Contents

1 Basic Principles

This chapter is a simple introduction to electricity, what it is and how it is produced. You will learn the standard units and symbols used in electronics and be shown the basic components.

Introduction

Developments in electronics over the years have had a profound effect on the way we lead our lives. We are so surrounded by electronic gadgets that if electricity had never been discovered it's almost impossible to imagine what our lives would now be like.

The result of numerous electrical discoveries and developments over the centuries means that we have today become more technologically aware than ever. Consequently, you will be reading this book because you want to learn more about electronics, components, and circuits.

To understand all of this, first you have to learn, in simple terms, a little bit about electricity and how it works because that is the power behind electronics – this is what this chapter shows you.

The world has become totally reliant on electricity as a prime energy source. Just think where we would be today if it had never been discovered.

The invisible force

Electricity was not invented but discovered. It is a form of energy that occurs in nature and so was always there, but we couldn't easily see it other than, for example, during a lightning storm. It was realized quite quickly that there existed some sort of strong, invisible energy or force that deserved investigating further.

Centuries of experimenting and development has given us the basic electrical laws and principles that now allow us to not only understand electricity, but to use it to create electronic circuits and make electricity work for us.

Here are three of those credited with some of the early work:

- **Benjamin Franklin** – established the connection between lightning and electricity.
- **Alessandro Volta** – discovered that certain chemical reactions could produce electricity, and created a crude electric battery.
- **Michael Faraday** – discovered a mechanical method of generating electricity when he created the electric dynamo.

So, electricity wasn't discovered by just one person. The concept of an invisible energy had been known about for thousands of years, but it was a combination of the individual efforts of many great minds that has given us the understanding we have today.

Although electricity can be fun to experiment with, it can also be dangerous when working with high voltages. A mistake could be fatal if the correct precautions are ignored, so always take note of any safety advice or warnings.

Electrical Terms

Energy can take many forms; like heat energy, for example. Electricity is simply the name given to electrical energy and, as with heat, there needs to be a difference in potential for it to travel from one point to another. But how does electricity travel?

All matter is made up of *atoms* bonded together in some way. At the center of the atom is the *nucleus*, made up of positively charged *protons* and *neutrons* (which have no charge). Negatively charged *electrons* orbit around the nucleus.

Basically, if the number of electrons and protons is equal then the atom is said to be stable and has no charge. Atoms can be made unstable by rubbing two materials together so that electrons transfer from one material to the other, leaving the atoms effectively with a positive or negative charge. You can see this *electrostatic* effect when pulling an item of clothing on or off over your head and it crackles or causes your hair to stand on end!

This movement of electrons from one point to another is seen as the flow of electricity. Below is some electrical terminology:

Charge (C)

All protons and electrons have a tiny amount of electrostatic charge. This charge is measured in *coulombs* (Q).

Current (I)

This is the movement of electrons around an electrical circuit and is defined as the rate of flow of charge. Its unit is the *ampere* (A).

Voltage (V)

Electromotive force (emf) is what creates the flow of current in a circuit and is measured in *volts*. The potential difference (pd) is the voltage difference or voltage drop between any two points.

Power (P)

This is a measure of the rate at which energy is transferred. Power is measured in *watts* (W).

Conductor

A material with lots of charge-carrying free electrons, such as metal.

Insulator

A material where the electrons are firmly bound to the nucleus of its atoms so that they cannot move and hence conduct charge.

Don't forget

Where an atom has more electrons than protons it is negatively charged, and positively charged if it has fewer electrons than protons.

Hot tip

One ampere of current is calculated by:

$I = Q/t$

(t is the time in seconds and Q is the charge.)

Don't forget

The effects of the flow of an electric current can be detected in many different ways – for example, as heat, light, magnetism, etc.

In 1799, a year after discovering methane, the noted pioneer of electricity and power, Alessandro Volta, proved that electricity can be produced by chemical means when he invented the voltaic pile: a crude form of battery.

Connecting several cells together forms what is called a *battery*.

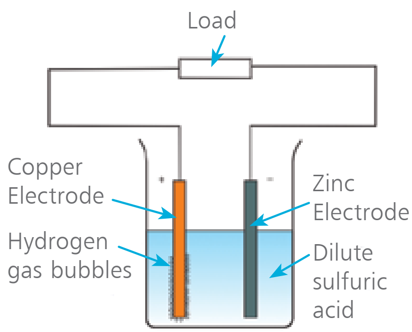
Primary cells use up the chemicals they contain. They cannot be recharged, as the action is non-reversible.

Primary Cells

Electrical energy can be produced by a number of means, including mechanical and chemical. A device that generates a charge when a chemical reaction takes place is called a *cell*. There are two main types: primary and secondary. First, we look at primary cells.

The simplest primary or *voltaic* cell consists of the following:

1. A positive electrode (anode) consisting of a copper plate
2. A negative electrode (cathode) consisting of a zinc plate
3. An electrolyte of dilute sulfuric acid

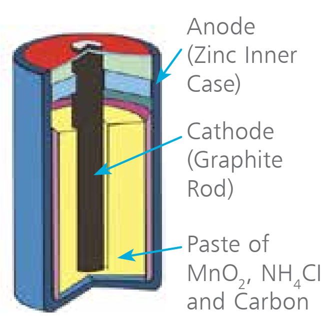


The sulfuric acid is poured into a container, and the electrodes are placed into the electrolyte. If the two electrodes are then connected together outside of the cell, a current will flow from the copper electrode to the zinc electrode, and through the electrolyte back to the copper electrode.

In this simple form, the voltaic cell only works properly for a short time. As it generates current, a layer of hydrogen bubbles starts to build up on the copper electrode, causing its output to become less and less. Also, the zinc electrode has to be totally pure. If not, any impurities will react with the zinc and the sulfuric acid, again reducing the cell's output.

Dry cell

The energy produced is called *electromotive force* (*emf*). A typical simple primary cell described above has an emf of about 1 volt. More common is the *dry cell*, as used in torches, producing about 1.5 V. This is an electric cell in which the electrolyte is in the form of a paste to prevent any spillage.

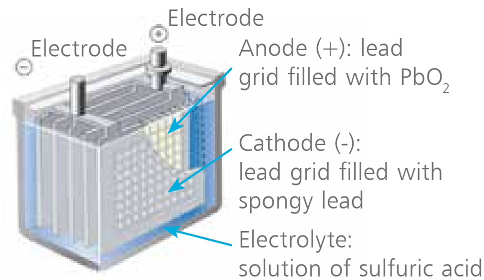


Secondary Cells

The lead-acid cell

This is one of the most common secondary cells and does not, on its own, generate electricity. The cell has to be initially charged with electrical energy from an external source; this energy then being stored in the cell as chemical energy.

1. The construction of the lead-acid cell is quite complex
2. Cells contain special interlaced positive and negative plates



3. The electrolyte is a mixture of sulfuric acid and water
4. A charged lead-acid cell has an emf of approximately 2.0 V when in use

The advantage of the lead-acid cell is that the charging process is reversible so that once charged, the chemical energy can be released in the form of an electric current as required.

When the cell has released all of the stored energy and has become discharged, then it can simply be recharged again from the external source and the process repeated.

You will actually be more familiar with this type of cell than you think. A car battery is, in fact, a number of lead-acid cells joined together. It stores and provides the electrical energy required by the motor vehicle, and is recharged when the engine is running.

Although not lead-acid, here are some popular everyday types of small rechargeable secondary cells you will recognize.

Secondary cells are reusable in that they can be charged from an external source and then discharged during use many times over.

Small rechargeable batteries in everyday use contain a chemical paste or *solid* electrolyte instead of sulfuric acid. Typical types include:

- Ni-Cd (Nickel Cadmium)
- Ni-MH (Nickel Metal Hydride)
- Li-ion (Lithium Ion)

The voltage rating of a Ni-Cd or Ni-MH rechargeable battery is usually a little lower than that of its dry cell equivalent. They should not be mixed in use!

Electrical Units

Before going any further, now is the time for an introduction to the units associated with electrical quantities and their symbols, where they come from, and where they are used. Knowing this important information will make it easier for you to understand electronic principles and circuit diagrams as we work through them. Some you will already know, but others will be new to you.

Hot tip

Basic SI units can be combined to form derived SI units – for example, meters per second (m/s).

SI units

Engineers use the International System of Units (Système Internationale d'Unités), which is metric based and usually simply called *SI units*. This system covers not only electrical units but other familiar units, as you can see from these few examples:

Quantity	Unit	Meaning
Electric Current	A	ampere
Time	s	second
Mass	kg	kilogram
Length	m	meter

The SI units can be made to represent smaller or larger quantities by using a prefix. This signifies how much to multiply or divide the value by:

Prefix	Name	Meaning
M	mega	multiply by 1,000,000 (i.e. value x 10^{6})
k	kilo	multiply by 1,000 (i.e. value x 10^{3})
m	milli	divide by 1,000 (i.e. value x 10^{-3})
μ	micro	divide by 1,000,000 (i.e. value x 10^{-6})
n	nano	divide by 1,000,000,000 (i.e. value x 10^{-9})
p	pico	divide by 1,000,000,000,000 (i.e. value x 10^{-12})

Beware

The prefix is case-sensitive so it is important to avoid mistakes by always using the correct upper or lower case letter.

For example, MV would mean megavolt; mA would mean milliamp; and μA would mean microamp.

Work (or energy)

Because electricity is a form of energy, this energy is measured using the standard unit of work or energy, the *joule* (J).

Power

The unit of power is the *watt* (W), and the symbol for power is P. One watt is equal to one joule per second and is calculated by:

power (P) = W/t therefore, energy (W) = Pt

(Where W is energy or the work done in joules, P is the power in watts and t is the time in seconds.)

Charge

The unit of charge is the *coulomb* (C), and the symbol for charge is Q. One coulomb is equal to one ampere second:

charge (Q) = It

(Where Q is the charge in coulombs, I is the current in amperes, and t is the time in seconds.)

Electrical potential (and emf)

The difference in potential between two points in a conductor or electric circuit is called *electrical potential.* A change in that electrical potential is called a *potential difference*. The unit of electrical potential is the *volt* (V), and the symbol is V. One volt is equal to one joule per coulomb. Voltage is calculated as follows:

volts (V) = P/I therefore, power (P) = IV

(Where V is the voltage in volts, P is the power in watts, and I is the current in amperes.)

Electromotive force (emf), symbol E, is also measured in volts.

Resistance

Opposition to the flow of electrical current is called *resistance*. Its unit is the *ohm* (Ω), and the symbol for electrical resistance is R. As one ohm equals one volt per ampere, resistance is calculated by:

resistance (R) = V/I therefore, $V = IR$ and $I = V/R$

(Where R is the resistance in ohms, V is the potential difference in volts across the resistance and I is the current in amperes flowing through the resistance. The above is called *Ohm's law*.)

Hot tip

You may remember Ohm's law from school. Although you probably thought you would never use it, it will now be very handy for simple calculations you may have to make – for example, establishing the current drawn by a circuit you have built so you can protect it with the correct value fuse.

Hot tip

Try not to become confused by all the symbols and abbreviations used. Take some time to study these few pages and all will become clearer later.

A capacitor is very much like a secondary cell in that it will hold a charge when a voltage is applied across it, but as this charge is small, it will release it very quickly compared with a cell.

Capacitance

When a voltage is applied across two parallel conducting plates separated from each other by air, for example, an electric field and hence an electric charge builds up in the area between the plates.

Capacitance is the term used to indicate how much charge can be stored between the plates for a given voltage. The unit of capacitance is the *farad* (F), and its symbol is C. It is calculated by:

capacitance $(C) = Q/V$ therefore, $Q = CV$

(Where C is the capacitance in farads, Q is the charge in coulombs and V is the potential difference in volts between the plates. Note that typical capacitance values are in the order of μF, nF or pF.)

Capacitors are covered in more detail in Chapters 2 and 3.

Summary of SI units and symbols

It is important to remember that there is a difference between a unit and a symbol. The unit expresses a value, whilst the symbol is just that: a symbol in a formula. Do not get the two mixed up.

Also, do not confuse the symbols, as they may not always be obvious. For example, it's easy to remember C is for capacitance but then it can't be used again for current, so current is allocated the symbol I, which appears unrelated! Use the table below to help you remember:

Do not confuse units with symbols and always remember that both upper case and lower case characters have specific meanings.

Quantity	Symbol	Unit Name	Unit
Work (or Energy)	W (or E)	joule	J
Power	P	watt	W
Charge	Q	coulomb	C
Potential Difference	V	volt	V
Electromotive Force	E	volt	V
Resistance	R	ohm	Ω
Capacitance	C	farad	F
Time	t	second	s
Mass	m	kilogram	kg
Length	l	meter	m

Insulators and Conductors

Another important element of understanding electricity is knowing what will conduct it and what won't, because all electronic components are based on these basics. To do this we take a quick look at what is meant by the *flow of electric current*.

Hot tip

Copper and gold are excellent conductors, and so are used extensively in electronic circuits. You will often come across gold-plated pins in high-quality connectors.

Atoms and electrons

In simple terms, everything is made up of *atoms* that consist of *protons*, *neutrons,* and *electrons*. The protons have a positive electrical charge and together with the neutrons, which have no charge, make up the nucleus of the atom. Outside of the nucleus are the tiny negatively charged particles we call electrons.

The atoms of different materials all have different numbers of these protons, neutrons, and electrons. A powerful force keeps everything bonded together and balanced, but it is also possible for an atom to "lose" an electron. The atom is now electrically unbalanced and has a positive charge, making it able to attract an electron from another atom.

This movement of electrons is normally random, but if a voltage is applied across the material then the electrons all move in the same direction. This movement is the flow of electric current. Some materials conduct electricity very well, whilst others conduct hardly any or none at all.

Insulators

Materials where the electrons are held tightly to their nucleus so that they exhibit hardly any current flow are called *insulators*. They have a high resistance to the flow of current.

Conductors

Materials that have loosely connected electrons to their nucleus are called *conductors* because these loose electrons are able to easily move from one atom to another through the material. They have a low resistance to the flow of current. Metals are in this category.

The table opposite lists some common insulators and conductors that you will be familiar with.

Insulators	Conductors
Rubber	Copper
PVC	Aluminum
Glass	Mild Steel
Wood	Gold

Don't forget

Wherever there is electricity it is always advisable to work with insulated tools to prevent shorting out connectors or components. It will also minimize the chance of receiving an electric shock if high voltages are present.

Circuit Components

With some of the electrical theory out of the way, you are now ready to take a look at the basic electronic components that are used in circuits. There are quite a few different ones, but the following are the most common ones that you will come across.

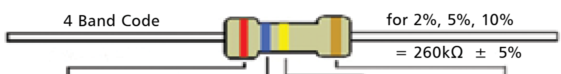
Resistors come in all shapes and sizes depending on their application. In general, small resistors are for very low wattage applications, whilst larger resistors are often used in high-current applications where they may get hot and so have to dissipate the heat.

Resistors

An electronic circuit will contain lots of resistors. They are used to limit the flow of current and are available in all sorts of shapes and sizes and a wide range of values and tolerances. There are also different types such as carbon, metal film, and wirewound. Which type is used depends on its specific purpose in the circuit.

The resistor color code

Because resistors are often very small it would be difficult to mark their value and tolerance on the casing. Such markings might also become burned off after prolonged use, as circuits generate heat. Instead, small resistors are commonly identified by colored bands. The four-band and the five-band resistor color codes are shown below, together with an example of each.



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1%
Red	2	2	2	100Ω	± 2%
Orange	3	3	3	1kΩ	
Yellow	4	4	4	10kΩ	
Green	5	5	5	100kΩ	± 0.5%
Blue	6	6	6	1MΩ	± 0.25%
Violet	7	7	7	10MΩ	± 0.10%
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1	± 5%
Silver				0.01	± 10%

The more you use the resistor color code table, the easier it becomes to remember the bands and their values.

The four-band is the most common as it is used for wide tolerance (and hence cheaper) resistors found in many circuits. The five-band code is used where very accurate resistance values are needed.

Note that the bands for the value are grouped together on the left, whilst the tolerance color is spaced apart at the other end. To read the value of a resistor with four colored bands just do this:

1. With the resistor the right way round, note the first color and look up the value in the 1st band column (e.g. Red = 2)
2. Note the second color and look up its value in the 2nd band column (e.g. Blue = 6, so the significant value is 26)
3. Note the third color, look up its value in the Multiplier band column and multiply the significant value with this figure (e.g. Yellow = 10 kΩ, so 26 x 10 kΩ = 260 kΩ)
4. Note the fourth band color and look its value up in the Tolerance band column to get the full resistor value (e.g. Gold = ±5%, giving the resistor's value of 260 kΩ ±5%)

Hot tip

Always check the value of a resistor with a multimeter set to the Ohm's range before using it in a circuit. Humans can make mistakes when reading a color, as can a manufacturer when labeling a resistor!

Capacitors

A capacitor is a device for storing energy in the form of an electrical charge, like a battery or cell, but stores a much smaller charge and can be charged or discharged almost instantly. Capacitors have many uses, such as in power supplies or tuned circuits.

Diodes

A diode is an electronic device that allows current to flow in one direction only, like a one-way valve but with no moving parts. There are various types of diodes with specific functions such as controlling a voltage level or emitting a colored light (LED).

Power sources

Electronic circuits require a power source to provide the electrical energy for them to work. Batteries are often used to provide a simple power source, but when carrying out repairs or practical experiments it is more common to use a stabilized power supply.

This type of mains-driven power supply provides an accurate voltage that can be set by the user. There is often a means of limiting the current that the unit will supply, and protection circuitry to effectively turn off its output if the circuit it is powering malfunctions.

Beware

Take care when working with large-value capacitors in case they are still charged. Always ensure they are fully discharged before attempting any work in that part of a circuit. The last thing you want is for the stored energy to discharge through another component with disastrous results, or worse, through YOU!

Standard Symbols

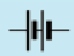
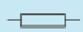
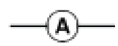
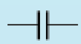
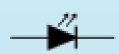
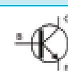
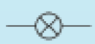
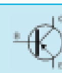
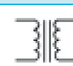
Old habits die hard with engineers. Many still hand draw circuits using the old symbol for a resistor – a sawtooth line like this:

Although we have standard symbols, you will often see "deviations" from these standards. For example, you may come across a diode drawn with a white body, not black, and the center wire going right through it. Don't be confused – the symbol will be close enough to the standard symbol for you to recognize which component it represents.

Circuit diagrams are the drawings used to show how components are connected together in an electrical or electronic circuit. For standardization, symbols are used to represent the components. This means that it should be possible to read and understand a circuit diagram created anywhere in the world.

Common standard component symbols

The following are some of the more common standard symbols used in electrical and electronic circuit diagrams that you need to become familiar with. Many of these will be covered in more detail as you work through this book.

Symbol	Meaning	Symbol	Meaning
	Cell		Wiring Connections
	Battery		Earth/Ground
	Battery (alternative)		Fuse
	Resistor		Voltmeter
	Variable Resistor		Ammeter
	Capacitor		Diode
	Capacitor (polarized)		Zener Diode
	Variable Capacitor		Light Emitting Diode
	Switch		NPN Transistor
	Lamp		PNP Transistor
	Inductor		Transformer

The above table only shows a selection of basic symbols; they may vary slightly depending on the actual component or by country. However, it is usually possible to easily interpret these variations.