If you have access to a laboratory electroscope, try charging it up with a glass rod that has been rubbed against a cloth. When the rod is pulled away from the electroscope, the foil leaves remain standing apart. The charge just sits there! If the electroscope drew any current, the leaves would fall back together again, just as the galvanometer compass needle returns to magnetic north the instant you take the wire from the battery.

Thermal Heating

Another phenomenon, sometimes useful in the measurement of electric currents, is the fact that whenever current flows through a conductor having any resistance, that conductor is heated. All conductors have some resistance; none are perfect. The extent of this heating is proportional to the amount of current being carried by the wire.

By choosing the right metal or alloy, and by making the wire a certain length and diameter, and by employing a sensitive thermometer, and by putting the entire assembly inside a thermally insulating package, a *hot-wire meter* can be made. The hot-wire meter can measure ac as well as dc, because the current-heating phenomenon does not depend on the direction of current flow.

A variation of the hot-wire principle can be used to advantage by placing two different metals into contact with each other. If the right metals are chosen, the junction heats up when a current flows through it. This is called the *thermocouple principle.* As with the hot-wire meter, a thermometer can be used to measure the extent of the heating. But there is also another effect. A thermocouple, when it gets warm, generates dc. This dc can be measured with a galvanometer. This method is useful when it is necessary to have a fast meter *response time.*

The hot-wire and thermocouple effects are sometimes used to measure ac at high frequencies, in the range of hundreds of kilohertz up to tens of gigahertz.

Ammeters

A magnetic compass doesn't make a very convenient meter. It has to be lying flat, and the coil has to be aligned with the compass needle when there is no current. But of course, electrical and electronic devices aren't all oriented so as to be aligned with the north geomagnetic pole! But the external magnetic field doesn't have to come from the earth. It can be provided by a permanent magnet near or inside the meter. This supplies a stronger magnetic force than does the earth's magnetic field, and therefore makes it possible to make a meter that can detect much weaker currents. Such a meter can be turned in any direction, and its operation is not affected. The coil can be attached directly to the meter pointer, and suspended by means of a spring in the field of the magnet. This type of metering scheme, called the *D'Arsonval movement*, has been around since the earliest days of electricity, but it is still used in some metering devices today. The assembly is shown in Fig. 3-4. This is the basic principle of the *ammeter.*

A variation of the D'Arsonval movement can be obtained by attaching the meter needle to a permanent magnet, and winding the coil in a fixed form around the magnet. Current in the coil produces a magnetic field, and this in turn generates a force if the coil and magnet are aligned correctly with respect to each other. This works all right, but the mass of the permanent magnet causes a slower needle response. This type of meter is also more prone to *overshoot* than the true D'Arsonval movement; the inertia of the magnet's mass, once overcome by the magnetic force, causes the needle to fly past the actual point for the current reading, and then to wag back and forth a couple of times before coming to rest in the right place.

There are some situations in which a digital meter is a disadvantage. One good example is the signal-strength indicator in a radio receiver. This meter bounces up and down as signals fade, or as you tune the radio, or sometimes even as the signal modulates. A digital meter will show nothing but a constantly changing, meaningless set of numerals. Digital meters require a certain length of time to lock in to the current, voltage, power, or other quantity being measured. If this quantity never settles at any one value for a long enough time, the meter can never lock in.

Meters with a scale and pointer are known as *analog meters.* Their main advantages are that they allow interpolation, they give the operator a sense of the quantity relative to other possible values, and they follow along when a quantity changes. Some engineers and technicians prefer analog metering, even in situations where digital meters would work just as well.

One potential hang-up with digital meters is being certain of where the decimal point goes. If you're off by one decimal place, the error will be by a factor of 10. Also, you need to be sure you know what the units are. For example, a frequency indicator might be reading out in megahertz, and you might forget and think it is giving you a reading in kilohertz. That's a mistake by a factor of 1000! Of course, this latter type of error can happen with analog meters, too.

Frequency Counters

The measurement of energy used by your home is an application to which digital metering is well suited. A digital kilowatt-hour meter is easier to read than the pointer-type meter. When measuring frequencies of radio signals, digital metering is not only more convenient, but far more accurate.

A *frequency counter* measures the frequency of an ac wave by actually counting pulses, in a manner similar to the way the utility meter counts the number of turns of a motor. But the frequency counter works electronically, without any moving parts. It can keep track of thousands, millions, or billions of pulses per second, and it shows the rate on a digital display that is as easy to read as a digital watch.

The accuracy of the frequency counter is a function of the *lock-in time.* Lock-in is usually done in 0.1 second, 1 second, or 10 seconds. Increasing the lock-in time by a factor of 10 will cause the accuracy to increase by one additional digit. Modern frequency counters are good to six, seven, or eight digits; sophisticated lab devices can show frequency to nine or ten digits.

Other Meter Types

Here are a few of the less common types of meters that you will occasionally encounter in electrical and electronics applications.

VU and Decibel Meters

In high-fidelity equipment, especially the more sophisticated amplifiers ("amps"), *loudness meters* are sometimes used. These are calibrated in *decibels*, a unit that you will often have to use, and interpret, in reference to electronic signal levels. A decibel is an increase or decrease in sound or signal level that you can just barely detect, if you are expecting the change.

Audio loudness is given in *volume units* (VU), and the meter that indicates it is called a *VU meter.* The typical VU meter has a zero marker with a red line to the right and a black line to the left, and is calibrated in decibels (dB) below the zero marker and volume units above it (Fig. 3-12). The meter might also be calibrated in *watts rms*, an expression for audio power. As music is played