About the Tutorial

This tutorial supplies basic information on how to use electronic components and explains the logic behind solid state circuit design. Starting with an introduction to semiconductor physics, the tutorial moves on to cover topics such as resistors, capacitors, inductors, transformers, diodes, and transistors.

Some of the topics and the circuits built with the components discussed in this tutorial are elaborately discussed in the ELECTRONIC CIRCUITS tutorial.

Audience

This tutorial should be useful for all readers who want to gain preliminary knowledge regarding the basic components used in electronic circuits.

Prerequisites

We don’t assume any prior knowledge of Electronics to understand this tutorial. The material is meant for beginners and it should be useful for most readers.

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Electronic Components
Matter is made up of molecules which consists of atoms. According to Bohr’s theory, “the atom consists of positively charged nucleus and a number of negatively charged electrons which revolve round the nucleus in various orbits”. When an electron is raised from a lower state to a higher state, it is said to be **excited**. While exciting, if the electron is completely removed from the nucleus, the atom is said to be ionized. So, the process of raising the atom from normal state to this ionized state is called as **ionization**.

The following figure shows the structure of an atom.

![Structure of Atom](image)

According to Bohr’s model, an electron is said to be moved in a particular **Orbit**, whereas according to quantum mechanics, an electron is said to be somewhere in free space of the atom, called as **Orbital**. This theory of quantum mechanics was proven to be right. Hence, a three dimensional boundary where an electron is probable to found is called as **Atomic Orbital**.

**Quantum Numbers**

Each orbital, where an electron moves, differs in its energy and shape. The energy levels of orbitals can be represented using discrete set of integrals and half-integrals known as quantum numbers. There are four quantum numbers used to define a wave function.

**Principal Quantum number**
The first quantum number that describes an electron is the **Principal quantum number**. Its symbol is \( n \). It specifies the size or order (energy level) of the number. As the value of \( n \) increases, the average distance from electron to nucleus also increases, as well, the energy of the electron also increases. The main energy level can be understood as a shell.

### Angular Momentum Quantum number

This quantum number has \( l \) as its symbol. This \( l \) indicates the shape of the orbital. It ranges from 0 to \( n-1 \).

\[
l = 0, 1, 2 \ldots n-1
\]

For the first shell, \( n = 1 \).

i.e., for \( n-1 \), \( l=0 \) is the only possible value of \( l \) as \( n=1 \).

So, when \( l=0 \), it is called as \( S \) orbital. The shape of \( S \) is spherical. The following figure represents the shape of \( S \).

The shape of \( S \) orbital is spherical

If \( n = 2 \), then \( l = 0, 1 \) as these are the two possible values for \( n = 2 \).

We know that it is \( S \) orbital for \( l =0 \), but if \( l = 1 \), it is \( P \) orbital.

The \( P \) orbital where the electrons are more likely to find is in **dumbbell** shape. It is shown in the following figure.
Magnetic Quantum number

This quantum number is denoted by $m_l$ which represents the orientation of an orbital around the nucleus. The values of $m_l$ depend on $l$.

$$m_l = \int (-l \text{ to } l)$$

For $l = 0$, $m_l = 0$ this represents S orbital.

For $l = 1$, $m_l = -1, 0, +1$ these are the three possible values and this represents P orbital.

Hence we have three P orbitals as shown in the following figure.
Spin Quantum number

This is represented by $m_s$ and the electron here, spins on the axis. The movement of the spinning of electron could be either clockwise or anti-clockwise as shown here under.

The possible values for this spin quantum number will be like,

$$m_s = \pm \frac{1}{2} \text{ up}$$

For a movement called spin up, the result is positive half.
For a movement called spin down, the result is negative half.

These are the four quantum numbers.

**Pauli Exclusion Principle**

According to Pauli Exclusion Principle, **no two electrons in an atom can have the same set of four identical quantum numbers**. It means, if any two electrons have same values of n, s, m_l (as we just discussed above) then the l value would definitely be different in them. Hence, no two electrons will have same energy.

**Electronic shells**

If n = 1 is a shell, then l = 0 is a sub-shell.

Likewise, n = 2 is a shell, and l = 0, 1 is a sub-shell.

Shells of electrons corresponding to n = 1, 2, 3..... are represented by K, L, M, N respectively. The sub-shells or the orbitals corresponding to l = 0, 1, 2, 3 etc. are denoted by s, p, d, f etc. respectively.

<table>
<thead>
<tr>
<th>Shell n</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Sub-shell</td>
<td>s</td>
<td>p</td>
<td>d</td>
<td>f</td>
</tr>
<tr>
<td>l</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>m_l</td>
<td>0</td>
<td>±1</td>
<td>0</td>
<td>±1</td>
</tr>
<tr>
<td>m_s</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>No. of electrons</td>
<td>2</td>
<td>8</td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>Total electrons</td>
<td>2</td>
<td>8</td>
<td>18</td>
<td>32</td>
</tr>
</tbody>
</table>

Let us have a look at the electronic configurations of carbon, silicon and germanium (Group IV –A).

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic number</th>
<th>Electronic Configuration</th>
</tr>
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<tbody>
<tr>
<td>C</td>
<td>6</td>
<td>1s^22s^22p^2</td>
</tr>
<tr>
<td>Si</td>
<td>14</td>
<td>1s^22s^22p^63s^23p^2</td>
</tr>
<tr>
<td>Ge</td>
<td>32</td>
<td>1s^22s^22p^63s^23p^63d^{10}4s^24p^2</td>
</tr>
</tbody>
</table>
It is observed that the outermost p sub-shell in each case contains only two electrons. But the possible number of electrons is six. Hence, there are four **valence electrons** in each outer most shell. So, each electron in an atom has specific energy. The atomic arrangement inside the molecules in any type of substance is almost like this. But the spacing between the atoms differ from material to material.
In gaseous substances, the arrangement of molecules is not close. In liquids, the molecular arrangement is moderate. But, in solids, the molecules are so closely arranged, that the electrons in the atoms of molecules tend to move into the orbitals of neighboring atoms. Hence the electron orbitals overlap when the atoms come together.

Due to the intermixing of atoms in solids, instead of single energy levels, there will be bands of energy levels formed. These set of energy levels, which are closely packed are called as Energy bands.

**Valence Band**

The electrons move in the atoms in certain energy levels but the energy of the electrons in the innermost shell is higher than the outermost shell electrons. The electrons that are present in the outermost shell are called as Valence Electrons.

These valence electrons, containing a series of energy levels, form an energy band which is called as Valence Band. The valence band is the band having the highest occupied energy.

**Conduction Band**

The valence electrons are so loosely attached to the nucleus that even at room temperature, few of the valence electrons leave the band to be free. These are called as free electrons as they tend to move towards the neighboring atoms.

These free electrons are the ones which conduct the current in a conductor and hence called as Conduction Electrons. The band which contains conduction electrons is called as Conduction Band. The conduction band is the band having the lowest occupied energy.

**Forbidden gap**

The gap between valence band and conduction band is called as forbidden energy gap. As the name implies, this band is the forbidden one without energy. Hence no electron stays in this band. The valence electrons, while going to the conduction band, pass through this.

The forbidden energy gap if greater, means that the valence band electrons are tightly bound to the nucleus. Now, in order to push the electrons out of the valence band, some external energy is required, which would be equal to the forbidden energy gap.

The following figure shows the valance band, conduction band, and the forbidden gap.
Depending upon the size of the forbidden gap, the Insulators, the Semiconductors and the Conductors are formed.

**Insulators**

Insulators are such materials in which the conduction cannot take place, due to the large forbidden gap. Examples: Wood, Rubber. The structure of energy bands in Insulators is as shown in the following figure.

**Characteristics**
The following are the characteristics of Insulators.

- The Forbidden energy gap is very large.
- Valance band electrons are bound tightly to atoms.
- The value of forbidden energy gap for an insulator will be of 10eV.
- For some insulators, as the temperature increases, they might show some conduction.
- The resistivity of an insulator will be in the order of $10^7$ ohm-meter.

**Semiconductors**

Semiconductors are such materials in which the forbidden energy gap is small and the conduction takes place if some external energy is applied. Examples: Silicon, Germanium. The following figure shows the structure of energy bands in semiconductors.

![Energy bands in Semiconductors](image)

**Characteristics**

The following are the characteristics of Semiconductors.

- The Forbidden energy gap is very small.
- The forbidden gap for Ge is 0.7eV whereas for Si is 1.1eV.
- A Semiconductor actually is neither an insulator, nor a good conductor.
- As the temperature increases, the conductivity of a semiconductor increases.
- The conductivity of a semiconductor will be in the order of $10^2$ mho-meter.
Conductors

Conductors are such materials in which the forbidden energy gap disappears as the valence band and conduction band become very close that they overlap. Examples: Copper, Aluminum. The following figure shows the structure of energy bands in conductors.

![Energy bands in Conductors](image)

Characteristics

The following are the characteristics of Conductors.

- There exists no forbidden gap in a conductor.
- The valance band and the conduction band gets overlapped.
- The free electrons available for conduction are plenty.
- A slight increase in voltage, increases the conduction.
- There is no concept of hole formation, as a continuous flow of electrons contribute the current.

Important Terms

There is a necessity to discuss a few important terms here before we move on to subsequent chapters.

Current

It is simply the flow of electrons. A continuous flow of electrons or charged particles, can be termed as Current. It is indicated by $I$ or $i$. It is measured in Amperes. This can be alternating current AC or direct current DC.
Voltage
It is the potential difference. When there occurs a difference in potentialities, between two points, there is said to be a voltage difference, measured between those two points. It is indicated by \( V \). It is measured in Volts.

Resistance
It is the property of opposing the flow of electrons. The possession of this property can be termed as resistivity. This will be discussed later in detail.

Ohm’s Law
With the terms discussed above, we have a standard law, which is very crucial for the behavior of all the electronic components, called as Ohm’s Law. This states the relation between current and voltage in an ideal conductor.

**According to Ohm’s law, the potential difference across an ideal conductor is proportional to the current through it.**

\[
V \propto I
\]

An ideal conductor has no resistance. But in practice, every conductor has some resistance in it. Now, this law states that, **the voltage and current are inversely proportional to the resistance it offers.**

\[
V \propto I \propto \frac{1}{R}
\]

Hence, in practice, an Ohm’s law can be stated as—

**According to Ohm’s law, the potential difference across a conductor is proportional to the current through it, and is inversely proportional to the resistance it offers.**

\[
V \propto I \propto \frac{1}{R}
\]

This law is helpful in determining the values of unknown parameters among the three which help to analyze a circuit.
3. Basic Electronics – Semiconductors

A semiconductor is a substance whose resistivity lies between the conductors and insulators. The property of resistivity is not the only one that decides a material as a semiconductor, but it has few properties as follows.

- Semiconductors have the resistivity which is less than insulators and more than conductors.

- Semiconductors have negative temperature co-efficient. The resistance in semiconductors, increases with the decrease in temperature and vice versa.

- The Conducting properties of a Semiconductor changes, when a suitable metallic impurity is added to it, which is a very important property.

Semiconductor devices are extensively used in the field of electronics. The transistor has replaced the bulky vacuum tubes, from which the size and cost of the devices got decreased and this revolution has kept on increasing its pace leading to the new inventions like integrated electronics. The following illustration shows the classification of semiconductors.
End of ebook preview

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