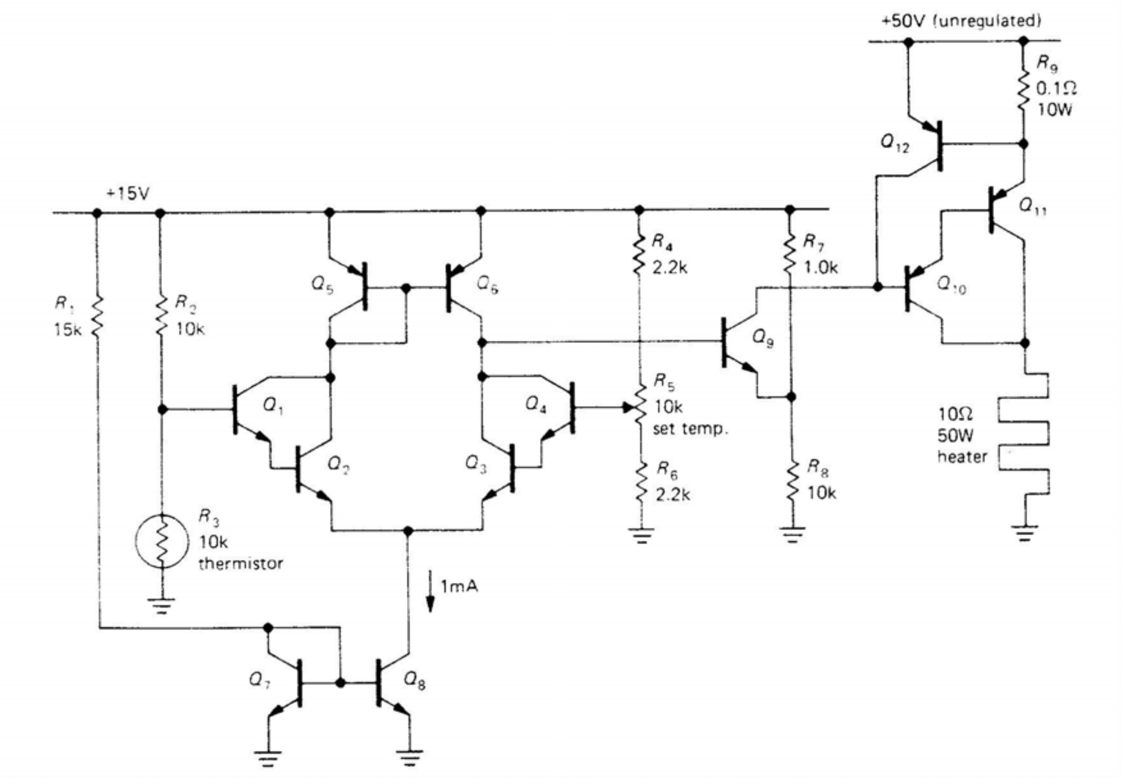
CIRCUIT DIAGRAMS

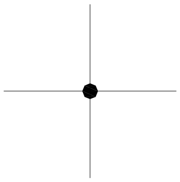


Circuit diagrams (also called *schematics*) provide a **model** of a real circuit in which we abstract away all the messy details of a real physical circuit and incorporate in our model only on the most important properties of the devices in the circuit.

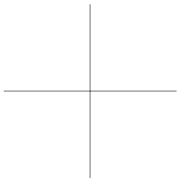
For example, it is normally assumed that:

> A wire in a circuit diagram is a perfect conductor with zero resistance, regardless of the size of the wire, how long it is, or what shape it's twisted into.
>
> The layout of the components and the wire lengths in a circuit diagram has nothing to do with the layout and wire lengths of an actual circuit built from the circuit diagram.
>
> A battery in a circuit diagram produces a fixed voltage, regardless of how much current is being drawn from it, what the temperature is, or how long it's been used.
>
> A resistor has a fixed, constant resistance as its only property, regardless of how it's built, it's temperature, or the current going through it. It has zero capacitance and zero inductance.
>
> A capacitor has a fixed, constant capacitance as its only property, regardless of how it's built, its temperature, or the current going through it. It has infinite resistance and zero inductance.
>
> An inductor has a fixed, constant inductance as its only property, regardless of how it's built, it's temperature, or the current going through it. It has zero capacitance and zero resistance.

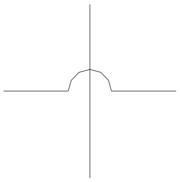
SOME BASIC CIRCUIT SYMBOLS



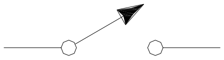
wires crossing
(connected)



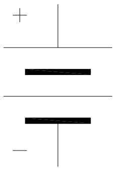
wires crossing
(unconnected)



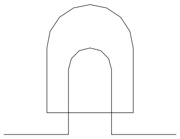
wires crossing
(unconnected)



switch

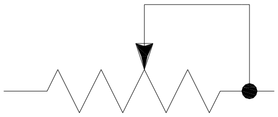


battery

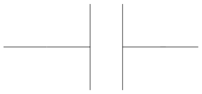


lamp

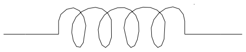
resistor



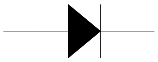
potentiometer
(variable resistor)



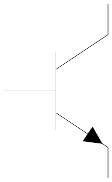
capacitor



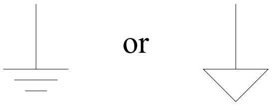
inductor



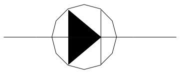
diode



NPN transistor



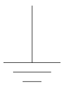
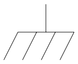
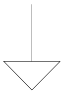
ground



LED

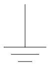
GROUND (Section 2.10 in text)

The concept of “ground” for a circuit is often a point of confusion.

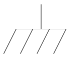
In most electrical circuit diagrams, one or more wires within the circuit are connected to “ground”, indicated by one of these symbols:  or  or 

What does a “ground” mean?

An electrical ground is a place whose electric potential (voltage) does not change appreciably even if current flows into or out of it.

The ultimate ground is earth ground, i.e., the earth itself. The electrical power system in all buildings and houses has a wire running to earth ground from every electrical outlet (it’s what the third round prong on your power cord plugs into). The earth ground is created by having the building’s ground wire connected to metal rods, rings, or a metal water pipe buried in the (preferably moist) dirt. The symbol for a direct earth ground is 

However, in practice, this same ground symbol is commonly used to indicate the ground reference point in any electrical circuit, a usage which can sometimes confuse beginners.

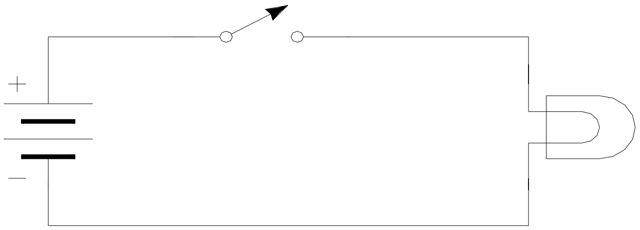
Nearly all electronic devices that plug into a wall outlet have their power cord’s ground wire connected to the case or chassis of the device. The symbol used for chassis ground is 

If one terminal of the device’s internal power supply is connected to the power cord’s ground.wire, that terminal is said to be grounded, and that point will show up on the circuit diagram as a ground symbol.

This ground point serves as the reference voltage for the other voltages in the circuit, and is conventionally taken to be zero volts.

Note that a circuit does not have to have a ground connection to operate – almost all battery powered electronic systems (like your flashlight or iPod) have no ground connection. Current just flows from the positive terminal of the battery or power supply through the circuitry and back to the negative terminal with no ground reference point.

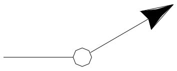
Flashlight:



SWITCHES (Section 3.3 in text)

Switches come in many varieties and have their own special nomenclature.

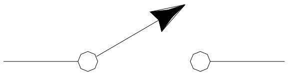
S = single
D = double

P = pole = 

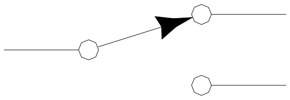
NO = normally open
NC = normally closed

T = throw = 

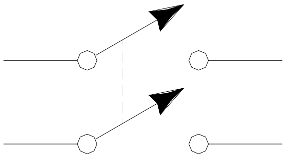
Some common switch types:



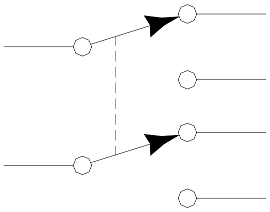
SPST switch



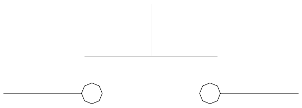
SPDT switch



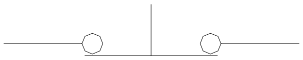
DPST switch



DPDT switch



NO pushbutton switch



NC pushbutton switch

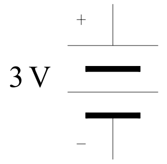
You can easily tell what variety a real switch is just by looking at the number of contacts.

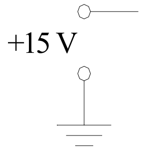
POWER SOURCES (Section 2.13 in text)

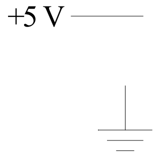
Nearly all electronic circuits require either a DC power supply or batteries to provide the energy they need to operate.

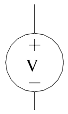
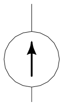
DC power supplies produce either a constant voltage difference between their + and – terminals, or (rarely) a constant current. Their internal workings are discussed later.

In circuit diagrams voltage sources are indicated in several ways:



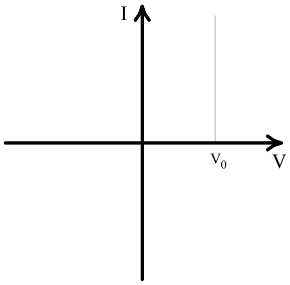




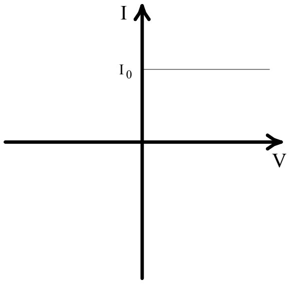
 and  are typically used in textbooks to indicate voltage and current sources.

All these symbols are to be interpreted as **ideal** sources.

An *ideal voltage source* provides a constant voltage difference between its + and – terminals, regardless of how much current must be produced to maintain that potential difference. Thus its *I-V* characteristic is:



An *ideal current source* provides a constant current flowing between its + and – terminals, regardless of how much voltage must be supplied to maintain that current. Thus its *I-V* characteristic is:



Real power supplies can come close to being ideal sources. Real DC voltage supplies will produce a nearly constant voltage difference unless a current greater than its maximum output current rating is required.

Real DC current supplies will supply a constant current until a voltage greater than its maximum output voltage (the compliance voltage) is reached.

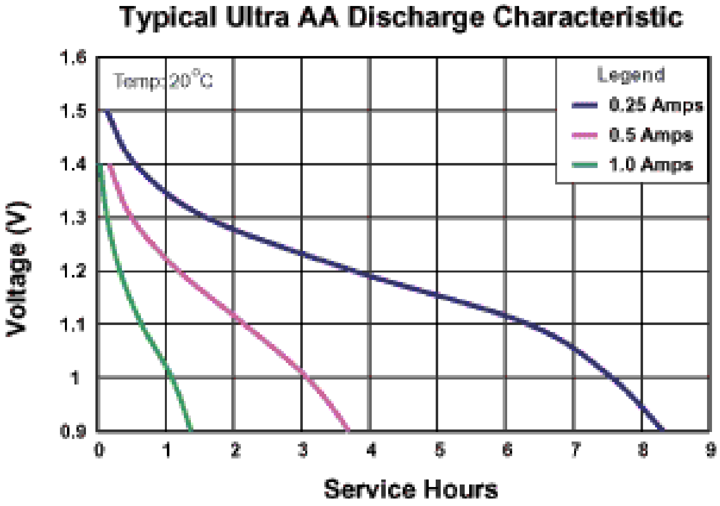
BATTERIES (Section 3.2 in text)

Batteries are very useful voltage sources, but they are by no means an ideal voltage source.

A battery has two very important characteristics that make it a non-ideal voltage source:

1. It has an *internal resistance* that causes the output voltage to drop with increasing output current.
2. Even for very low output currents, the output voltage depends upon the charge state of the battery

As a typical example, look at the performance of a AA alkaline battery:



Batteries can be modeled in a circuit diagram as an ideal voltage source in series with a small resistor (perhaps 0.05 to 0.5 Ω for small batteries)

Batteries are rated in terms of Ah (ampere-hours) or mAh.

For example, AA batteries are typically rated at 1200 mA-h

This is proportional to the total energy the battery can produce since energy is power times time

$$Energy = \int P(t)\,dt = \int I(t)\,V(t)\,dt$$

When used as a voltage source for electronic circuitry, batteries usually power a voltage regulator, which can provide a constant voltage until the battery voltage falls below the regulator's dropout voltage.

Some common battery types:

Alkaline – 1.5 V. Inexpensive, good energy density (2000 mAh for an AA battery), but usually nonrechargeable.

NiMH – 1.2 V. Very high capacity (2500 mAh for an AA battery). Most popular rechargeable battery.

NiCd – 1.2 V Similar characteristics to NiMH, but now obsolete. Less capacity than NiMH, shorter service life, and environmentally unfriendly.

Lithium Ion – 1.5 V. Highest energy density (3000 mAh for an AA battery), but most expensive.

Lead-acid – 2.0 V per cell. cheapest power, Automotive lead-acid batteries usually have 6 cells in series and have capacities of several hundred Ah.

Silver Oxide – 1.5 V. Low capacity (typically 50-100 mAh), but extremely flat discharge curve. Usually in the form of miniature button batteries.

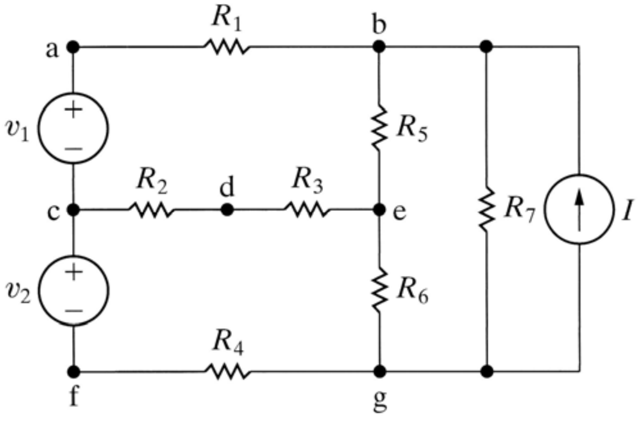
CIRCUIT NODES AND BRANCHES

In an electrical circuit:

A *node* is a point where two or more circuit elements join.

A *branch* is a path along the circuit that connects two adjacent nodes. Thus, any circuit element with two terminals connected to it is a branch.

For example,



The nodes in this circuit are *a*, *b*, *c*, *d*, *e*, *f*, and *g*. The branches in this circuit are v_1, v_2, R_1, R_2, R_3, R_4, R_5, R_6, R_7, and I.

KIRCHHOFF'S VOLTAGE LAW (KVL) (Section 2.17 in text)

The algebraic sum of the voltage drops around any closed path in a circuit at every instant of time must equal zero. This follows from the definition of voltage and the fact that, by conservation of energy, we must have, for any closed loop,

$$\oint_C \mathbf{E} \cdot d\mathbf{l} = 0,$$

Mathematically, Kichhoff's voltage law can be written as:

$$\sum_{k=1}^{N} V_k = 0$$

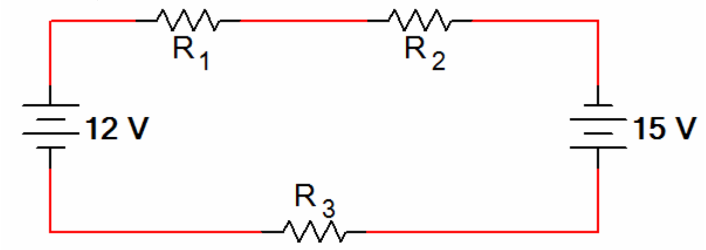
where V_k is the voltage (drop or rise) across the *k*th branch of the *N* branches in the loop.

KVL is really just a statement of conservation of energy.

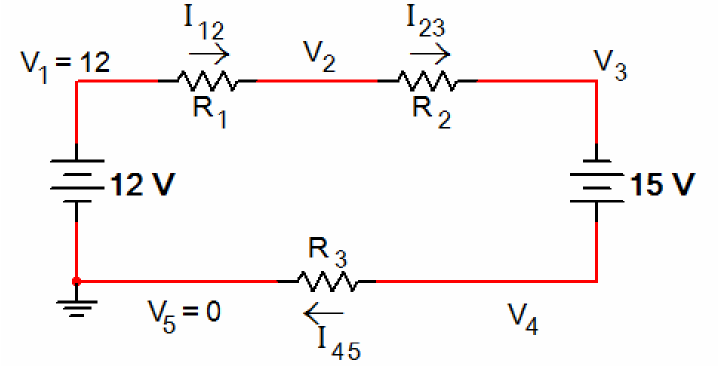
Sign Convention

To do voltage and current calculations for a circuit, a consistent sign convention must be used. In using KVL, write the voltage across a circuit element with a + sign if the side of that element with the more positive voltage is encountered first in going around the loop, otherwise write the voltage with a – sign.

To see how KVL is used, consider this circuit:



The first thing to do is to put voltage labels on all the nodes, and put current arrows next to all the resistors. The values for all voltages and currents that are known initially should be shown as well.



This may seem like overkill, but it ensures that we will be able to properly keep track of all the terms in the KVL equations, including signs.

We can start our loop wherever we want. The ground point is often a convenient place to start, so we'll do that here. Going around the circuit loop we have

$$-12+(V_1-V_2)+(V_2-V_3)-15+(V_4-V_5)=0$$

Notice that the power supply voltages enter with a minus sign here because we encounter the negative side of the supplies first when we go around the loop clockwise.
Since V_1 and V_5 are known values, we can substitute those in to get

$$-12+(12-V_2)+(V_2-V_3)-15+(V_4-0)=0$$

In most problems, perhaps counterintuitively, we use KVL to find the <u>currents</u> through the resistors first rather than the voltages V_i. We do this by just using Ohm's law for each resistor. This gives

$$-12+I_{12}R_1+I_{23}R_2-15+I_{45}R_3=0$$

In this circuit, all the components are in series, so there is only a single value of current everywhere, i.e.,

$$I=I_{12}=I_{23}=I_{45}$$

so the KVL equation becomes

$$-12+IR_1+IR_2-15+IR_3=0$$

Solving this for the current gives

$$I=\frac{27}{R_1+R_2+R_3}$$

Given the current, we can now calculate the voltage drops across each resistor, and from those we can find the voltages at each node:

$$V_2=12-IR_1 \qquad V_3=V_2-IR_2 \qquad V_4=IR_3$$

KIRCHHOFF'S CURRENT LAW (KCL) (Section 2.17 in text)

At any node, the algebraic sum of all currents entering and leaving the node at every instant of time must be zero. Mathematically,

$$\sum_{k=1}^{M} I_k = 0$$

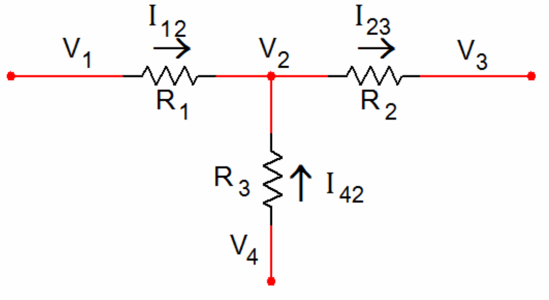
where I_k is the *k*th of the *M* currents entering or leaving the node. By convention, currents entering a node are positive, and currents leaving a node are negative.

KCL is really just a statement that electrical charge is conserved.

Sign Convention

In using KCL, use a + sign for all currents leaving a node, and a − sign for all currents entering a node. This convention is consistent with the sign convention for KVL, ensuring that the direction of current flow is from positive to more negative voltages.

Here is an example of how KCL is used:



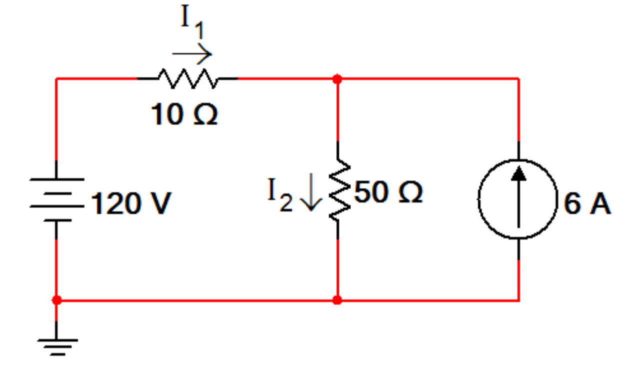
Using KCL, we have

$$-I_{12} - I_{42} + I_{23} = 0$$

Sometimes we want to use KCL to help determine voltages. In that case, Ohm's law can be used to rewrite the KCL equation as

$$-\frac{V_1 - V_2}{R_1} - \frac{V_2 - V_3}{R_2} + \frac{V_4 - V_2}{R_3} = 0$$

KVL and KCL are most often used together to determine the voltages and currents in a circuit. For example, suppose we have the following circuit:



To find I_1 and I_2, we apply KCL to the circuit node where the 10Ω and 50Ω resistors meet, which gives

$$-I_1 - 6 + I_2 = 0$$

We can then apply KVL to the left-hand circuit loop to find

$$10I_1 + 50I_2 - 120 = 0$$

Upon solving these two equations for I_1 and I_2, we obtain

$$I_1 = -3\,\text{A} \qquad \text{and} \qquad I_2 = 3\,\text{A}$$