CHAPTER 5

Electronics

What are thermionic emission and cathode rays?

What are the function and uses of a semiconductor diode?

What are the functions of a npn transistor or pnp transistor?

How does a transistor function in an amplifier circuit?

How does a transistor function as an automatic light-controlled switch and heat-controlled switch?

You will learn:

- 5.1 Electron
- 5.2 Semiconductor Diode
- 5.3 Transistor

Learning Standards and List of Formulae in Chapter 5

Information Portal

The invention of the semiconductor diode and transistor in the 20th century has led to the Digital Revolution. This period has transformed life as we know it due to the technological development from mechanical and analog to digital. Diodes and transistors in the form of electronic microchips, which are central of all of our electronic devices are easily available and have many benefits. The light emitting diode or LED is used as the source of light. LED is also used as indicator lamp in industrial machines.

In addition, Artificial Intelligence (AI) is increasingly dominating our lives. Many of the devices today can function automatically, such as robots and self-driving cars. Most of the electronic chips today are designed to be increasingly smaller. Smaller chips not only save space and electrical power but also improve the overall efficiency of the system.

https://bit.ly/31M6J7Q

Importance of the Chapter

In the era of the Fourth Industrial Revolution (IR 4.0), understanding the nature of electrons, applications of diodes and transistors, artificial intelligence (AI) and 5G internet enables electronic engineers and algorithm experts to create smart electronic devices and automation systems. Such progress can improve the industry's productivity and national revenue.

Futuristic Lens

Artificial intelligence (AI) enables in-depth studies on robots and self-driving cars. Research into this field also contributes to the development of smart cities which are more nature-friendly to maintain a sustainable lifestyle.

https://bit.ly/2QHtiEc

5.1 Electron

Thermionic Emission and Cathode Rays

You have learnt that current, I is the rate of flow of charges in a conductor. An electric current is produced when charged particles (electrons) flow in a conductor. Can electrons move through a vacuum without a conductor?

Activity 5.1

ISS / ICS

Aim: To generate idea on thermionic emission and cathode rays

Instructions:

1. Carry out this activity in groups.
2. Scan the QR code to watch the video on thermionic emission and cathode rays.
3. Based on the video, discuss the following:
   (a) What is thermionic emission?
   (b) What are the functions of the 6 V power supply and the extra high tension (E.H.T) power supply?
   (c) Why must the tube be in a state of vacuum?
   (d) How can cathode rays be produced in a vacuum tube?
4. Present your findings.

SCAN ME
EduwebTV: Thermionic emission and cathode rays
https://bit.ly/3gJuQH

Figure 5.1 explains the thermionic emission and the production of cathode rays in a vacuum tube using extra high tension (E.H.T.) power supply.

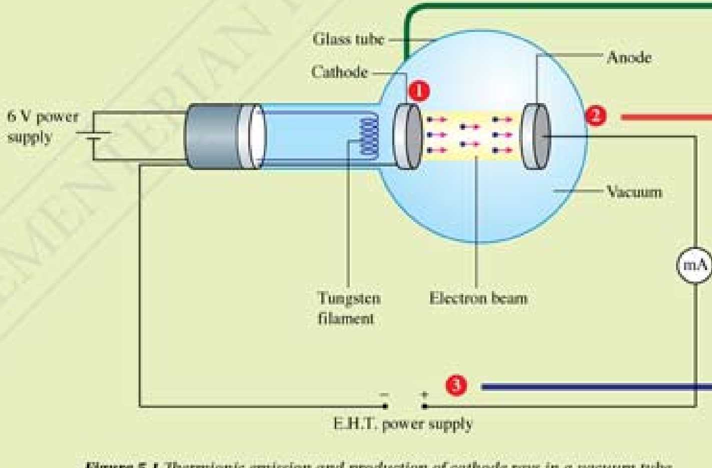
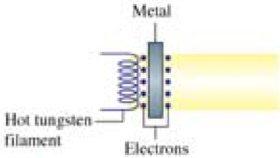


***Figure 5.1** Thermionic emission and production of cathode rays in a vacuum tube*

1

There are many free electrons in a metal wire, for example, tungsten filament. When the 6 V d.c. power supply is switched on, the temperature of the tungsten filament will rise and the free electrons will gain sufficient kinetic energy to leave the metal surface. Thermionic emission is **the emission of free electrons from a heated metal surface.**



Info GALLERY

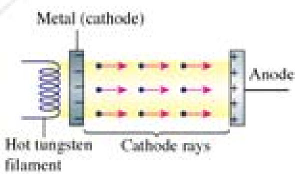
If a layer of metal oxide like barium oxide or strontium oxide is coated on the metal surface cathode in the vacuum tube, the temperature required to release the electrons will be reduced.

2

In a glass vacuum tube, the electrons are able to accelerate towards the anode without colliding with air molecules. Hence, there is no energy loss and electrons move with the maximum velocity.

3

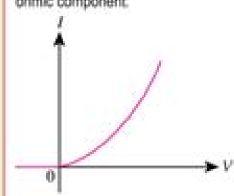
- When a vacuum tube is connected to an E.H.T. power supply, the electrons emitted from the cathode will be attracted to the anode at high velocity to form an electron beam. This **high velocity electron beam** is known as cathode rays. The electron beam will complete the E.H.T. power supply circuit and the milliammeter reading will show that a current is flowing.



- If the connection to the E.H.T. power supply is reversed, the milliammeter will not show any reading.

Info GALLERY

The graph below shows a graph of current against voltage for a thermionic diode. This shows that a thermionic diode is a non-ohmic component.



Graph of I against V

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Effects of Electric Field and Magnetic Field on Cathode Rays

Cathode rays are **beams of electrons moving at high speed in a vacuum**. The characteristics of cathode rays can be studied using a deflection tube and a Maltese cross tube. Carry out Activity 5.2 and Activity 5.3 to study the effects of electric field and magnetic field on the direction of cathode rays.

Activity 5.2 — Teacher's demonstration

Aim: To study the effects of an electric field on cathode rays using a deflection tube

Apparatus: Deflection tube, 6 V power supply, E.H.T. power supply and connecting wires

Instructions:

1. Set up the apparatus as shown in Figure 5.2.

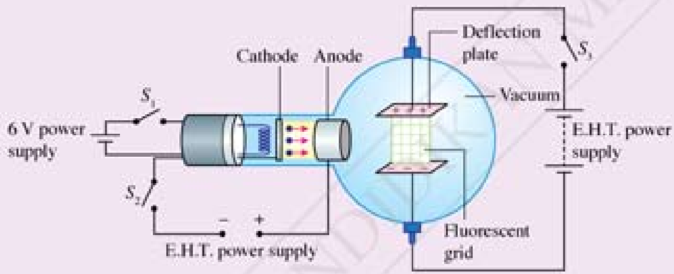

Figure 5.2 Deflection tube

2. Turn on switch S_1 for the 6 V power supply and switch S_2 for the E.H.T. power supply. Record your observations.
3. Turn on switch S_3 at the E.H.T. power supply that is connected to the deflection plates. Observe the cathode rays deflection on the fluorescent grid.
4. Reverse the connection at the E.H.T. power supply that is, connected to the deflection plates and repeat step 3.
5. Record all your observations.

SCAN ME
Demonstration video of a deflection tube
https://bit.ly/2Z92QZ9

Discussion:

State your observations on the fluorescent grid when:

(a) switches S_1 and S_2 are turned on
(b) switches S_1, S_2 and S_3 are turned on
(c) switches S_1, S_2 and S_3 are turned on and the potential difference at the deflection plates is reversed

Safety Precaution

- Do not touch any metal part of the deflection tube while using the E.H.T. power supply.
- Ensure that the E.H.T. power supply is switched off when no observations are made.

Activity 5.3

Teacher's demonstration

Aim: To study the effects of a magnetic field on cathode rays using a Maltese cross tube

Apparatus: Maltese cross tube, 6 V power supply, E.H.T. power supply, bar magnet and connecting wires

Instructions:

1. Set up the apparatus as shown in Figure 5.3.

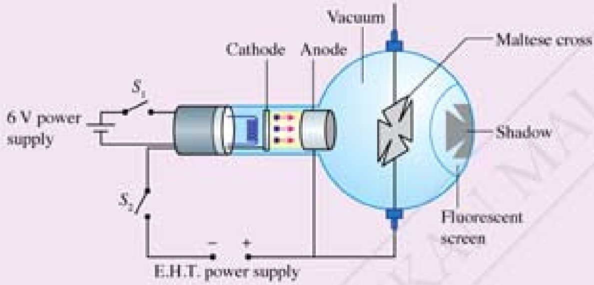

Figure 5.3 *Maltese cross tube*

2. Turn on switch S_1 of the 6 V power supply. Observe the shadows formed on the fluorescent screen. Record your observation.
3. Turn on switch S_2 and observe the shadow formed on the fluorescent screen again.
4. Bring the north pole of a magnet to the right side of the Maltese cross tube and observe changes of the shadow.
5. Record all your observations.

Discussion:

1. State your observations of the shadow formed on the fluorescent screen when:
   (a) switch S_1 is turned on
   (b) switches S_1 and S_2 are turned on
   (c) switches S_1 and S_2 are turned on and the north pole of a magnet is brought to the side of the Maltese cross tube.
2. Explain your observations when the north pole of a magnet is brought to the right side of the Maltese cross tube.

SCAN ME
Demonstration video of a Maltese cross tube
https://bit.ly/3bf1SPR

Safety Precaution
- Do not touch any metal part of the Maltese cross tube while using the E.H.T. power supply.
- Ensure that the E.H.T. power supply is switched off when no observations are being recorded.

Note
Ensure that the Maltese cross tube is properly earthed when the experiment is running.

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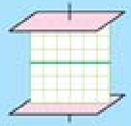
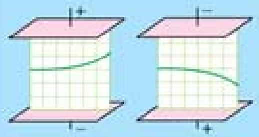
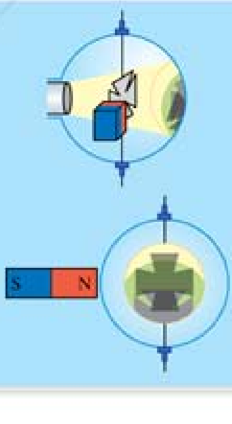
Table 5.1 summarises the effects on electric field and a magnetic field on cathode rays.

***Table 5.1** Observations and explanations on the characteristics of cathode rays*

Apparatus	Condition of switch	Observations	Explanation
Deflection tube	S_1 and S_2 are turned on		• Cathode rays travel in a straight line.
	S_1, S_2 and S_3 are turned on		• Cathode rays **can be deflected by an electric field**. They are deflected towards the positive plate in a parabolic path. • Cathode rays are **negatively charged**.
Maltese cross tube	S_1 is turned on		• Light from the hot tungsten filament is be blocked by an opaque object (Maltese cross) to form a shadow. Light travels in a straight line.
	S_1 and S_2 are turned on		• Cathode rays are **blocked** by Maltese cross to form a shadow. Cathode rays **travel in a straight line**. • Cathode rays also **produce a fluorescent effect** on the screen surrounding the shadow. This shows that cathode rays **possess momentum and kinetic energy**.
	S_1 and S_2 are turned on and magnet is placed near the tube		• One shadow is due to the light from the hot tungsten filament. • The other shadow is due to the deflection of the cathode ray by the bar magnet that is placed near the tube. • The deflection of cathode rays can be determined by Fleming's left-hand rule.

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Velocity of an Electron in a Cathode Ray Tube

Figure 5.4 shows the formation of cathode rays in a vacuum tube. The electrical potential energy, E of an electron is given by:

$$E = eV$$

where E = electrical potential energy
e = charge of an electron
V = potential difference between the cathode and the anode of the E.H.T. power supply

The charge of an electron is 1.6×10^{-19} C

SCAN ME
Demonstration video of a cathode ray tube
https://bit.ly/34TKCye

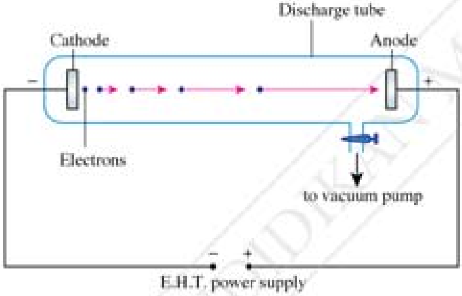

Figure 5.4 *Cathode ray tube*

When the E.H.T. power supply is turned on, electrons are attracted by the positively charged anodes. As there are no air molecules in the vacuum tube, electrons will accelerate to the anode without any collision. These electrons will achieve maximum velocity, v_{max} when they reach the anode.

Applying the principle of conservation of energy,

The electrical potential energy = the maximum kinetic energy

$$eV = \frac{1}{2}mv_{max}^2$$

where e = charge of an electron
V = potential difference between cathode and anode
m = mass of an electron
v_{max} = maximum velocity of an electron

The charge of an electron is 1.6×10^{-19} C and the mass of an electron is 9.11×10^{-31} kg

Brain-Teaser

Before the invention of plasma and LCD televisions, the old versions of televisions were bulky because they used a cathode ray tube. What innovation has led to the invention of plasma and LCD television?

Example 1

LET'S ANSWER
https://bit.ly/3bgsC25

Figure 5.5 shows an electron beam that is accelerated from the cathode to the anode in a vacuum. The potential difference across the cathode and the anode is 550 V.
[Mass of an electron, $m = 9.11 \times 10^{-31}$ kg, charge of an electron, $e = 1.6 \times 10^{-19}$ C]
(a) What is the electrical potential energy of an electron?
(b) What is the kinetic energy of an electron when it reaches at the anode?
(c) What is the maximum velocity of an electron when it reaches at the anode?

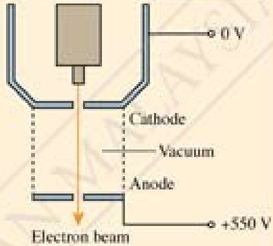

Figure 5.5

Solution

Potential difference across cathode and anode, $V = 550$ V
Charge of an electron, $e = 1.6 \times 10^{-19}$ C
Mass of an electron, $m = 9.11 \times 10^{-31}$ kg

(a) Electrical potential energy of an electron $= eV$
$= 1.6 \times 10^{-19} \times 550$
$= 8.8 \times 10^{-17}$ J

(b) Applying the principle of conservation of energy:
Kinetic energy gained by an electron
= Electrical potential energy of an electron
$= 8.8 \times 10^{-17}$ J

(c) $\frac{1}{2}mv^2_{max} = eV$

$$v_{max} = \sqrt{\frac{2eV}{m}}$$
$$= \sqrt{\frac{2 \times 8.8 \times 10^{-17}}{9.1 \times 10^{-31}}}$$
$$= 1.39 \times 10^7 \text{ m s}^{-1}$$

Formative Practice 5.1

1. (a) What are thermionic emission and cathode rays?
   (b) State the characteristics of cathode rays.
2. (a) State the function of the components of a cathode ray tube below:
   (i) heating filament
   (ii) cathode
   (iii) anode
   (iv) fluorescent screen
   (b) Why must a cathode ray tube be in a state of vacuum?
3. When an electron beam moves from the cathode to the anode in a vacuum tube, state:
   (a) the type of motion of the electron beam
   (b) the transformation of energy
   (c) the relationship between the voltage of E.H.T. power supply and the velocity of the electron
4. When an E.H.T. with power of 800 V is connected across the cathode and the anode, what is the velocity of the electron? What is the effect on the velocity of the electron if the voltage is increased by four times?
   [Charge of an electron, $e = 1.6 \times 10^{-19}$ C, mass of an electron, $m = 9.11 \times 10^{-31}$ kg]

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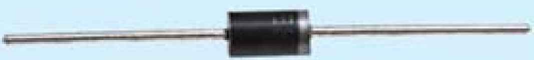
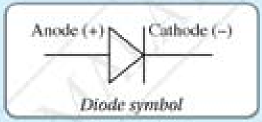
5.2 Semiconductor Diode

You have learnt that the transmission of electrical power to consumers through a network is in the form of alternating current (A.C.). However, in everyday life, many electrical devices can only function with direct current (D.C.). Therefore, the alternating current has to be converted into a direct current. Photograph 5.1 shows a semiconductor diode which functions to convert alternating current into direct current.





Diode symbol

Photograph 5.1 *Semiconductor diode*

Activity 5.4

Aim: Discuss the function of a semiconductor diode

Apparatus: Diode, dry cell, cell holder, bulb and connecting wires

Instructions:

1. Connect the diode in forward biased as shown in Figure 5.6, that is, the positive terminal of the dry cell is connected to the anode and the negative terminal to the cathode.
2. Observe the bulb and record your observation.
3. Reverse the connection of the dry cell so that the diode is in reverse biased as shown in Figure 5.7, that is, the positive terminal of the dry cell is connected to the cathode and the negative terminal to the anode.
4. Observe the bulb and record your observation.

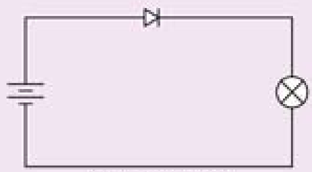


Figure 5.6 *Circuit A*

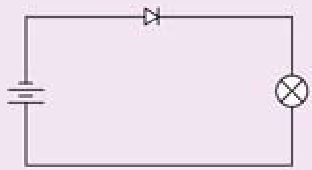


Figure 5.7 *Circuit B*

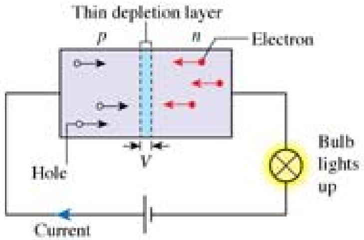
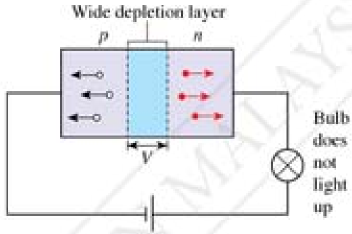
Discussion:

1. What is the function of the diode in this activity?
2. State the condition when a diode allows current to pass through it.
3. If the dry cell is changed to alternating current power supply, what will happen to the bulb?

The Function of a Semiconductor Diode

A semiconductor diode is an **electronic component which allows electric current to flow in one direction only**. A semiconductor diode is formed by joining a p-type semiconductor and an n-type semiconductor to form a p-n junction. Table 5.2 explains the diode connections.

Table 5.2 *Diode connection in a simple circuit*

Forward Biased Circuit	Reverse Biased Circuit
	
When a diode is forward biased, the holes will move towards the n-type semiconductor while the electrons will move towards the p-type semiconductor.	When a diode is reverse biased, the holes and the electrons will both move away from the depletion layer in opposite directions.
Depletion layer becomes thinner.	Depletion layer becomes thicker.
Junction voltage, *V* across the depletion layer decreases and the resistance of the diode becomes very small.	Junction voltage, *V* across the depletion layer increases until it reaches the potential difference of the battery. The resistance of the diode becomes very high.
The current passes through the diode, causing the bulb to light up.	The current stops flowing and the bulb does not light up.

Info GALLERY

P-type semiconductors and n-type semiconductors are produced through a doping process, in which foreign atoms are added into a lattice structure of a pure semiconductor. The majority charge carriers for p-type semiconductors are holes whereas the majority charge carriers for n-type semiconductors are electrons. The holes act as positive charge carriers.

The Use of Semiconductor Diode and Capacitor in the Rectification of Alternating Current

Photograph 5.2 shows a smartphone is being connected to an alternating current power supply at home. However, the smartphone can only be charged with a direct current. How does a semiconductor diode convert an alternating current to a direct current?

Photograph 5.2 *A smartphone is connected to an alternating current power supply*

The process of converting an alternating current into a direct current is known as **rectification**. There are two types of rectification which are half-wave rectification and full-wave rectification.

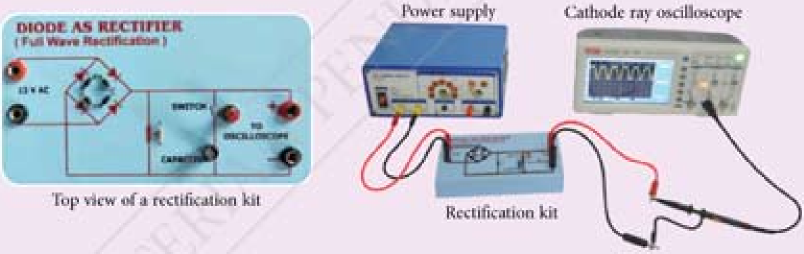
Activity 5.5

Aim: To build a rectification circuit

Apparatus: Rectification kits, cathode ray oscilloscope, 100 Ω resistor, power supply and connecting wires

Instructions:

***Photograph 5.3** Half-wave rectification kit*



***Photograph 5.4** Full-wave rectification kit*

1. Connect the 100 Ω resistor to a 2 V alternating current power supply. Adjust the cathode ray oscilloscope until a clear sinusoidal waveform appears on the screen. Observe the sinusoidal waveform and record your observation.
2. Connect the half-wave rectification kit as shown in Photograph 5.3. Observe the trace display on the screen and record your observation.
3. Repeat step 2 with the full-wave rectification kit as shown in Photograph 5.4.

Discussion:

State the use of the semiconductor diode in a rectification circuit.

Half-wave Rectification

A complete cycle of alternating current consists of two half cycles: a positive half cycle and a negative half cycle. During the positive half cycle, the semiconductor diode is **forward biased** and allows current to flow through it. During the negative half cycle, the semiconductor diode is **reverse biased** and there is no current flow. This half-cycle rectification process is called **half-wave rectification** as shown in Figure 5.8.

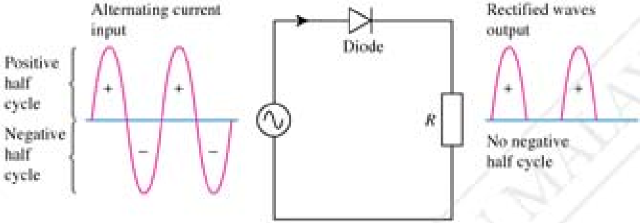


Figure 5.8 *Half-wave rectification*

Full-wave Rectification

The arrangement of four diodes as shown in Figure 5.9 and Figure 5.10 is called a **bridge rectifier**. This arrangement allows a complete cycle of current to flow in the same direction through the load, *R*.

Positive half cycle

- Diodes D_1 and D_2 are forward biased while D_3 and D_4 are reverse biased.
- Therefore, D_1 and D_2 allow current to flow while D_3 and D_4 prevent current from flowing as shown in Figure 5.9

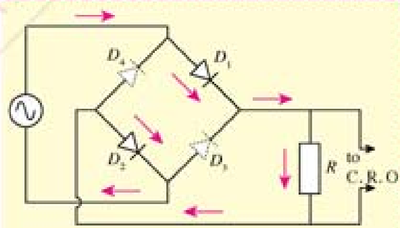


Figure 5.9

Negative half cycle

- Diodes D_3 and D_4 are forward biased while D_1 and D_2 are reverse biased.
- Therefore, D_3 and D_4 allow current to flow while D_1 and D_2 prevent current from flowing as shown in Figure 5.10

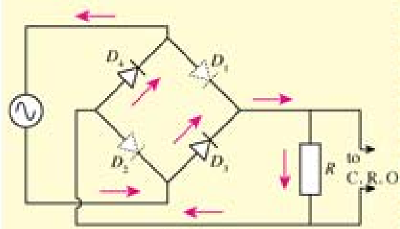


Figure 5.10

Full-wave rectification is a process where both halves of every cycle of an alternating current is made to flow in the same direction. Full-wave rectification displayed on the cathode ray oscilloscope screen is shown in Figure 5.11.

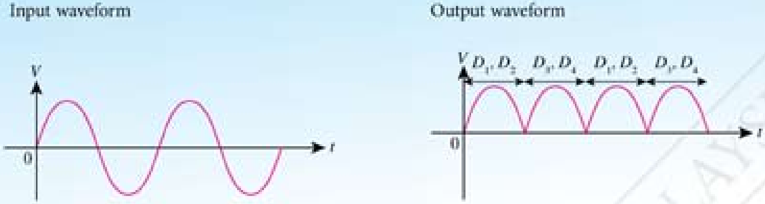
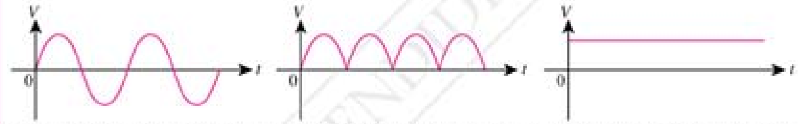


***Figure 5.11** Display of full-wave rectification on the cathode ray oscilloscope*

Info GALLERY

These are several types of currents common in electronic studies. A smooth direct current is essential for a circuit to function well.



(a) Example of an alternating current *(b) Example of a direct current* *(c) Example of a steady direct current*

Capacitors in Smoothing Direct Current

Half-wave and full-wave rectifications produce a direct current which is not smooth. Therefore, a capacitor is used to smooth the current in a rectification circuit.

Activity 5.6

Aim: To collect information on the function of a capacitor in a rectification circuit

Instructions:

1. Carry out the activity in pairs.
2. Collect information related to:
   (a) the function of a capacitor in a rectification circuit
   (b) the factors influencing the effect of current smoothing such as capacitance value and capacitor type
3. You may obtain information from a website or reading resources in the school resource centre.
4. Present your findings.

SCAN ME
Video on capacitors
https://bit.ly/3hfV1DU

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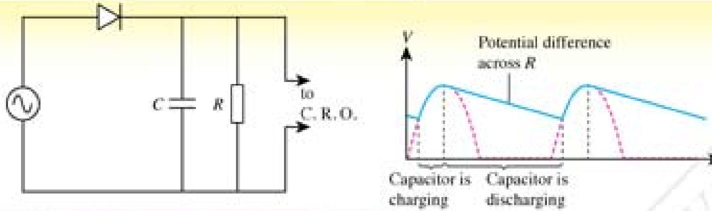
Smoothing of Half-wave Rectification Output



Smoothing of Full-wave Rectification Output

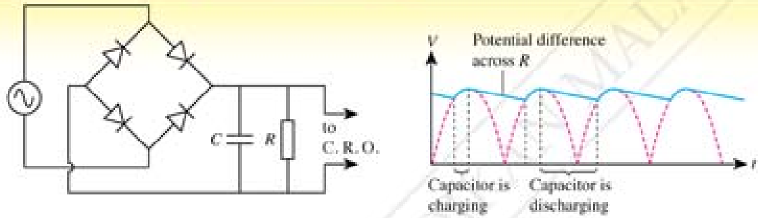


Figure 5.12 *Smoothing of full-wave and half-wave rectification output by a capacitor*

- Capacitor, *C* is connected in parallel to the load, *R*. When the power supply is turned on, the output current becomes smooth.
- When the potential difference increases, the capacitor will be charged and energy is stored in the capacitor.
- When the potential difference decreases, the capacitor will discharge so that the output current does not fall to zero. The energy stored in the capacitor will maintain the potential difference across the resistor, *R*.
- The smoothed output waveform shows that the capacitor is functioning as current smoother.

Formative Practice 5.2

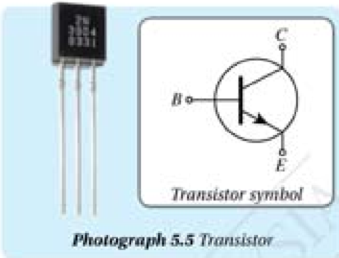
1. What is the meaning of the following terms?
   (a) Semiconductor diode
   (b) Forward biased
   (c) Rectification
2. Draw a full-wave rectification circuit using four semiconductor diodes. Then, sketch the voltage output displayed on the cathode ray oscilloscope if one of the semiconductor diodes is burnt.
3. (a) Name the electronic component that is used to smooth the output current of the full-wave rectification circuit.
   (b) Explain the working principle of the electronic component in 3(a).

5.3 Transistor

Photograph 5.5 shows a transistor. A transistor is an electronic component that has three terminals, namely emitter, *E*, base, *B* and collector, *C*. What is the function of a transistor?

Emitter, *E* supplies charge carriers to the collector. Base, *B* is a thin layer in the middle of a transistor to control the flow of charge carriers from emitter to the collector. Collector, *C* receives charge carriers from the emitter.

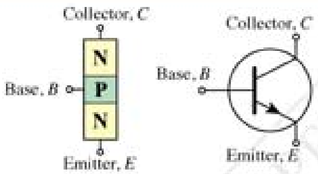
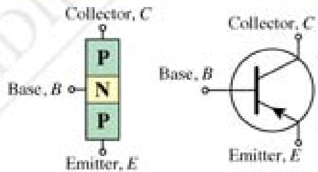
There are two types of transistors: the npn transistor and the pnp transistor as shown in Table 5.3.



Photograph 5.5 Transistor

SCAN ME
EduwebTV: Transistor
https://bit.ly/3bdul8w

***Table 5.3** npn transistor and pnp transistor*

npn transistor	pnp transistor
 Collector, *C*; Base, *B*; N P N; Emitter, *E*	 Collector, *C*; Base, *B*; P N P; Emitter, *E*
The arrow in the symbol shows the direction of current from *B* to *E*.	The arrow in the symbol shows the direction of current from *E* to *B*.

Activity 5.7

ISS ICS

Aim: To collect information on
- npn transistor and pnp transistor
- transistor circuit connected with a npn transistor and a pnp transistor

Instructions:

1. Carry out the activity in groups.
2. Gather information from various reading resources and websites on:
   (a) the terminals of a transistor
   (b) npn and pnp transistors
3. Discuss a transistor circuit based on the following:
   (a) base circuit and collector circuit
   (b) minimum voltage applied to the base circuit of the transistor to turn on the collector circuit
   (c) resistance at the base circuit to limit the base current
4. Present your findings in a suitable mind map.

Transistors are widely used in digital circuits like computers. What are the characteristics of transistor circuits? How are npn transistors and pnp transistors connected in a circuit?

A transistor circuit consist of two main parts which are a base circuit and a collector circuit. Figure 5.13 shows an npn transistor circuit and a pnp transistor circuits.

BRIGHT Info

For pnp transistors, the polarity of the battery for both base circuit and collector circuit has to be reversed. Hence the directions of flow of the base current, I_B, collector current, I_C and emitter current, I_E are also reversed.

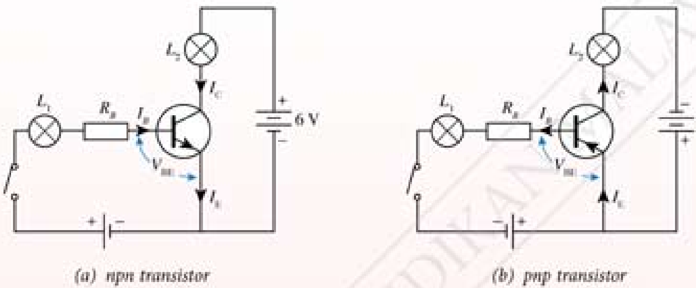


Figure 5.13 Transistor circuits

- When the switch is open, bulb L_1 does not light up as the circuit is incomplete and the base current, I_B is zero.
- Bulb L_2 does not light up although the collector circuit is complete because the transistor is not turned on and the collector current, I_C is zero.
- When the switch is closed, bulb L_1 is dim because R_B has a high resistance and the base current, I_B is very small. Bulb L_2 lights up very brightly because the collector current, I_C is large compared with the base current, I_B.
- A small base current can produce a minimum base voltage, V_{BE} to turn on the collector circuit.
- The base current, I_B can control the flow of the collector current, I_C. This enables the transistor to act as a switch.
- The resistance at the base circuit, R_B is large to limit the base current, I_B so that the transistor will not become too hot and burn.

A Transistor Functions as a Current Amplifier

A transistor can magnify an electric current. In Figure 5.14, the voice of the singer can be amplified by an amplifier system.

Figure 5.14

Activity 5.8

Aim: To study the use of a transistor as a current amplifier

Apparatus: Transistor circuit kit, resistors (2.2 kΩ, 3.9 kΩ, 4.7 kΩ, 6.8 kΩ, 8.2 kΩ), milliammeter (0 – 1 mA), milliammeter (0 – 100 mA), 6 V power supply, 1.5 V dry cell, cell holder and connecting wires

Instructions:

1. Arrange the circuit as shown in Figure 5.15 using a 2.2 kΩ resistor.

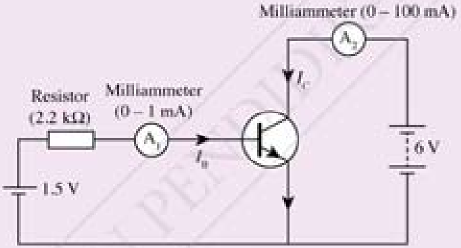


Figure 5.15

2. Record the readings of A_1 as I_B and A_2 as I_C in Table 5.4.
3. Replace the 2.2 kΩ resistor with the 3.9 kΩ, 4.7 kΩ, 6.8 kΩ and 8.2 kΩ resistors and repeat step 2.

Results:

Table 5.4

Resistance / kΩ	2.2	3.9	4.7	6.8	8.2
I_B / mA					
I_C / mA					

Discussion:

1. Based on the results in Table 5.4, plot the graph of I_C against I_B.
2. Determine the gradient of your graph and calculate the amplification factor of the amplifier, β.

$$\beta = \frac{I_C}{I_B}$$

LS 5.3.1

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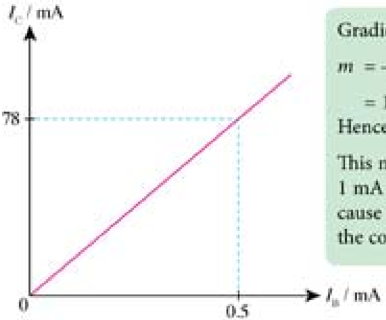
Based on Activity 5.8, you will obtain a graph of I_C against I_B which shows a straight line passing through the origin with a positive gradient as shown in Figure 5.16. This proves that when there is no base current flow ($I_B = 0$), then there is no collector current ($I_C = 0$). When the base current, I_B increases, the collector current, I_C also increases. The gradient of the graph is the amplification factor, β of the transistor.



Gradient of graph,

$$m = \frac{78.0 - 0}{0.5 - 0} = 156$$

Hence, $\beta = 156$

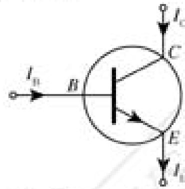
This means that a change of 1 mA in the base current will cause a change of 156 mA in the collector current.

Figure 5.16 Graph of I_C against I_B

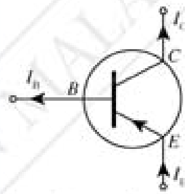
A small increase in the base current, I_B will cause a big change in the collector current, I_C. Hence, a transistor can function as a current amplifier.

BRIGHT Info

npn transistor



pnp transistor



- If $I_B = 0$, then $I_C = 0$
- $I_B < I_C < I_E$
- $\beta = \frac{I_C}{I_B}$

In a transistor circuit, the power supply or battery will supply a fixed potential difference. The transistor requires a potential difference, V_{BE} which is more than the minimum voltage for it to function. To acquire this small potential difference, a potential divider circuit can be used.

In the potential divider method, two resistors with resistances, R_1 and R_2 should be connected in series with a power supply, V_{in} as shown in Figure 5.17. As the same current is flowing through both the resistors, the relationship between the voltage and the resistance is shown by the following equation:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

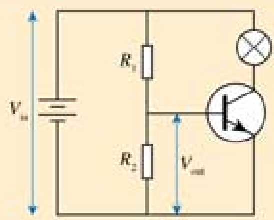


Figure 5.17 Potential divider

Info GALLERY

The minimum voltages, V_{BE} to turn on the silicon transistor and germanium transistor are 0.7 V and 0.3 V respectively.

The Use of a Transistor as an Automatic Switch

In a transistor circuit, the current does not flow in the collector circuit unless there is a current flowing in the base circuit. This means that a transistor can function as a switch by turning the base current on or off. The potential divider method studied earlier can be applied to control the base current to turn the transistor on or off automatically.

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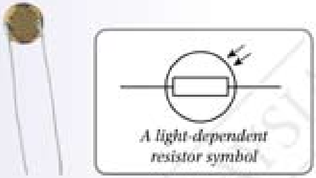
Light-dependent resistor in a light-controlled switch

- Light-dependent resistor (LDR) is a type of resistor. Its resistance changes with the intensity of light. The LDR resistance value is high when the light intensity is low and vice versa.
- In the dark, LDR resistance is very high. Based on the concept of potential divider, voltage across LDR, V_{LDR} will increase. When the V_{LDR} value exceeds the minimum voltage across B and E, base current, I_B will flow and turn on the transistor. This condition causes high collector current, I_C to flow in the collector circuit and the bulb will light up.
- Under bright conditions, resistance of LDR is low. Thus, V_{LDR} will decrease. When the value of V_{LDR} is less than the minimum voltage across B and E, then no base current, I_B flows to turn on the transistor. This situation causes collector current, I_C not to flow and the bulb does not light up.
- This circuit is used in automatic street lights.



Photograph 5.6 *A light-dependent resistor*

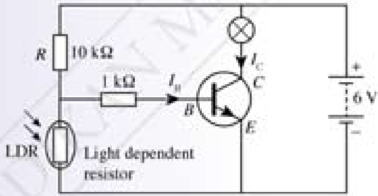


Figure 5.18 *A light-controlled switch circuit*

Thermistor in a heat-controlled switch

- A thermistor is a resistor. Its whose resistance changes with its surrounding temperature. The resistance is high under room temperature conditions (low temperature).
- As the surrounding temperature increases, the resistance becomes low and voltage across the thermistor decreases. Based on the concept of potential divider, when the voltage across the thermistor decreases, the voltage across the resistor R, V_R will increase. When the value of V_R exceeds the minimum voltage across B and E, the base current, I_B will flow and the transistor will be turned on. This situation will result in a high collector current I_C flowing in the circuit causing the bulb to light up.
- This circuit is suitable as an automatic switch in a temperature-controlled system.

Photograph 5.7 *A thermistor*

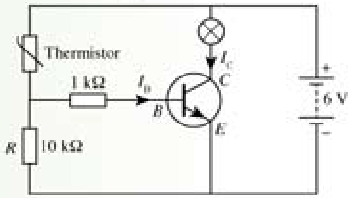


Figure 5.19 *A temperature-controlled alarm circuit*

Activity 5.9

Aim: To study the function of a transistor as an automatic switch using a transistor kit

SCAN ME
Method to carry out Activity 5.9 without transistor kit
https://bit.ly/3bbJqaK

A Light-controlled switch

Apparatus: Light-controlled switch transistor kit, 6 V power supply and connecting wires

Instructions:

Photograph 5.8 *A light-controlled switch transistor kit*

1. Connect the light control switch transistor kit to a 6 V direct current power supply.
2. Switch on the power supply and observe whether the LED lights up.
3. Then, cover the LDR with a finger. Observe whether the LED lights up.

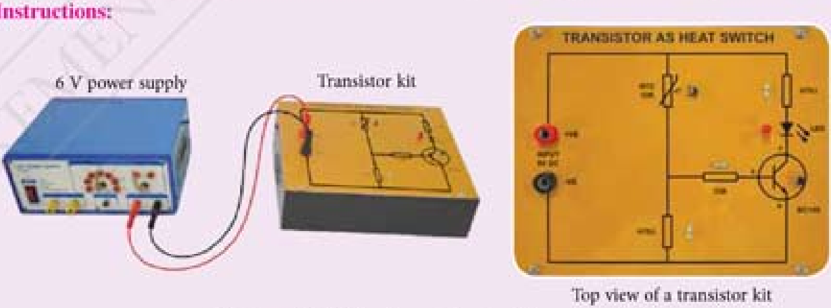
Discussion:

1. Explain your observations:
   (a) after the power supply is switched on
   (b) while the LDR is covered with a finger
2. How does the transistor function as an automatic light control switch?

B Heat-controlled switch

Apparatus: Heat-controlled switch transistor kit, 6 V power supply and connecting wires

Instructions:



Photograph 5.9 *A heat-controlled switch transistor kit*

1. Connect the heat-controlled switch transistor kit to a 6 V direct current power supply.
2. Switch on the power supply and observe whether the LED lights up.
3. Rub your hands together until they become warm and then touch the thermistor. Observe whether the LED lights up.

Discussion:

1. Explain your observations:
   (a) after the power supply is switched on
   (b) when the thermistor is touched with warm fingers
2. How does the transistor function as an automatic heat-controlled switch?
3. What modifications are needed to be made so that the LED can be replaced with an electric bell?

Formative Practice 5.3

1. Figure 5.20 shows the symbol for an electronic device.
   (a) What is the name of the electronic device?
   (b) What is the function of terminal *X* on the electronic device?

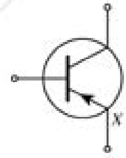


Figure 5.20

2. Figure 5.21 shows a transistor circuit which consists of two circuits, namely circuits *A* and *B*. When switch *S* is closed, bulb *P* is lighted dimly while bulb *Q* lights up brightly.

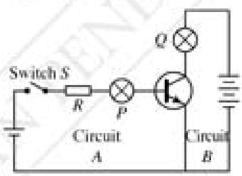


Figure 5.21

   (a) Name circuit *A* and circuit *B*.
   (b) Why does bulb *P* light up dimly when switch, *S* is closed?
   (c) Draw the modifications to the transistor circuit if the npn transistor is replaced with a pnp transistor.

3. Figure 5.22 shows a temperature-controlled alarm circuit. Resistor, *R* has a resistance of 10 kΩ. The potential difference across *XY* must be at least 5.5 V to turn on the 6 V, 60 mA bulb. What is the resistance of the thermistor when the bulb lights up?

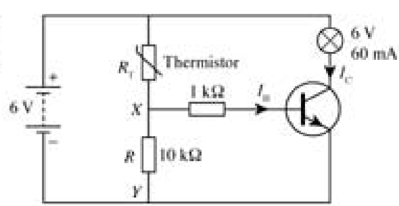


Figure 5.22

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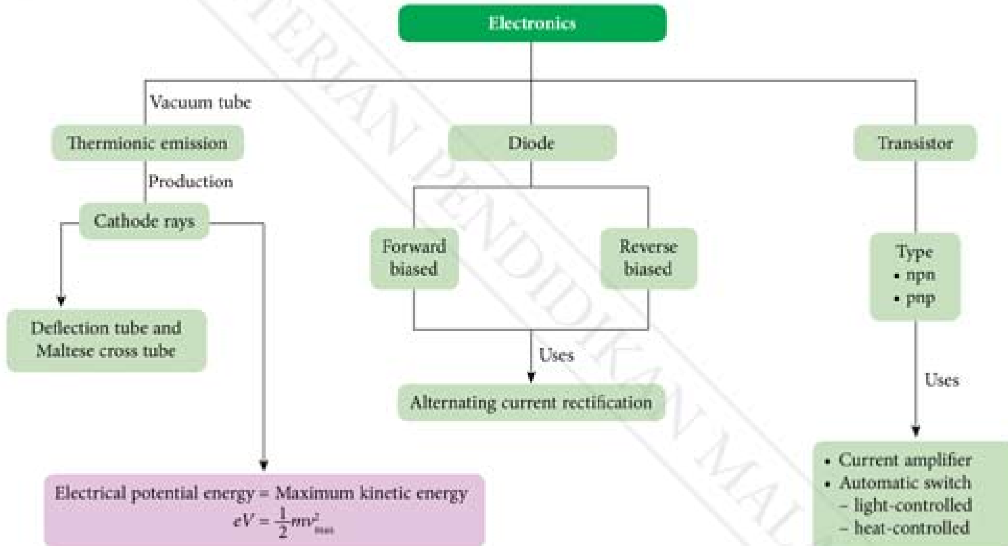
Concept Chain

Interactive Games
https://bit.ly/32FXnKd



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Self-Reflection

SCAN ME
Download and print Self-Reflection
https://bit.ly/34Prhyj

1. New things I have learnt in the chapter on 'Electronics' are ____________.
2. The most interesting thing I have learnt in this chapter is ____________.
3. The things I still do not fully understand are ____________.
4. My performance in this chapter.

   Poor | 1 | 2 | 3 | 4 | 5 | Very good

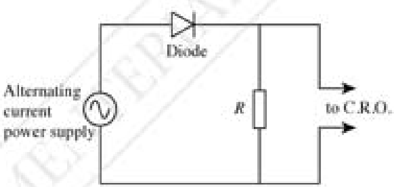
5. I need to ____________ to improve my performance in this chapter.

QUIZ
https://bit.ly/2YUeNSh

Summative Practice

1. (a) Using appropriate electronic symbols, draw a forward biased semiconductor diode in an electronic circuit.
   (b) What will happen if the battery connection in 1(a) is reversed?

2. Figure 1 shows a half-wave rectification kit connected to an alternating current power supply and a cathode ray oscilloscope (C.R.O.).



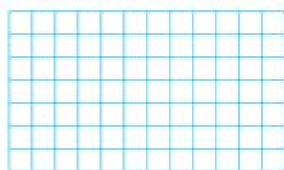


Figure 1

   (a) Sketch what is displayed on the cathode ray oscilloscope screen.
   (b) If a capacitor is connected in parallel with the resistor, *R*, sketch the changes to what is displayed on the cathode ray oscilloscope screen.

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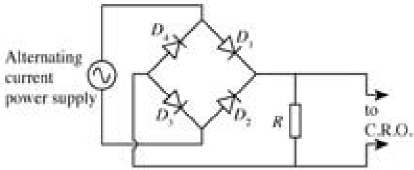
3. Figure 2 shows a full-wave rectification kit connected to an alternating current power supply and a cathode ray oscilloscope.



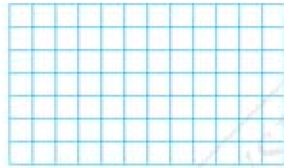


Figure 2

(a) Draw arrows to show the flow of current through the diode during the positive half cycle and the negative half cycle.

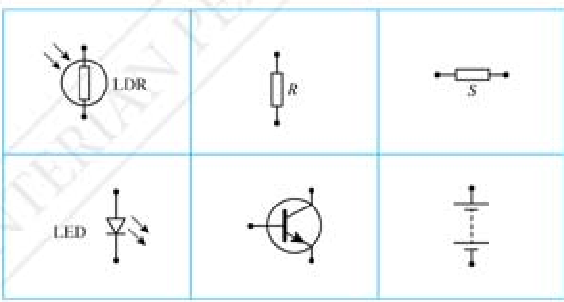
Key:
⟶ Positive cycle
- - - -▸ Negative cycle

(b) Sketch what is displayed on the cathode ray oscilloscope screen if a capacitor is connected parallel to the resistor, R. What is the role of the capacitor?

(c) What will happen to the output current if the connection to diode, D_1 is reversed?

4. Table 1 shows the main components that are required for a transistor to function as an automatic light-controlled switch.

Table 1



(a) Draw an automatic switch transistor circuit using the components provided in the table above.

(b) Discuss whether the LED is lighted when the LDR is under bright conditions.

(c) State the modification of the automatic switch transistor circuit to an automatic temperature-controlled alarm circuit so that the alarm will ring when its surrounding temperature becomes very high.

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5. Figure 3 shows an electronic circuit used to study the function of a npn transistor in the circuit. Readings I_B and I_C are obtained from microammeter, A_1 and miliameter A_2 respectively. The rheostat is adjusted to obtain different values of I_B and I_C as shown in Table 2.

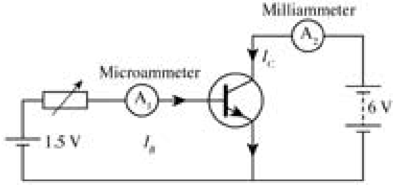


Figure 3

Table 2

I_B / μA	I_C / mA
0	0
20	2.1
40	4.2
60	6.3
80	8.4

(a) Plot the graph of I_C against I_B.

(b) Based on your graph in 5(a):

(i) state the relationship between I_B and I_C and explain your answer

(ii) state the roles of the transistor in the circuit and explain your answer

(c) Draw a new electronic circuit if the npn transistor is replaced with a pnp transistor.

21st Century Challenge

6. Amar carried out an electronic project to create an automatic switch circuit for a fire alarm system. Figure 4 shows an incomplete electronic circuit. Table 3 shows the symbols of nine possible components which may be used to complete the circuit.

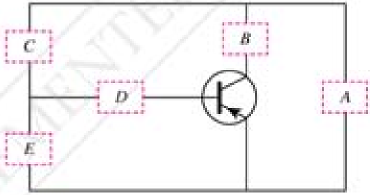
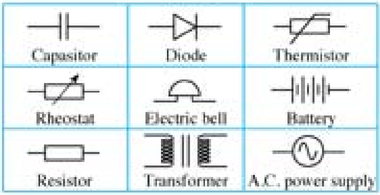


Figure 4

Table 3



(a) Based on your knowledge of electronics, select any suitable components from Table 3 to complete the transistor circuit as an automatic switch for a fire alarm system.

(b) State the justification for each of your choice.

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