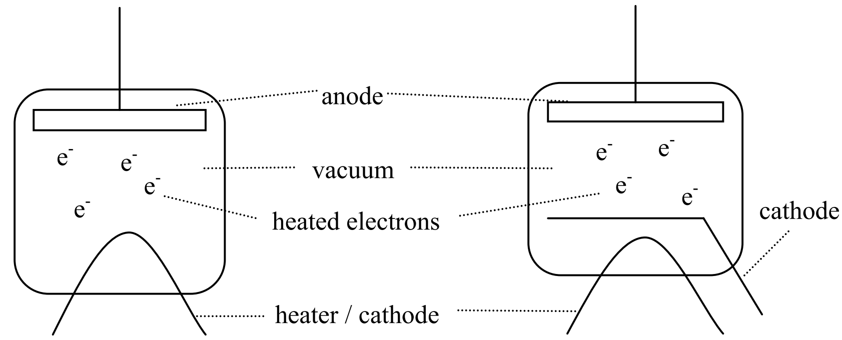
CHAPTER 9
ELECTRONICS

9.1 Cathode Rays

9.1.1 Thermionic Emission

Thermionic emission is the emission of electrons from a heated metal surface.

<u>Direct heating</u> **<u>Indirect heating</u>**

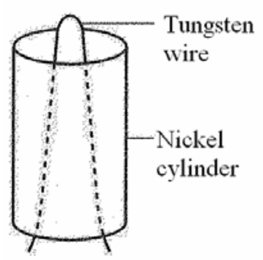


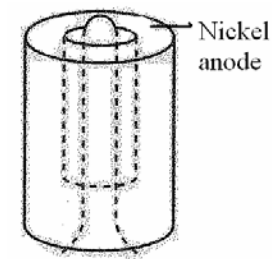
Direct heating

- Tungsten wire as the heater and cathode
- Cylindrical nickel as anode

Indirect heating

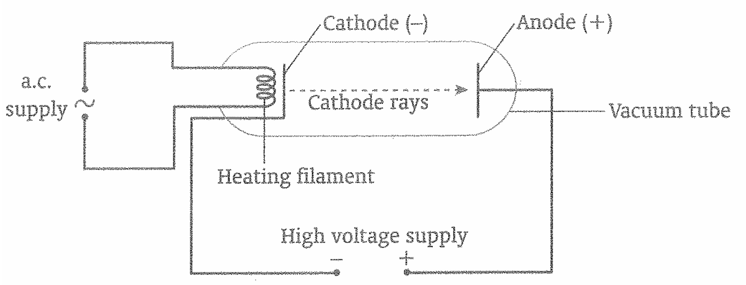
- Tungsten wire as heater
- Nickel cylinder coated with a mixture of barium oxide or strontium oxide as cathode
- Cylindrical nickel as anode





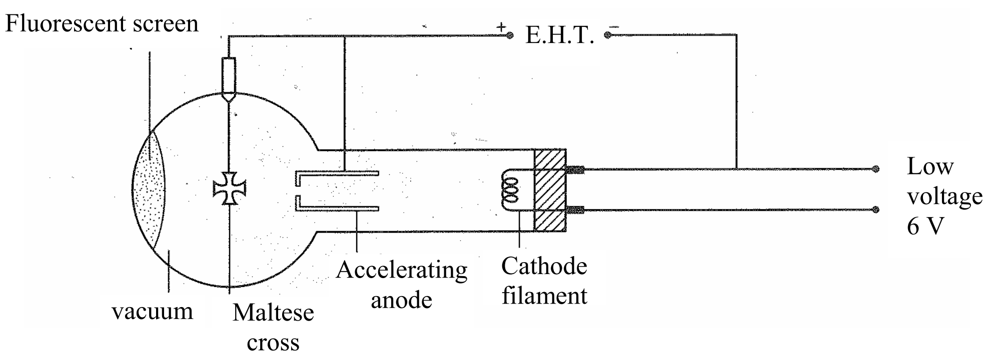
Factors that influence the rate of thermionic emission:

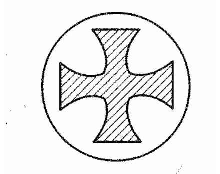
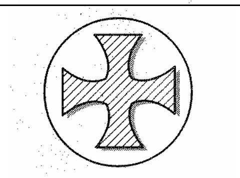
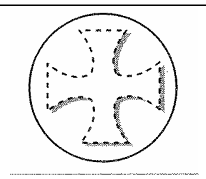
- **Temperature** (dependent on current) – the hotter the temperature, the higher the rate
- **Surface area** – the larger the area, the higher the rate
- **Type of metal** – different metals have different rates of emission
- **Metal surface** – if coated with a mixture of barium oxide or strontium oxide, the rate is increased



Cathode rays are the beam of electrons which move at high speed from the **cathode** to the **anode**.

9.1.2 Maltese Cross Tube

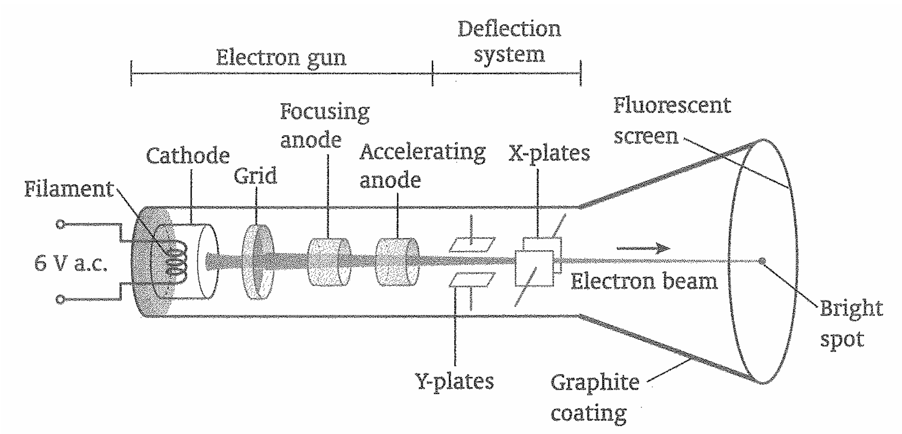


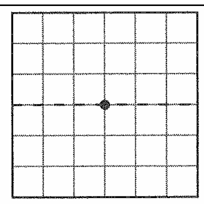
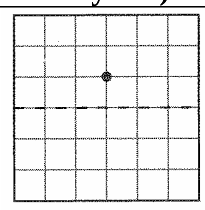
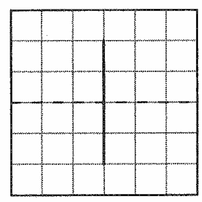
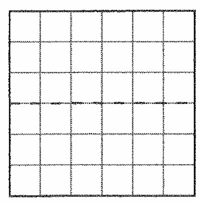
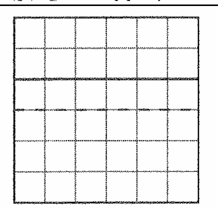
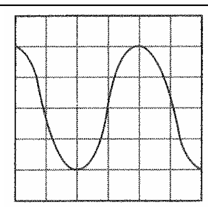
Situation	**Results seen on the fluorescent screen**	**Explanation**
The low voltage is switched on; the extra high voltage is off		Shadow of the Maltese cross caused by the light emitted from the hot filament
Both low voltage and extra high voltage are switched on		Green shadow of the Maltese cross caused by the electron beams
A magnetic bar is placed near the fluorescent screen		The green shadow of the Maltese cross is deflected. Deflection is downwards if the north pole is placed near the screen. Direction of deflection can be determined by the left-hand Fleming rule.

9.1.3 Electron Beam Characteristics

1) Movement is in a straight line because it is light and has high velocity.
2) Has momentum and energy; fluorescent effect when connects with fluorescent items.
3) Negatively charged → deflected towards positive plates.
4) Can be deflected by magnetic fields.
5) When collides with metal targets, kinetic energy → 99% light and X-rays

9.1.4 Cathode Ray Oscilloscope (CRO)



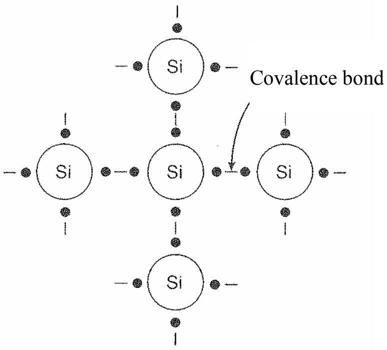
CRO Reading	No input	Direct current (from dry cell)	Alternating current
Time-based switched off			
Time-based switched on			

Cathode ray oscilloscopes are used to:
- Measure potential difference
- Measure short time intervals
- Display wave forms

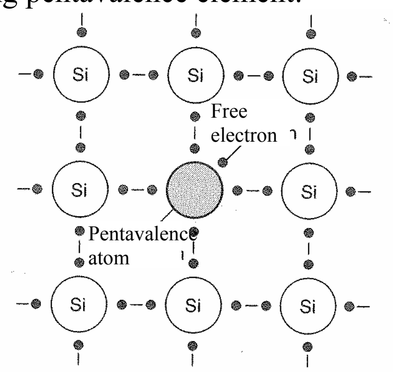
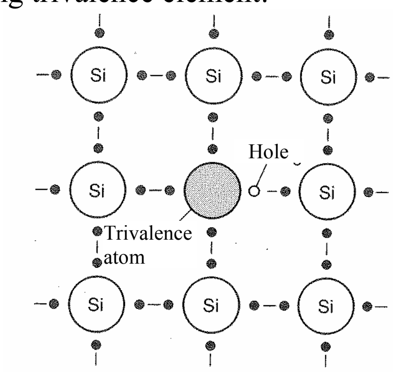
9.2 Semiconductors

9.2.1 Doping of Semiconductors

Doping process is the addition of a small quantity of foreign objects into a semiconductor to increase its conductivity. The atom size of the foreign object has to be about the same size as the atom size of the semiconductor.

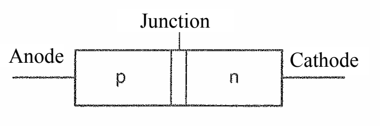


Typical semiconductor: Silicone

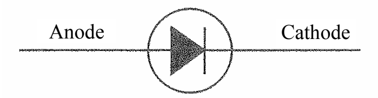
n-type semiconductor	**p-type semiconductor**
Adding pentavalence element: 	Adding trivalence element: 
The pentavalence atom is known as a donor atom	The trivalence atom is known as a recipient atom
Negatively charged (extra electrons)	Positively charged (less electrons)
Antimony, arsenic, phosphorus	Boron, gallium, indium, aluminium
Major charge carrier: **electrons** Minor charge carrier: **positively-charged holes**	Major charge carrier: **positively-charged holes** Minor charge carrier: **electrons**

9.2.2 Diodes

A diode consists of a combination of an n-type and a p-type semiconductor.

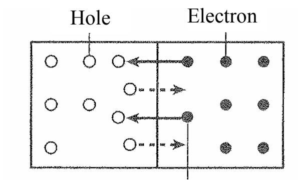


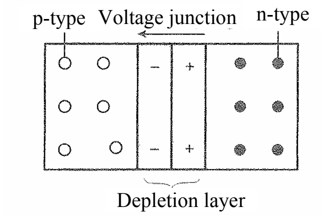
Diode construction

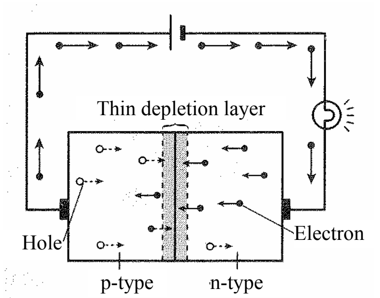
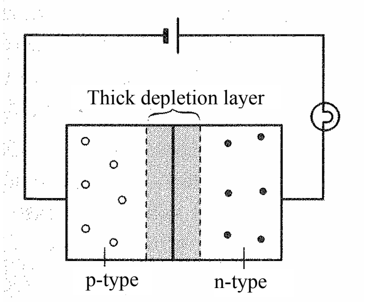


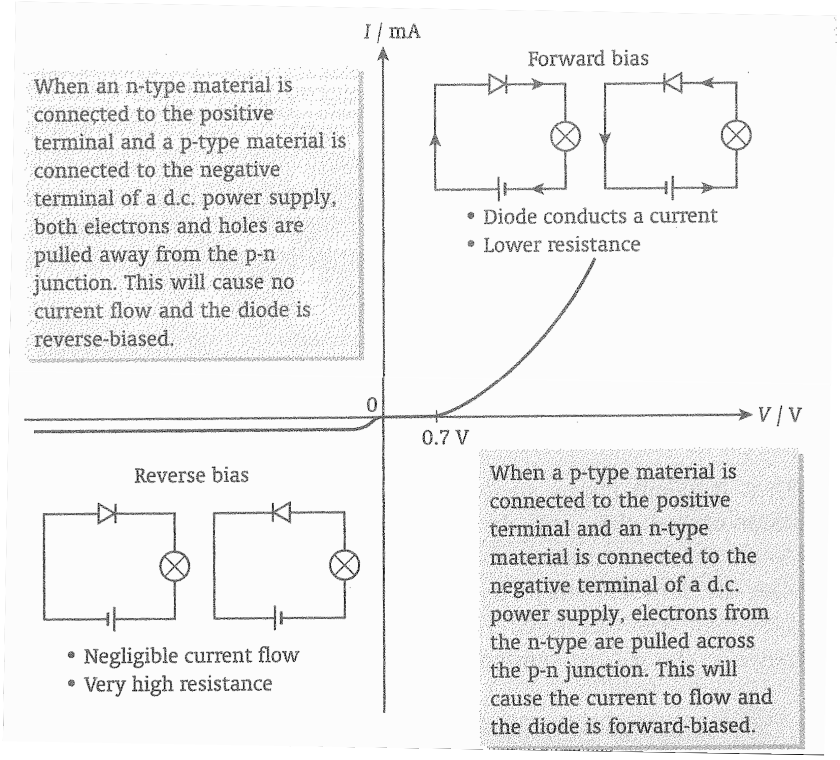
Diode symbol

- At the junction of these two semiconductors, the electrons from the n-type semiconductor will float over to fill up the holes in the p-type semiconductor.
- This will cause opposite charges to exist within the semiconductors; and this will create a **voltage junction** which prevents further floatation of the electrons.
- A layer about 1 μm will exist at the voltage junction known as a **depletion layer**.
- Junction voltages for silicone and germanium are approximately 0.6 V and 0.1 V respectively.



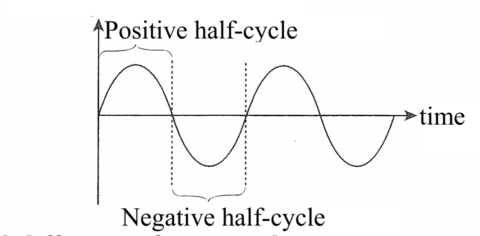


Diode Connection	**Current Flow Mechanism**
Forward bias  	• E.m.f. > voltage junction • Current is big enough to light the light bulb • Current is created by the 'movement' of the holes and the electrons in opposite directions across the junction
Reverse bias  	• A very small current flows through the diode and the light bulb does not light • The holes are attracted to the negative terminal and the electrons to the positive terminal • This attraction pulls the holes and electrons away from the p-n junction and widens the depletion layer • The junction voltage increases until it is the same as the potential difference of the cell and prevents the current from crossing the p-n junction



9.2.3 Diodes as Rectifiers

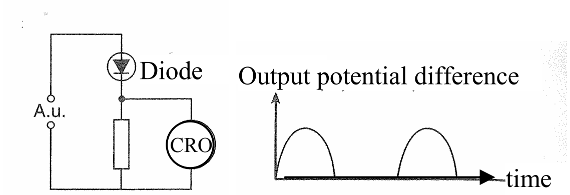
Rectification – the process of converting a.c. to d.c. This is done with a diode as diodes allow current to flow only in one direction.



Potential difference from an alternating current source

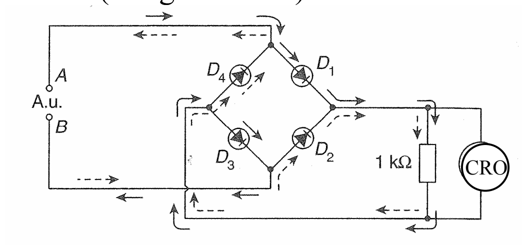
<u>Half-wave Rectification</u>

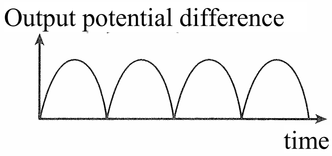
Using a single diode:

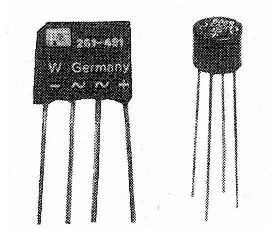


Full-wave Rectification

Using four diodes (bridge rectifier):



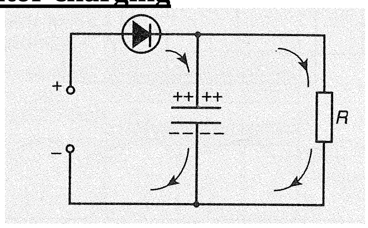
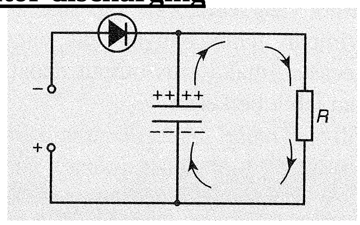


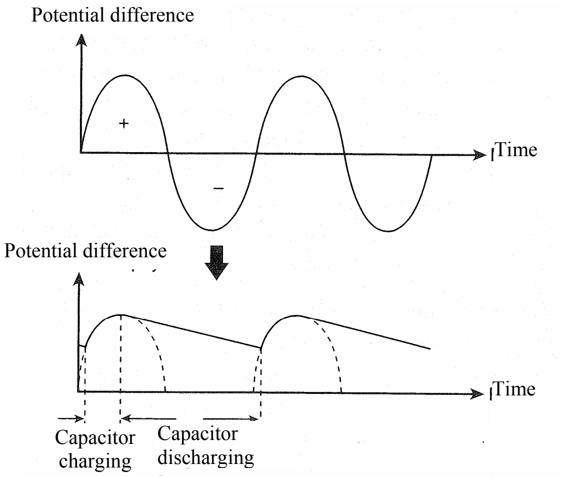


Note: The four-diode arrangement can be combined into a bridge rectifier. There are four terminals on a bridge rectifier: 2 to the a.c. source, and 2 to the resistor.

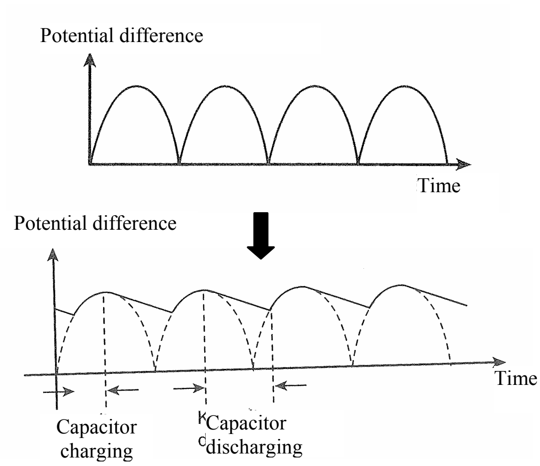
9.2.4 Capacitors

Capacitors are used to smoothen out the current. Using capacitors with full-wave rectification creates smoother current flows for optimal use with electrical appliances.

Capacitor charging	**Capacitor discharging**
 • For the positive half-cycle, the diode is in forward bias • Current flows through the capacitor and the resistor • Capacitor is charged and energy is stored	 • For the negative half-cycle, the diode is in reverse bias • Current is not allowed to flow through the diode • Capacitor discharges and the energy stored is used to maintain the potential difference across the resistor



Half-wave rectification with capacitor



Full-wave rectification with capacitor

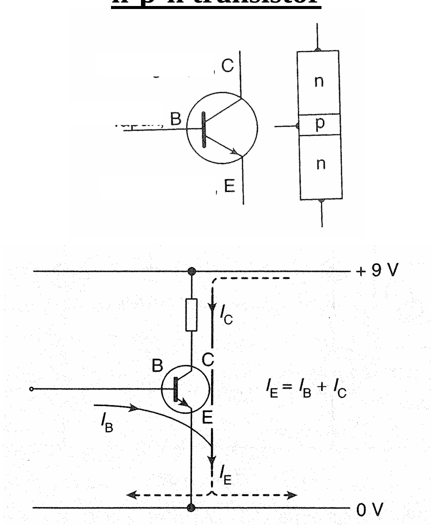
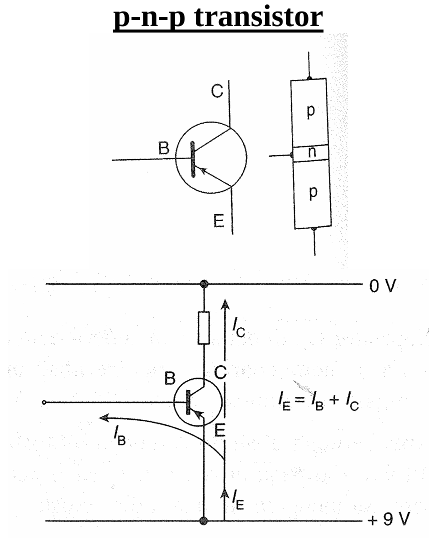
9.3 Transistors

Transistors are electronic devices that act as a transfer resistor to control the current and potential difference within an electronic circuit.

Transistors are a combination of two types of semiconductors, i.e. type p and type n. Transistors have three electrodes:

- Base (B)
- Collector (C)
- Emitter (E)

There are two types of transistors:

n-p-n transistor	p-n-p transistor
	

Transistor basics:
For both n-p-n and p-n-p transistors:

$$I_E = I_B + I_C$$
$$\text{Current magnification} = \frac{I_C}{I_B}$$

where I_E = emitter current [A]
I_B = base current [A]
I_C = collector current [A}

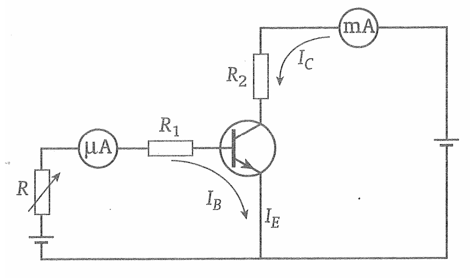
Current magnification ≈ 50 – 150 for normal transistors

R_B is a high resistance resistor to limit the flow of I_B in the base current.

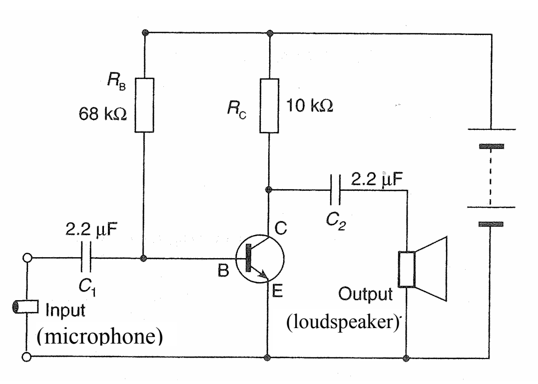
Note:
- $I_C \propto I_B$; i.e. $I_B = 0$, $I_C = 0$
- $I_B \not\propto I_C$; i.e. $I_C = 0$, $I_B \neq 0$
- A small change in I_B causes a big change in I_C.

9.3.1 Transistors as amplifiers

Transistor as a current amplifier

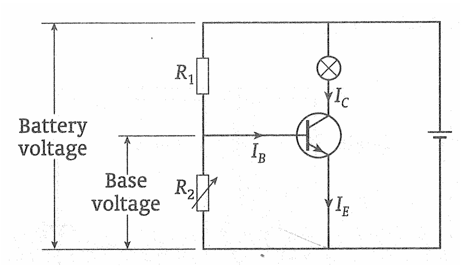


Transistor as a sound amplifier



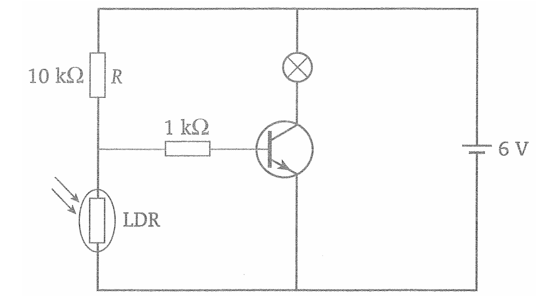
Component	Function
Microphone	Converts sound signals to electrical signals
Capacitor	Prevents d.c. from flowing into the transistor and loudspeaker
Transistor	Amplifies input signal
Loudspeaker	Converts electrical signals to sound

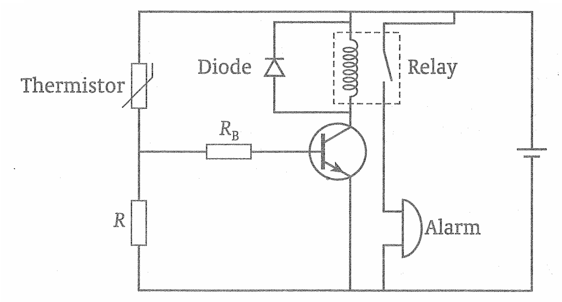
9.3.2 Transistors as automatic switches



- When resistance of R_2 increases, the potential difference across R_2 increases. This causes current to flow through the base circuit
- If there is base current, there will be collector current; therefore the light bulb will light up

$R = 0$, $V_R = 0 \rightarrow I_B = 0$, $I_C = 0$
R √, V_R √ → I_B √, I_C √





Light controlled switch
- Light-dependent resistor (LDR) changes resistance depending on presence of light
- Very high resistance in the dark
- Low resistance in bright light

Heat controlled switch
- Thermistor is a heat-dependent resistor
- Resistance increases when it is cold
- Resistance drops when it is hot

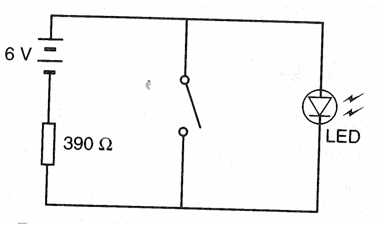
9.4 Logic Gates

Logic gates
- electronic devices that have one or more input and only one output
- also electrical circuits which determine whether or not an input signal is allowed to be sent to the output
- they function as automatic switches

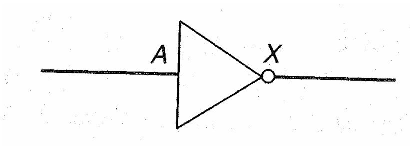
Truth table
- a table which lists all possible situations for input and output through logic gates
- the number of possible combinations N for n input variables:

$$N = 2^n$$

9.4.1 Logic Gate NOT



Circuit representation



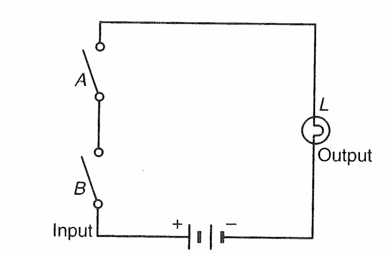
NOT symbol

INPUT	OUTPUT
A	***X***
0	1
1	0

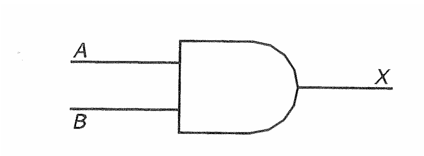
Boolean equation for NOT:

$$X = \bar{A}$$

9.4.2 Logic Gate AND



Circuit representation



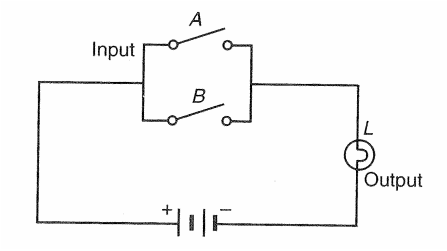
AND symbol

INPUT		OUTPUT
A	***B***	***X***
0	0	0
1	0	0
0	1	0
1	1	1

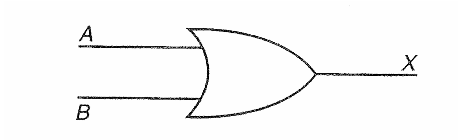
Boolean equation for AND:

$$X = A \bullet B$$

9.4.3 Logic Gate OR



Circuit representation



AND symbol

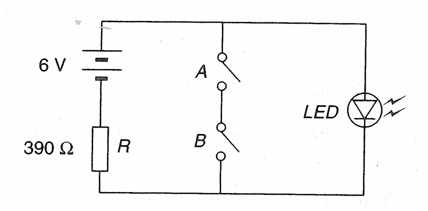
INPUT		OUTPUT
A	***B***	***X***
0	0	0
1	0	1
0	1	1
1	1	1

Boolean equation for OR:

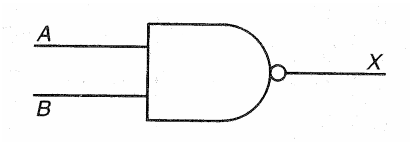
$$\boldsymbol{X = A + B}$$

9.4.4 Logic Gate NAND

Combination of NOT and AND



Circuit representation



NAND symbol

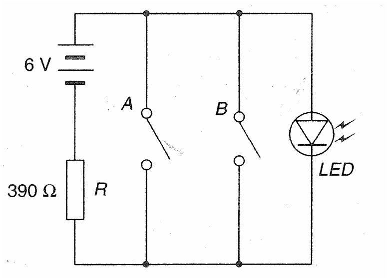
INPUT			OUTPUT
A	***B***	***C = A • B***	***X***
0	0	0	1
1	0	0	1
0	1	0	1
1	1	1	0

Boolean equation for NAND:

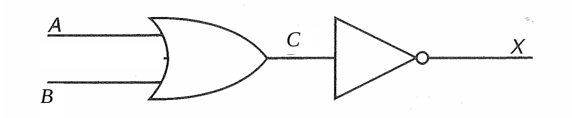
$$\boldsymbol{X = \overline{A \bullet B}}$$

9.4.5 Gate NOR

Combination of NOT and OR



Circuit representation



NOR symbol

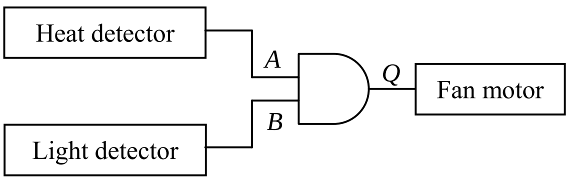
INPUT			OUTPUT
A	***B***	$C = A + B$	***X***
0	0	0	1
1	0	1	0
0	1	1	0
1	1	1	0

Boolean equation for NOR:

$$X = \overline{A + B}$$

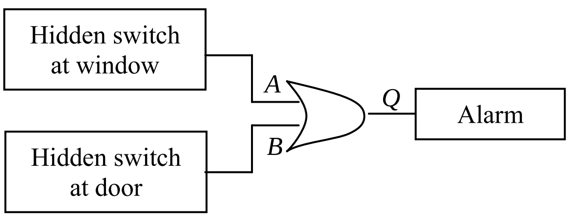
9.4.6 Logic Gates Application

9.4.6.1 Fan Motor Control System



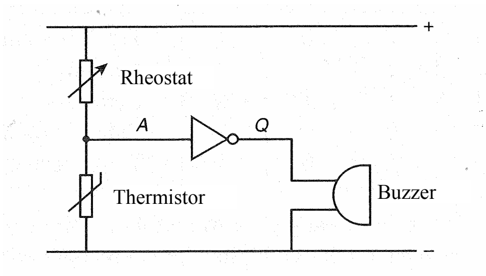
INPUT		OUTPUT
A	***B***	***Q***
0	0	0
1	0	0
0	1	0
1	1	1

9.4.6.2 Burglar Alarm System



INPUT		OUTPUT
A	***B***	***Q***
0	0	0
1	0	1
0	1	1
1	1	1

9.4.6.3 Fire Alarm System



INPUT	OUTPUT
A	***X***
0	1
1	0