Electrical Current

Electrical current consists of moving electrons

Conductors such as copper are filled with movable charge somewhat like a cloud of electrons. A net flow of these charges within the conductor constitutes electrical current flow. An external influence is required to cause the electrons to move through the conductor. This force is usually an applied electric field. When the electric field pushes against the electron cloud, the entire cloud, acting as one, moves. In this way electrons are caused to flow at the opposite end of the electron cloud.

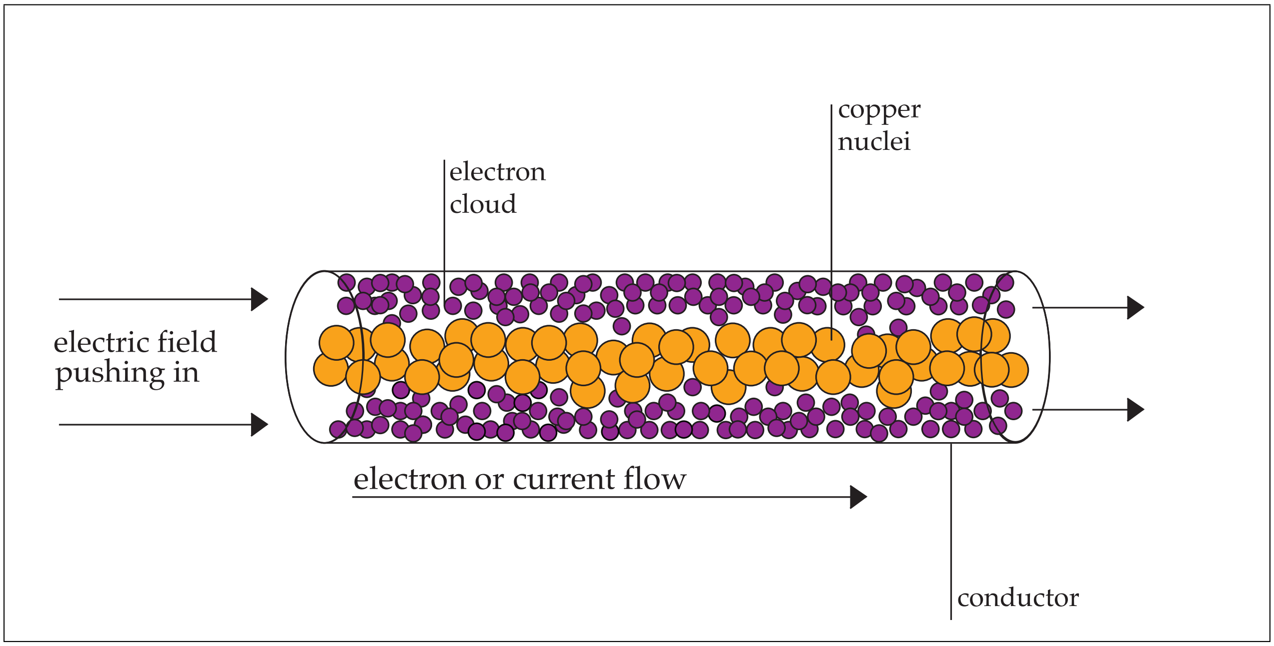

Figure 1: Current Flow in a Copper Conductor

Here is another way to think about current flow; the *pipe and ball* analogy. A conductor is like a pipe full of electrons. If an electron is pushed into one end of the pipe, another electron must fall out at the other end. Electrons flowing through a wire are like balls traveling through a pipe, not like an empty pipe which electrons fall through.

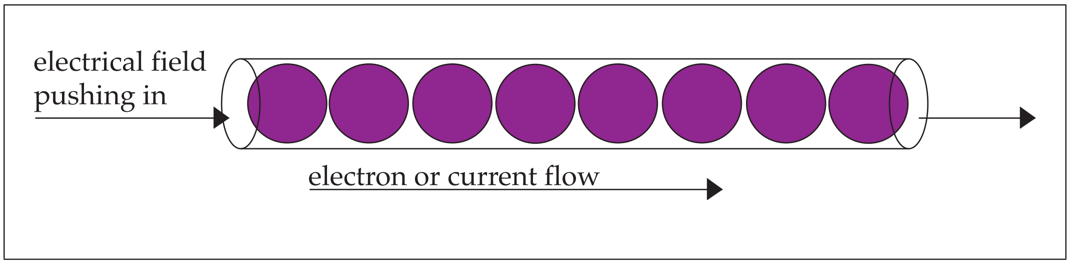

Figure 2: Last Electron In $\neq$ First One Out

Measuring current

Both water molecules and electrons are small. We don't measure water flow in molecules per minute but by gallons (many, many molecules) per minute. We measure electron flow in much the same way.

Electron flow is measured in $\frac{Coulombs}{sec}$. One Coulomb (C) is equal to $6.25x10^{18}$ electrons. The term that refers to one Coulomb per second of current flow is the Ampere (A). It is informally referred to as an "Amp". Thus,

$$1A = 1\frac{C}{sec} \tag{1}$$

To restate, the rate of electron movement that would cause one Coulomb of electrons to move across a plane surface bisecting a wire in one second is called 1 Ampere of electron flow.

Specifying electrical current flow in a conductor

To accurately specify a current flowing in a conductor, three bits of information must be known.

1. The magnitude of the current flow
2. The reference direction of the current flow
3. The conductor the current is flowing through

All the above items are commonly conveyed by placing a arrow adjacent to the conductor of interest with the magnitude of the current given by a numerical value and an arrow indicating the reference direction to which the numerical value refers. See the example in figure 3.

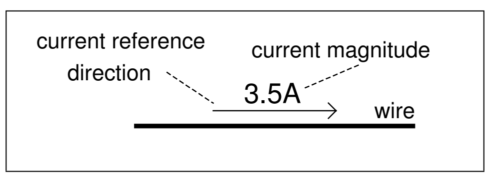

Figure 3: Specifying Current: Arrow, Magnitude, and Conductor

The direction of the arrow alone does not necessarily indicate the actual direction of current flow. The arrow indicates the reference direction. When coupled with the sign of the current magnitude, the actual direction of current flow may be determined. See the examples in figure 4.

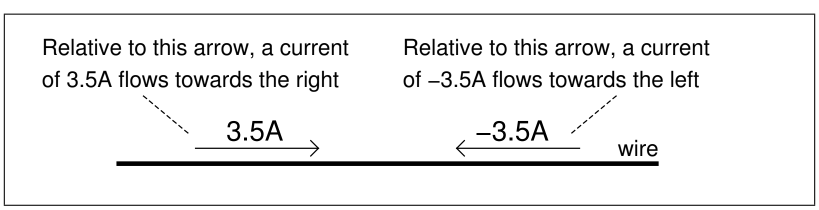

Figure 4: Specifying Current is Relative to the Current Arrow

To flip an arrow's direction, simply change the sign on the current magnitude. To allow changing the sign on the magnitude, flip the arrow. Remember however the arrow does not necessarily indicate the actual direction current flow. See figure 5.

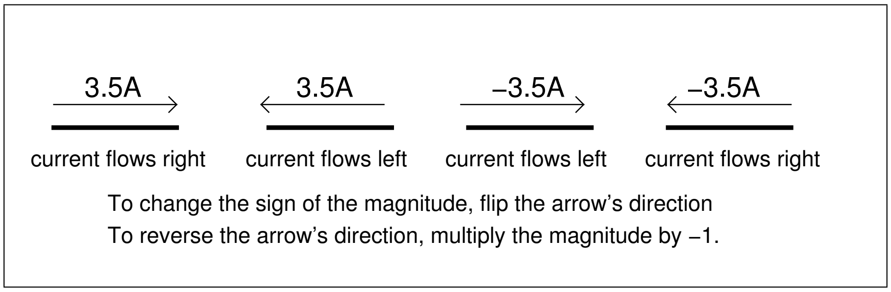

Figure 5: Specifying Current is Relative to the Current Arrow

When solving for unknown currents in a circuit, neither magnitude or direction of the current will be known. In such cases, we assume a reference direction of current flow. Based on this assumption, the mathematical solution will result in a positive or negative value for the unknown current. If our current is positive, then the current flow is in the assumed direction. If the current is negative, the current flows in the opposite direction. Either answer is correct however.

Current measurements with a digital multimeter (DMM)

To measure electrical current with a DMM, we must insert the meter into the path of the current flow. However, critical to any measurement is the necessity of not disturbing the original circuit. Inside the DMM is a special calibrated low resistance wire that allows the current measurement to me made. To the external world however, it simply looks like a very, very low resistance piece of wire. The meter becomes essentially invisible to the circuit while still measuring the current flowing through it. Figure 6 shows the inside of a DMM. The large diameter wire arching over the board is the calibrated very low resistance wire that allows current measurments at the 10 amp level.

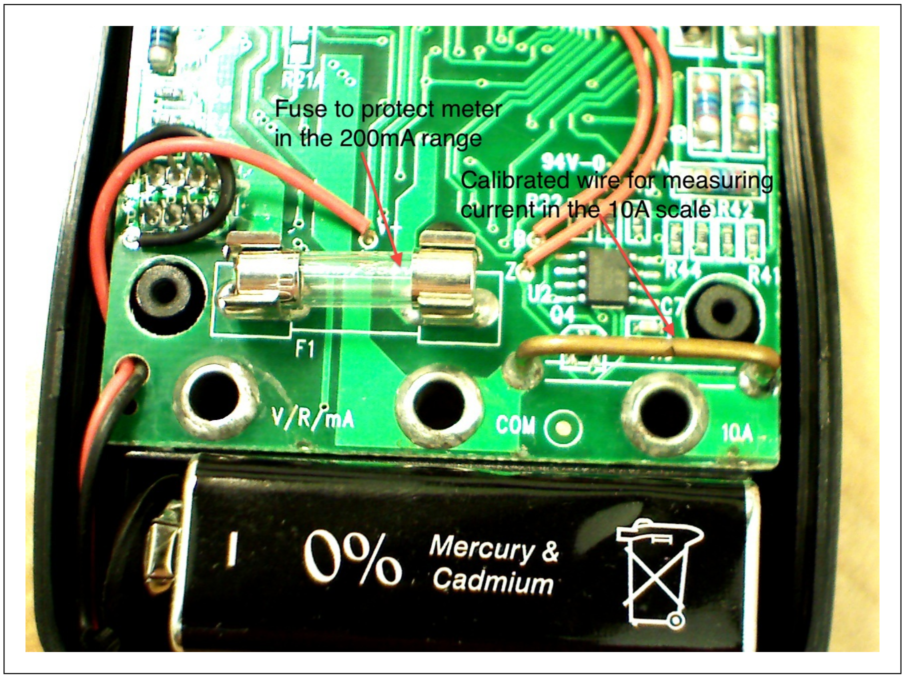

Figure 6: Inside back of DMM showing current sense wire and fuse

Figure 7 shows how we would open the circuit up to measure the current flowing by inserting a DMM into the loop.

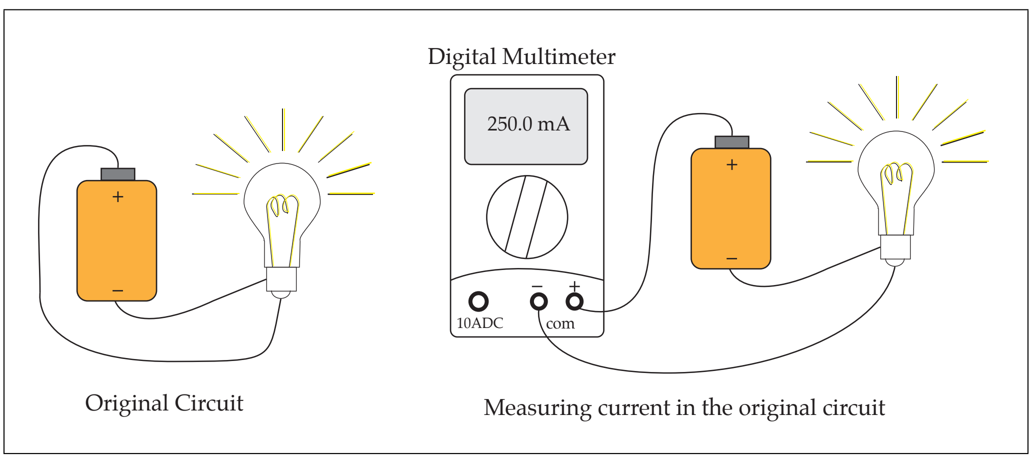

Figure 7: Opening a circuit to make a current measurement

Note that the DMM has terminals marked as (+) and (−) or COM on it. These markings indicate the reference current direction for the meter. The meter expects positive current to flow into the positive terminal marked with the (+) for there to be a positive reading. In other words, if current actually flows into the positive terminal, the reading on the display will be positive. If the current is flowing out of the positive terminal, the current reading will be negative. The meters (+) and (−) signs make more sense when measuring voltage rather than current. As such, you could imagine that an invisible arrow is on the meter terminals to indicate the expected reference direction as shown in figure 8.

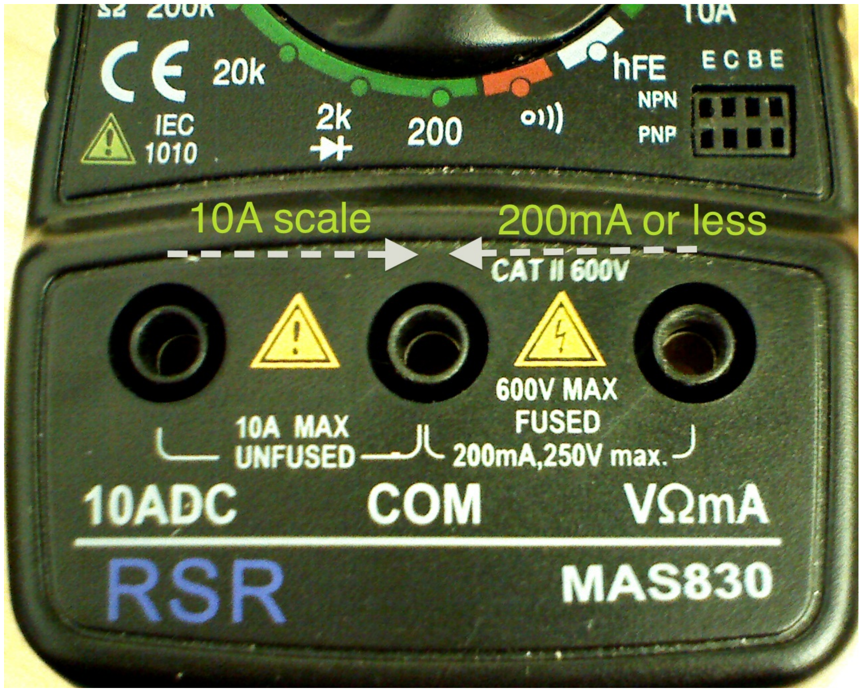

Figure 8: Face of DMM showing imaginary reference current arrows.

For measuring larger currents (greater than about 200mA), the very low resistance wire is used inside the DMM. This necessitates the use of a second jack on the DMM. It is just used for high current measurements. This is seen in figure 8 as the "10ADC" (10 Amps Direct Current) jack on the DMM. The "COM" terminal is also known as the negative $(-)$ terminal. The one marked with ΩmA is the positive or $(+)$ terminal.

When magnitude and direction of current flowing in a circuit does not vary with time, the current is referred to as *direct current* (DC). If the current continuously varies amplitude and direction, it is referred to as *alternating current* (AC). See figure 9.

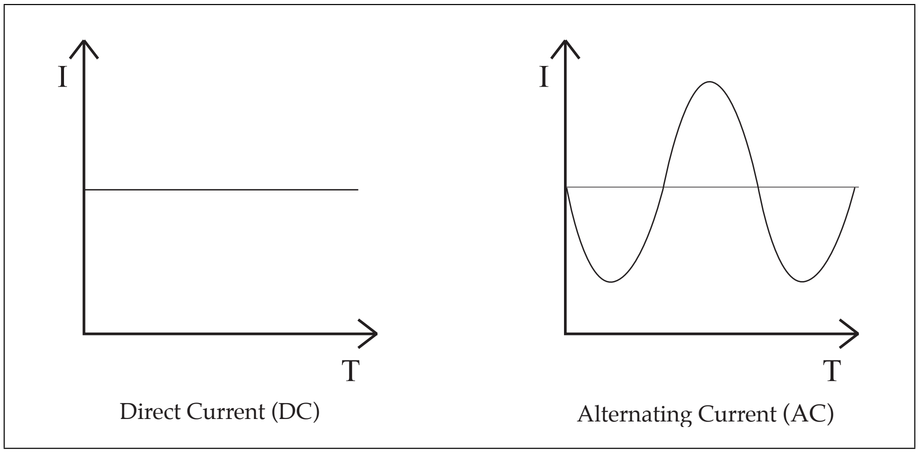

Figure 9: AC and DC Currents

Ranges of current flow

Typical electrical currents vary a great deal:

integrated circuit (chips)	0.1 μA- 10,000mA
flashlight	100 mA - 1A
home stereo	1 - 2A
bathroom heater	10A (110VAC outlets are 15A - 20A rating)
automobile starter motor	100 - 400A
power distribution	200 - 1 kA
lighting bolt	$>$ 10 kA

In practice, the ranges of current, voltage and resistance can be very large. It is necessary for engineers to be thoroughly familiar with the engineering unit prefixes. The most common ones are in Table 1.

Table 1: Commonly Used Engineering Unit Prefixes

Prefix	Abbreviation	Value	Multiplication Factor
tera	T	10^{12}	1,000,000,000,000
giga	G	10^{9}	1,000,000,000
mega	M	10^{6}	1,000,000
kilo	k	10^{3}	1,000
none		10^{0}	1
milli	m	10^{-3}	.001
micro	μ	10^{-6}	.000001
nano	n	10^{-9}	.000000001
pico	p	10^{-12}	.000000000001
femto	f	10^{-15}	.000000000000001
atto	a	10^{-18}	.000000000000000001