Relevant Knowledge

I Concepts of System

In S1 Teaching Material 6, we have introduced various kinds of control systems. On page 5 of the teaching material, we have used a block diagram to describe the input, processing and output processes of a fully automatic washing machine. In this teaching material, we will further discuss the optimisation of control systems.

Open Loop and Closed Loop Control System

Control systems can be categorised into two basic types: open loop systems and closed loop systems. Both can be illustrated by block diagrams. A block diagram uses blocks to represent processes and arrows to connect different input, processing and output parts.

(i) Open Loop Control System

The operation of a basic open loop control system is very simple. When an input signal instructs a control element to respond, an output will be resulted. Examples of open loop control systems include washing machines, light switches and gas cookers.

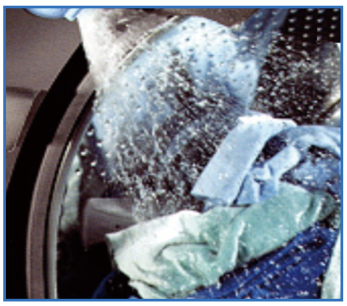
(a) Washing machine

(b) Light switches

Examples of open loop control systems

Relevant Knowledge

Dirty clothes



Rolling inside a washing machine for cleaning

Clean clothes

A simple **washing machine** is an example of an open loop control system. The input and output of an open loop system are independent of each other. For example, the cleanliness of the clothes is irrelevant to the operation of a washing machine. Instead, the washing machine runs based on the preset time. Both the structure and the control process of an open loop control system are very simple. The effectiveness of the output depends on whether the input signals are set appropriately.

Block diagram of an open loop control system for a washing machine

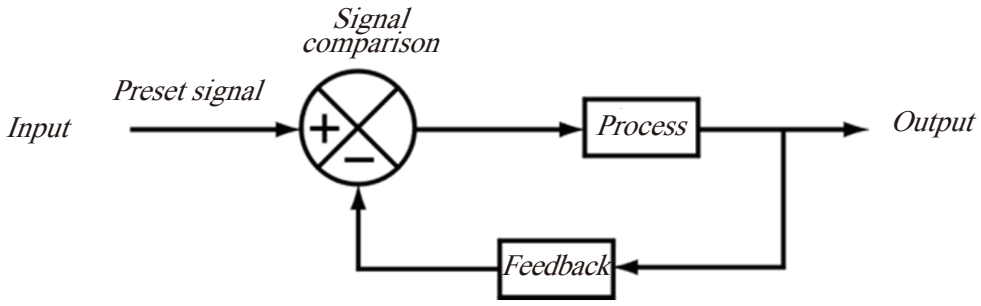
A **burglar alarm** system is an example of a more sophisticated example of an open loop control system. The electronic sensors of the alarm system are used to collect data about the house being monitored. When a sensor is triggered, for example, by an approaching person, it will send a signal to a receiver. The receiver will activate the alarm, which will in turn generate an alarm signal. The alarm signal will not cease until the alarm is stopped manually.

Block diagram of an open loop control system for a burglar alarm system

The drawback of an open loop control system is its lack of automatic control. Even when the output is excessive or insufficient, the system cannot make appropriate adjustment by itself. Therefore, this kind of systems is not suitable for use in complex control. Sometimes users have to monitor and make intervention. For instance, users have to check whether the clothes are clean after a washing machine finishes its cleaning processes. If they are not, users will have to put them back into the machine and wash again.

(ii) Closed Loop Control System

When we use the output of a control system to adjust its input signal, such a process is called feedback. Feedback is a characteristic of closed loop control systems. These systems compare the output with the expected results or command status, and then conduct appropriate control actions to adjust the input signal. Therefore, a closed loop control system is always equipped with sensors for monitoring the output, which is used to compare with the expected result. The following figure shows a simple closed loop control system, whose output signal is fed back to the input for generating a new output. A well-designed feedback system can improve the accuracy of the output.



Block diagram of a closed loop control system

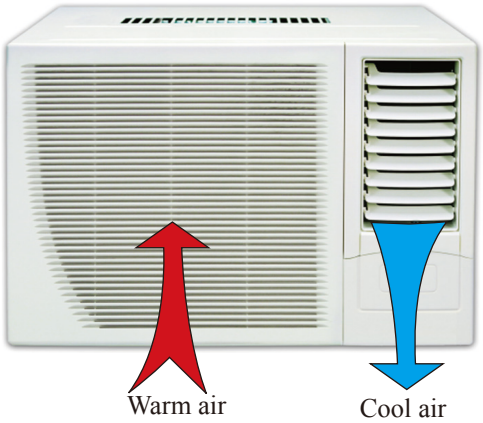
Feedback can be categorised into positive feedback and negative feedback. Positive feedback causes the new output to deviate from the existing command status. For example, when a speaker is put next to a microphone, the input volume will keep amplifying, resulting in a very high output volume. On the contrary, negative feedback directs the new output towards the existing command status, bringing about a more sophisticated control. For example, a driver steers his/her car continuously in order to keep the car moving on the right track.

Most electrical appliances and machinery are equipped with closed loop control systems for automatic control. Examples include air conditioners, refrigerators, rice cookers and automatic ticketing machines in MTR stations.

Relevant Knowledge

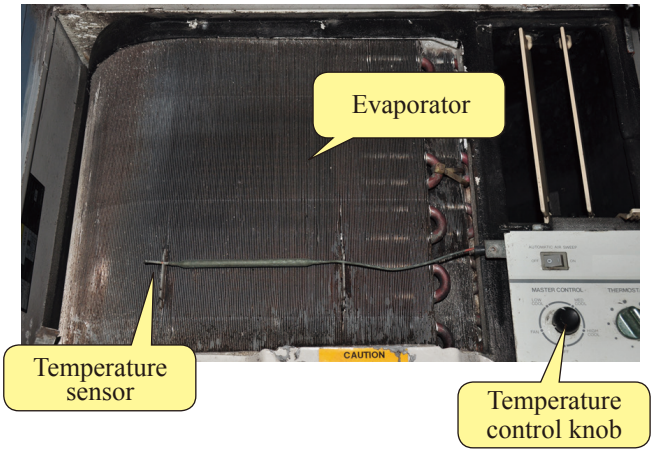
Taking an **air conditioner** as an example, the refrigerant circulated in the machine will absorb indoor heat, which will then be routed from the evaporator to the condenser continuously. The warm air is then blown to the outdoors by a fan.

Input	Warm air
↓	
Process	Refrigerating
↓	
Output	Cool air



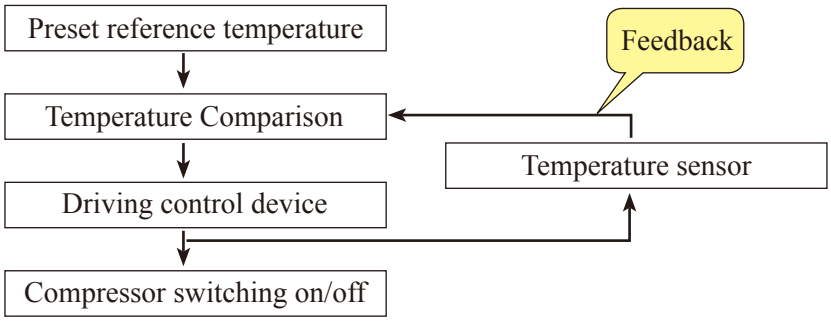
An air conditioner

Air conditioners are always equipped with a temperature adjustment device for users to specify the degree of cooling. When the temperature of the cool air inside a room is lower than the one specified, the controller of the air conditioner will stop the compressor from running, so that the refrigerant will stop circulating. A temperature sensor installed near the evaporator will keep detecting the indoor temperature and the results will be transmitted to the controller for further processing.



An air conditioner with its front cover removed

Below is a block diagram showing the control of refrigeration of an air conditioner.



Comparing the system of an air conditioner to that of a washing machine, the former has extra components for sensing and making comparison to provide feedback. The feedback is used to adjust the temperature of the coolness of the output air and to alter the operation of the air conditioner (pausing and resuming the operation of the compressor).

The advantage of closed loop control systems is its ability to adjust the output automatically through a feedback mechanism, which allows part of the output signals to be fed back to the input. When the load changes, error signals generated by the system will adjust the output. However, closed loop control systems tend to have more complex structures and thus their production costs are usually higher.

Relevant Knowledge

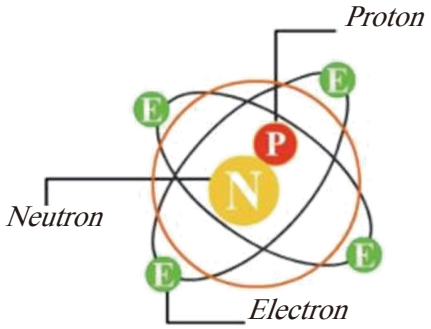
II Application of Systems

Interconnection of Systems and Sub-systems

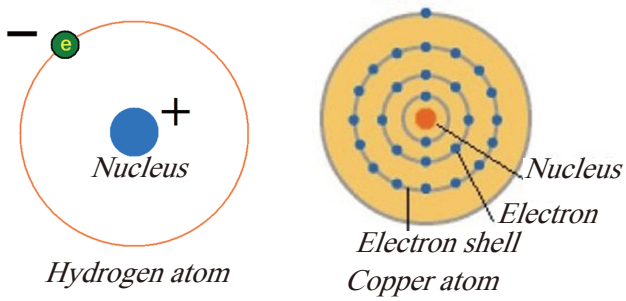
1 Basic Electricity

a. Voltage, Current and Resistance

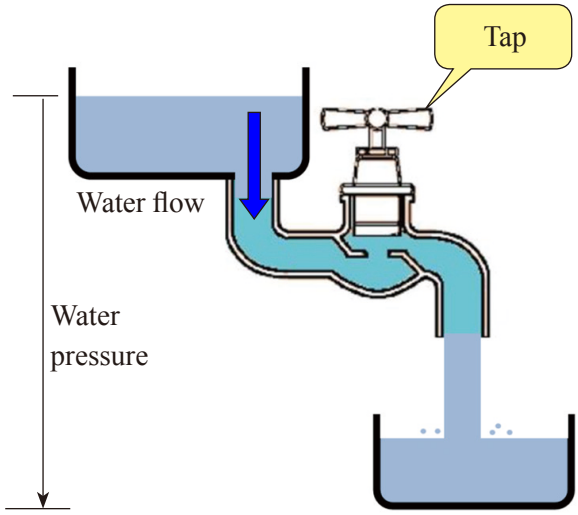
Most electronic and electrical components, and the circuits formed by them, are related to the control of voltage, current and resistance. To understand the fundamental concepts of voltage and current, we need to have certain knowledge about atoms and their structures. A hydrogen atom is the simplest atom, which consists of two particles – a proton and an electron.



Copper is the most commonly used conductive metal in the electronics industry. It has 29 electrons distributed on four electron shells orbiting around the nucleus. An electron is a negatively charged particle in an atom. In conductive materials, an electron can 'jump' from one atom to another atom. Jumping of electrons occurs only when the electrons are in an imbalanced state. In conductors, this state happens when there are more electrons at one end than the other end.



When there is a force, there will be a flow of **charge**. This forms the electric current. The force leading to the generation of current is called **voltage**. Difference in voltages between different points causes the charge to move, similar to the case that difference in water pressure causes water to flow through a pipe.

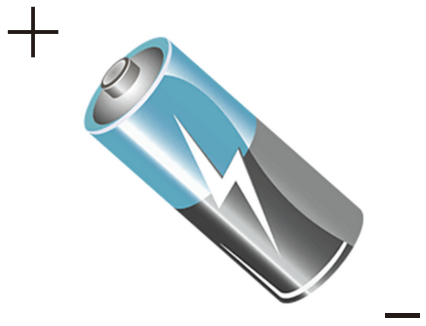


The definition of electric current is the flow of 'Holes' (positive charge) or the flow of electrons (negative charge).

i. Voltage (V)

All circuits must have at least one voltage source. Voltage, or more precisely, electrical potential difference, is the electromotive force in electricity. Electrical potential difference is responsible for the pushing / pulling of electrons or the flow of electric current in a circuit.

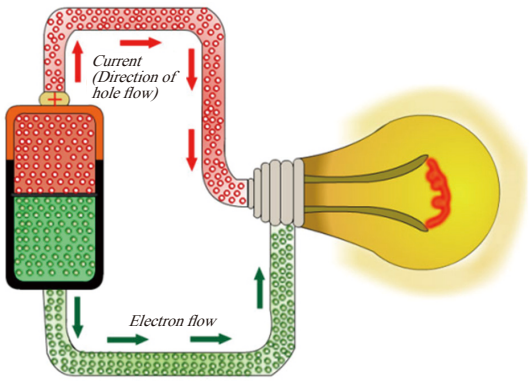
To produce a drift of electrons along a conducting wire, a difference in electric potential must exist between the two ends of the wire. The units for measuring electric potential difference are volts (V).



ii. Current (I)

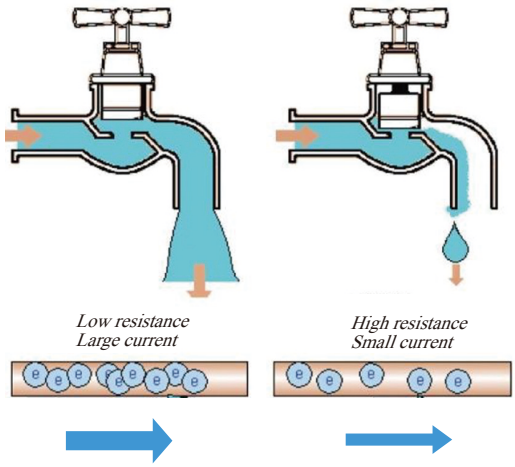
A current is a flow of electrons, which are forced into motion by voltage. Atoms of good electrical conductors, such as copper, have one or more free electrons moving away from their outermost shells constantly. Electrons from adjacent atoms will fill the 'holes' immediately. In electrical conductors, billions of electrons are moving in all directions randomly at all times.

The current in a circuit is measured in amperes (A). Smaller units of amperes are mA (1 / 1,000 of an ampere) and μA (1 / 1,000,000 of an ampere).



iii. Resistance R

Certain materials, such as copper, contain many free electrons, while other materials have relatively fewer of them. Yet some materials, such as glass, rubber and mica, have almost no free electrons moving and are therefore good insulators. At the two ends of the continuum of electrical conductivity, silver and copper are the best conductors while glass and rubber are amongst the best insulators. Between the two ends, there are a range of other conductors with relatively lower conductivity. These substances will limit the flow of electrons. The ability to oppose the flow of electrons is called resistance and its unit is Ohm (Ω).



Relevant Knowledge

b. Ohm's Law and Its Applications

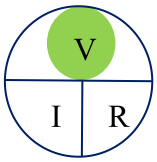
We need to express the quantities of various properties of a circuit in order to describe the circuit clearly. The following table shows the standard units of measurement for electric current, voltage and resistance.

	Symbol	Unit of measurement	Abbreviation of unit
Voltage	V	Volt	V
Current	I	Ampere	A
Resistance	R	Ohm	Ω

These units and symbols are very important to the measurement of electricity and we are going to find out the relationships between them in a circuit. To begin with, the relationship between electric current, voltage and resistance is called **Ohm's Law**, which was discovered by Georg Simon Ohm.

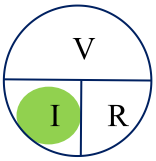
Ohm's primary discovery was that the amount of electric current passing through a metal conductor in a circuit is directly proportional to the voltage across it. Ohm expressed his discovery with a simple equation, which described the interrelationship between voltage, current and resistance:

$$V = I \times R$$

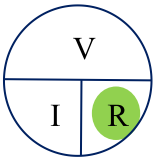


In this expression, voltage (V) equals current (I) multiplied by resistance (R). This equation has two algebraic variations for solving I and R respectively:

$$I = \frac{V}{R}$$



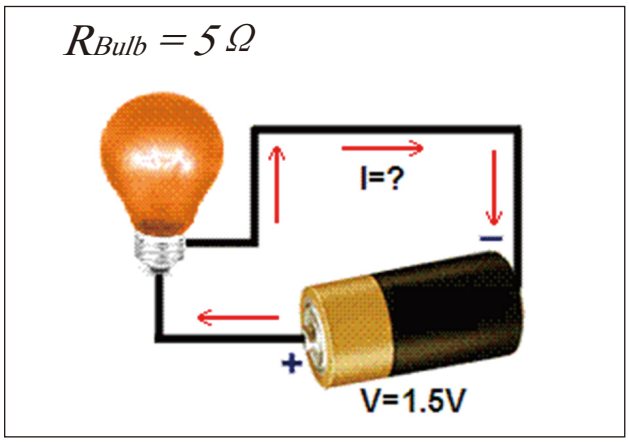
$$R = \frac{V}{I}$$



Relevant Knowledge

c. Relationship between Voltage, Current and Resistance

Let's see how these equations help us analyse simple circuits.

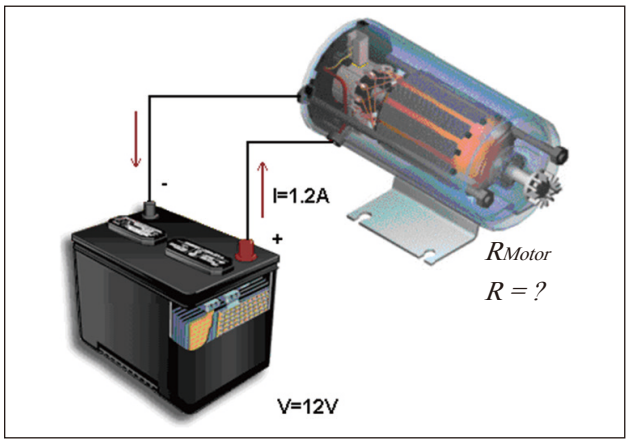


Given that:

$V = 1.5V$

$R = 5\Omega$

$$I = \frac{V}{R} = \frac{1.5V}{5\Omega} = 0.3A$$

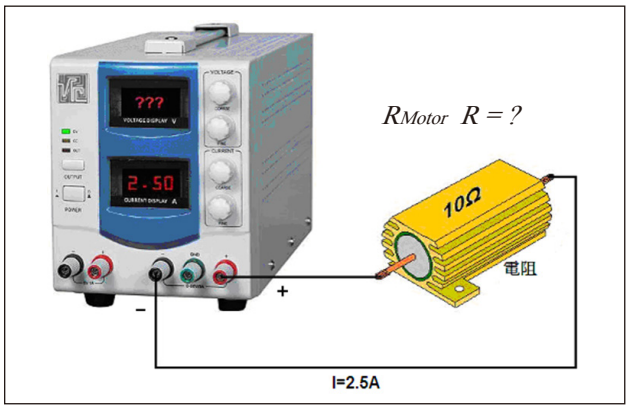


Given that:

$V = 12V$

$I = 1.2A$

$$R = \frac{V}{I} = \frac{12V}{1.2A} = 10\Omega$$



Given that:

$I = 2.5A$

$R = 10\Omega$

$$V = I \times R = 2.5A \times 10\Omega = 25V$$

Summary:

Voltage is measured in volts and is denoted by the symbol 'V'.

Current is measured in amperes and is denoted by the symbol 'I'.

Resistance is measured by ohms and is denoted by the symbol 'R'.

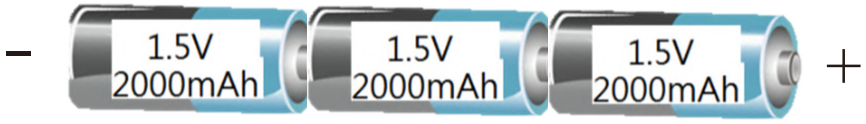
Ohm's Law: $V = IR$;

$I = V/R$;

$R = V/I$

d. Batteries Connected in Series and in Parallel

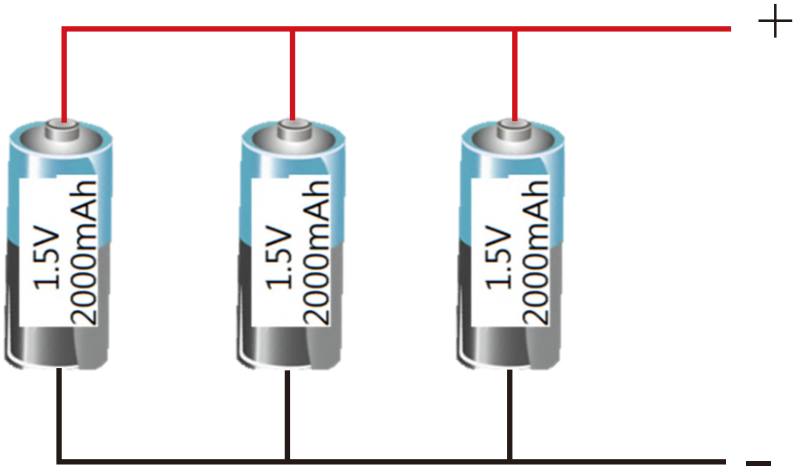
Different effects will result when batteries are connected in series and in parallel.



Voltage = 1.5V × 3 = 4.5V
Charge provided = 2000mAh (remains unchanged)

Note: 2000mAh means that a device requiring a current of 2000mA can run for an hour. For a device requiring only 500mA, the time it can run is 4 hours.

Batteries Connected in Parallel:



Voltage = 1.5V (remains unchanged)
Charge provided = 2000mAh × 3 = 6000mAh

Discussion:

1. The advantage of connecting batteries in series is_____,

   the drawback is_____。

2. The advantage of connecting batteries in parallel is _____,

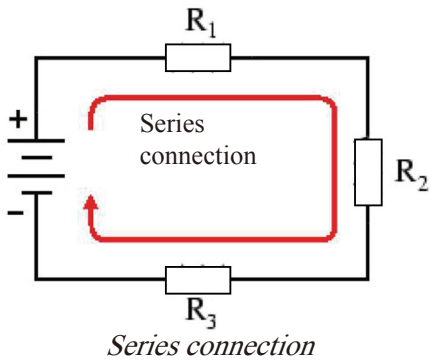
   the drawback is _____。

e. Series Circuit and Parallel Circuit

A circuit usually has two or more components connecting to each together. These components can be connected in two distinct ways: series and parallel.

Series Circuit:

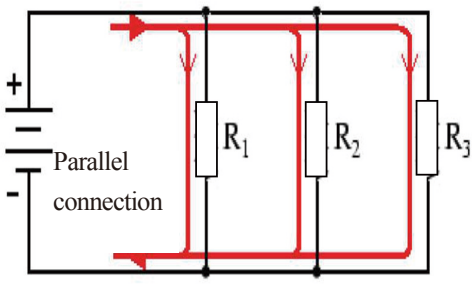
In the figure, three resistors R_1, R_2 and R_3 are connected in series. All components are connected end-to-end. The characteristic of a series circuit is that the current flows along a single path.



Series connection

Parallel Circuit:

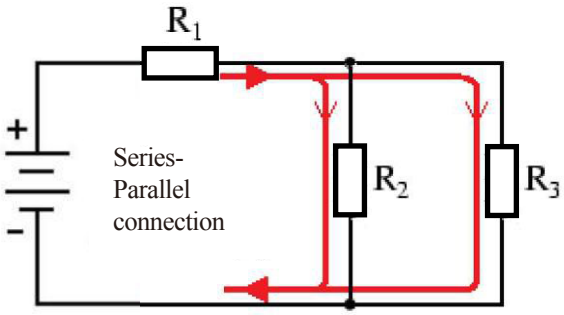
Again, there are three resistors R_1, R_2 and R_3. This time they form more than one continuous path for the current to flow through. Each individual circuit passing R_1, R_2 and R_3 is called a **branch**.



Parallel connection

Series-Parallel Circuit:

A circuit can have a combination of a series circuit and a parallel circuit. In this configuration, R_2 and R_3 are in parallel, while R_1 is in series with the parallel combination of R_2 and R_3.

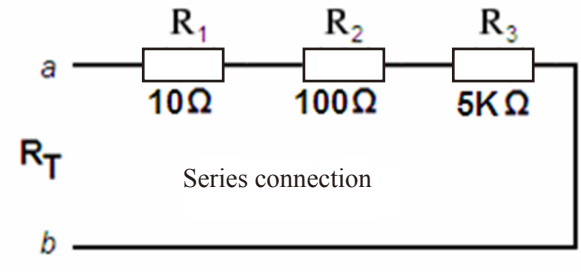


Series-Parallel connection

Relevant Knowledge

f. Calculation of Series and Parallel Circuits

Connecting resistors in series will increase the resistance between points a and b. In fact, the total resistance is the sum of the resistances of the three resistors, that is RT = RT = $R_1 + R_2 + R_3$.

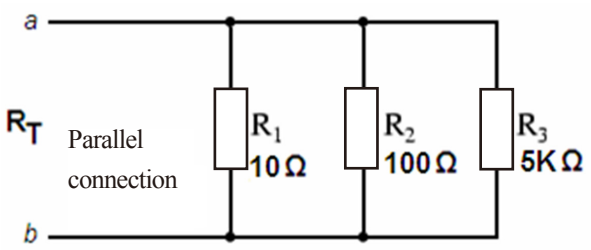


$$R_T = R_1 + R_2 + R_3$$
$$R_T = 10\Omega + 100\Omega + 5K\Omega$$
$$R_T = 5{,}110\Omega$$

In general, the total resistance of a series configuration is the sum of the resistances of all resistors.

$$\boxed{R_T = R_1 + R_2 + R_3 + R_4 + \ldots + R_N}$$

Unlike series configuration, the total resistance of a parallel configuration is always lower than the resistance of the smallest resistor in the circuit.



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$\frac{1}{R_T} = \frac{1}{10\Omega} + \frac{1}{100\Omega} + \frac{1}{5K\Omega}$$
$$R_T = 9.07\Omega$$

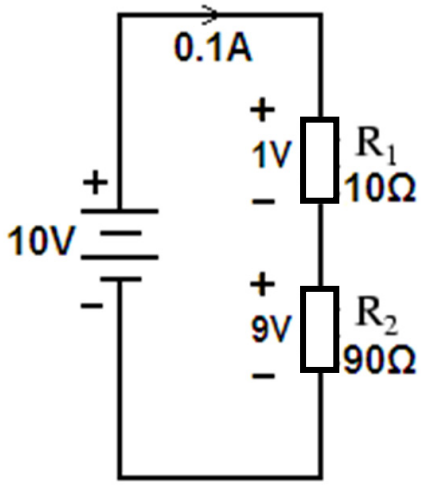
In general, for a parallel configuration, the reciprocal of the total resistance is the sum of the reciprocals of all resistances. The more resistors are connected in parallel, the smaller is the resultant resistance.

$$\boxed{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \ldots + \frac{1}{R_N}}$$

Relevant Knowledge

g. Voltage Division

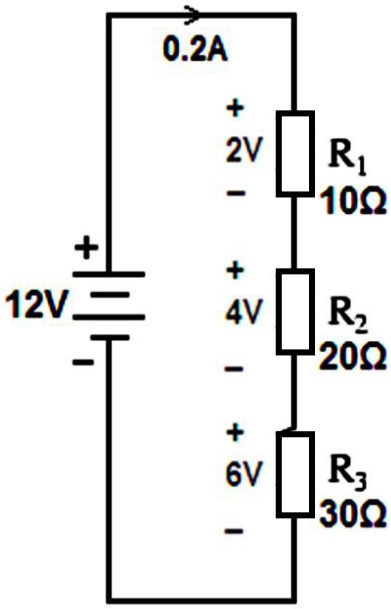
In a voltage divider circuit, the ratio of individual resistance to total resistance is the same as the ratio of individual voltage drop to total supply voltage. This is known as the voltage divider formula, and it is a short-cut method for determining voltage drop in a series circuit without going through the current calculations of Ohm's Law. (In Teaching Material 7, we will introduce the use of a voltage divider circuit in the control of transistors.)



- The voltage across each resistor in a series circuit will be shared according to its resistance.
- The higher the resistance of a resistor in a series circuit, the more voltage it will be supplied.
- The ratio of the voltages across the resistors connected in series is the same as the ratio of their resistances.

$$V_{R1} = V_{Battery} \times \frac{R_1}{R_1 + R_2} \quad \text{or} \quad V_{R2} = V_{Battery} \times \frac{R_2}{R_1 + R_2}$$

Example:



$$V_{R1} = 12V \times \frac{10\Omega}{10\Omega + 20\Omega + 30\Omega}$$

$$V_{R1} = \underline{\underline{2V}}$$

$$V_{R2} = 12V \times \frac{20\Omega}{10\Omega + 20\Omega + 30\Omega}$$

$$V_{R2} = \underline{\underline{4V}}$$

$$V_{R3} = 12V \times \frac{30\Omega}{10\Omega + 20\Omega + 30\Omega}$$

$$V_{R3} = \underline{\underline{6V}}$$

Relevant Knowledge

2 Conversion of Electrical Energy

When electric currents flow, magnetic fields will be produced and electrical energy can be converted to power and sound; when they flow through resistive wires, heat and light will be produced. For each of the following electrical appliances, point out what conversion the electrical energy has undergone and what purpose has been achieved.

Speaker: Electrical energy is converted to _____

The purpose is_____

Fan: Electrical energy is converted to_____

The purpose is_____

Rice cooker: Electrical energy is converted to _____

The purpose is_____

Light bulb: Electrical energy is converted to _____

The purpose is_____

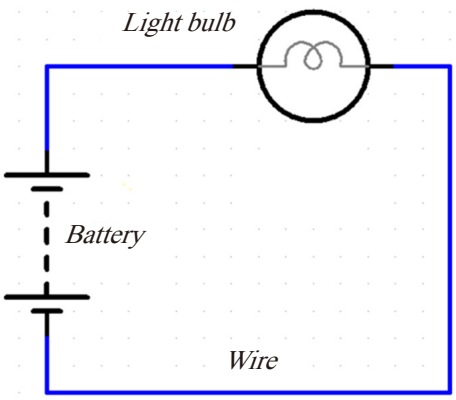
Relevant Knowledge

3 Basic Electrical Components

Simple Circuit

A simple circuit consists of three parts:

1. A source for providing electric charges or voltage, such as batteries.
2. A path for electric charges to flow through, such as copper wires.
3. An object that implements electrical resistance, or simply an object that relies on electricity to operate, such as light bulbs.



Power Supply:

Electrical appliances used in schools and homes are connected to the power sockets on the walls. They are the most commonly used power sources. Due to high voltage, they must be used with care. (In Hong Kong, household voltage is 220V.)

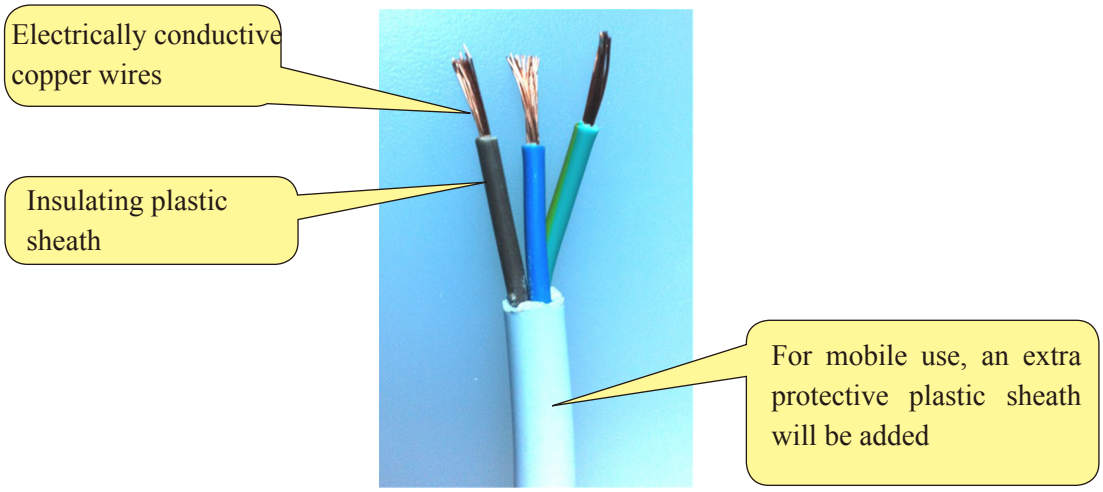
For mobile use, for example, in cars or by street vendors, storage batteries are often used. (Common voltage of them is 12V.)

Dry batteries are often used by small appliances. (Common voltage of them is 1.5V.)

Relevant Knowledge

Wire:

To connect appliances to the power sources, wires are needed.



Output:

After energy conversion, appliances can perform their intended functions. This has been covered in the previous section.

Control:

For appliances used in schools and homes, there are always switches acting as the main control.

Smaller appliances are usually equipped with smaller switches or variable resistors for controlling the output.

A switch

A variable resistor

Protection:

Fuses are used in power systems, which melt when the currents flowing through them are larger than the current ratings. Once melted, they stop current from flowing through, so as to protect the appliances and users.

Relevant Knowledge

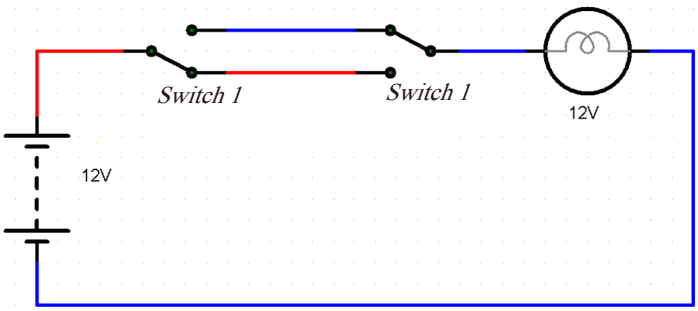
4 Use of Electricity

Electricity exists everywhere in nature. In autumn, when the weather is dry, we will feel slight electric shock when we put on and take off sweaters.

In 1752, American scientist, Benjamin Franklin, conducted a kite experiment. In the experiment, he attached a metal key to a kite with a metal wire and flew it into the clouds. The metal wire wet by the rain led the lightning in the sky to somewhere between the key and his fingers. The concept of electric current was then proposed for the first time after the experiment. Other scientists carried out various relevant experiments to make verification on different subjects and establish different theories. One of the most influential inventions to humans may be the light bulbs with tungsten filaments invented by Thomas Edison in 1906, which are used until today.

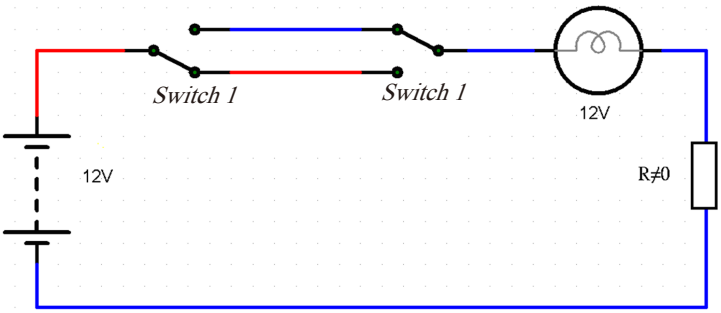
Like other electrical appliances, light bulbs need to be connected to a complete circuit to function properly. A simple circuit has been introduced earlier; a more complex one will be introduced in the following.

i. This is a light switch circuit. Why are there two switches, switch 1 and switch 2?



ii. Where can we find this kind of circuit?

If a resistor is connected in series to the above circuit, what will happen to the light bulb?



5 Safe Use of Electrical Appliances

If electrical appliances are not purchased or used properly, or lack appropriate maintenance, accidents such as fires and electric shocks may occur. Therefore, care must be taken.

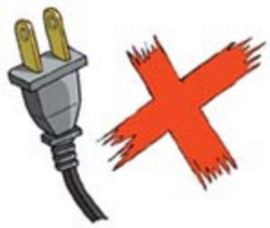
1. Choosing and Safe Use of Electrical Appliances:

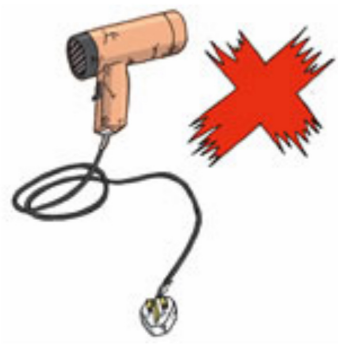
   a. The appliances should fulfil local power supply specifications (e.g. voltage rating and frequency) and be suitable to be used under local environment (e.g. temperature and humidity).

   b. The appliances must be fitted with three-pin plugs that comply with the safety standard.

   c. Before using, the appliances (including the plugs and the wires) must be checked for damages, especially when they have not been used for a period of time.

   d. Places that have high humidity, high temperatures and insufficient ventilation are not suitable for using common electrical appliances.





2. Maintenance and Repair

   a. Clean the appliances (e.g. air filters) regularly according to their instruction manuals.
   b. The appliances need to be inspected and repaired regularly by qualified personnel.

Regarding the use and maintenance of specified electrical appliances, apart from their user manuals, we may refer to the guidelines provided by Electrical and Mechanical Services Department.
http://www.emsd.gov.hk/emsd/chi/pps/electricity_handbook01_content.shtml

Relevant Knowledge

6 Glossary of Terms

Open loop system	開環式系統	Resistance	電阻
Closed loop system	開環式系統	Atom	原子
Feedback	反饋	Electron	電子
Input	輸入	Electron hole	空穴
Output	輸出	Ohm's law	歐姆定律
Process	處理	Series circuits	串聯電路
Sensor	感應器	Parallel circuits	並聯電路
Voltage	電壓	Electric charge	電荷
Current	電流	Fuse	保險絲

7 Interactive Information

	Website	Content
1.	http://www.yenka.com/	Computer modelling tools
2.	http://www.technologystudent.com/elec1/elecex.htm	Learning materials with animations

Relevant Knowledge

Exercise

1. Point out which of the following electrical appliances use **open loop** systems and which use **closed loop** systems.

An automatic hand dryer is a/an_____system,

because_____

A hairdryer is a/an_____system,

because_____

An electric fan is a/an_____system,

because_____

A rice cooker is a/an_____system,

because_____

A refrigerator is a/an_____system,

because_____

Project Activity – Electric Circuits (Soft Soldering of Wires)

Project Activity Guidelines

1. Objectives

a. Use straight lines with different colours to make a design.
b. Learn to solder wires on a circuit board.

2. On completion of the design project, students should be able to

a. master the basic soldering techniques;
b. understand the characteristics of circuit boards.

3. Design Brief

Design a pattern composed of colourful straight lines. (LEDs and battery clips can be added to make the design more interesting.)

4. Recommended Time

6 teaching periods × 40 minutes (total 240 minutes)

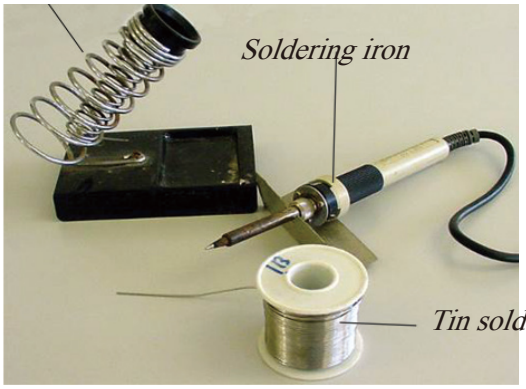
5. Required Materials and Tools

a. Breadboards
b. 20 wires in four different colours
c. A soldering iron and tin wires
d. LEDs and battery boxes (depending on students' design)

Reference Information: Soldering

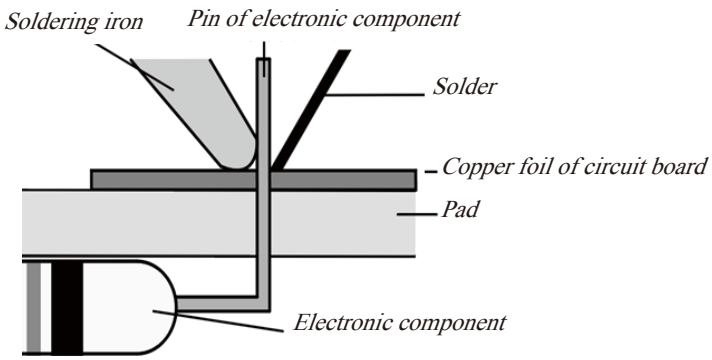
Soft Soldering

Tin soldering is one of the different kinds of soft soldering method. Tin solder is an alloy of tin and lead. It has a low melting point (about 200°C). Added in its core is flux (Rosin), which is used for cleaning the joints. There are non-temperature-controlled and temperature-controlled **soldering irons.** The power ratings for non-temperature-controlled soldering irons are usually between 40W and 60W, which are sufficient for soldering common electronic components in general.



Procedures and Precautions for Soldering Electronic Components

1. Before soldering, heat up the soldering iron.
2. Ensure the tip of the soldering iron is clean and has a shiny silvery surface.
3. A wet sponge can be used to remove excessive solder on the soldering iron. Care must be taken when doing so to prevent from getting burnt.
4. Cut the pin of an electronic component at the height of 3mm from the soldering point for best soldering result.
5. Heat the pin of the electronic component and the copper foil of the circuit board. Melt the solder at the soldering point in a ‘sandwich’ manner as shown in the following figure.



6. Add solder at the site of soldering so that the solder can melt and flow around the pin.

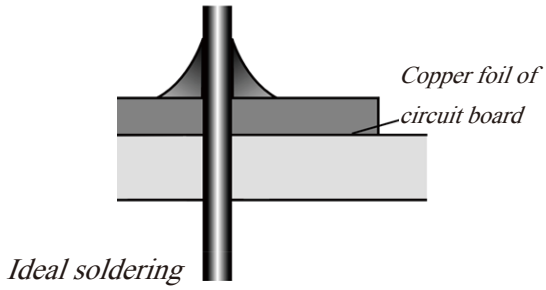
7. If the solder cannot flow around the soldering site in two to three seconds, the soldering iron, pin or copper foil of the circuit board may be dirty. Before cleaning, we must allow these parts to cool completely first. Do not let the soldering iron in contact with the electronic component for over five seconds, or else the electronic component may be damaged.

8. Do not use excessive solder.

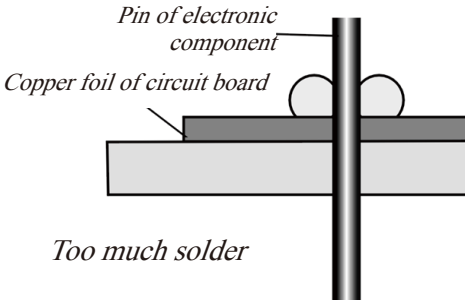
9. Do not move the workpieces before the solder solidifies.

10. Check that all workpieces are soldered properly, the circuit is correctly connected and the polarity is not mistaken. Also ensure that the circuit is not a short circuit. The figure on the right shows a soldering problem known as insufficient wetting. It happens when the tip of the soldering iron is not touching the copper foil, such that the solder only adheres to the pin of the electronic component but is not connecting with the circuit board. A pear-shaped solder results, easily causing the circuit to malfunction.

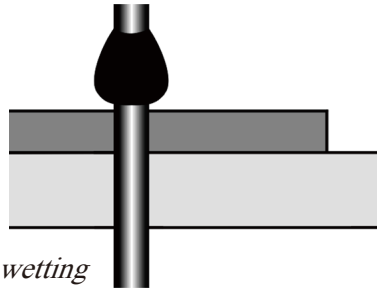
11. Trim the pin of the electronic component that is too long.



Ideal soldering

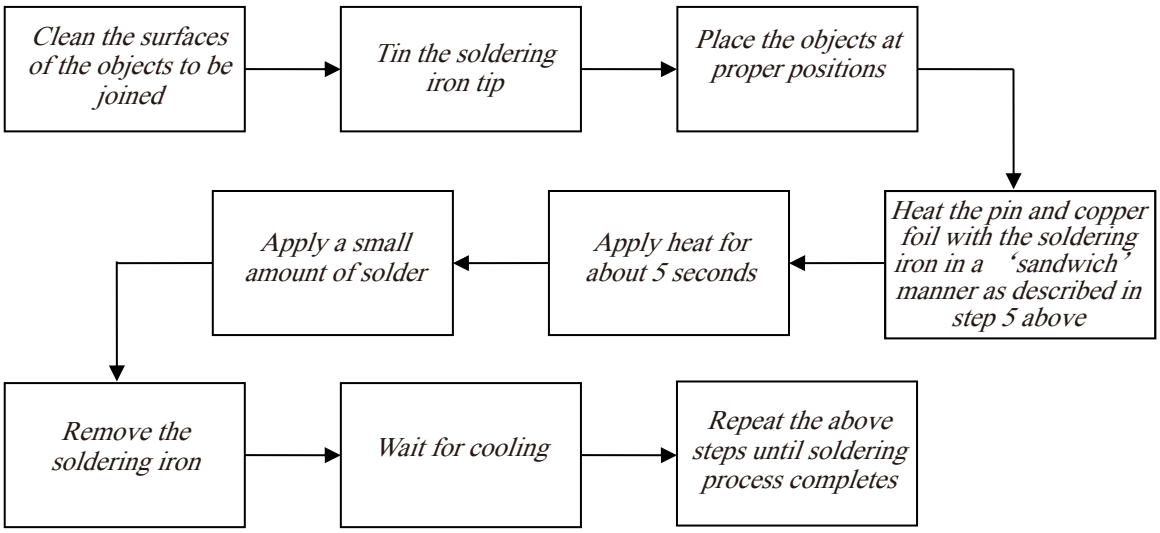


Too much solder



Insufficient wetting

The procedures of soldering are as follows:



The soldering iron and soldering materials are very hot. Care must be taken during use to avoid getting burnt.
Do not allow the soldering iron to get in touch with the power line to prevent electric shocks.

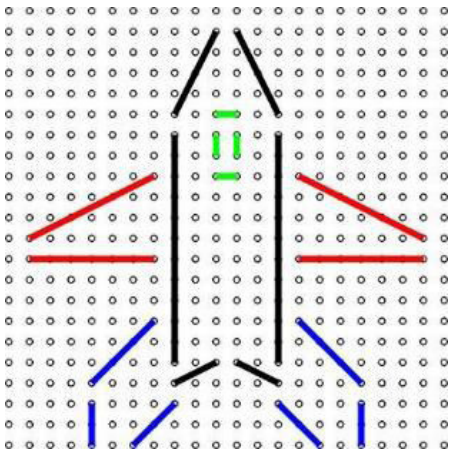
Pattern Design

Use **pens in four different colours** to represent wires in four different colours.

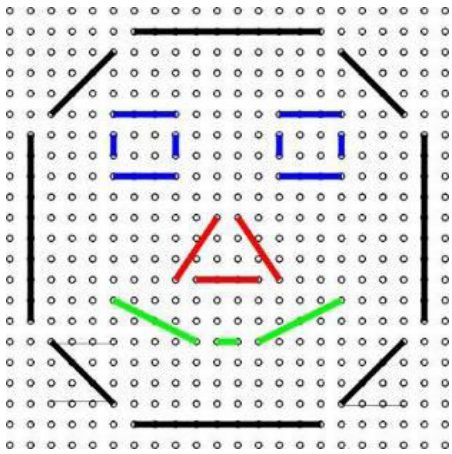
Design the patterns with **vertical, horizontal** and **diagonal lines.**

The **nodes** on the patterns are the locations where the wires are soldered on the circuit boards. Each hole can only fit with one wire.

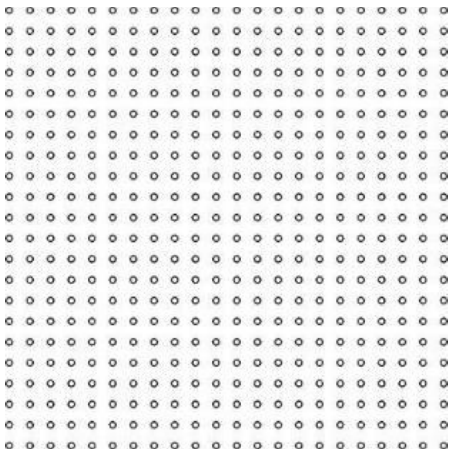
Example 1 (aeroplane)



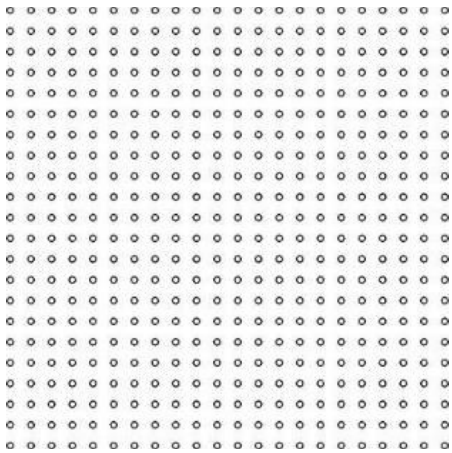
Example 2 (face)



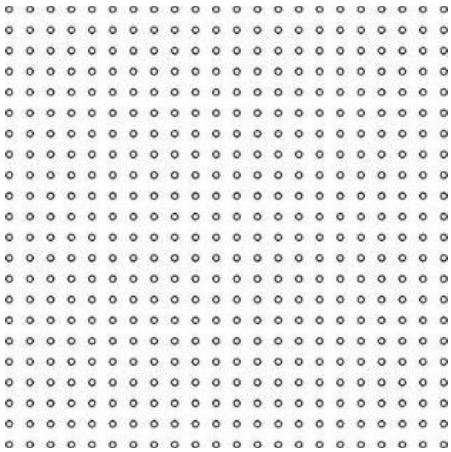
Design 1



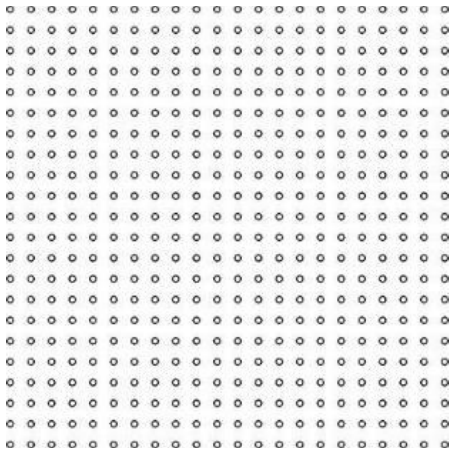
Design 2



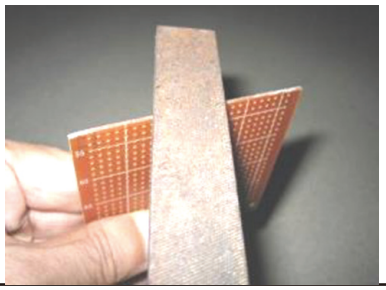
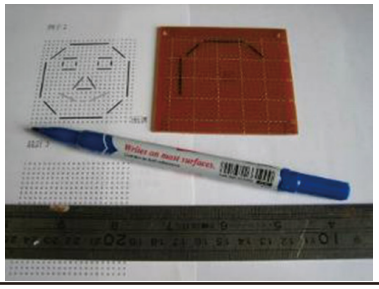
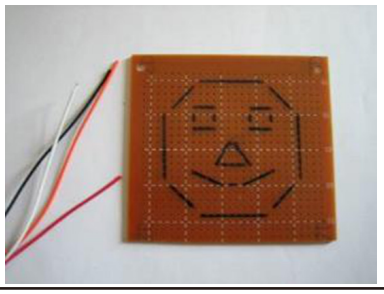
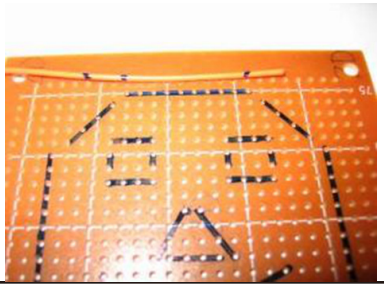
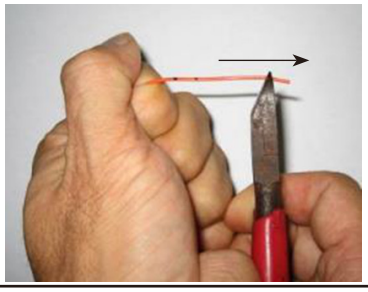
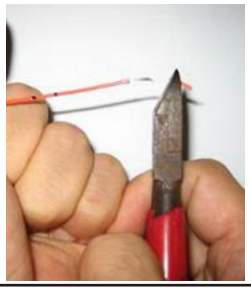
Design 3

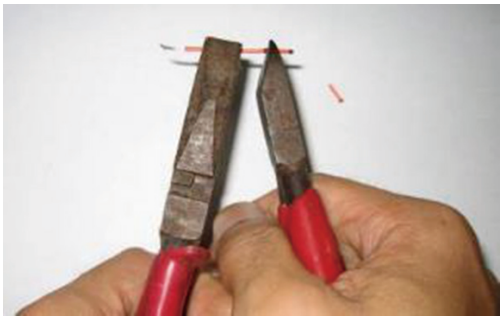
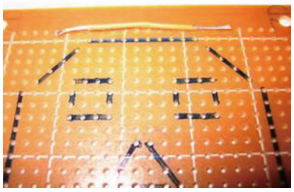
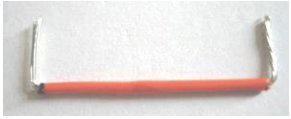
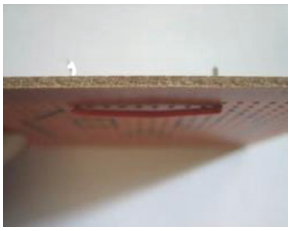
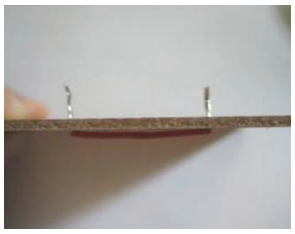
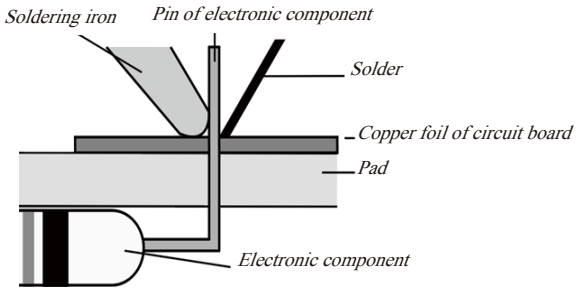
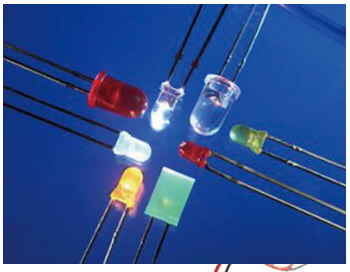
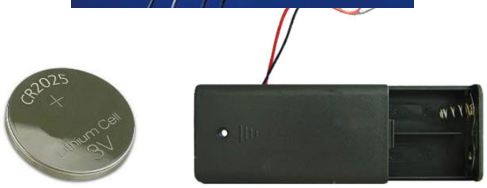


Design 4



Making Procedures:

1. At an angle of 45°, use a hand file to file the sides of the circuit board to remove the sharp edges.	
2. Use a pointed marker pen to draw the pattern on the circuit board according to the design. (Draw on the side with no copper foils.)	
3. When finished drawing, pick wires with appropriate colours.	
4. Put a coloured wire next to a line of the pattern. Use the marker pen to mark the required length on the wire. Leave lengths of about three holes long (5 – 10 mm) at the two sides of the wire for soldering.	
5. Use diagonal cutting pliers to cut half of the plastic sheath at the points marked by the marker pen.	
6. Holding the wire tightly with the left hand, grip the pliers gently with the right hand and pull it to the right side to remove the plastic sheath.	 

7. Remove the plastic sheath at the other end of the wire. (Use pliers to hold the wire if it is difficult to hold it with the hand.)	
8. Put the wire back on the pattern on the circuit board to check its length. If correct, bend the two ends of the metal wire 90° and insert them into the holes on the circuit board from the side without copper foils.	   
9. Solder the wire to the circuit board.	
10. Make it more interesting: LEDs, switches, battery boxes, etc. can be added according to the design.	 

Reflection:

Which part of this assignment do you find most difficult?

How do you overcome it?