

Electricity

William Gilbert (1544 – 1603) is generally regarded as the father of electrical engineering or the study of electricity and magnetism. He was the inventor of the **electroscope** which he used to study what is now called '**static electricity**'. In 1600 he published a book (*De magnete*) in which he described his findings.

The study of electricity and magnetism really took off following the invention of the **electric battery** in 1800 by Volta (1745 – 1827). The battery could produce a continuous flow of **electric charge**, or what we now call an **electric current**. It was quickly discovered that an electric current could produce a heating effect and a chemical effect (e.g. **electrolysis**). In 1820 the magnetic effect of electric current was discovered.

By the end of the 19th century all sorts of electrical devices were in widespread use: **telegraph**, lights, heaters, cookers and motors. In the 1890s electric trams began to replace the horse-drawn trams in Dublin.

What is electronics?

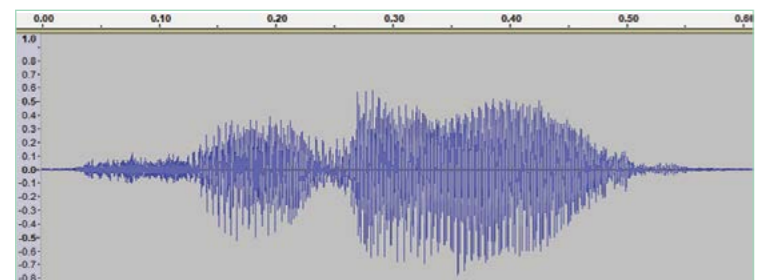
The invention in 1904 of the so-called 'vacuum tube' is generally taken as the beginning of **electronics**. The vacuum tube could conduct electricity in one direction — it was what we now call a '**diode**'. Because of this effect the vacuum tube diodes were also known as 'valves'. By 1906 other types of valve (such as triode and pentode) that could be used as **amplifiers** were also developed. These are regarded as **active** components in contrast to switches, lamps and electromagnets which are regarded as '**passive**' components. Radio transmissions began in the 1920s although few homes had a radio receiver. In the US commercial television transmissions started in the 1940s.

Since the 1950s vacuum tubes have been largely replaced by solid-state **semiconductor** devices such as **transistors**. These are smaller, cheaper and more reliable than vacuum tubes and require much less electrical power. Portable transistor radios and tape recorders became commonplace in the 1960s.

Although the distinction between electrical and electronic devices is not entirely clear cut, today electronics generally involves the use of semiconductors.

Analogue electronics

When you speak into a **microphone** the rapidly varying sound pressure of your voice causes the microphone to produce a corresponding varying voltage. If this signal were fed into an **amplifier** and **speaker** the original sound could be reproduced. In this case the signal (i.e. the varying voltage) is proportional to the sound pressure at each instant. It is, in other words, an **analogue** signal. The image below represents the varying sound pressure produced just by saying the word "Hello".



What is digital electronics?

The processing of an audio signal (or indeed of any analogue signal) can involve several steps. At each step the signal may be slightly distorted or may have some unwanted 'noise' added to it. All early methods of recording sound suffered from this problem.

With the arrival of small and relatively cheap microprocessors in the 1970s it became much easier to convert audio signals from analogue to **digital** form. The digital signal could be processed, transmitted or recorded without being degraded. Using complex electronics the audio signal is '**sampled**', typically at 44,100 times per second. The resulting data is converted into binary numbers and stored as discrete 'bits' (binary digits). Each sample is assigned one of 65,536 levels (i.e. 16-bit resolution or 2^{16} levels). Sixty minutes of stereo recording generated about 635 million bits of data. The original disc capacity was 700 **megabits**. Digital audio recordings of this kind were launched in 1982 as 'Compact Discs' (CDs).

To reproduce the original sound the digital signal must be converted back to analogue again and fed into a speaker. So the whole process involves conversion from analogue to digital and back again.

What are logic gates?

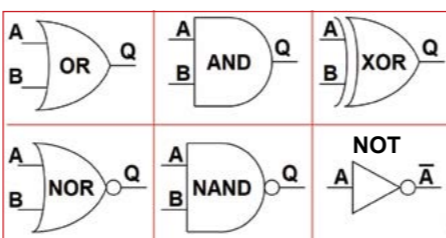
Logic gates are the fundamental building blocks of computers. They can be combined to perform basic operations such as add or subtract two binary numbers, store binary numbers and convert binary to decimal numbers.

The main logic gates are the AND, OR, NAND, NOR and NOT gates. They can be represented by the symbols shown in the diagram. The XOR gate (Exclusive OR) can be implemented using the simpler gates. Inputs of logic gates must be either High or Low, that is, they must be near 5 volts or near zero volts.

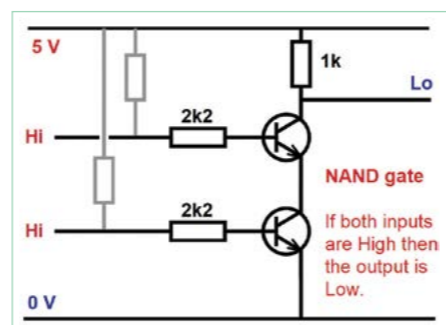
The outputs are also either High or Low. These states are represented by the binary numbers 1 and 0 respectively.

The operation of a particular gate can be summarised in a table (usually called a '**truth table**'). For instance, the AND gate shown above has two inputs, labelled A & B, and one output, labelled Q. The output is High only if **both** inputs are High; otherwise the output is Low. Its truth table is shown above.

Logic gates can be constructed from discrete components such as transistors and **resistors**. The diagram shows how a NAND gate can be implemented. Other gates can be similarly constructed.



A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1



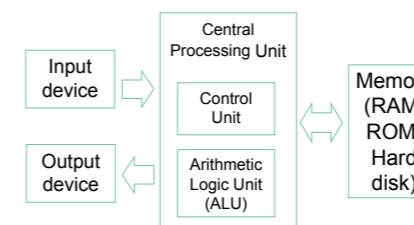
Integrated Circuits (ICs)

During the 1960s it became possible to form several discrete components on a single **silicon** 'chip'. The number of transistors in these **integrated circuits** gradually increased from about 10 (in 1964) to about 10,000 (in 1971) and to over a million in 1984. Some of today's processors have over a thousand million transistors.

In 1971 Intel produced the first **microprocessor** chip, the 4004. This four-bit processing unit was used in some electronic calculators. It contained 2,300 transistors.

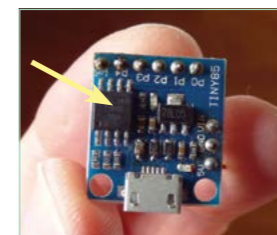
The main parts of a computer

As well as a 'processor' (CPU = Central Processing Unit) modern computers also have main memory (RAM = Random Access Memory), some permanent memory (ROM = Read Only Memory), an input device (keyboard, mouse, touch screen), an output device (screen or printer) and storage memory (hard disk). A mathematical processor (ALU = Arithmetic Logic Unit) may also be part of the CPU.



Single chip computers

Over the last twenty years or so inexpensive single chip computers have come on the market, often costing less than €5. They can be programmed and used as microcontrollers in consumer products such as washing machines and fridges. In fact, modern motor cars may have thirty or more microprocessors to monitor or control such things as engine ignition, windscreen wipers, automatic emergency braking, tyre pressure, internal environment, voice commands and navigation. Additional components, such as motors or sensors, may be required for particular functions.



This 8-pin device is a 20 MHz microcontroller with RAM, ROM and programmable input-output lines

Microcomputers in medicine

Today single chip microcontrollers are widely used in medicine to, for example, monitor patients' temperature, breathing, heartbeat or blood oxygen level. They can send continuous data to a central monitoring station and alert staff if dangerous conditions arise.

People with increased risk of a heart attack can be given an **ICD** (Implantable Cardioverter Defibrillator) which is inserted under the skin. It can monitor the heart for years and if it detects a dangerous heart condition it delivers life-saving **defibrillation** therapy in the form of an electric shock to restore normal heart rhythm.



An S-ICD (Subcutaneous Implantable Cardioverter Defibrillator) by Boston Scientific

Boston Scientific is a leading innovator of medical solutions that improve the health of patients around the world. Its products and technologies are used to diagnose or treat a wide range of medical conditions, including heart, digestive, pulmonary, vascular, urological, women's health, and chronic pain conditions. It continues to innovate in these areas and is extending its innovations into related areas.

With approximately 23,000 employees and 12 manufacturing facilities around the world and market presence in 100 countries, Boston Scientific is dedicated to transforming lives through innovative medical solutions that improve the health of patients around the world.

With corporate headquarters in Marlborough, Massachusetts and major operations in North and South America, Boston Scientific has established three key strategic sites in Ireland – Clonmel, Cork and Galway – employing in excess of 3,500 people in a broad range of activities.

Boston Scientific in Clonmel

The Clonmel operation is responsible for the production of over 250,000 implantable medical devices per annum. Boston Scientific Clonmel manufactures lifesaving pacemakers and defibrillators for patients suffering from cardiac arrhythmias and heart failure.

Boston Scientific Clonmel also produces life enhancing neuromodulation devices for patients who suffer from chronic pain and motor movement disorders. It actively promotes and participates in the local community through initiatives such as its Schools Programme where Boston Scientific facilitates Transition Year students on work experience and sponsors a Student of the Year award in local schools, culminating in an opportunity for summer work. Boston Scientific is actively involved in Junior Achievement activities, with over 19 employees delivering programmes in the region.

Find out more about the work of Boston Scientific at www.bostonscientific.com

Find this and other lessons on www.sta.ie

Syllabus References

The main syllabus references for the lesson are:

Leaving Certificate Technology

- Input, process and output: switches, relays, sensors, resistors, capacitors, transistors
- construction of simple circuits; simple transistor circuits; use of a potential divider to control the voltage applied to a transistor
- basic logic gates AND, OR and NOT; truth tables (p. 25)

Junior Certificate Technology

- Simple electronic systems: input, process and output
- input sensors; process units to include decision making (digital logic), amplification; output to include light, sound...(p. 8)

Leaving Certificate Physics

- Electric current, Sources of emf and electric current
- Conduction in metals, ionic solutions, gases, vacuum
- Conduction in semiconductors: p-type and n-type (p. 17)

Science and Technology in Action is also widely used by Transition Year classes.

Learning Outcomes

On completion of this lesson, students should be able to:

- Outline the main developments in electricity in the 1800s
- Explain, in general terms, the difference between passive (e.g. resistors) and active components (e.g. transistors)
- Describe the difference between digital and analogue electronics
- Outline the operation of logic gates and describe how a logic gate can be constructed from discrete components
- Explain what is meant by the term 'integrated circuit' and outline how microprocessors revolutionised electronics.

General Learning Points

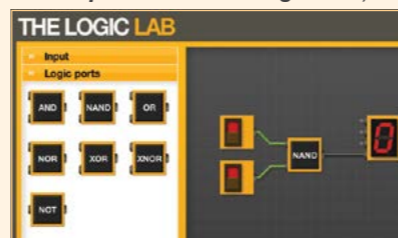
These are additional relevant points which are used to extend knowledge and facilitate discussion.

- In the 1800s great advances were made in the application of electricity — electric telegraph, motors, generators.
- With the invention of the vacuum tube diode (in 1904) the electronic revolution began.
- The first programmable digital computer was completed in 1941.
- The transistor was invented in 1947 and by the mid 1950s fully transistorised digital computers had been constructed.
- The development of integrated circuits in the 1960s, and of microprocessors in the 1970s, laid the foundation for today's information and communications technology.

Student Activities

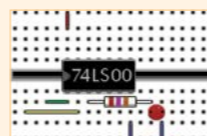
1. The Logic Lab (<http://www.neuroproductions.be/logic-lab/>) is one of many websites with online logic circuit simulators.

Use this (or a similar website) to explore the operation of logic gates.



2. A more practical way to set up logic circuits is to use what is known as a prototyping 'breadboard'. The diagram shows a Quad NAND Gate chip (74LS00) arranged on a breadboard. It contains four NAND gates.

The 74LS08 is a Quad AND gate. It can be set up in a similar way, as described in the following YouTube video: <https://www.youtube.com/watch?v=cdMJvFT-Afc>



3. Some logic gates are said to be 'universal' because they can be arranged to form the other types of gate. Find out how an Exclusive OR Gate can be made using four NAND gates. Set up the circuit using the online simulator or using the actual chip (74LS00) on a breadboard and verify that it has the correct truth table.

A	B	Q
0	0	0
0	1	1
1	0	1
1	1	0

True/False Questions

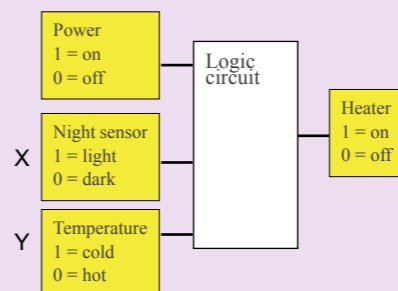
- a) The vacuum tube diode was invented in 1904. T F
- b) The production of portable electronic equipment was facilitated by the invention of the transistor in 1947. T F
- c) A microphone produces a digital electronic signal. T F
- d) Logic gates are the building block of digital computers. T F
- e) An analogue signal can be digitised by sampling it rapidly and assigning discrete values to each sample. T F
- f) An integrate circuit is made by connecting many discrete components to form a single circuit. T F
- g) Single chip computers were invented in the 1950s. T F
- h) The first microprocessor chip had over 1000 transistors. T F
- i) The resolution of a digital signal depends on the number of bits assigned to the sampled values. T F
- j) Single chip microcontrollers are widely used in medicine. T F
- k) Today's motor cars may have thirty or more microprocessors to monitor such things as engine ignition, emergency braking, tyre pressure and internal environment. T F

Check your answers to these questions on www.sta.ie.

Examination Questions

Leaving Certificate Technology (HL) 2012, Q. 2 d

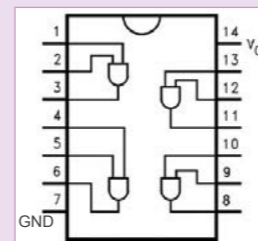
A gardener builds a device to switch on a heater when there is frost at night. There is an override switch to turn off the device during the warmer summer months.



- (i) Draw a logic gate and truth table for this system.
- (ii) Identify sensing components for use at X and at Y.

Leaving Certificate Technology (OL) 2018, Q. 2 c

The image shows an IC which incorporates four AND logic gates.



- (i) Explain what is meant by the abbreviation IC when referring to electronic components.
- (ii) State the pin numbers for the outputs of the chip shown.

Leaving Certificate Technology (HL) 2016, Q. 4

The robot shown can be assembled from a kit containing a programmable microcontroller, suitable sensors, two geared motors with drive wheels, a free turning wheel, a battery and a frame.



- (i) Outline the purpose of the microcontroller.
- (ii) Outline how the microcontroller is programmed.
- (iii) Briefly outline how the robot can perform each of the following actions:
 - move forward and turn right
 - avoid an obstruction.
- (iv) Sketch a design change necessary to allow the robot to travel over soft ground.

Leaving Certificate Technology (OL) 2015, Q. 1

The images show a microcontroller chip and a chip socket used with printed circuit boards (PCBs).

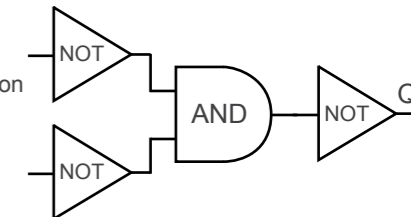


- (i) Briefly describe the benefits of using an 18-pin microcontroller in terms of the inputs and outputs available to a student.
- (ii) Give two reasons why chip sockets are used when soldering PCBs.

Did You Know?

Truth tables

Truth tables can be used to explore the possible outcomes from a combination of logic gates or to verify logical identities. For example, if the inputs to an AND gate are inverted and the output is also inverted the resultant combination turns out to be an OR gate.



In this example A and B are the two inputs. When these are inverted we get \bar{A} and \bar{B} . The AND function is represented by the '•'.

A	B	\bar{A}	\bar{B}	$\bar{A} \cdot \bar{B}$	$\overline{\bar{A} \cdot \bar{B}}$
0	0	1	1	1	0
0	1	1	0	0	1
1	0	0	1	0	1
1	1	0	0	0	1

Biographical Notes

Paul Minogue – Test Development Engineer

Paul Minogue joined Boston Scientific in 2018 after six years in the wider electronics sector.



He graduated from Waterford Institute of Technology in 2012 with a bachelor's degree in Physics & Computer Science. This course allowed him to develop broad expertise across software, electronics, and materials science. The Medical Devices sectors is a perfect place to showcase these skills.

Paul works as part of a multi-site Test Development team based in Clonmel, Co. Tipperary. Test Development involves developing electrical and electromechanical solutions to test the functionality of Medical Devices at various stages of the manufacturing process.

Revise The Terms

Can you recall the meaning of the following terms? Revising terminology is a powerful aid to recall and retention.

amplifier, analogue, defibrillation, digital, diode, electric battery, electric charge, electric current, electrolysis, electronics, electroscope, ICD, integrated circuits, logic gates, megabits, microphone, microprocessor, resistors, sampled, semiconductor, silicon, speaker, static electricity, telegraph, transistors, truth table.

Check the Glossary of terms for this lesson on www.sta.ie