Thermionic Emission

**Definition:**
The emission of electrons when a metal is heated to a high temperature

**Explanation:**
In metals, there exist free electrons which are able to move around freely but cannot escape from the surface of the metal due to attractive forces of the atomic nuclei. When the metal is heated, these electrons may gain enough energy to escape from the surface.

**Process:**
Thermionic emission can be produced by electrically heating a fine tungsten filament by passing a current through it with typical values of the voltage and current used is 6V and 0.3 A.

**Sources to produce the thermionic emission:**
Thermionic emission can be only be produced with certain metals, because it occurs at temperatures similar to their melting point. A tungsten filament lamp was found to release electrons from it is filament at 2 300K.

**Factors that affect the rate of thermionic emission:**
- **Surface area of the cathode**
  As the surface area of the cathode increases the rate of thermionic emission increases
- **Temperature of the cathode**
  As the temperature of the cathode increases the rate of thermionic emission increases
- **Types of metal**
  Different types of metal has different rate of thermionic emission. The good metals are tungsten, barium oxide and strontium oxide.

**Cathode ray:**
Cathode ray is a narrow beam of a fast electrons moving in a vacuum.

**To investigate the properties of cathode rays**
The properties of cathode rays are investigated by using Maltase cross tube and deflection tube.

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**Maltase cross tube**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Observation</th>
<th>Explanation</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>6V heater supply is connected</td>
<td>A shadow of the cross is seen</td>
<td>The shadow is formed by the ray from the heated filament</td>
<td>Light rays travel in a straight line</td>
</tr>
<tr>
<td>6V heater supply and 3 kV power supply are connected</td>
<td>The green shadow of the cross is seen at the same size and at the same position as the shadow form by the light</td>
<td>The shadow is formed by the cathode rays</td>
<td>Cathode rays travel in a straight line. Cathode rays cause fluorescence. Cathode rays carry kinetic energy and converts to light energy when they hit the screen.</td>
</tr>
<tr>
<td>A bar magnet is brought close to the cathode rays</td>
<td>The cathode ray shadow is moved and distorted</td>
<td>The catapult force is produced because and the cathode rays carry a charge</td>
<td>Cathode rays can be deflected by magnetic fields. The Fleming's left-hand rule is used to determine the direction of motion.</td>
</tr>
</tbody>
</table>
### Deflection Tube

![Deflection Tube Diagram](image)

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Observation</th>
<th>Explanation</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>6V heater supply and 3 kV power supply are connected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No electric fields between two the metal plates</td>
<td>Light rays travel in a straight line</td>
<td></td>
</tr>
<tr>
<td>6V heater supply and 3 kV power supply are connected and also 1000 V power supply is connected to the metal plates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electric field exists between two plates</td>
<td>Cathode ray is negatively charged</td>
<td></td>
</tr>
<tr>
<td>6V heater supply and 3 kV power supply are connected and also 1000 V power supply is connected to the metal plates in reverse</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electric field exists between two plates</td>
<td>Cathode ray is negatively charged</td>
<td></td>
</tr>
</tbody>
</table>

### Properties of Cathode Rays

1. Travel in a straight line in vacuum.
2. Possess kinetic energy and momentum
3. Produce fluorescent effect
4. Negatively charged
5. Deflected by an electric field towards a positive plate
6. Deflected by a magnetic field. The direction of deflection is determined by using Fleming's Left-hand rule
7. Cause ionization of gas molecules
8. Can penetrate thin aluminium foil, thin paper and thin graphite layer
9. Affect photographic plates
10. Produce heat and X-radiation in a X-ray tube
11. Charge of one electron, \(e = 1.6 \times 10^{-19} \text{ C}\)
12. Mass of electron, \(m_e = 9 \times 10^{-31} \text{ kg}\)

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PROPERTIES OF ELECTRON

*The electron gun*

The figure above shows the basic structure of the **electron gun**.

- Electrons are produced by **thermionic emission** from tungsten filament heated by a 6 V supply.
- A **positive potential** (several thousand volts) is connected to the cylindrical anode so that the electrons will be accelerated to a high speed and they move in a straight line in a fine beam. We call this beam as **cathode rays** as they are produced from the cathode (negative electrode).

**Deflection by electric field**

![Diagram of deflection by electric field]

An electric field can be set up by **applying a p.d. across two parallel metal plates**. The figure above shows that the cathode rays are **deflected** by the electric field. It is deflected towards the positive plate as electrons are attracted by the positive charges on the positively charged plate (which implies that cathode rays are **negative**).

The **greater the electric field** strength, the **greater the deflection** of the electron beam.

**Deflection by Magnetic Field**

![Diagram of deflection by magnetic field]

Magnetic field is applied at **right angles** to the beam of electrons. The electron beam is **deflected** by the magnetic field.

Direction of deflection can be determined by using Fleming’s Left Hand rule with the exception that the direction of current is opposite to the direction of electron flow.(i.e. flow of electrons is always opposite to the flow of the conventional current)
CATHODE RAY TUBE - The Cathode Ray Oscilloscope (CRO)

What does an oscilloscope do?

An oscilloscope is easily the most useful instrument available for testing circuits because it allows you to see the signals at different points in the circuit. The best way of investigating an electronic system is to monitor signals at the input and output of each system block, checking that each block is operating as expected and is correctly linked to the next. With a little practice, you will be able to find and correct faults quickly and accurately.

An oscilloscope is an impressive piece of kit:

Cathode ray tubes have become part of our lives. We find them in TVs and computer monitors. In the physics lab we are using the Cathode ray Oscilloscope (CRO) to study waveforms.

Main components of the CRO

- The electron gun
- The deflecting plates
- A fluorescent screen

The whole setup is placed in an evacuated tube so that air molecules would not interfere (collisions) with the advancement of highly accelerated electrons.
<table>
<thead>
<tr>
<th>Main part</th>
<th>Component</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron gun</td>
<td>Filament</td>
<td>To heat up the cathode</td>
</tr>
<tr>
<td></td>
<td>Cathode</td>
<td>Emits electrons through the thermionic emission process</td>
</tr>
<tr>
<td></td>
<td>Control Grid</td>
<td>Controls the number of electrons that will through it and hence control the brightness of the image on the screen</td>
</tr>
<tr>
<td></td>
<td>Focusing anode</td>
<td>Focuses the electrons into a beam</td>
</tr>
<tr>
<td></td>
<td>Accelerating anode</td>
<td>To accelerate electrons to towards the screen</td>
</tr>
<tr>
<td>Deflection</td>
<td>Y-plates</td>
<td>To deflect the electron beam vertically</td>
</tr>
<tr>
<td>system</td>
<td>X-plates</td>
<td>To deflect the electron beam horizontally</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>Fluorescent screen</td>
<td>To convert the kinetic energy of the electron beam into the light energy</td>
</tr>
<tr>
<td>screen</td>
<td>Graphite coating</td>
<td>To channel the electrons striking the screen to the Earth</td>
</tr>
</tbody>
</table>

**Using the CRO**

*The Time Base*
When we switch on the time base, we are actually applying a saw tooth voltage to the X plate.

Application of the voltage allows the electron beam to sweep across the screen at a constant speed. It will sweep the beam from the extreme left to the extreme right of the screen.

By knowing the period of each cycle, T, we can know how fast the beam is sweeping across the screen. The time base is a measure of time for the oscilloscope.

**Measuring short intervals of time**

With the time base switched on, it can be used to measure short intervals of time.

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An example is the time taken for sound to travel to and fro a short distance. With the knowledge of time taken and measuring the distance travelled, the speed of sound can be determined.

Set up the apparatus as shown. A pulse of sound is produced by a speaker/microphone. This is shown as the first pulse on the cro. The pulse bounces off the wall and is received by the microphone in which the oscilloscope shows as a second pulse.

The distance, \( x \), between the two pulses is a measure of time taken for the sound to travel to and fro the distance between the microphone and the wall. Hence the speed of sound can be deduced.

**Measuring Voltages**

The voltage to be measured is applied to the Y-plates via the Y-input terminals. The time base is switched off.

An electric field is set up in the Y plates (due to the input). The deflection of the beam is proportional to the voltage applied.

The gain of the CRO determines the sensitivity of the oscilloscope. E.g. a gain of 0.5 V/div means that an input of 1.5 V, the deflection would be 3 divisions.

**Displaying Voltage Waveforms**

With the time base switched on and selecting a suitable frequency for the time base, we can display the voltage waveform using the cro. The voltage waveform to be examined is input at the Y-terminals.

The function of an oscilloscope is extremely simple: it draws a \( V/t \) graph, a graph of voltage against time, voltage on the vertical or Y-axis, and time on the horizontal or X-axis.

As you can see, the screen of this oscilloscope has 8 squares or divisions on the vertical axis, and 10 squares or divisions on the horizontal axis. Usually, these squares are 1 cm in each direction:

Many of the controls of the oscilloscope allow you to change the vertical or horizontal scales of the \( V/t \) graph, so that you can display a clear picture of the signal you want to investigate. 'Dual trace' oscilloscopes display two \( V/t \) graphs at the same time, so that simultaneous signals from different parts of an electronic system can be compared.

**Setting up**

1. Someone else may have been twiddling knobs and pressing buttons before you. Before you switch the oscilloscope ON, check that all the controls are in their 'normal' positions.

   - all rotating controls are CENTRED
   - the central TIME/DIV and VOLTS/DIV and the HOLD OFF controls are in the calibrated, or CAL position

Check through all the controls and put them in these positions:
2. Set both VOLTS/DIV controls to 1 V/DIV and the TIME/DIV control to 0.2 s/DIV, its slowest setting:

3. Switch ON, red button, top centre:

The green LED illuminates and, after a few moments, you should see a small bright spot, or trace, moving fairly slowly across the screen.

4. Find the Y-POS 1 control:

What happens when you twiddle (PLAY) this?

The Y-POS 1 allows you to move the spot up and down the screen. For the present, adjust the trace so that it runs horizontally across the centre of the screen.

5. Now investigate the INTENSITY and FOCUS controls:

When these are correctly set, the spot will be reasonably bright but not glaring, and as sharply focused as possible.

6. The TIME/DIV control determines the horizontal scale of the graph which appears on the oscilloscope screen.

With 10 squares across the screen and the spot moving at 0.2 s/DIV, how long does it take for the spot to cross the screen?

The answer is 0.2 x 10 = 2 s. Count seconds. Does the spot take 2 seconds to cross the screen?

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Now rotate the TIME/DIV control clockwise:

With the spot moving at 0.1 s/DIV, it will take 1 second to cross the screen.

Continue to rotate TIME/DIV clockwise. With each new setting, the spot moves faster. At around 10 ms/DIV, the spot is no longer separately visible. Instead, there is a bright line across the screen. This happens because the screen remains bright for a short time after the spot has passed, an effect which is known as the persistence of the screen. It is useful to think of the spot as still there, just moving too fast to be seen.

Keep rotating TIME/DIV. At faster settings, the line becomes fainter because the spot is moving very quickly indeed. At a setting of 10 µs/DIV, how long does it take for the spot to cross the screen?

7. The VOLTS/DIV controls determine the vertical scale of the graph drawn on the oscilloscope screen.

Check that VOLTS/DIV 1 is set at 1 V/DIV and that the adjacent controls are set correctly:
What do these controls do?

Y-POS 1 moves the whole trace vertically up and down on the screen, while X-POS moves the whole trace from side to side on the screen. These controls are useful because the trace can be moved so that more of the picture appears on the screen, or to make measurements easier using the grid which covers the screen.

These are the most important controls on the oscilloscope.

The function of an oscilloscope is to draw a \( V/t \) graph. You know how to put all the controls into their 'normal' positions, so that a trace should appear when the oscilloscope is switched on. You know how to change the horizontal scale of the \( V/t \) graph, how to change the vertical scale, and how to connect and display a signal.

What is needed now is practice so that all of these controls become familiar.

**Cathode ray oscilloscope traces**

The following diagram shows you various patterns that can be made on the screen with two different inputs:

- D.C. input
- A.C. input

The speed of the time base will change what we see on the screen even if the input signal is kept the same. The following four diagrams show this.

Because the deflection of the spot depends on the voltage connected to the Y plates the CR0 can be used as an accurate voltmeter. The oscilloscope is also used in hospitals to look at heartbeat or brain waves, as computer monitors, radar screens and is also the basis of the television receiver.
The cathode ray tube screen showing various inputs

(a) Time base off (the small circles have been added to help you see the spot)

<table>
<thead>
<tr>
<th>Y-input</th>
<th>Timebase circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Switched off</td>
</tr>
<tr>
<td>None</td>
<td><img src="http://easyphysics.wordpress.com" alt="Diagram" /></td>
</tr>
<tr>
<td>d.c. power supply</td>
<td><img src="http://easyphysics.wordpress.com" alt="Diagram" /></td>
</tr>
<tr>
<td>a.c. power supply</td>
<td><img src="http://easyphysics.wordpress.com" alt="Diagram" /></td>
</tr>
</tbody>
</table>

(b) time base on

- no input
- d.c. input - upper plate positive
- d.c. input - lower plate positive
- low frequency a.c. input
- high frequency a.c. input
- a.c. input with a diode
Handling CRO

<table>
<thead>
<tr>
<th>Knob / switch</th>
<th>Function / control</th>
</tr>
</thead>
<tbody>
<tr>
<td>On/off</td>
<td>To on or off the CRO</td>
</tr>
<tr>
<td>Brilliance</td>
<td>To control the intensity of the bright spot</td>
</tr>
<tr>
<td>X-shift</td>
<td>To adjust the horizontal position of the bright spot</td>
</tr>
<tr>
<td>Y-shift</td>
<td>To adjust the vertical position of the bright spot</td>
</tr>
<tr>
<td>Y-gain</td>
<td>To amplified the small voltage across the Y-plates to deflect the electron beam. The control is calibrated in volt per cm</td>
</tr>
<tr>
<td>Time-base controls</td>
<td>Connected to the X-plates to control the frequency at which the beam sweeps horizontally across the screen. The control is calibrated in time per cm</td>
</tr>
<tr>
<td>X-input</td>
<td>To connect the source of potential difference to X-plates</td>
</tr>
<tr>
<td>Y-input</td>
<td>To connect the source of potential difference to Y-plates</td>
</tr>
<tr>
<td>AC/DC switch</td>
<td>Selected according to the type of input received</td>
</tr>
</tbody>
</table>
CIRCUIT COMPONENTS

DIODES

Diode Symbol

A semiconductor device that allows current to flow easily in one direction only.

Diode in forward bias: Current flows.
Diode in reverse bias: No current flows.

Showing that a diode only conducts in one direction

When the diode is connected as shown in the first diagram the bulb lights up. This means that the diode is conducting current easily (also called forward-biased).

If it is reversed as shown in the second diagram, the diode has high resistance and hence current will not flow (reverse-biased), thus bulb will not light up.

Rectifying Circuit

The input voltage $V_i$ is an a.c. voltage (a).
The output voltage $V_R$ is across the resistor (b).
At time interval $0 \rightarrow 1, 2 \rightarrow 3$, the diode is in forward bias.
At time interval $1 \rightarrow 2, 3 \rightarrow 4$, the diode is in reverse bias therefore no conduction takes place, $I = 0$, $V_R = IR = 0$

Power Diode Rectifier

Diodes can be used individually as above or connected together to produce a variety of rectifier circuits such as "Half-Wave", "Full-Wave" or as "Bridge Rectifiers".
**Half Wave Rectification**

A rectifier is a circuit which converts the Alternating Current (AC) input power into a Direct Current (DC) output power. The diode in a half wave rectifier circuit passes just one half of each complete sine wave of the AC supply in order to convert it into a DC supply. Then this type of circuit is called a "half-wave" rectifier because it passes only half of the incoming AC power supply as shown below.

**Half Wave Rectifier Circuit**

During each "positive" half cycle of the AC sine wave, the diode is forward biased as the anode is positive with respect to the cathode resulting in current flowing through the diode. 

During each "negative" half cycle of the AC sine wave, the diode is reverse biased as the anode is negative with respect to the cathode therefore, No current flows through the diode or circuit.

**The Full Wave Bridge Rectifier**

Another type of circuit that produces the DC output waveform as the half wave rectifier circuit above is that of the Full Wave Bridge Rectifier. This type rectifier uses four individual rectifying diodes connected in a closed loop "bridge" configuration to produce the desired output. The secondary coil of a transformer is connected to one side of the diode bridge network and the output to the other side as shown below.

**The Diode Bridge Rectifier**

The four diodes labelled D1 to D4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below.

**The Positive Half-cycle**

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During the positive half cycle of the supply, diodes D1 and D2 conduct in series, but diodes D3 and D4 switch "OFF" as they are now reverse biased. The current flows through the load in only one direction.

**The Negative Half-cycle**

During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch "OFF" as they are now reverse biased. The current flowing through the load is the same direction as before. However in reality, during each half cycle the current flows through two diodes instead of just one.

**CAPACITOR**

Capacitors are components that are used to store an electrical charge and are used in timer circuits. A capacitor may be used with a resistor to produce a timer. Sometimes capacitors are used to smooth a current in a circuit. When power is supplied to a circuit that includes a capacitor, the capacitor charges up. When power is turned off the capacitor discharges its electrical charge slowly.

It consists of a pair of metal plates separated by air or insulator (paper, oil, mica)

**Charging a capacitor**

To charge a capacitor, the capacitor is attached to an emf source as shown.

When switch is closed, electrons on plate B are drawn towards the positive terminal. At the same time, electrons are attracted to plate A from the negative terminal to plate A. Plate A becomes negatively charged and plate B becomes positively charged and both of them have equal charges.

The flow of electrons stops when the pd between the plates equals that of the emf of the source.

**Discharging a Capacitor**

Connect the two oppositely charged plates to form a closed circuit as shown.
On closing the switch, the electrons will be attracted to the positive plate. Electrons flow, which implies that a current is present. The flow of electrons will stop when B and A are completely discharged. During discharging, stored energy is changed to electrical energy which then dissipated as heat and light energy.

**The 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. The full-wave bridge rectifier however, gives us a greater mean DC value (0.637 Vmax) with less superimposed ripple while the output waveform is twice that of the frequency of the input supply frequency. We can therefore increase its average DC output level even higher by connecting a suitable smoothing capacitor across the output of the bridge circuit as shown below.

### Full-wave Rectifier with Smoothing Capacitor

The smoothing capacitor converts the full-wave rippled output of the rectifier into a smooth DC output voltage.

**TRANSISTOR**

We use transistors as electronic switches or amplifiers.

Transistors have 3 leads known as base, collector and emitters. There are basically 2 types of transistors: The NPN and the PNP. Notice the arrowhead, coming out from the base in NPN transistors. The arrowhead goes into the base from the emitter in PNP transistor.

As shown in the figure below, a variable voltage is used at the base.

The following can be observed as the base input voltage is varied:

When the base input voltage is < 0.7 V, the lamp will not light up. When the base input voltage is > 0.7 V, the lamp will light up. We see that the transistor acts well as a very sensitive switch. The base input voltage just needs to be slightly above 0.7 V, a relatively large current will flow from the collector to the emitter and light up the lamp. This means that the transistor is switched on.

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USAGE OF THERMISTORS AND LDR AS INPUT TRANSDUCERS

Transducers are devices which converts a non-electrical signal into electrical signals.

When temperature increases, the resistance of thermistor decreases.

The resistance of LDR decreases with increasing light intensity. Thus voltmeter would register lower voltage reading since pd across LDR decreases.

Light operated transistor switch - burglar alarm

![Light operated switch (burglar alarm)](image)

Notice that the LDR and the resistance are actually a potential divider.

When the circuit is in the dark, LDR has high resistance which is much greater than resistance R. The voltage V across the resistor R is thus small (<0.7 V). Thus transistor is not switched on and the electric bell does not ring.

However when light shines upon LDR, its resistance drops. The voltage V across R will then increase. When V > 0.7V, the transistor will switch on and the bell will ring. Hence when there is light, the bell will ring.

Temperature-operated transistor switch - fire alarm

![Temperature operated switch using a thermistor (Fire alarm)](image)

Again by using the same potential divider method but replace the LDR with a thermistor.

Under normal temperature, the thermistor has high resistance. The voltage V across R is less than 0.7 V. The bell is not sounded.

In case of fire, the higher temperature will cause the resistance of the thermistor to decrease. The voltage V will increase. When V > 0.7 V, the transistor will switch on and the bell will ring.

THE POTENTIAL DIVIDER

The basic circuit is shown in the first circuit diagram.

Note that the input voltage (V) supplied by the battery is constant. The current flowing through both resistors is the same (series circuit) and so the output voltage across one of them depends simply on the two resistance values and the input voltage.
Replacing R2 with a Light dependent resistor (LDR)

The LDR is a component that has a resistance that changes when light falls on it. As the intensity of the light is increased so the resistance of the LDR falls.

If the LDR is connected as part of a potential divider as shown in the diagram then as the light level is increased its resistance falls and the proportion of the input voltage dropped across it will also fall.

So in the light V2 is low and in the dark V2 is high.

Replacing R2 with a thermistor

Something very similar happens if R2 is replaced by a thermistor. As the temperature of the thermistor rises its resistance falls and so the voltage dropped across it falls.

When the thermistor is hot V2 is low and when the thermistor is cold V2 is high.

Of course both these examples have considered R2 being replaced by another component. If R1 is replaced then if the voltage across this component rises the output voltage across R2 will fall. (The total voltage across both the resistor and the other component in the circuit must always stay the same and be equal to the supply voltage of the battery.)
DIGITAL LOGIC CIRCUITS

Logic gates are the building blocks in any digital circuit, in computers and calculators. They operate with binary signals (i.e. 1's or 0's)

Example:  
\[ V_{\text{out}} = 5 \text{ V} \text{ signal} = \text{logic 1 (or logic High)} \]  
\[ V_{\text{out}} = 0 \text{ V} \text{ signal} = \text{logic 0 (or logic Low)} \]

The common logic gates used are the NOT, AND, OR, NAND & NOR gates.
We need to study the truth table in order to know the outcome of the results if we input certain values in the gates. The truth table is very important.