preliminary way to display measured data. If the purpose of the study was to determine the relationship between the parameters, the engineer would be more likely to recognize a trend from the scatterplot than from just the numbers in a table.

Figure 6.4 shows the characteristic head for a centrifugal pump as a function of the flow rate. Although the trend can be easily recognized in the scatterplot, adding the appropriate trendlines, as in Figure 6.5, makes the head-flow rate characteristic exceedingly clear. The second-order curve fit for pump head (proportional to pressure) as a function of mass flow rate (proportional to velocity) conforms to the theoretical expectation that pressure varies with the square of velocity.

Two points should be noted in Figures 6.4 and 6.5. The legend is included in the caption as an example of doing so, in case an organization or publisher requires no annotation on the plot surface. The use of scientific notation (for example, 1.0×10^{-4}) along the axes is usually recommended when the number of decimals exceeds the length of the scientific notation text. Council of Science Editors (2006) recommends using scientific notation for values of 10^4 and greater and for values of 10^{-4} and smaller.

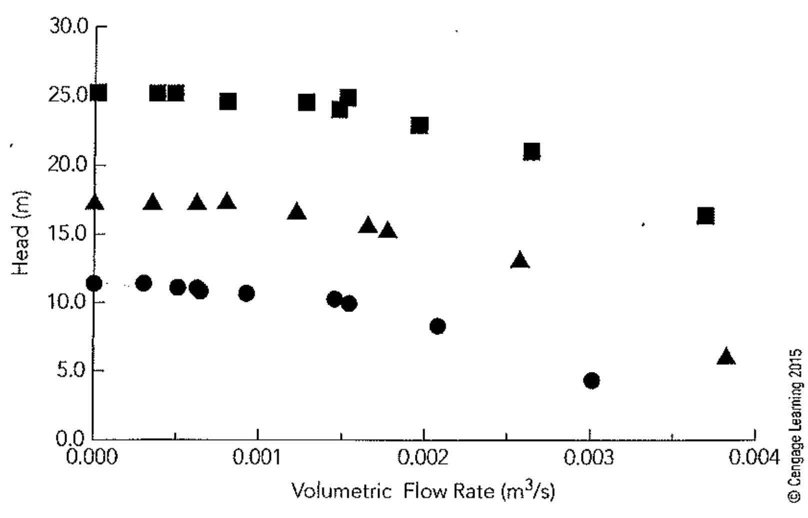

FIGURE 6.4 | Head characteristics of a centrifugal pump. Circles are for an operating speed of 2,000 RPM, triangles for 2,500 RPM, and squares for 3,000 RPM.

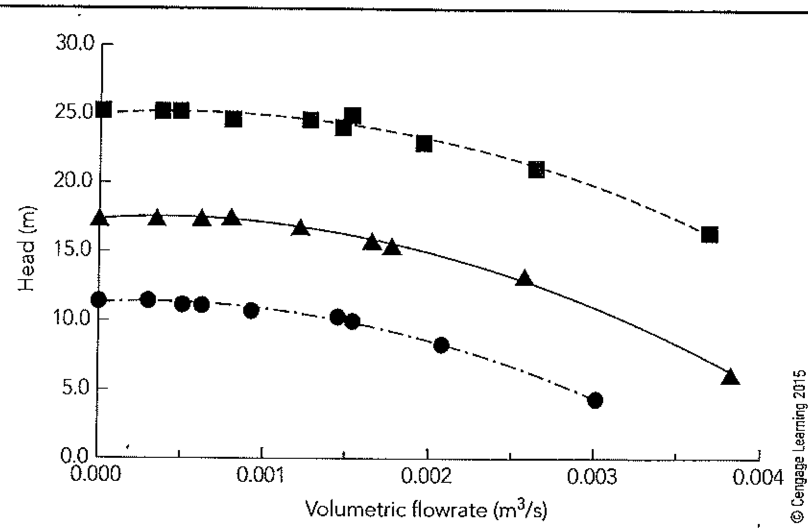

FIGURE 6.5 Head characteristics of a centrifugal pump with second-order polynomial trendlines. Circles are for an operating speed of 2,000 RPM, triangles for 2,500 RPM, and squares for 3,000 RPM.

Points Connected by Straight or Smoothed Lines In experimental studies, the independent variable is usually changed at discrete intervals that are convenient to measure. For example, a biochemical engineer who is designing a novel heat-resistant enzyme might measure the activity of this enzyme at a few selected temperatures over the range of interest, not at every degree or even half-degree. When the sampled data points are plotted on an *x–y* graph, the enzyme activity is likely to increase up to a certain temperature and then decrease beyond that temperature. To show this trend more clearly, the engineer would connect the points with straight lines, as shown in Figure 6.6. The use of straight lines, rather than smoothed lines, implies that no assumptions are made about the behavior of the system between the measured points.

Trends over Time Another instance in which the points would be connected with straight lines is when a response is measured over time. For example, the variation of CO_2 concentration in the atmosphere is frequently cited as a key indicator of potential global warming. Figure 6.7 shows the monthly CO_2 concentration at Mauna Loa in Hawaii. The seasonal trends are much easier to recognize when the points are connected.

Graph with a Line, but no Points The focus of Figure 6.8 is the long-term development of motive power since the start of the Industrial Revolution. Filling the graph area with hundreds of data points would serve only to obscure the intended message. If a linear scale had been used, all data prior to 1900 and all data for all means of motive power other than steam, gas, and water turbines would have been indistinguishable. All of these other data are several orders of magnitude smaller than steam, gas, and water turbine values.

Linear Best-fit Lines If the data points lie close to a straight line and the *x* and *y* parameters are *expected* to have a linear relationship, a best-fit line (least-squares regression line)

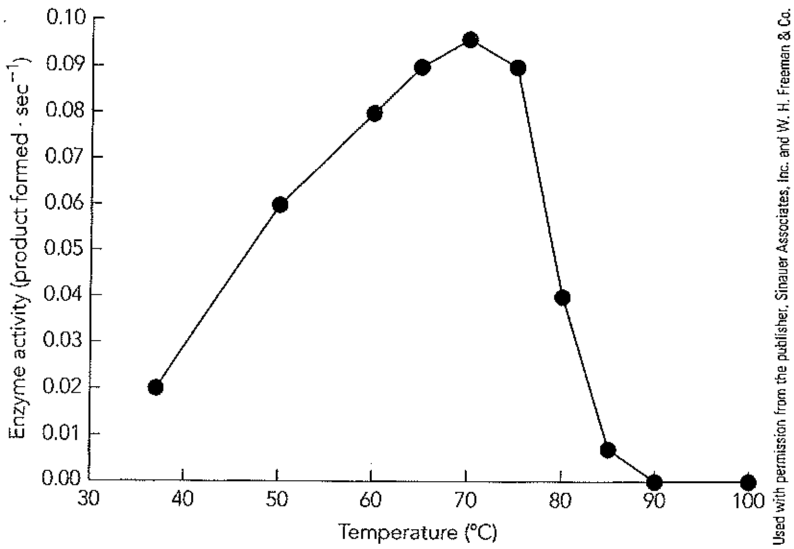

FIGURE 6.6 | Effect of temperature on the activity of a fictitious heat-resistant enzyme

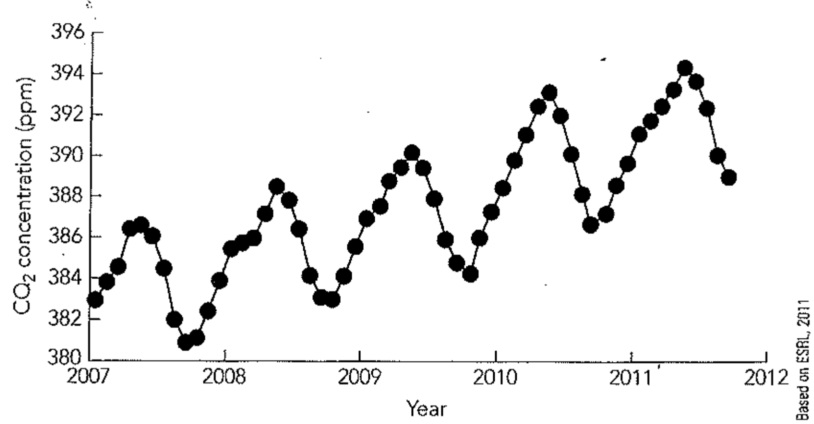

FIGURE 6.7 | Monthly average CO_2 concentration at Mauna Loa, Hawaii

can be added to the graph. Most graphing calculators and software programs with statistics capability will calculate the equation of the line for you.

A calibration curve is a common example in engineering when a **least-squares regression line** and its equation are used to predict one parameter when the other is known. Recall that the equation of a straight line is

$$y = mx + b \tag{6.4}$$

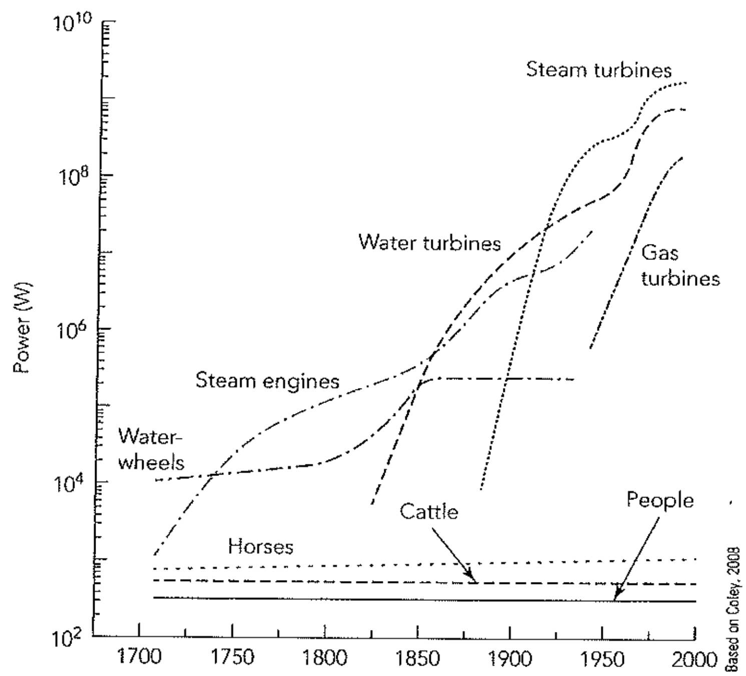

FIGURE 6.8 Historical development of motive power from 1700 to 2000 showing an effective use of a logarithmic scale on the *y*-axis of a line graph

where *m* is the slope and *b* is the *y*-intercept. If *x* is known, for example, a rough estimate for *y* could be made simply by reading up and over on the graph. Substituting *x* into the equation would result in a more precise value for *y*.

Figure 6.9 shows a calibration curve for an orifice flow meter in flow with relatively large-amplitude low-frequency pulsations. The flow rate was obtained by capturing the system discharge in a bucket over a measured time and weighing the bucket before and after filling. Practical considerations did not permit capturing the discharge over a sufficient time period to obtain a representative average. The flow rate is expected to vary with the square root of the pressure drop across the orifice plate. By plotting the square of the measured flow rate as a function of the measured pressure drop (as a percent of full-scale meter deflection), a calibration equation was generated from the linear fit to the data.

On other occasions, a calibration equation might be sought for devices or systems that are known to have nonlinear characteristics. If one suspects an **exponential relationship** between dependent and independent variable, a semi-log plot is ideal for confirming this exponential dependence. Figure 6.10 shows a scatterplot with an exponential trendline fit for the loss coefficient for a butterfly valve as a function of the opening angle of the valve. The R^2 value indicates that the data are well represented by the straight line on the semi-log coordinates. The advantage of using a semi-log plot is the linearity of the resultant curve fit, permitting a very quick visual check of the appropriateness of the chosen trendline.

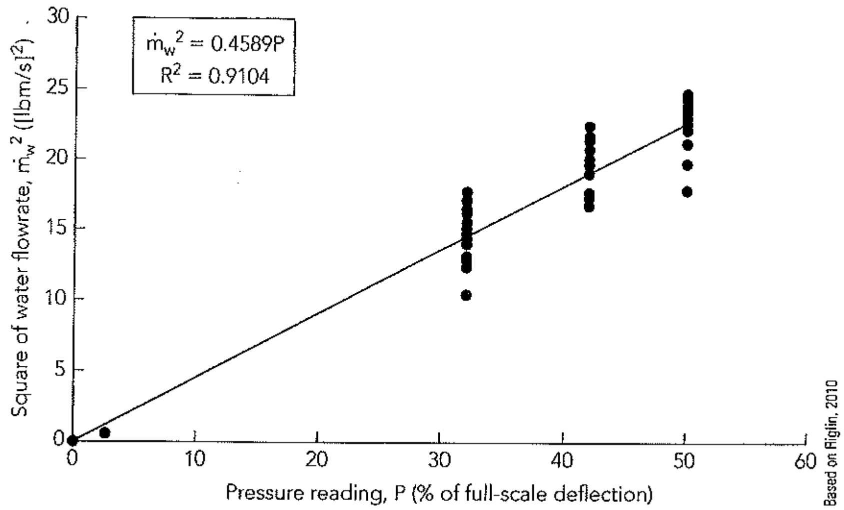

FIGURE 6.9 Calibration of an orifice flow meter in a flow with low-frequency pulsations, yielding a calibration curve with a better than 90% regression coefficient

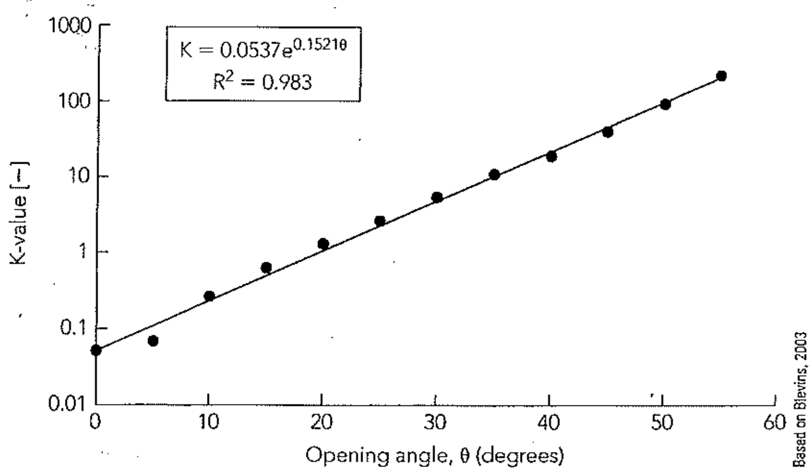

FIGURE 6.10 Loss coefficient value for flow through a butterfly valve as a function of the angle of the valve

Other devices, systems, and phenomena may have **power law relationships** between input and output parameters. A **power law** is expressed as the following relationship between x and y:

$$y = Ax^n \tag{6.5}$$

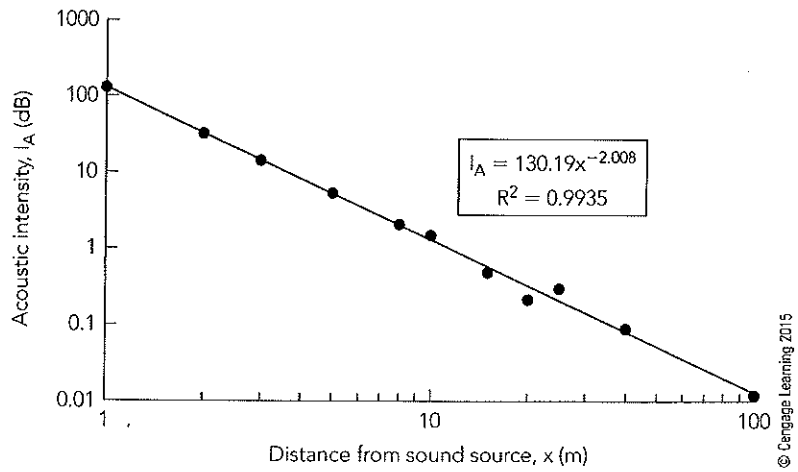

FIGURE 6.11 | Curve fit to hypothetical acoustic intensity data showing linear trend for intensity with distance on log-log coordinates

Many types of radiating wave phenomena from surface waves to acoustic waves to electromagnetic waves exhibit $1/r^2$ attenuation. In Figure 6.11, hypothetical acoustic intensity data are plotted in log-log coordinates. The log-log format permits power law curve fits to appear as straight lines, again giving the reader immediate and obvious visual confirmation of the validity of the expected curve fit.

Tech Tip—Generating x–y Plots in Excel

Microsoft Excel's default graph settings are not consistent with engineering graph format. ***Do not accept defaults—modify to comply!***

Always choose "Scatter," not "Line," in Excel to generate x–y plots. Line charts space data at equal intervals regardless of the value of the x-axis parameter. For example, in a line chart, the x-values of 1, 5, and 15 would be spaced equally, when in fact there should be 4 units in the first interval and 10 in the second. Remember: When you want to make an x–y graph in Excel, use "Scatter."

Instructions for plotting x–y graphs as well as bar graphs and pie charts in Excel 2010 and Excel for Mac 2011 are given in Appendix II.

FORMATTING GRAPHS—DETAILS

Professional societies and journal publishers have developed a standard format for graphs. Although the format among different organizations is slightly different, there are also many common features. The guidelines presented in this section provide a good starting point for engineering students. Experienced authors know to check the requirements of each organization for which the writing is being undertaken.

Figure 6.19 shows an excerpt from an engineering report, in which the author describes the most important results in words and references the figure by number (either parenthetically or as the subject of the sentence). This format allows readers to visualize the information described in the text while they process the visual information in the graphic. By convention, a visual element is always positioned as close as possible after the text in which it is first described.

Axes and Scales

The axes on a graph should be carefully selected to provide an accurate picture of the relationship between two or more parameters. Consider the following guidelines when preparing graphs:

- Plot the independent parameter on the x-axis (horizontal or abscissa).
- Plot the dependent parameter on the y-axis (vertical or ordinate); in mathematics; this axis is $f(x)$.

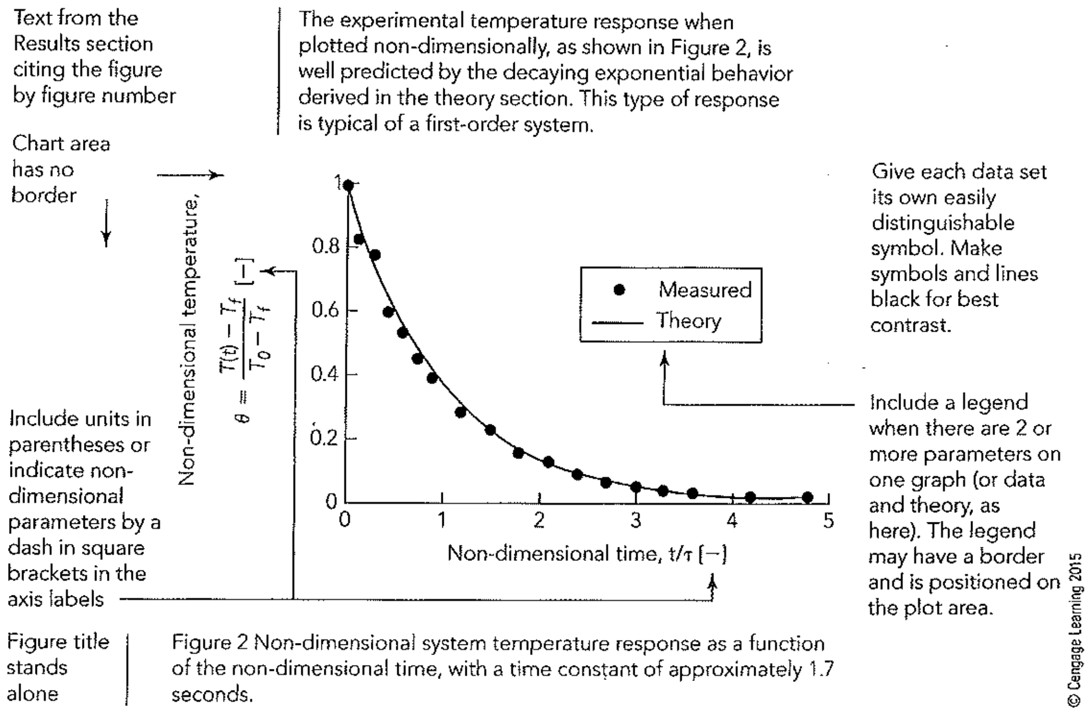

FIGURE 6.19 Excerpt from a Results section showing a properly formatted figure with one data set accompanied by a theory curve. A legend is needed to distinguish the measured data from the theory. The figure is described in the text, and the number is referenced for clarity.

- Include the origin (zero) on any linear scale, when appropriate. If the focus of the graph is on changes or fluctuations about a large mean value, it is not necessary to include the origin.
- Select the maximum value so that it does not distort the data, but is also a convenient multiple of the major scale divisions on the axis.
- Select major scale divisions of axes as multiples of 1, 2, or 5 for ease of reading and subdivision.
- Adjust maximum axis values so that the data extend over a range that fills the area inside the axes to avoid "dead space."
- Space major tick marks equally on axes with the tick marks projecting inward. Most English-language engineering publications tend to have inward-pointing tick marks; many European journals tend to use outward-pointing tick marks.
- Include an initial zero on scale numbers less than one, for example, 0.20 rather than .20.
- Use scientific notation for scale numbers equal to 10^4 or greater, and for numbers equal to 10^{-4} or smaller, for example 2.0×10^4 or 5.00×10^{-6}.

Gridlines

When the purpose of a graph is to show a relationship between the parameters, do not use gridlines. Gridlines detract from the data. To illustrate this point, compare the graphs in

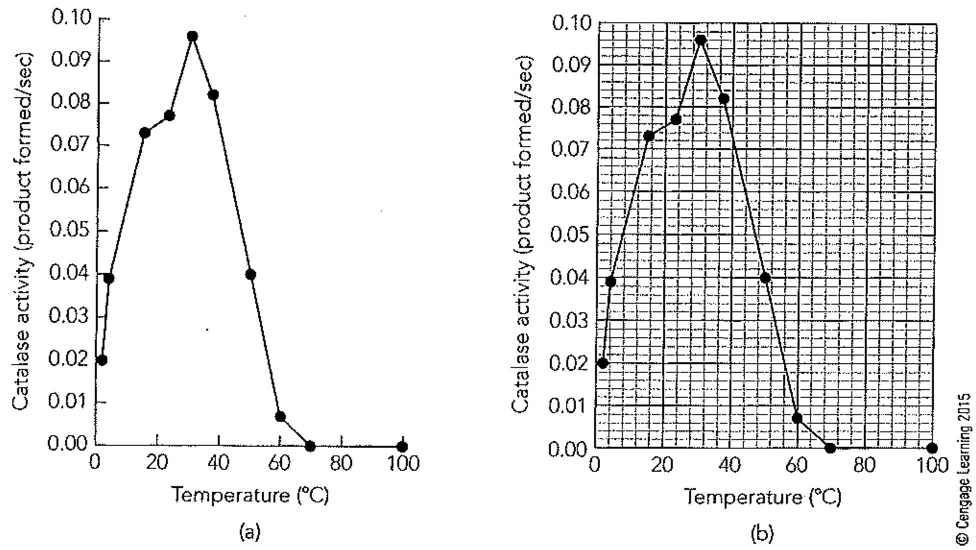

FIGURE 6.20 (a) Appropriate and (b) inappropriate use of gridlines. Gridlines should be displayed only on graphs used for calibration, as shown in Figure 6.21.

Figures 6.20a and b. When the data-ink ratio (the ink devoted to the actual data divided by the total ink on the graphic) is high, the clutter that would potentially obscure the trend shown by the data is low.

On the other hand, when a graph is intended for precise reading of data (e.g., a calibration curve), gridlines may aid the reader in determining data values (Figure 6.21). In this case, gridlines must be both horizontal and vertical.

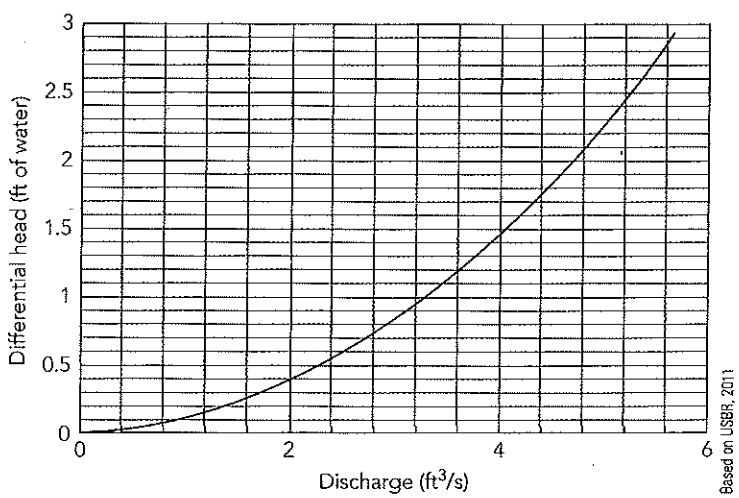

FIGURE 6.21 Typical calibration curve for an 8-inch venturi meter showing appropriate use of gridlines.

TABLE 6.8 | Council of Science Editors (2006) suggested order of preference for data point symbols

Preference	Symbol	Preference	Symbol	Preference	Symbol	Preference	Symbol
1st	○	3rd	Δ	5th	□	7th	◇
2nd	●	4th	▲	6th	■	8th	◆

Based on Council of Science Editors, 2006

Symbols and Legends

The most important criteria for symbols are ease of recognition and good contrast in black and white publications. To meet these requirements, publishers often specify the use of filled and unfilled circles, triangles, and squares, as shown in Table 6.8. Diamonds may be used only if it is necessary to have more than six data sets on a graph. When plotting a large number of data sets on a single graph, make sure that each data set is legible and can be

Guidelines for Symbols and Legends

Do

- Use diamonds and then inverted triangles if additional symbols are needed.
- Use the symbols consistently when the same data sets are used in multiple graphs.
- Make the curve fitted to the data the heaviest line on the graph.
- Display the equation of the line on the graph or in the caption (when the equation is required for analysis).
- Make data points and axis labels LARGE. They must still be legible when the figure is reduced for publication.
- Include a legend when there is more than one data set on a graph. Position the legend inside the plot area (within the extent of the axes). A border around the legend helps the reader distinguish symbols in the legend from the data symbols.
- Make the legend meaningful.

Do not

- Use X, +, or * as data points. They are not as visually prominent as circles and polygons and are easily obscured by curve fits (CSE, 2006).
- Use left ◀ and right ▶ pointing triangles. They cannot be distinguished from upward and downward pointing triangles with even a slight copy reduction.
- Use colored symbols. They will appear as various shades of gray when printed with a black and white printer.
- Use colored lines for curves without data points. They will appear as various shades of gray when printed with a black and white printer.
- Include meaningless legends like Excel defaults "Series 1," "Series 2," and so on.
- Connect data points with lines without knowing the purpose of the connecting lines
- Place a fitted correlation curve "over" unfilled data points; ideally, the curve should be "behind" the data points. *Note:* Excel does not appear to be able to accommodate this guideline.

distinguished from the others. The "Guidelines for Symbols and Legends" sidebar provides more information on this topic.

Landscape versus Portrait Orientation

Guidelines for the orientation of graphs are as follows:

- Portrait (vertical) orientation is preferred.
- If landscape format is used, make sure that the bottom of the graph is on the right side of the page. In other words, when the page is rotated 90° clockwise, the graph reads from left to right.

Titles, Captions, Labels, and Margins

- In written reports do not use a title on a graph; use a caption that contains a number and a title. Position captions *beneath* figures, but *above* tables.
- For oral presentations and posters, use a title, centered above the graph.
- Center axis labels along the axis. Use sentence-style capitalization and include appropriate units, preferably enclosed in parentheses, for example, (N/m^2) or alternatively in square brackets.
- Orient the y-axis label so that it can be read left to right when the page is rotated 90° clockwise.
- Make sure the font size on the axis labels is sufficiently large to be read even when reduced.
- Maintain all margins on the page when inserting figures into the manuscript

Tech Tip—Making Complicated Labels for Graphs in Windows 7.0

To create a complex label such as $\sigma = \sqrt{\frac{d_1^2 + d_1^2 + \dots d_n^2}{n-1}}$ for a graph, follow these steps:

1. Create the label in Word using the Equation Tools Design tab (see Appendix I).
2. Use the zoom slider in the bottom right corner to make the expression as large as possible, but still fitting on the screen.
3. Select and copy the expression using a screen capture utility such as the Snipping Tool or Grab. To access the Snipping Tool, click the **Start** button on your PC, type "snipping tool" into the search box, and click **Snipping Tool** from the results list. For Macs, type "grab" into the search box, and select the desired mode from the **Capture** menu.
4. Paste the image into the Excel graph, and re-size it to fit the graph.
5. You can save the captured image as a .png file for later re-use.
6. If you are using an older version of Windows, see instructions by Morrison (2009).

Morrison (2009)