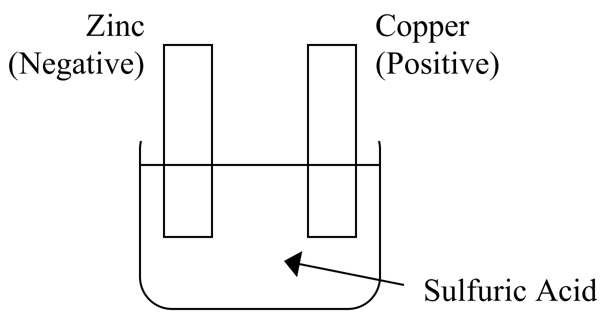
Electric Circuits

In the 1700s, Michael Faraday performed a number of experiments in which he observed that many different objects were capable of producing effects commonly associated with electricity (producing sparks). He created a series of elaborate tables in which he classified all electricity into one of five types:

1. Voltaic
2. Common
3. Magneto
4. Thermo
5. Animal

In the late 1700s, Alessandro Volta designed a device known as a **voltaic cell** (the first battery). A typical cell consists of two metal strips (one zinc, one copper), called **electrodes** or **terminals**, immersed in an ion solution (sulfuric acid), called an **electrolyte**. The electrolyte solution may be a liquid (called a **wet cell**), or a paste (called a **dry cell**).



He observed that, while static devices used up all of their charge in producing a spark, the voltaic cell was capable of producing multiple sparks over a long period of time. From this observation, he reasoned that some devices were capable of producing a continuous supply of charge. Further, through a series of thorough experiments, Volta was able to show that all electricity belongs to only two types:

1. Static Electricity
2. Current Electricity

In modern terms, a voltaic cell is a source of energy. It converts chemical energy into electrical energy, which, in turn, is converted into other forms. A **battery** is simply one or more cells connected together.

Electric Current

When we use a conducting wire to provide a continuous path from one terminal of a battery to the other, charge begins to flow through the wire. We define **electric current** as the rate at which charge flows through a conductor. If we use the symbol I for electric current, we have

$$I = \frac{q}{t}$$

where q is the amount of charge that passes a given point during the time interval t.

In this course, we consider only the case in which the charge always flows in the same direction. This is called **direct current** or **DC**. The current that flows through household circuits changes direction sixty times each second. This is called **alternating current** or **AC**.

Note: The unit of electric current is the **ampere** (A).

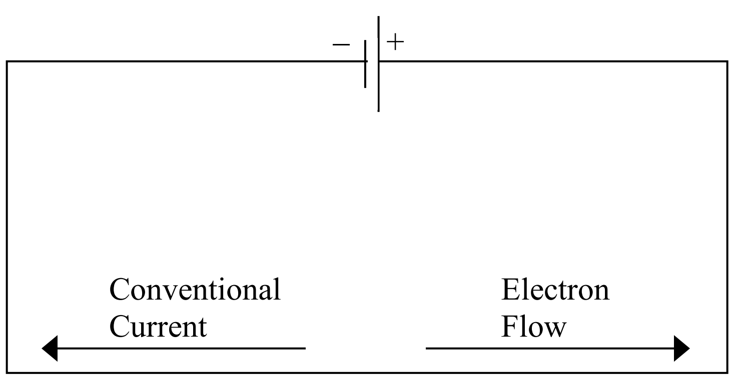
$$1 \text{ ampere} = \frac{1 \text{ coulomb}}{\text{second}}$$

The source of the current that flows through the wire is the battery. In particular, the battery provides a **potential difference**, or **voltage** ΔV, between its terminals. Charges within the wire will move through this potential difference, thus generating an electric current. As the charges move through this potential difference, they release energy according to

$$E = q\Delta V$$

Energy can be released from a battery only when the current has a complete conducting path available from one terminal to the other. We call this conducting path a complete **electric circuit**.

By convention, the current in a circuit is said to be directed from the positive terminal to the negative terminal of the battery. This corresponds to the direction that positive charges would move through the wire. According to our current model of electricity, however, it is electrons that move through the wire. The direction of electron flow would be opposite to that of the conventional current.



The average speed at which electrons flow through a conductor is called the **drift velocity**. It ranges from a few hundredths of a millimeter per second to several centimeters per second. The drift velocity is the rate at which the electrons themselves move through the wire; it is not the rate at which electric signals move. The speed of electric signals is very high, close to the speed of light.

Electromotive Force

The potential difference that appears between the terminals of a battery when no current is present is called the **electromotive force** or **emf**. (The emf is not a force, despite its name.) The symbol for emf is $\mathscr{E}$. The emf is measured in volts, like any other potential difference.

Any device that can maintain a potential difference and supply current to a circuit is a source of emf. Examples include batteries, solar cells, and generators. If the emf of a battery is zero, then no current will flow through the circuit. If the emf is not zero, then current will flow. The greater the emf, the greater the current.

An alkaline cell typically has an emf of 1.5 volts; lithium cells sometimes used in watches and calculators have an emf of 3 volts; and a nickel-cadmium rechargeable cell has an emf of about 1.2 volts.

Example

When you press the buttons on a pocket calculator, the $3.0\ V$ battery provides a current of 300 μA for 10 ms.

a. How much charge flows during this time?

b. How many electrons flow in that time?

c. How much energy is supplied by the battery to the calculator circuit?

Circuits Worksheet #1

1. A steady electric current of $0.50\ A$ flows through a wire.

   a) How many coulombs of charge pass through the wire per second? ($0.50\ C$)

   b) How many per minute? ($30\ C$)

2. A charge of $1020\ C$ was passed through a wire in $5.50\ \min$. What was the average electric current during that interval? ($3.09\ A$)

3. A charge of $833\ C$ was passed through a wire in $1.00\ \min$. What was the average electric current during that interval? ($13.9\ A$)

4. How long does it take for $67\ C$ to pass a given point in a wire that carries an electric current of $0.80\ A$? ($83.75\ s$)

5. A charge corresponding to one electron for every person in the United States passes a point in $10.0\ ms$. What is the resulting current? (Take the population to be 320 million people. The charge on an electron is $1.60 \times 10^{-19}\ C$.) ($5.12 \times 10^{-9}\ A$)

6. A battery does $24\ J$ of work on $4\ C$ of charge. What is the voltage of the battery? ($6\ V$)

7. Danielle recharges her dead $12\ V$ car battery by sending $28\ 000\ C$ of charge through the terminals. How much energy must Danielle store in the car battery to make it fully charged? ($336\ 000\ J$)

8. A $12\ V$ car battery supplies $1\ 000\ C$ of charge to the starter motor. How much energy is used to start the car? ($12\ 000\ J$)

9. What is the voltage of a refrigerator if $125\ C$ of charge transfers $16\ 000\ J$ of energy to the compressor motor? ($128\ V$)

10. A flash of lightning transfers $3\ 000\ 000\ 000\ J$ of energy between a cloud and the Earth. If the potential difference (voltage) between the Earth and the cloud is $48\ 000\ 000\ V$, what is the amount of charge transferred in the lightning bolt? ($62.5\ C$)

11. How much energy is gained by an electron whose charge is $1.6 \times 10^{-19}\ C$ as it moves through a $45\ 000\ V$ potential difference? ($7.2 \times 10^{-15}\ J$)