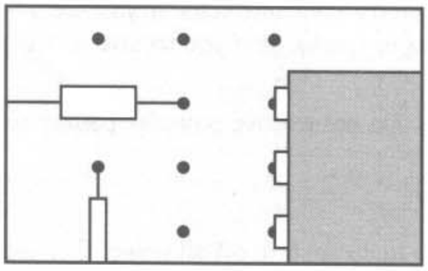


GOOD LAB PRACTICES AND OTHER USEFUL HINTS

You need to know several things before even starting the first experiment in this book. Good lab practices are the key to safe and successful experiments. This chapter contains many important suggestions for you. You may not be able to understand everything at first, as some of the suggestions are given in a context you will encounter later on. Nevertheless, you should read the chapter carefully in its entirety now, so that when the situation arises you will be aware of this material. You should then come back to this chapter and reread as appropriate.

Safety

It is imperative to minimize the dangers of receiving an electric shock by following certain safety procedures. The effects of electric shock are determined by the value of the current that passes through the body, the frequency, the path followed by the current, the time the current persists, and so on. The effects of an electric current can vary from a startling reaction (with unpredictable results) to involuntary muscle contraction (resulting in the "can't let go" effect) to pain, burns, fainting, heart failure, respiratory paralysis, and death.

The amount of current that passes through the body is determined by the voltage applied to it and by the resistance through which the current flows. The resistance can become especially small if there are cuts, if the skin is wet or moist, and if the contact area is large (e.g., through a metallic object such as a watch or a bracelet). Furthermore, the resistance decreases once a current begins to pass. When the body resistance is small, even moderate amounts of voltage can cause a harmful amount of current. It is therefore wise to consider any voltage as dangerous and to take precautions to limit the chances of receiving an electric shock, as well as to be familiar with what to do in case one of your colleagues receives a shock.

- Before starting to work in the lab, familiarize yourself with the location of the circuit breakers and know where to call for help and what to do in case one of your colleagues is injured. Consult appropriate posters or leaflets. If in doubt, ask your instructor.
- Never work in the lab alone.
- Use equipment with three-wire power cords and with a properly grounded case (see the following chapter on ground connections).

- Inspect all cords, plugs, and equipment for possible damage, and notify your instructor if you see any such damage. Also notify your instructor if you see any other sign of trouble, such as loose wall sockets or sparks, or if you receive an electric shock, however small.
- Be careful when inserting or removing a plug. Do not remove plugs by pulling on the cord.
- While making connections, keep the power off.
- Do not touch bare wires and parts. If you have to do so, turn off all power first and unplug the equipment. Even then, be aware that capacitors can store electric charges and can give you an electric shock, especially if their capacitance is large and they are charged to a large voltage.
- Do not work when your skin is wet. Wear shoes while working, and be sure they are dry.
- Do not wear metallic objects such as bracelets, necklaces, rings, or chains while working.
- Do not lean against metal surfaces, such as the case of a piece of equipment, pipes, or the frame of your lab bench.
- Do not leave lose metal parts, including wires, on your bench.
- Do not place drinks or food on your bench.
- If somebody else in the lab receives an electric shock, immediately turn off the power and/or remove the victim from the source of electricity *without* coming into electrical contact yourself (e.g., use a dry piece of wood, a dry piece of cloth, or a nonmetallic belt). Follow appropriate procedures for calling for help, providing artificial respiration and/or cardiopulmonary resuscitation, and otherwise providing aid until medical help arrives.

Possibilities for hazards other than electric shock also exist in an electronics laboratory. Do not exceed the voltage and/or power rating of electronic components. Be very careful to observe the polarity of electrolytic capacitors, which can explode if connected in the wrong way. Be aware of the fact that electronic components can overheat. Be careful with sharp objects, such as wire ends, component terminals, and integrated circuit pins. Be careful with soldering irons; they can cause burns or fires. Long hair and loose clothing can cause hazards when tangled with circuit boards, equipment, soldering irons, or machinery with moving parts.

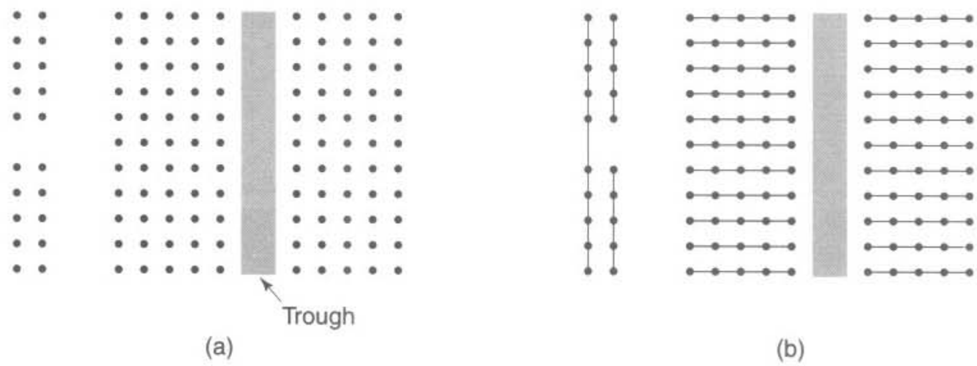
Additional considerations and rules may apply in your situation and environment. If in doubt, consult your instructor.

Wiring Your Circuit

There are several ways in which you can build an experimental circuit (as opposed to a permanent one, meant for repeated use). A common way to conveniently assemble a circuit without having to solder is to use a plastic "proto" board. This section has been written for the use of such boards, but many of the wiring suggestions given here apply to other types of boards as well.

A plastic proto board has sets of holes into which wires can be inserted. Inside each hole, invisible to you, is a metallic socket appropriate for snugly receiving a wire pushed into the hole. Sets of sockets, arranged in rows and columns, are connected

Fig. 1



together internally. An example of part of a proto board is shown in Fig. 1. The holes as they appear externally are shown in (a); the internal connections under the surface are revealed in (b). Each set of holes connected together as shown can form a single node in a circuit. Most sets contain five or six holes and are used for internal nodes in the circuit. Other sets, such as the ones shown vertically in (b), are used for power supply and ground connections. On some boards, some of these sets may be broken into separate parts, as indicated in the second vertical line in (b). There are several variations of proto boards, more or less based on this general scheme. Your instructor can explain the internal connections of the particular board you will be using (or you can find them out yourself by using an ohmmeter as a continuity tester, as explained in Experiment 2; you can attach small pieces of wires to the ohmmeter's probes and insert those into the holes). Proto boards are appropriate for low-frequency work (up to a few MHz). At higher frequencies, the large capacitance between adjacent rows of connector holes can interfere with proper operation.

To make connections to a proto board, use pieces of insulated solid (not stranded) wire of an appropriate diameter (usually #22 to #24 AWG), the insulation of which has been removed on both ends, exposing about 12 mm (or about 0.5 inches) of bare wire. Several different lengths of such wires may be appropriate for a given circuit. Sets of connecting wires are commercially available in various lengths and colors. To insert a connecting wire, make sure its bare ends are straight and push each end vertically all the way into a hole. A pair of long-nosed pliers can help in this task. Electronic components such as resistors, capacitors, or integrated circuits can also be plugged directly into a proto board. In the case of resistors, common ½ W ones have lead diameters that are well suited for this purpose. Resistors with a larger power rating may have leads that are too thick, which can damage the connections in the board.

It is very important to get into the habit of wiring a circuit neatly right from the beginning. A neatly built circuit is less likely to contain mistakes, it is easier to debug, and it is easier for a colleague or for your instructor to understand. Figure 2(a) shows a neatly wired circuit, whereas Figure 2(b) shows a messy one. In principle, both wirings implement the same circuit; but if your wiring habits are like those in Figure 2(b) you will soon run into trouble. Several hints to help you form good wiring habits follow. You can interpret several of them by referring to Figures 2(a) and 2(b).

- Keep the power off while you are wiring your circuit, as well as while you are changing anything in it.

- Always start with a carefully drawn schematic of the circuit you want to build, properly labeled with component types or values and pin numbers for integrated circuits. Do not try to do things directly from memory.

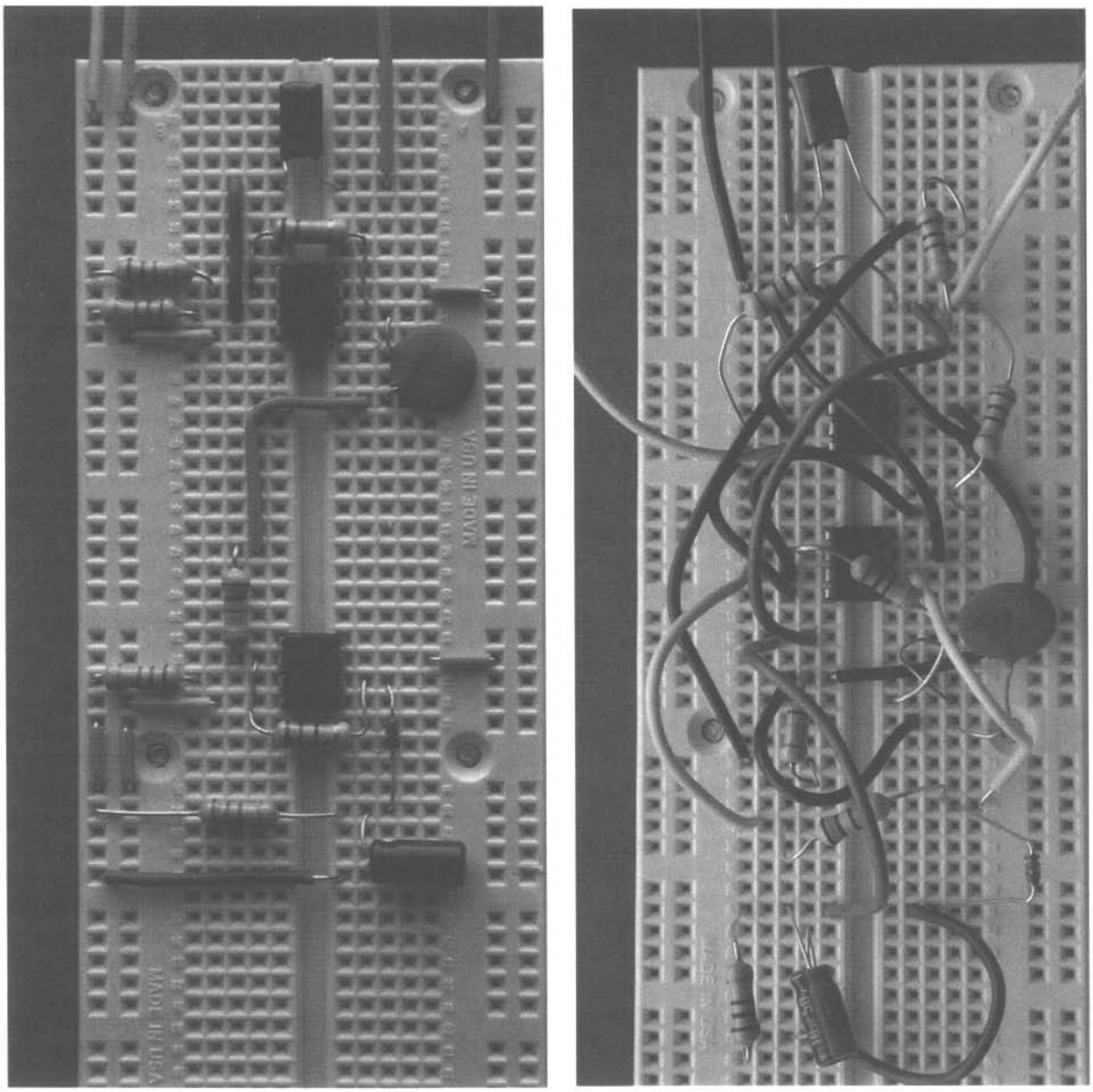


Fig. 2 *(a)* *(b)*

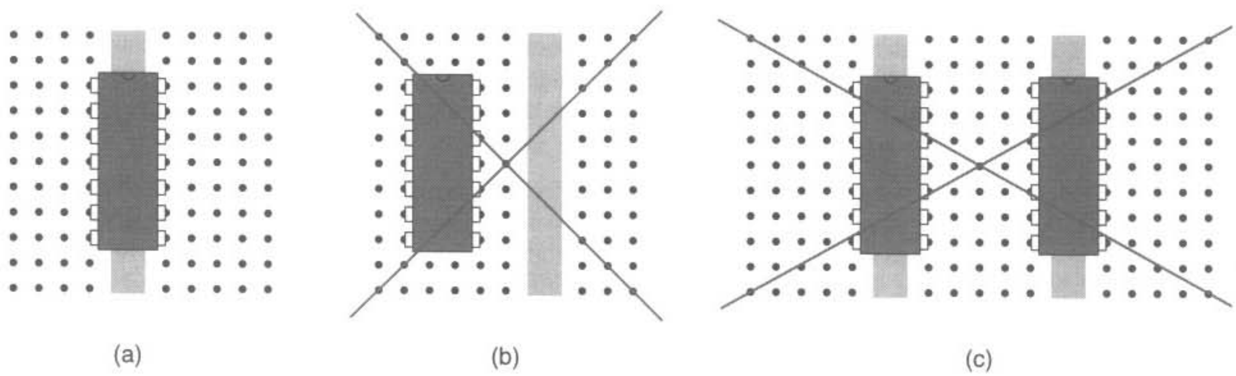


Fig. 3

- Mark all completed connections on your diagram as you go, for example, by using a color marker.
- Use connections as short as possible. Long wires contribute to messiness and can cause interference through undesirable capacitive, inductive, or electromagnetic interaction with other parts of the circuit. (This suggestion does not imply that you need to cut each wire exactly to size; for this lab, it will be sufficient to choose the right length among several pre-cut wires commonly found in a wire kit.)
- Keep wires down, close to the board's surface.
- As a rule, if you can connect components such as resistors or capacitors directly (without extra wires connected to them), do so.
- Plug in chips so that they straddle the troughs on the proto board. In this way, each pin is connected to a different hole set, as shown in Fig. 3(a). Fig. 3(b) shows a common mistake (for a six-hole set proto board). Why is this practice wrong? You can answer this question by considering how the holes are connected together internally [Fig. 1(b)]. You can also see why the practice shown in Fig. 3(c) for a two-trough board is most likely inappropriate when working with more than one chip.
- Do not pass wires over components (or over other wires, if you can avoid doing so without significantly lengthening a connection). This makes the circuit difficult to figure out, and it makes it difficult to remove a component if you have to replace it.
- Use the longer strings of holes as power and ground "buses." For example, use one such string for the connections to the power supply pins of your chips and other components, and wire that string to your power supply.
- Be sure that bare wires or component terminals are clear of each other so that they cannot become accidentally shorted together if something is moved.
- Do not use more wires than you have to. The more connections, the more likely it is that something can go wrong (e.g., a wiring error can occur, or a connection in the proto board can be loose).
- Use color coding for your wire connections (e.g., red for all wires connected to the positive power supply and black for all wires connected to "ground"). This makes it easier to inspect and debug the circuit.

- If convenient, locate components associated with a circuit with a well-defined function, close to each other in one group. For example, if your circuit includes a preamplifier, all components that are part of the preamplifier should be physically located close to each other, in an easily identifiable block. This can help later during the debugging process (see below).

- Before plugging ICs (integrated circuits) into a proto board, be sure that their pins are straight. The tips of the two rows of pins on the ICs you will be using in this lab should be 0.3″ apart. Sometimes you will find some ICs with their pins bent; in that case, straighten them before plugging in the ICs. A pair of long-nosed pliers can make this task easy, as then each row of pins can be straightened at one time.

- Be aware of the fact that ICs, especially those made with MOS technology, can be instantly damaged by static electricity, such as that accumulated by your body. You should make sure you are "discharged" before handling them, by momentarily touching the metal case of a properly grounded instrument.

- Be sure to use resistors with a sufficiently high power rating (½ W resistors are fine in almost all circuits in this lab) and capacitors with a sufficiently high voltage rating. Observe the polarity on electrolytic capacitors—they can explode if connected in the wrong way.

- Be sure capacitors are discharged before plugging them into a circuit. If in doubt, short their leads (in critical cases you may have to do so at least twice, as a capacitor can have residual charges even after you have discharged it once).

- Unplug ICs very carefully, to avoid bending the pins. You may want to try an IC extractor if one is available in your lab.

- For points that must be connected to external instruments such as power supplies and function generators, connect a wire from an appropriate hole on your proto board to a sturdy post (such as a banana or coaxial socket, often available on the larger test board on which a proto board may be mounted). Then, use an appropriate cable to connect that post to the instrument. This helps make your connections mechanically stable.

- For the inputs of measuring instruments, such as voltmeters and oscilloscopes, you should normally follow the same practice as above. An exception to this rule occurs when you want to probe several different points in your circuit by moving the instrument probe from point to point or when the connection to the instrument probe must be as short as possible. If you have to connect an instrument probe to a hole on your proto board, you can do so through a short piece of wire; be sure the connection of this wire to the probe is not loose and does not touch any other connections.

- The coaxial connector of oscilloscope probes (Experiment 3) should only be connected to the input of the oscilloscope. It should never be connected to the function generator, to other instruments, or to your test board.

- Be especially careful of ground connections. Read carefully the chapter on ground connections.

- When finished wiring a circuit, inspect all connections to make sure you have made no mistakes. Only when you are happy with the result should you turn on the circuit.

- If you have connected a signal source (such as the output of a function generator), do not turn it on until after you have turned on the power supplies, if any are used in your circuit. Some ICs can be damaged if you do otherwise. If you later want to turn off the power, turn off the signal source first. In short, never have a signal connected to a circuit with power supplies unless those supplies are on.

Debugging

It is very likely, despite the care with which you may have wired your circuit, that it will not work when you first turn it on, perhaps because of a defective component or a wrongly designed circuit; often, however, this is due to a missing or wrongly connected wire, a loose connection, bent IC pins that have not been properly inserted into holes on the board, an unintended short between two bare wires or terminals, and so on. You will then need to debug, or troubleshoot, your circuit. Trying to do so for a large circuit can be a very difficult task (made easier with experience). Following are some tips to help you debug your circuit.

- Turn off your circuit and visually inspect it for wrong connections or accidental shorts.
- Be sure that you know the correct underlying connection pattern of your proto board and that you have not made any mistakes in this respect. Beware of breaks in some power supply or ground buses on some boards [see Fig. 1(b)]. Beware of mistakes such as those shown in Figs. 3(b) and 3(c).
- If you suspect that a connection is not made as intended, you can use an ohmmeter as a continuity tester (see Experiment 2), but first make sure that all power to the circuit has been turned off.
- A malfunctioning circuit may have overheated components. Be careful with them. On the other hand, a hot component may be a clue to the problem.
- If your power supplies have a current meter, observe it. If the current is zero, it may be a sign of a missing connection. If it is excessive, it may be a sign of a short or other problem.
- In some power supplies you can a set a current limit. You may want to limit the current accordingly, to protect your components in case of circuit errors. On the other hand, if this limit has been set too low (lower than the expected total current for the circuit), it may be the very reason the circuit does not work properly.
- Use a voltmeter to test whether the power supply voltage reaches an intended point in the circuit, attaching one of its terminals to ground and the other to that point. Test all such points if necessary. A zero voltage may indicate a broken connection or a short to ground. If a voltage is correct at some point, move your probe to the next point where this voltage, or part of it, is supposed to appear, and remeasure. It is usually better to do this type of testing with only the power supplies on and any signal sources off.
- If the preceeding procedure does not reveal the problem and if your circuit contains a signal source, turn it on and do some further sleuthing with the oscilloscope: Is the signal present at the output of the signal source? If so, is it present at the input of your test board? If not, you may have a bad cable or a short to ground. If there is a signal at the input of the board, is it also present at the next logical point (e.g., at an IC pin to which the board input is supposed to be connected)? The idea is to eliminate possible problems one by one until you hit the points that are causing the trouble.

- Unless the circuit is very simple, do not try to check its behavior all at once. Rather, do some sleuthing to find out where the problem lies. If the circuit can be broken down (physically or mentally) into two independent parts, check each part separately (e.g., the preamplifier and the power amplifier of the sound system in Experiment 5). To do this, you may need to power the part being tested separately from the rest of the circuit, apply to it an appropriate signal (e.g., obtained from the function generator), and check its output accordingly (e.g., using an oscilloscope). The use of the function generator and oscilloscope is described in Experiment 3.
- You can carry the above hint one step further: When wiring a large circuit, you can first wire a part of it and test it by itself to make sure it is correct before proceeding to wire the rest. For this approach to work, of course, you need to be sure that the part you are testing is independent of the rest and is supposed to work correctly by itself.
- If you must try to find out what the problem is by changing things on your test board, change them one at a time, observing the result in each case. If you change more than one thing at once, not only may you be unable to isolate the cause of the problem, but also the second change may undo the result of a first, correct change, and you will have missed your chance to make the circuit work.
- In some cases problems can be caused by external interference (from a TV station, from lighting or other equipment in the room, etc.). Such interference can be picked up by long wires connected to your circuit (e.g., those carrying power to your setup), which can act as antennas. In such cases, you may be seeing a signal at the output of your circuit, even though no signal is being applied at its input. If you suspect interference problems, you may have to combat them by using bypass circuits, as explained in Appendix D.
- If all else fails, and only as a last resort, you may have to disassemble your circuit and start from scratch, especially if sloppy wiring in your first version prevents you from identifying the problem. This time, it is hoped, you will be more careful and neat with your wiring.
- This last solution should not be overused. You should stick with your original circuit and persist in looking for the problem. You can learn a lot not only from properly working circuits but also from knowing what went wrong in bad ones.

Lab Reports

There are many types of lab reports, which vary according to the kind of information that has to be reported, the level of informality, and so on. Your instructor will let you know what type of report he or she expects. Unless your instructor indicates otherwise, it is wise to adopt the following practices.

- Use a pad of quad graph paper (with squares ¼" on a side). The squares will make it easier for you to construct tables and plots and to draw schematics.
- Be sure your report is orderly and neat. Conciseness is appropriate for some styles of reporting, but sloppiness isn't. Even *you* may find it hard to follow your own sloppy report a few weeks after you have written it.
- Include a careful schematic for each circuit you have built, labeled with component values, types and pin numbers of ICs, and other pertinent information. This is needed for anyone (including your instructor, your colleagues, or even yourself at a

later time) to be able to interpret what you have done. In some cases, you may even want to include a board-level layout of your components and connections, corresponding to their physical location on your proto board.

- When preparing plots, label your axes appropriately, including tics and values along them; the quantity being plotted along each axis; and the corresponding units.
- Show experimentally obtained points as dots or small circles on plots. Be sure to take a sufficient number of points to appropriately show the behavior you are investigating, especially in regions where rapid variations are observed. Points that are far apart may completely bypass such regions.
- Pass a best-fit line through the points on your plot. Do not simply join them with straight-line segments.
- When asked to plot a variable y versus a variable x without further specification, consider what ranges and values are appropriate. When asked to plot current versus voltage for a resistor, for example, it is appropriate to use both positive and negative voltage values unless instructed otherwise.

Preparation

Always study the experiment you are going to do before coming to the lab. Read each instruction carefully, trying to imagine your experimental setup. Try to anticipate the probable results of your measurements, as well as what to watch out for and what problems are likely to arise. Take notes as appropriate. Being fully prepared is necessary for you to be able to finish an experiment in the time allowed and to be able to benefit from it as much as possible. The experiments in this book are based on the assumption that you will have fully prepared yourself before doing each one. You also owe it to your lab partner to be fully prepared, so that you can contribute to the experiment.

Running the Experiment

- Always read each step in its entirety before acting. Do not stop in the middle of a step and start wiring or measuring, as the rest of the step may contain information relevant to those tasks, which can save you time or trouble.
- Try to guess the likely result of each step before you perform it. This will enhance your understanding and will prepare you to catch a possible problem, saving time.
- Do not put off plotting or other tasks until the end of the experiment. Do plots when asked to. This is because some plots reveal information that can be useful in interpreting your results and identifying potential problems before time is wasted on a possibly malfunctioning circuit. Plots can also tell you whether you need to measure more points before going further, while you still have your circuit connected for doing so. Finally, they can give you intuition and information that will help you in the subsequent steps. Again, completing each task when asked to in each experiment can save time and trouble.
- Measurements are never exact. Keep this in mind, but otherwise try to obtain measurements as accurately as possible. Think about the sources of measurement error in each case, and interpret your results accordingly.
- Use an appropriate range on measuring instruments to obtain enough significant digits. On the other hand, you should not overdo this. It is not appropriate to give the

impression of precision by keeping more digits than makes sense in a given situation. Also, with some instruments (such as some ammeters; see Experiment 1), the range chosen can affect the degree to which the instrument affects the circuit under measurement.

- Be very careful if you need to obtain a small quantity by subtracting two much larger quantities. For example, $1.344 - 1.336 = 0.008$, but if the two numbers had been measured with three significant digits, you would have gotten $1.34 - 1.34 = 0$.
- Become very familiar with your test instruments. Do not arbitrarily push buttons until you get something; *know* which buttons to push.
- If you are doing an experiment with a lab partner, make sure you both contribute equally. If you do not contribute, you are not only being unfair to your partner but also not really learning. Passive observation cannot replace doing. If, instead, you are the type that takes over and would rather do the lab by yourself, you are hurting your partner's learning process. Be sure both of you have a chance to do each type of task. For example, if you wire and your partner takes measurements, the next time around your partner should do the wiring and you should measure.

- Above all, **resist the temptation to just blindly follow the procedures.** If you just do so, take all the measurements correctly, and write your report, you will have wasted several hours. Observe, think, act, and discover. Many of the "why" questions in this book are meant to just make you think. But do not stop there. Ask yourself, as often as you can, why something is done in a certain way, why it works or doesn't, or what would happen if something were done differently. This is a very important part of your education. Discuss such questions with your lab partner. If you have ideas that you want to try, first make sure they are safe; if in doubt, ask your instructor.