



YABELLO IFA BORU SPECIAL BOARDING SECONDARY SCHOOL

PHYSICS SHORT NOTE FOR GRADE 10

**BY:
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(2015 E.C)**

UNIT: 6

Introduction To Electronics

Introduction

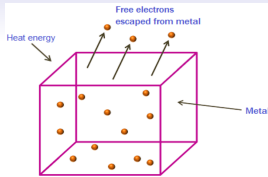
- **Electronics** is the branch of science (physics and electrical engineering) that deals with the study of flow and control of electrons (electricity) and the study of their behavior and effects in vacuums, gases, and semiconductors, and with devices using such electrons.
- Electronics uses active devices to control electron flow by amplification and rectification. Electronics has hugely influenced the development of modern society.
- It is the study and design of systems that use the flow of electrons through such components as semiconductors, resistors and capacitors.
- Many of the concepts which we met in Unit 4 (Current Electricity) are also relevant to electronic circuits, but several of the components used in electronic circuits have very specialized characteristics.

6.1 Vacuum tube devices

- A Vacuum tube is an electronic device used in many older model radios, television sets, and amplifiers to control electric current flow. The cathode is heated, as in a light bulb, so it will emit electrons. This is called **thermionic emission**.
- The anode is the part that accepts the emitted electrons. The device may have other parts. Vacuum tubes must be hot to work. Most are made of glass, thus are fragile and can break. Vacuum tubes were used in the first computers, which were large and need much work to continue operating.
- A vacuum tube or electron tube is a device that controls electric current flow in a high vacuum between electrodes to which an electric potential difference has been applied.
- The simplest vacuum tube, the diode, invented in 1904 by **John Ambrose Fleming**, contains only a heated electron-emitting cathode and an anode.
- Electrons can only flow in one direction through the device—from the cathode to the anode. Adding one or more control grids within the tube allows the current between the cathode and anode to be controlled by the voltage on the grids.

Thermionic emission

- The process by which free electrons are emitted from the surface of a metal when external heat energy is applied is called thermionic emission.
- Thermionic emission occurs in metals that are heated to a very high temperature. In other words, thermionic emission occurs, when large amount of external energy in the form of heat is supplied to the free electrons in the metals.
- So, Thermionic emission is the escape of electrons from a heated metal surface.
- Thermionic emission process plays a major role in the operation of electronic devices. In Unit 4 we learned about electrons (conduction electrons) that are free to move around within a metal at random, even without the application of a voltage to cause a general drift in one direction.

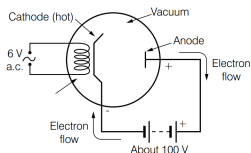


- If the metal is heated up, they move faster, and some of the more energetic electrons can then escape from the surface of the metal in a way very similar to evaporation of the faster molecules from the surface of a liquid.
- The effect is known as thermionic emission. Its rate is negligible at ordinary temperatures, and does not become significant until high temperatures are reached. So, thermionic emission is the escape of electrons from a heated metal surface.
- Thermionic emission provides a controllable supply of electrons in a vacuum. This is the basis of the cathode ray oscilloscope, a piece of equipment that has important uses in studying and displaying electrical signals or oscillations.

Vacuum tubes

I. The thermionic diode

- A diode is a two-terminal electronic component that conducts current primarily in one direction (asymmetric conductance); it has low (ideally zero) resistance in one direction, and high (ideally infinite) resistance in the other.
- A diode vacuum tube or thermionic diode is a vacuum tube with two electrodes, a heated cathode and a plate, in which electrons can flow in only one direction, from cathode to plate.
- **Diode** is an electrical component with two electrodes, used for rectification.
- **Rectification** is converting alternating current to direct current.
- The thermionic diode, a vacuum tube, is now almost obsolete; its job is now being performed by the semiconductor diode, which we shall study later in this unit. Nevertheless it is still useful to take a quick look at how it worked.

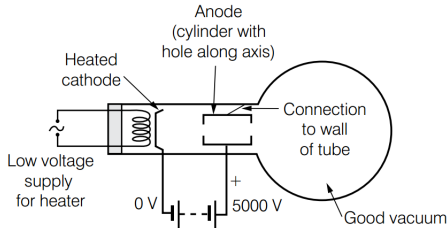


- The name diode refers to the fact that the device has two electrodes an anode and a cathode.
- A metal plate was heated so as to emit electrons. This was done electrically by placing the cathode in front of what amounted to an electric heater, as shown.
- This heater was a tungsten wire like the filament of a light bulb, being run at red heat. It operated off a few volts, either a.c or d.c. the 6 V a.c. in the drawing was typical.
- The electrons “boiled off” from the hot cathode and were attracted to the anode a cold metal plate which was commonly at about +100 V with respect to the cathode. In this way the circuit was completed, and current flowed.
- The main use of the device was for rectification to obtain a d.c. current from an alternating voltage. It behaved like a valve in a water pipe and permitted one-way flow only. Current could pass across it in the direction shown in Figure but if the polarity of the main battery was reversed, the cold anode would not emit electrons into the vacuum and so current would not flow. A diode valve was wasteful of power because of the heater.

Cathode rays

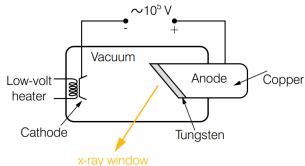
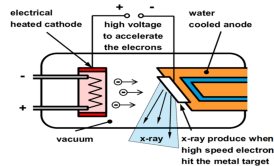
- Cathode rays (electron beam or e-beam) are streams of electrons observed in discharge tubes.
- If an evacuated glass tube is equipped with two electrodes and a voltage is applied, glow behind the positive electrode is observed to glow, due to electrons emitted from the cathode (the electrode connected to the negative terminal of the voltage supply).
- They were first observed in 1869 by German physicist **Julius Plücker** and **Johann Wilhelm Hittorf**. Cathode-ray tubes (CRTs) use a focused beam of electrons deflected by electric or magnetic fields to render an image on a screen.
- Cathode rays are a beam of electrons moving through a vacuum at a high speed. They are produced by an electron gun, which is a vacuum tube device. Electron gun is an electrical component producing a beam of electrons moving through a vacuum at high speed. A simple example of one is shown in Figure below.

- Practical examples may include arrangements for controlling the number of electrons in the beam and for focusing the beam to counteract the natural tendency of the particles to spread out. Nevertheless the drawing shows the principles.
- As in the thermionic diode, electrons are released from the heated cathode by thermionic emission, and are attracted towards the anode. Unlike the diode, the voltage on the anode may be as high as 5000 V relative to the cathode. The electrons are pulled towards the centre of the anode, accelerating to a very high speed of the order of a tenth that of light – shooting straight through the hole along the axis of the anode.



X-ray tube

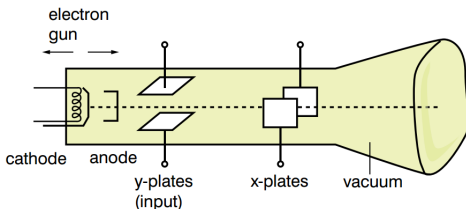
- The X-ray machine (figure below) is also a vacuum tube device. Electrons are released from the cathode by thermionic emission and are then accelerated through a p.d. of the order of 100 kV so as to hit the anode at an extremely high speed.
- When such fast -moving cathode rays are suddenly stopped, X-rays are produced.
- Most of the beam's energy is released as heat rather than X-rays, so the anode gets very hot. To minimize this it is made of a large block of copper to conduct the heat away – the other end being equipped with cooling fins or having cold liquid pumped round it.



- Even so, the working tip of the anode is made from tungsten because of its high melting point.

Cathode ray oscilloscope (CRO)

- Cathode ray oscilloscope is electronic test equipment that provides visual images of electrical signals and oscillations.



- In a cathode ray oscilloscope the beam of electrons produces a spot on a fluorescent screen at the end of the tube. Before reaching the screen it passes between two sets of deflecting plates – one pair to deflect it in the y-direction and the other in the x-direction.
- Any rapidly varying voltage you wish to examine is connected across the y-plates. This may be the output from a microphone, for instance, or from an a.c. power supply. This voltage will cause the spot to move quickly up and down the screen (the deflection being proportional to the voltage), so a vertical line is visible.
- Because of the very low mass of the electrons which make up the beam, they can respond to very rapidly changing voltages.

Some uses of the CRO

i. Direct current

- The CRO can be used as a voltmeter and will represent the voltage of a source of direct current as a stationary spot of light on the screen. It can be calibrated by using a known voltage across the y plates so that the value of an unknown voltage can be measured.
- It can also be used to display electrical signals such voltage, current, frequency and periodic time.

a. Sensitivity

- The sensitivity the size of the deflection caused by the voltage applied across the y-plates of a CRO. It can be adjusted using the gain control. For example, if the sensitivity is set to 3 V per cm and the spot is deflected by 2 cm by an unknown p.d., the value of the p.d. must be $2 \times 3 = 6$ volts.

$$\text{Sensitivity} = \frac{\text{Known Voltage}}{\text{vertical displacement of the spot for the known voltage}}$$

How to measure DC-voltage

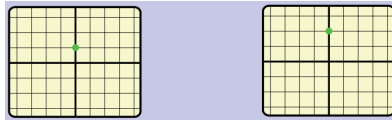
1. First determine the size or degree of the deflecting of the spot (the sensitivity) caused by known voltage across the Y-plate. In volt per each cm (V/cm)
2. Then connect the unknown voltage in the place of known voltage across the Y-plate and measure the size of deflection or vertical displacement in centimeter.
3. Calculate the unknown voltage by

$$\text{Unknown voltage} = \text{Sensitivity} \times \text{Vertical displacement by unknown voltage}$$

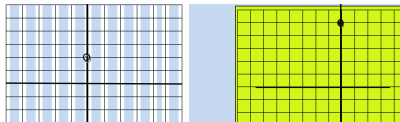
Example

1. A 1.5 V cell is connected to the y-plates of a CRO and the gain control adjusted so that the trace is 1 cm above the zero line (Figure below). The cell is removed, an unknown p.d. applied to the y-plates and a new trace is seen on the screen of the CRO (Figure below). What is the size of the unknown p.d.?

Example



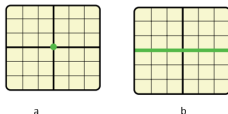
2. When a 3V cell is connected to the Y-plates of a CRO, the spot of light on the screen indicates 2cm above zero line. After removing the known cell, unknown p.d is applied to the Y-plate and a new trace is seen on the screen of the CRO as shown below. What is the size of the unknown p.d. Assume that each square is 1cm by 1cm.



3. In a certain CRO, the sensitivity is adjusted to 4.5V/cm . When unknown DC-source is connected to the Y-plates of the CRO, the spot of the light on the screen deflects by 6cm from the zero line. What is the amount of the unknown voltage?

b. Time base

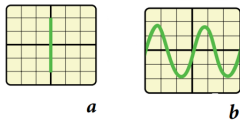
- To discover more about a signal being studied a voltage called a time base is applied to the x-plates. This pulls the spot across the screen from left to right at a steady rate; it then flies back to the left-hand side and repeats its movement. If the time base is applied to a signal made by a direct current, the trace changes from a dot (Figure a) to a line (Figure b).



- The time base control can be calibrated (in milliseconds per cm) to show how long the spot takes to cross each centimeter of the screen. For example, if it is set to 1 ms/cm the spot takes 1 ms (1 millisecond) to move 1 cm to the right. This can be very useful in measuring distances if, for example, traces of a sonar signal and its echo are studied.
- Provided the gain control and the time base are synchronized (and the instrument does this for you), what appears on the screen is an apparently static graph of the input voltage plotted against time.

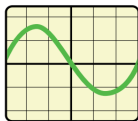
ii. Alternating current

- The voltage of an alternating current varies between a (positive) maximum to a (negative) minimum.
- If the time base is switched off, this is represented as a vertical line on the screen of a CRO (Figure a).
- If the time base is switched on, this becomes a curve (Figure b) whose shape is known as a sine wave.

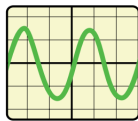


- **Finding the period and frequency of alternating currents or voltages using the CRO**
- In the same way that an unknown d.c. voltage can be measured using a CRO by comparing its trace with that made by a known p.d., the CRO can measure frequency by comparing a wave of unknown frequency with one of known frequency.

- The known signal is applied to the CRO and the time base adjusted so that one complete wave appears on the screen (Figure 5.8a). The unknown signal is then applied in place of the known signal, without altering any of the CRO controls, and the trace on the screen is studied (Figure b).



a

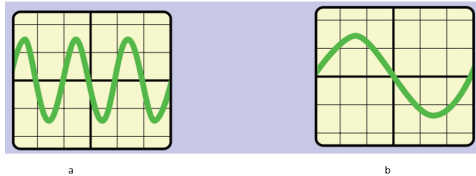


b

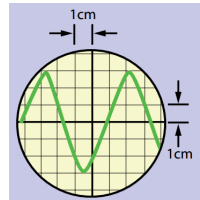
- As Figure b shows two complete waves it follows that the unknown frequency is twice that of the known signal, i.e. $2 \times 50 = 100$ Hz.

Example

- Figure (a) shows the trace on a CRO made by a 100 Hz signal. What is the frequency of the signal in Figure (b) (which was made without altering any of the CRO controls after measuring the 100 Hz signal)?



- The sensitivity of a CRO is set as 5 V/cm, and the time base setting is 1 ms/cm. Find the peak voltage and frequency of the a.c. signal shown in Figure below.

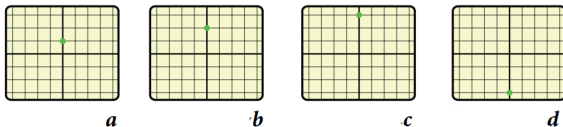


Cathode ray tube (CRT)

- A cathode-ray tube (CRT) is a vacuum tube containing one or more electron guns, the beams of which are manipulated to display images on a phosphorescent screen.
- The images may represent electrical wave forms (oscilloscope), pictures (television set, computer monitor), radar targets, or other phenomena.
- A CRT on a television set is commonly called a picture tube. CRTs have also been used as memory devices, in which case the screen is not intended to be visible to an observer.
- A CRT works by electrically heating a tungsten coil which in turn heats a cathode in the rear of the CRT, causing it to emit electrons which are modulated and focused by electrodes.
- The electrons are steered by deflection coils or plates, and an anode accelerates them towards the phosphor-coated screen, which generates light when hit by the electrons.

Exercise

1. In an oscilloscope tube what is the purpose of:
a) the heater b) the cathode c) the anode d) the x- and y-plates?
2. Explain what it means if the time base of an oscilloscope is set at 2 ms/cm (1 ms = 0.001 s.)
3. Figure (a) shows a reading of 1.5 V. Give the values displayed in (b), (c) and (d).



4. Explain carefully why a cathode ray oscilloscope: a) acts as a voltmeter b) responds to changes in that voltage within less than a millionth of a second c) draws virtually no current from the voltage source.
5. Why is the anode of the X-ray tube drawn in Figure 5.3 made of copper with a tungsten tip?
6. Describe three different uses for X-rays. Say what precautions should be taken while using them, and explain why.

6.2 Conductors, semiconductors and insulators

- i. **Insulators**, such as glass and plastic, which do not conduct electricity because every electron in them is tightly bound to its parent atom.
- ii. **Conductors**: such as metals. All the electrons in the inner shells are still tightly bound to their atoms. However, those electrons in the outermost shell of every atom are free to move within the metal. We describe them as being in the conduction band.
- iii. **Semiconductors**: Just a few of the outermost electrons have enough energy to be in the conduction band (that is, to break free from their parent atom), but this number rises as the material becomes hotter. Silicon, germanium, lead sulphide, selenium and gallium arsenide are all semiconductors.
- Semiconductors are a solid or liquid materials, able to conduct electricity at room temperature more readily than an insulator, but less easily than a metals(conductors).

- At low temperatures, pure semiconductors behave like insulators. Under higher temperatures or light or with the addition of impurities, however, the conductivity of semiconductors can be increased dramatically, reaching levels that may approach those of metals.
- While the resistance of metallic conductors rises as they warm up, with semiconductors the resistance falls greatly as their temperature goes up.
- This is because when the temperature of a semiconductor is raised, more electrons (charge carriers) have enough energy to break free.
- As the number of charge carriers increases, the resistance of the semiconductor material decreases and the material conducts better.
- The motion of holes through the lattice is like the motion of the empty chair in this line. As the people move from right to left, the empty chair moves from left to right.

6.3 Intrinsic and Extrinsic (doped) Semiconductors

- **Intrinsic semiconductor** is a pure semiconductor not containing any dopant(impurity) hole the lack of an electron at a position where one could exist in an atomic lattice. An intrinsic (pure) semiconductor also called an undoped semiconductor When an impurity is added to pure semiconductor elements in a controlled way then the semiconductor becomes doped semiconductor or extrinsic Semiconductor.
- Adding impurities into a pure semiconductor is known as doping. A semiconductor can be a conduct a electricity when it is doped or heated to a high temperature.
- The last one is not convenient but the first one the easiest way to make a semiconductor to be a conductor.
- There are two types doped semiconductors, **P-type** and **N-type**

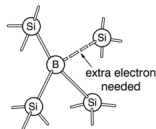
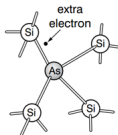
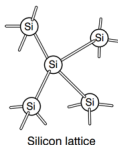
- **P-type** semiconductor can be formed by adding **trivalent** atoms or impurity atoms having three valence electrons in their outer most shell.
- Examples of these atoms are Boron, Gallium and Indium
- **P-type = Silicon atoms + Boron impurity**
- The majority charge carries in the P-type semiconductor are holes.
- **N-type** semiconductor can be formed by adding **pentavalent** atoms or impurity atoms having five valence electrons in their outer most shell.
- Examples of these atoms are Phosphorus, Arsenic and Antimony
- **N-type = Silicon atoms + Arsenic impurity**
- The majority charge carries in the N-type semiconductor are electrons.

- In **semiconductor production**, doping is the intentional introduction of impurities into an intrinsic semiconductor for the purpose of modulating its electrical, optical and structural properties. The doped material is referred to as an extrinsic semiconductor.
- Small numbers of dopant atoms can change the ability of a semiconductor to conduct electricity. The variety of uses to which semiconductor materials such as silicon can be put in devices such as transistors and diodes depends on introducing minute quantities of impurities into their atomic lattice structure in a process called **doping**.
- This process introduces extra charge carriers by replacing atoms in the semiconductor lattice with atoms of an impurity of similar size (this is important so as to minimize the distortion of the semiconductor lattice). This alters the semiconductor's conducting properties by introducing extra large carriers to the semiconductor lattice, forming what is called an **extrinsic semiconductor**.
- **Extrinsic semiconductor** is a semiconductor that has been doped.

Majority and minority carriers

- **Majority carriers:** the type of carrier, electron or hole, that constitutes more than half the carriers in a semiconductor.
- **Minority carriers:** the type of carrier, electron or hole, that constitutes less than half the carriers in a semiconductor.
- n-type semiconductor is a semiconductor in which the majority carriers are electrons, due to doping.
- p-type semiconductor a semiconductor in which the majority carriers are holes, due to doping.
- The more abundant charge carriers are called **majority carriers**, which are primarily responsible for current transport in a piece of semiconductor.
- In n-type semiconductors they are **electrons**, while in p-type semiconductors they are **holes**.
- The less abundant charge carriers are called **minority carriers**; in n-type semiconductors they are **holes**, while in p-type semiconductors they are **electrons**.

- Silicon is in group 4 of the Periodic Table, which means the outer shell of the neutral silicon atom contains four electrons.
- Suppose that atoms of an impurity from group 5 of the Periodic Table (neutral atoms in group 5 have five electrons in their outer shell) such as arsenic are added to the silicon lattice.
- The crystal as a whole remains uncharged, but these impurities help to provide 'spare' free electrons to the crystal, causing much improved conduction.
- Since the majority carriers in this type of semiconductor material are negative electrons, we describe this as an n-type semiconductor. (The minority carriers in n-type semiconductor material are holes.) Arsenic is described as a **donor** impurity, because it releases free electrons into the lattice.



- Alternatively, if silicon is doped with impurity atoms from group 3 of the Periodic Table (neutral atoms in group 3 have three electrons in their outer shell) such as boron, there is again no overall charge.
- However, the apparent electron deficiency can shift from one atom to another and so behave like a kind of positive 'hole' which can move through the crystal and thereby carry a current through it.
- These 'holes' are the majority carriers in this type of semiconductor –called p-type semiconductor and the minority carriers are electrons.
- Boron is an example of an **acceptor** impurity which traps electrons when introduced into the lattice, resulting in an increase in the number of positive holes.
- **Acceptor** impurity atoms added to a semiconductor which traps electrons.
- **Donor** impurity atoms added to a semiconductor which release free electrons.

Conduction in a doped semiconductor

- The number of free electrons and holes can be altered dramatically by doping. For example, the addition of only one arsenic atom per million silicon atoms increases the conductivity 100,000 times. Figure below shows how these processes occur.



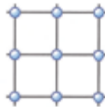
A silicon atom has four electrons in its outer shell.



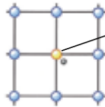
An arsenic atom has five electrons in its outer shell, enabling it to form five covalent bonds.



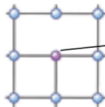
A boron atom has three electrons in its outer shell, enabling it to form the covalent bonds.



Sharing an electron with another atom produces a strong attractive force between the two atoms, which chemists call a covalent bond. Each silicon atom can form four covalent bonds, so the silicon lattice consists of silicon atoms.



Arsenic atom fits into lattice in place of silicon atom.



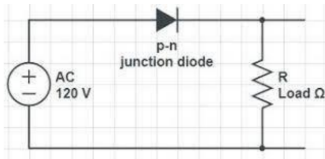
After making four covalent bonds the arsenic atom has one electron over. This electron becomes a free electron, available to conduct electricity.

Boron atom fits into lattice in place of silicon atom.

The boron atom makes only three covalent bonds. This leaves the lattice one electron short and so there is a positive hole at this point.

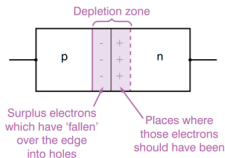
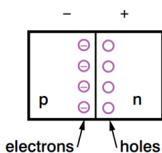
The p-n junction diode

- A p-n junction diode is a basic semiconductor device that controls the flow of electric current in a circuit. It has a positive (p) side and a negative (n) side created by adding impurities to each side of a silicon semiconductor. The symbol for a p-n junction diode is a triangle pointing to a line.



- Suppose a p-type semiconductor (with 'spare' positive holes) is in contact with an n-type one (with 'spare' mobile electrons).
- It is important to realize that before they were brought into contact both pieces of semiconductor were electrically neutral overall. At the junction where they meet, some of the n-type's electrons move, or 'fall' into the p-type's holes (Figure below). This movement is known as **diffusion current**.

- This diffusion current causes the p-type to become slightly negative while the n-type is left equally positive, leaving a '**depletion zone**' for a small distance each side of the boundary (of the order of 1 μm) a shortage of 'holes' on one side and of free electrons the other (Figure below).

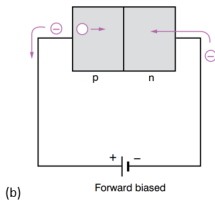
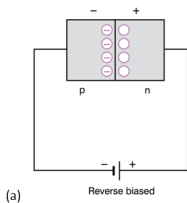


- This adverse voltage (of about 0.6 V for silicon) between the p-type and n-type semiconductors will prevent any more electrons from crossing the boundary, so the diode will not conduct in that direction. In the depletion zone there are no more 'holes' in the p-type and no free electrons in the n-type, so it forms a non-conducting strip which blocks all current.

Reverse and Forward bias

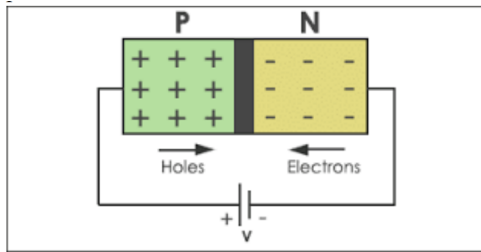
- **Biasing** refers to placing the voltage across the terminals of the device.
- **Reverse biased** is connecting the positive terminal of a cell to the n-type region of a diode, and the negative terminal to the p-type region, preventing conduction.
- In reverse bias a voltage is applied across the device such that the electric field at the junction increases. The higher electric field in the depletion region decreases the probability that carriers can diffuse from one side of the junction to the other, hence the diffusion current decreases.
- Imagine a cell connected as shown in Figure (a). Remember that it tries to move electrons from its negative terminal round the circuit to its positive terminal, which will only serve to make the situation at the boundary worse. After this momentary transfer, the voltage at the boundary (which is opposing that of the cell) becomes as large as that of the cell. No current will then flow. We say the junction is reverse biased.

- If instead you apply a voltage across the diode to make the p -type positive, and make it more than 0.6 V so as to overcome the depletion-zone voltage across the junction, then the junction is said to be forward biased (Figure (b)). In this direction the cell is helping to keep the transfer going.
- Excess electrons are being removed from the p-type, and are being fed back into the n-type to fill the extra 'holes'. That could go on forever in this direction the junction will conduct.



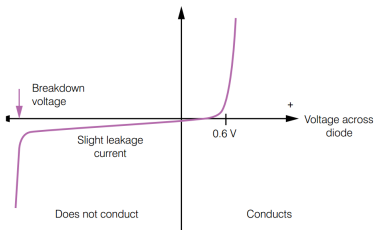
- Electrons will exit from the left-hand lead, continually leaving fresh positive 'holes' behind them. The voltage across the crystal will cause these holes to move to the right . At the junction, each hole meets a free electron and so ceases to exist. All the time, replacement electrons are flowing round the circuit and into the n-type via the right hand lead and so the whole process is maintained.
- **Forward biased** is connecting the positive terminal of a cell to the p-type region of a diode, and the negative terminal to the n-type region, allowing conduction.
- Forward bias or biasing is where the external voltage is delivered across the p-n junction diode. In a forward bias setup, the p-side of the diode is attached to the positive terminal and n-side is fixed to the negative side of the battery. Here, the applied voltage is opposite to the junction barrier potential.

- In a standard diode, forward biasing occurs when the voltage across a diode permits the natural flow of current, whereas reverse biasing denotes a voltage across the diode in the opposite direction.
- A reverse bias strengthens the potential barrier, whereas a forward bias diminishes the potential barrier of the electric field across the potential. A reverse bias has an anode voltage that is less than its cathode voltage. In contrast, a forward bias has an anode voltage that is greater than the cathode voltage.



Current–voltage characteristics of the semiconductor diode

- The p–n junction as described acts as a diode: in one direction it will conduct, in the other direction it will not. The behavior of such a diode may be illustrated by a current –voltage graph like the one shown in Figure below.

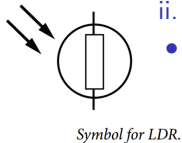
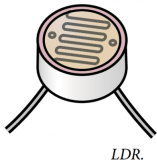
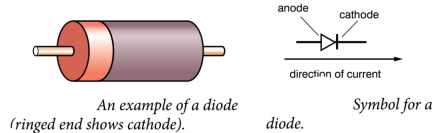


- In the forward direction, silicon requires about 0.6 V before conduction will start, but after that the current is usually limited by the resistance of the rest of the circuit. In the other direction, notice there will be a tiny leakage current. If the reverse p.d. becomes too great for the device, the barrier at the junction breaks and permits a large current to flow.

Some semiconductor devices

i. Diode

- A diode is an electronic component with two electrodes – an anode and a cathode – which will only allow electric current to pass through it in one direction.
- The semiconductor diode - formed from a layer of p-type semiconductor joined to a layer of n-type semiconductor material as seen above is a very important electronic component.



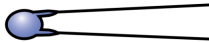
ii. LDR

- A light-dependent resistor (LDR for short) conducts electricity, but in the dark it has a very high resistance. Shining light on it appears to 'unjam' it, because its resistance falls. The brighter the light, the better it conducts. The symbol for an LDR is shown in Figure.

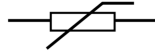
The brighter the light, the better it conducts. The symbol for an LDR is shown in Figure.

iii. Thermistor

- The thermistor shown in Figure is a piece of semiconductor material that has a high resistance in the cold. Its resistance drops as it becomes warmer.

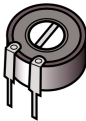


Thermistor.

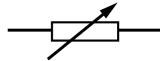


*Symbol for
thermistor.*

- ### iv. Variable resistor(Rheostat)
- The variable resistor is a very useful component in electronic circuits, particularly in circuits containing transistors.



Variable resistor.



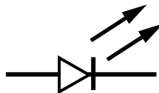
*Symbol for
variable resistor.*

V. LED

- The light emitting diode, whose symbol is shown in Figure, can be seen in a multitude of devices. When a current is passed in the forward direction, an LED emits light. The LED is a very useful component – if there is one in a circuit, it is possible to see immediately if current is flowing. LEDs are now available in a range of colors – red, green, blue, white. White LEDs are increasingly being used in lighting; they produce light very efficiently (using relatively little energy).

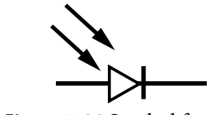


LED.



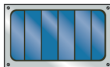
Symbol for LED.

- vi. **Photodiode** The photodiode is a light-sensitive diode used to detect light or to measure its intensity. Photodiodes are reverse biased so they do not conduct. Light incident on the photodiode frees a few more electrons and the device starts to conduct.



vii. **Photovoltaic cell**

- Photovoltaic cell is a cell that converts solar energy into electrical energy. The photovoltaic cell is a form of photodiode. The base layer of a photovoltaic solar cell is made of p-type semiconductor material. This is covered with a layer of n-type semiconductor material. When light strikes the junction between n and p-types of semiconductor, electrons flow through the structure of the cell.



Photovoltaic cell .



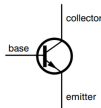
Symbol for
photovoltaic cell .

viii. Transistor

- Transistor is a semiconductor device used to amplify or switch electronic signals. The transistor is a very significant semiconductor component which we shall learn more of it in the next Section.



Transistor.



Symbol for transistor.

- **Bipolar junction transistor** is a device in which the current flow between two terminals, the collector and the emitter is controlled by the amount of current that flows through a third terminal, the base.
- A bipolar junction transistor is made of three layers of doped semiconductor and it has three terminals – the base is connected to the central layer, the other two (the collector and the emitter) are each connected to one of the outer layers.
- n-p-n transistor, which has a layer of p-type semiconductor sandwiched between two layers of n-type.
- p-n-p transistor, which has a layer of n-type semiconductor sandwiched between two layers of p-type.

Rectification using the p-n junction diode

- **Rectification** is the process of converting AC (Alternating Current) to DC (Direct Current) using a rectifier, after connection a diode or a group of diodes in the circuit.
- **A rectifier** is an electronic device that converts alternating current (AC) to direct current (DC) which reverses its direction periodically to direct current (DC) and flows only in one direction.
- There are two ways of rectification such as half-wave rectification and full-wave rectification. In both cases, rectification is performed by utilizing the characteristic that current flows only in the positive direction in a diode.
- Half wave rectifiers use one diode, while a full wave rectifier uses multiple diodes.

Half-wave Rectification

- A half wave rectifier is the simplest form of rectifier available. The working of a half wave rectifier takes advantage of the fact that diodes only allow current to flow in one direction.
- The diagram below illustrates the basic principle of a half-wave rectifier. When a standard AC waveform is passed through a half-wave rectifier, only half of the AC waveform remains because it only allow one half-cycle (positive or negative half-cycle) of the AC voltage through and will block the other half-cycle on the DC side, as seen below.
- In half-wave rectification removes just the negative voltage component using a single diode before converting to DC.

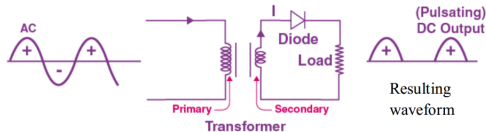
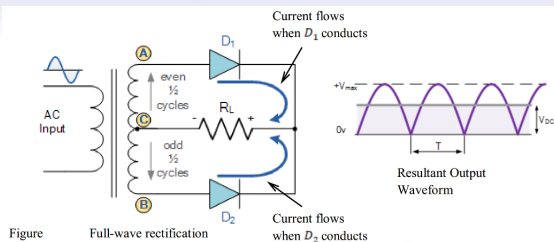


Figure Half-wave Rectification

Full-wave rectification

- The full-wave rectifier converts both halves of each waveform cycle into pulsating DC signal using a group of rectification diodes. It rectifies the negative component of the input voltage to a positive voltage, and then converts it into DC (pulse current) utilizing a diode bridge configuration.
- In a Full Wave Rectifier circuit we can use two or four diodes in a bridge circuit. Consider now two diodes are used, one for each half of the cycle. A multiple winding transformer is used whose secondary winding is split equally into two halves with a common centre tapped connection, (C).
- This configuration results in each diode conducting in turn when its anode terminal is positive with respect to the transformer centre point C producing an output during both half-cycles, twice that for the half wave rectifier as shown below.



- The full wave rectifier circuit consists of two power diodes connected to a single load resistance (R_L) with each diode taking it in turn to supply current to the load. When point A of the transformer is positive with respect to point C, diode D_1 conducts in the forward direction as indicated by the arrows.
- When point B is positive (in the negative half of the cycle) with respect to point C, diode D_2 conducts in the forward direction and the current flowing through resistor R is in the same direction for both half-cycles. As a result of this process there is current flow through the load R_L throughout the full time of the AC wave.

Half-Full wave Rectifier with Smoothing Capacitor

- We saw in the previous section that the single phase half-wave rectifier produces an output wave every half cycle and that it was not practical to use this type of circuit to produce a steady DC supply. We can improve the average DC output of the rectifier while at the same time reducing the AC variation of the rectified output by using smoothing capacitors to filter the output waveform.
- Smoothing capacitors connected in parallel with the load across the output of the half-full wave rectifier circuit increases the average DC output level even higher as the capacitor acts like a storage device as shown below.

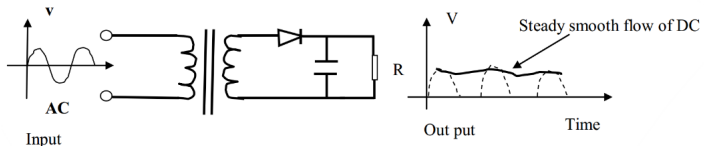
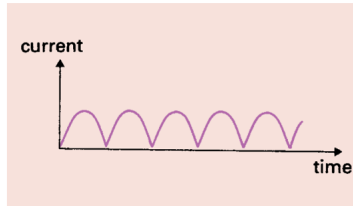
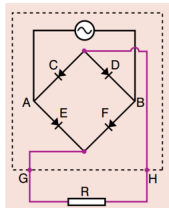


Figure Smoothing the flow of DC

- The capacitor connected parallel to the load/resistor makes smooth the fluctuation of the resulting current (DC).
- It is filled up to the peak voltage of the supply, then as the power supply's voltage drops to zero we can think of the capacitor as feeding the outside circuit.
- It has to keep doing this until the supply voltage next peaks and the capacitor is once more filled up.

Bridge Rectifier

- An arrangement made from four diodes is known as a bridge rectifier. To understand how it works needs some thought from you, so you are invited to work through it yourself. In Figure below, the dotted line is the outside casing of a d.c. power pack. Inside are an a.c. power supply marked AB (obtained from the mains via a transformer) and four diodes labeled C, D, E and F. G and H are the terminals that connect it to an outside circuit, represented by resistor R.

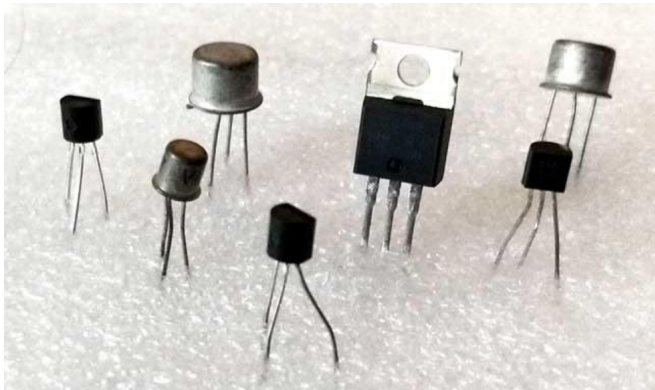


- Remember that a current can flow only if a continuous circuit is provided from one terminal of power supply AB right round to the other. Check that at a moment when A is positive and B negative, conventional current has such a route through AEGRHDB. Now find the complete circuit half a cycle later, when B is the positive terminal and the conventional current starts from there. What do you notice about the direction in which the current passes through R on each half of the alternating cycle? This is known as fullwave rectification, and has the form shown in Figure above.

6.4 Transistors (p-n-p, n-p-n)

- A transistor is a semiconductor device used to amplify or switch electrical signals and power.
- The transistor is one of the basic building blocks of modern electronics.
- It is composed of semiconductor material, usually with at least three terminals for connection to an electronic circuit.
- A voltage or current applied to one pair of the transistor's terminals controls the current through another pair of terminals.
- Because the controlled (output) power can be higher than the controlling (input) power, a transistor can amplify a signal.
- Some transistors are packaged individually, but many more are found embedded in integrated circuits.
- Most transistors are made from very pure silicon, and some from germanium, but certain other semiconductor materials are sometimes used.

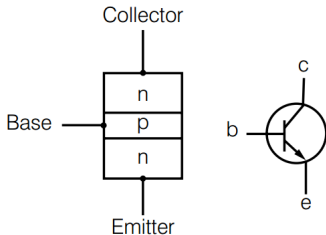
- A transistor may have only one kind of charge carrier, in a field-effect transistor, or may have two kinds of charge carriers in bipolar junction transistor devices.
- Compared with the vacuum tube, transistors are generally smaller and require less power to operate.
- Certain vacuum tubes have advantages over transistors at very high operating frequencies or high operating voltages.



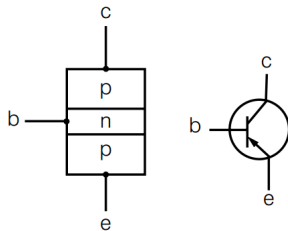
The bipolar junction transistor

- A bipolar junction transistor (bipolar transistor or BJT) is a type of transistor that uses both electrons and holes as charge carriers.
- A bipolar junction transistor, also called bipolar transistors, is a three-terminal device that can function as electronic switches or signal amplifiers.
- The two types of bipolar transistors are the p-n-p Transistor and n-p-n Transistor. Transistors use the input of relatively small signals to control circuits carrying large currents.
- This makes them very important as switches and amplifiers. As we saw in Section 6.3, the bipolar junction transistor is a three-layer semiconductor device.
- The outer layers can be n-type materials with a p-type layer in the centre (in which case it is described as an n-p-n transistor), or it may be a p-n-p transistor with the layers the other way round.

- A transistor of this type has three terminals – one to each semiconductor layer. The connection to the central layer is known as the base. The outer two are called the collector and the emitter.
- Base is one of three regions forming a bipolar junction transistor. This layer separates the emitter and collector layers. If a voltage greater than around 0.6 V is applied to the base terminal, current will flow through the transistor from base to emitter.
- Collector is one of the three regions forming a bipolar junction transistor. When used in a circuit, a positive voltage is applied to the collector terminal.
- Emitter is one of the three regions forming a bipolar junction transistor. Current will only flow from the emitter terminal if a voltage greater than around 0.6 V is applied to the base terminal.



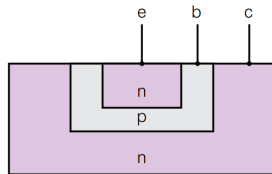
An n-p-n transistor



A p-n-p transistor

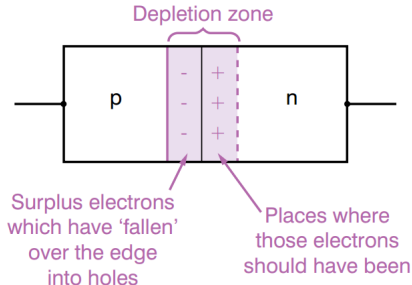
- The arrow on the circuit symbol indicates the way conventional current should flow through it. The term 'bipolar' means that both negative electrons and positive 'holes' play a part in conduction through the transistor, but it should be remembered that in the connecting leads the current will actually be a flow of electrons in the opposite direction to the arrow.

- Such an arrangement is sometimes described as two diodes back to back. We have already seen that the diode (a single layer of n-type semiconductor joined to a layer of p-type semiconductor) only allows current to flow in one direction, when the p-type layer is connected to a positive voltage.
- It might therefore seem that two diodes back to back would never allow current flow, but the important thing about the transistor is that, as we shall see below, by applying a small voltage to the base connection, the transistor can be 'unblocked' and current will flow through the it. This is the feature which makes the transistor so valuable as an electrical component.
- Two essential features of the transistor are:
 - The base layer has to be extremely thin.
 - The collector must be arranged so as to be in physical contact with and surround as much of the base as possible.

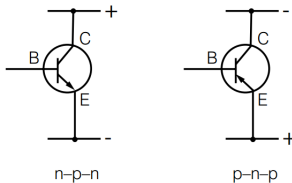


Transistor biasing

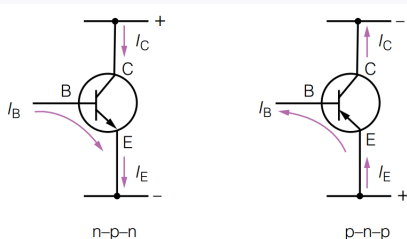
- **Biasing** refers to placing voltages across the terminals of a device.
- A diode is said to be 'forward biased' if a voltage is applied to it which enables it to conduct (from Figure below that will be when the positive side of the battery is connected to the p-type material).
- If the voltage is applied the other way round, the diode is said to be 'reverse biased' and it will not conduct.



- The arrow on the emitter of a transistor tells you the direction of the conventional current it will allow through. Considering the emitter–collector as the through route, this means that the polarity of the battery across the device must be as in Figure below.



- Despite this there should be no current flowing from C because the first junction, the one from collector to base, is reverse biased.
- While this is true, it turns out that a small current via the base terminal somehow seems to ‘unblock’ it, and in those circumstances current will flow from C to E.
- Current sent into the base has only one possible route out. The junction towards the collector is reverse biased, so it all has to escape via the emitter (Figure below).



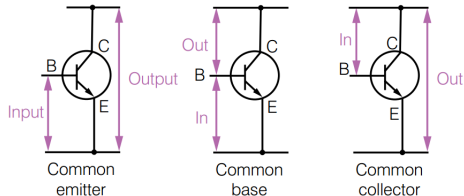
- By Kirchhoff's current law, (the total current entering any junction in a circuit equals the current leaving it)

$$I_E = I_C + I_B$$

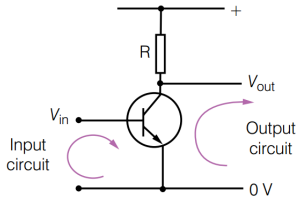
- In terms of voltages, the base has to be at a voltage intermediate between that of the emitter and the collector. Provided V_{BE} is greater than about 0.6V, the base-collector junction will conduct, so a base current will flow.

Transistor characteristics

- We will consider just the n-p-n transistor because that is the more common one. By its characteristics we mean how one variable affects a second one, all other variables staying constant.
- In most applications, the signal at the base is used to control what is received at the collector.
- Two leads are needed to feed an input into a transistor, how ever, and two leads will be needed for the output as well. A transistor has only three terminals, so one of them will inevitably be common to both. It can be any of the three, so the circuitry can be classified as common emitter, common base or common collector (Figure below).



- These diagrams do not depict actual circuits – although the input and output are essentially currents, a resistor in the lead between the positive line at the top and the collector will enable the changing voltage across it to be used as an output. Such a common-emitter arrangement is shown in Figure below.

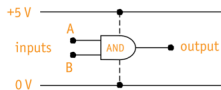


Logic gates

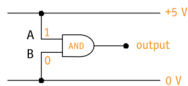
- Logic gate is an electronic device that performs a logical operation on two inputs and produces a single logic output.
- A logic gate is a device that acts as a building block for digital circuits. They perform basic logical functions that are fundamental to digital circuits. Most electronic devices we use today will have some form of logic gates in them. For example, logic gates can be used in technologies such as smartphones, tablets or within memory devices. In a circuit, logic gates will make decisions based on a combination of digital signals coming from its inputs.
- Most logic gates have two inputs and one output. Logic gates are tiny silicon chips on which are etched combinations of transistors and resistors. They typically have two inputs and one output. What happens at the output is determined by the situation at those inputs. An example is the AND gate, which we shall consider first.

The AND gate

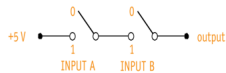
- The power supply needed will be a steady smooth d.c. of around 5 V. Each gate must be connected to this power supply by two wires, which are not normally indicated on the diagrams: one at +5 V, and the other at 0 V (Figure a).
- Each input may either be joined to the 0 V line, in which case we say the input is a '0', or it may be joined to the +5 V line, in which case the input is a '1'. In Figure 5.63 input A is a '1' and B is a '0'.
- The output may be a '0' (so it is at the same voltage as the 0 V line) or it may be a '1' (and so acts as if it was the +5 V line). The output of a logic gate is shown by its truth table which is a list of all possible input combinations, showing what you get each time at the output.
- In Figure (b), you can see that input A is '1', input B is '0'. From the truth table you can see that the output for these input values is '0'.



(a)



(b)



(c)

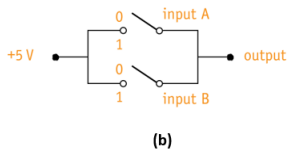
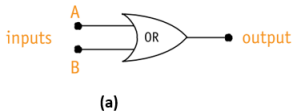
- Table below shows the truth table for the AND gate. As its name suggests, the only way to get a '1' at the output is to have a '1' at input A and a '1' at input B.

INPUT A	INPUT B	OUTPUT
0	0	0
0	1	0
1	0	0
1	1	1

- You can think of an AND gate as a bit like two switches in series (Figure c). Both switches must be placed in the '1' position to make the output 'live' (that is, at +5 V).
- The circuit symbol for AND gate is shown in the figure (a) and (b)
- As the inputs are voltages and not currents, all you have to do is touch the input contact onto the 'live' (+5 V) line for a '1', or touch it on the earth line for a '0'. The input resistance is huge, so in effect no current flows into the gate.

The OR gate

- The OR gate may not be quite what you would expect from its name. If the AND gate could be pictured as two switches in series, the OR gate behaves like the same two switches in parallel (Figure b).
- You might not have expected the last line in the table from what we normally understand by the word 'or', but if you think of those two switches in parallel (Figure b), you should soon be able to work out the correct truth table. The output will always be at +5 V except when both switches are at 'zero'.
- The circuit symbol for OR gate is shown in figure (a).



- The truth table for the OR gate is shown in Figure below.

INPUT A	INPUT B	OUTPUT
0	0	0
0	1	1
1	0	1
1	1	1

The NOT gate

- Yet another gate is the NOT gate. This has a single input, and its output is always the opposite. A '0' at the input means a '1' at the output, and vice versa. Figure (a) shows the symbol for a NOT gate.
- If you are puzzled as to how a '1' can come out when nothing is going in, you are forgetting that the gate also has connections to the power supply which are not shown. If the input is connected to earth (0), therefore, the +5 V of the 'live' line appears at the output.
- The truth table for the NOT gate is shown in Figure (b).



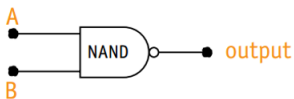
(a)

INPUT	OUTPUT
0	1
1	0

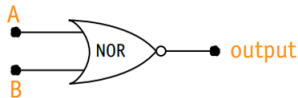
(b)

The NAND gate and the NOR gate

- There are two final gates to consider - the NAND gate and the NOR gate. These are just the AND gate and the OR gate respectively, but with the output inverted. Instead of a '0' there is a '1', and instead of a '1' a '0'. Their symbols are shown in Figure (a) and (b) and the little circle at the output indicates that each value is reversed.



(a)



(b)

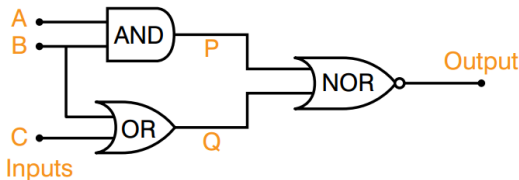
- The four truth tables are summarized in Figure below.

			Output		
INPUT A	INPUT B	AND	NAND	OR	NOR
0	0	0	1	0	1
0	1	0	1	1	0
1	0	0	1	1	0
1	1	1	0	1	0

- Nobody would expect you to sit and learn that table by heart. You should be able to work out how the AND and OR gates behave, and then obtain the other two simply by reversing their outputs.

Combinations of logic gates

- More than one logic gate may be combined to increase the range of control tasks that can be performed.
- As an example, consider the arrangement shown in Figure below. How does it behave?



- Start by preparing a table with columns for all possible combinations of inputs for the corresponding logic states at intermediate points P and Q, and finally for the output.

- There are three inputs this time, which will give $2^3 = 8$ different combinations of 0s and 1s. If you know your binary notation, the neatest way to write them down is in sequence by listing in turn the binary equivalents of 0 to 7. Figure below shows the truth table filled in with these figures.

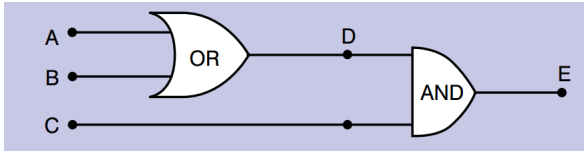
INPUT A	INPUT B	INPUT C	POINT P	POINT Q	OUTPUT
0	0	0			
0	0	1			
0	1	0			
0	1	1			
1	0	0			
1	0	1			
1	1	0			
1	1	1			

- Once the inputs are entered, work out the states of points P (from inputs A and B) and Q (from inputs B and C) and record them in the table (Figure below).
- Then use P and Q as inputs to the final gate in order to find the output.

INPUT A	INPUT B	INPUT C	POINT P	POINT Q	OUTPUT
0	0	0	0	0	1
0	0	1	0	1	0
0	1	0	0	1	0
0	1	1	0	1	0
1	0	0	0	0	1
1	0	1	0	1	0
1	1	0	1	1	0
1	1	1	1	1	0

Example

1. Consider the arrangement shown in Figure 5.75. How does it behave?



- Start by preparing a table with columns for all possible combinations of inputs (A, B and C). There are three inputs this time, which will give $2^3 = 8$ different combinations of 0s and 1s.

- As seen above, the neatest way is to write them down in sequence by listing in turn the binary equivalents of 0 to 7. Figure below shows the table filled in like this.

INPUT A	INPUT B	INPUT C	POINT D	POINT E
0	0	0		
0	0	1		
0	1	0		
0	1	1		
1	0	0		
1	0	1		
1	1	1		

- Now fill in the column for the logic state at intermediate point D (remember to use columns for Input A and Input B to work out the results for point D), and finally for the output, E (using the columns for Input C and point D). Figure below shows the completed table.

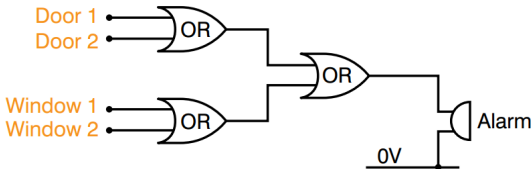
INPUT A	INPUT B	INPUT C	POINT D	POINT E
0	0	0	0	0
0	0	1	0	0
0	1	0	1	0
0	1	1	1	1
1	0	0	1	0
1	0	1	1	1
1	1	1	1	1

The action of logic gates

- In this section we will give some circuits involving logic gates and say what they are meant to do. Your task each time is to try to explain how they work.

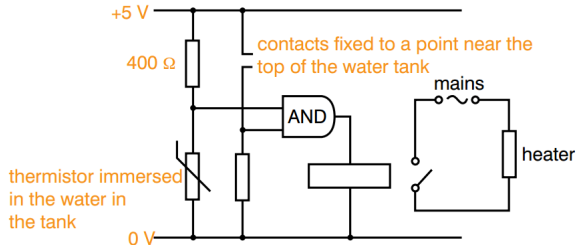
i. A simple burglar alarm

- In the circuit drawn in Figure below, two doors and two windows are equipped with micro-switches such that if they are opened the switch closes and the signal from it changes from a 0 to a 1.
- The switches are connected to one of a pair of two-input OR-gates, so if any of the inputs becomes a 1 the alarm will sound.



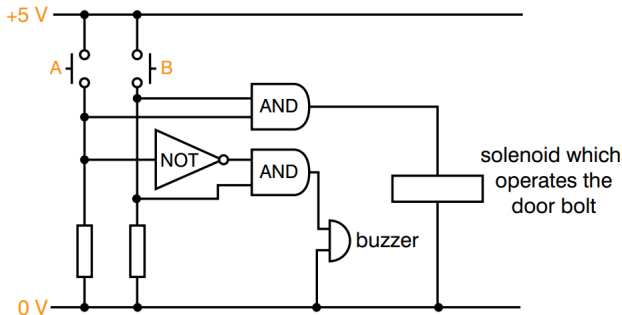
ii. A thermostat for a hot water tank

- In the circuit drawn in Figure below,
 - a. two contacts are fixed near the top of the tank and when submerged (i.e. when the water is deep enough) the water completes a circuit between the contacts, signalling that the water is deep enough,
 - b. a thermistor (set to the required temperature) is immersed in the water in the tank; it signals if the temperature of the water is too cold.
- The water heater will only be switched on if both (a) the tank is full of water AND (b) the water is too cold.



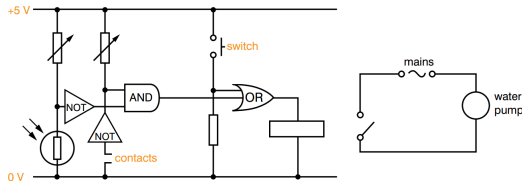
iii. A security lock to get 'behind the counter' at a bank

- In the circuit drawn in Figure below, button A is on the bank manager's desk and button B is by the door of the bank, on the outside.
- The solenoid which pulls the bolt in, unlocking the door, is only activated if both button A AND button B are pressed and held down.
- The warning buzzer sounds if button B is pressed AND button A is NOT pressed.



iv. An automatic plant waterer

- In the circuit drawn in Figure below:
 - a. Contacts sensing moisture content are placed in the soil. These generate a signal when the soil is damp. As the system is required to switch the pump on when the soil is dry, the signal passes through a NOT gate.
 - b. A light sensor, consisting of a photovoltaic cell, generates a voltage when light falls on it, but as the system is required to switch on when it is dark, the signal passes through a NOT gate.
 - c. Switch S is a manual override. Pressing this switch will switch on the pump whatever the conditions. The solenoid switching on the pump to water the plants will come on if the soil is dry AND it is dark OR if the manual override switch is pressed.



Integrated circuits

- Logic gates are grouped together in circuits – such as the gate shown in Figure 5.85a. The tiny silicon chip is encased in resin and is connected to the outside world via its 14 metal ‘legs’ (Figure 5.85b). Note that the gates are identified just by their symbols. It is a ‘quad 2-input NAND’ meaning that it contains four separate NAND-gates, each with an input A and an input B. A single $+5\text{ V}$ connection and a single 0 V one serve all four gates inside.

