Lecture-01: Basic Electrical Terminology

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Introduction:

Modern society views electricity as an essential form of energy. Applications of electrical energy include such necessities as lighting, heating, ventilation, and refrigeration.

A basic understanding of the fundamental concepts of electricity, current and voltage requires a degree of familiarity with atom and its structure.

Atoms and Their Structure:

- An atom is a constituent particle of matter (or a molecule) supposed to be made up of subordinate particles like electron, proton and neutron. It can be thought of as consisting of a central nucleus surrounded by orbiting electrons.
- Every atom contains one or more electrons orbiting round the nucleus.
- The nucleus is a largely cluster of protons and neutrons.
- The atomic structure of any stable atom has an equal number of electrons and protons. That is, atoms will have the same number of electrons in the orbit as there are protons in the center (nucleus).
- Different atoms have different number of electrons in the orbit.
- Each electron in an atom has a negative charge of 1.602×10^{-19} Columb, whereas each proton has a positive charge of the same magnitude.
- For all other elements except hydrogen, the nucleus also contains neutrons, which are slightly heavier than protons and have no electrical charge.
- Compared to the mass of the nucleus, electrons are relatively tiny particles of almost negligible mass. Protons and neutrons each have masses about 1800 times the mass of an electron.
- All atoms are normally electrically neutral, because, the protons and electrons are equal in number and equal but opposite in charge, so they neutralize each other electrically.
- **Positive ion:** If an atom loses an electron (somehow), it has lost some negative charge. Thus, it becomes positively charged and is referred to as a positive ion. Due to the absence of an electron, a hole is created there.
- **Negative ions:** Similarly, if an atom gains an additional electron, it becomes negatively charged and is termed as a negative ion.

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- **Atomic number:** total number of protons in an atom is referred to as the atomic number of the atom.
- **Atomic weight**: It is approximately equal to the total number of protons and neutrons in the nucleus of the atom.
- **Orbital ring/ shell**:
  - Electrons can occupy only certain orbital rings or shells at fixed distances from the nucleus. An atom may have its outer shell completely filled or only partially filled.
  - Each shell can contain only a particular number of electrons. The first orbit, which is closest to the nucleus, can contain only two electrons. If an atom has three electrons, the extra electron must be placed in the next orbit.
  - The maximum number of electrons in each succeeding orbit is determined by $2n^2$ where n is the orbit number.
- Copper is the most commonly used metal in the electrical / electronic industry. Figure below shows its atomic structure.

Name: Copper
Symbol: Cu
Atomic Number: 29
Number of Protons: 29
Number of Electrons: 29
Number of Neutrons: 35

Number of Energy Levels: 4

First Energy Level: 2
Second Energy Level: 8
Third Energy Level: 18
Fourth Energy Level: 1

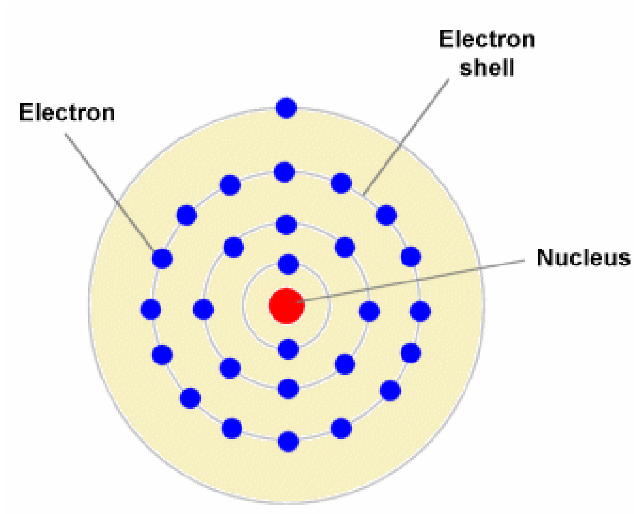

Figure: The atomic structure of copper

- **Valence electrons**: The electrons in the outer shell determine the electrical (and chemical) characteristics of each particular type of atom. These electrons are usually referred to as valence electrons.
- There are two important things to note:

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- First, the fourth orbit, which have a total of $2n^2=2(4^2)=32$ electrons, has only one electron. Hence the outermost orbit is incomplete.
- Atoms with complete orbit (that is a number of electrons equal to $2n^2$) are usually quite stable.
- Those atoms in the outermost orbit are normally considered somewhat unstable and volatile.
- Second, the 29^{th} electron is the farthest electron from the nucleus. Opposite charges are attracted to each other, but the further apart they are, the less attraction.

Conductors:

- There are some materials that electricity flows through easily. These materials are called conductors. Conductor has a relatively low resistance to the flow of electricity. Basically, electricity needs a **conductor** in order to move.
- **Conductors** have electrons that can detach from their atoms and move around. These are called **free electrons** that can move freely.
- The loose electrons make it easy for electricity to flow through these materials, so they are known as **electrical conductors**.
- Most conductors are metals. Copper and aluminum are the most common conductors.
- Four good electrical conductors are gold, silver, aluminum and copper. This is due to the presence of a large number of free or loosely-attached electrons in their atoms.
- Elements with less than 4 Electrons in their outer rings make good conductors, because the Electrons are easily dislodged from their orbit and pushed to the atom next to them.

Insulators:

- Insulators are materials that do not let electricity flow through them.
- In insulator, the electrons are tightly bound to the atoms and do not allow free movement of electrons.

- Because the electrons don't move, these materials cannot conduct electricity very well. They are used to protect conducting wire from the environment and to protect people and animals from electric shock.
- Insulator offers relatively greater difficulty or hindrance to the passage of free electrons. In other words, insulators have very high resistance.
- Some good insulators are glass, air, plastic, dry wood, mica and porcelain.
- Elements with More than 4 Electrons in their outer rings make good insulators, because the Electrons remain in the outer rings when electromotive force (voltage) is present.

Superconductor:

- All materials show some resistance, except for superconductors, which have a resistance of zero.

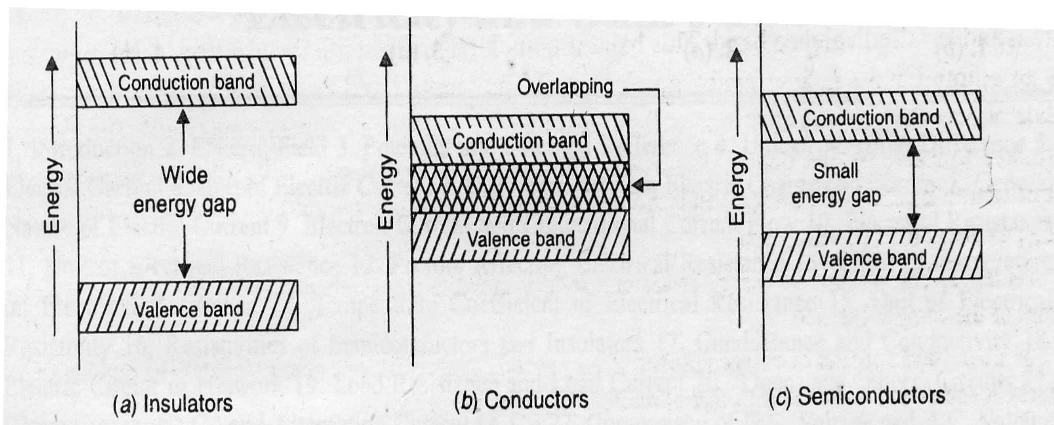
Semiconductor:

- A semiconductor is a material that is neither a good conductor nor an insulator - it is somewhere in between.
- Semiconductor materials typically have four electrons in the outermost valence ring.
- Germanium and silicon are the example of semiconductor.
- It can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current.
- Semiconductor materials are the foundation of modern electronics, including radio, computers, telephones, and many other devices. Semiconductors are used to make diodes, transistors, and integrated circuits.
- For semiconductor materials, an increase in temperature results in a decrease in resistance level, hence an increase in the number of free carriers in the material for conduction.
- The specific properties of a semiconductor depend on the impurities, or dopants, added to it.
- Current conduction in a semiconductor occurs via mobile or "free" electrons and holes, collectively known as charge carriers.

- Doping a semiconductor (such as silicon) with a small amount of impurity atoms (such as phosphorus or boron) greatly increases the number of free electrons or holes within the semiconductor.
- Semiconductor materials typically have four electrons in the outermost valence ring.

Contrast Among Conductor, Insulator and Semiconductor

Figure below shows the energy band for conductor, insulator and semiconductor.



- In insulator, conduction and valence bands are separated by a wide energy gap (≈ 15 eV). A wide energy gap means that a large amount of energy is required, to free the electrons, by moving them from the valence band into the condition band.
- In conductors, conduction and valence bands overlap which indicates a large number of electrons available for conduction. Hence the application of a small amount of voltage results a large amount of current.
- In semiconductors, the conduction and valence bands are separated by a small energy gap (~1eV i.e. 1.1eV for Si and 0.7eV for Ge). A small energy gap means that a small amount of energy is required by the valence electrons to free them to cross over from the valence band to the conduction band. Even at room temperature, some of the valence electrons may acquire sufficient energy to enter into the conduction band and thus become free electrons. However, at this temperature, the number of free electrons available is very small. Therefore, at room temperature, a semiconductor is neither a good conductor nor an insulator.

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Electric Charge:

- Electric charge is the physical property of matter that causes it to experience a force when close to other electrically charged matter.
- In an atom of matter, an electrical charge occurs whenever the number of protons in the nucleus differs from the number of electrons surrounding that nucleus.
- The symbol Q or q is often used to denote a charge and its SI unit is coulomb (C).
- There are two types of electric charges:

1. Positive charge (+):

- An object will be positively charged if it has an excess of protons, that is, positive charge has more protons than electrons ($N_p > N_e$).
- Positive charge is denoted with plus (+) sign.
- Positively charged substances are repelled from other positively charged substances, but attracted to negatively charged substances;
- An atom or object with positive charge is said to have positive electric polarity.

2. Negative charge (-):

- An object will be negatively charged if it has an excess of electrons, that is, negative charge has more electrons than protons ($N_e > N_p$).
- Negative charge is denoted with minus (-) sign.
- Negatively charged substances are repelled from negative and attracted to positive.
- An atom or object with negative charge is said to have negative electric polarity;

- **Electric charge calculation:**
  - When electric current flows for a specified time, we can calculate the charge for constant current flow:

$$Q = I \cdot t$$

Q is the electric charge, measured in coulombs [C].

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I is the current, measured in amperes [A].

t is the time period, measured in seconds [s].

Electricity:

- It is a form of energy to perform "work" by moving electrons between atoms.
- Electricity starts with **electrons.**

Current:

- Current is the flow of electrons through a conductor. An electric current can be compared to the flow of air through a vent, or the flow of water in a pipe.
- Water flowing through a hose is a good way to imagine electricity. Here **water** is like **electrons** in a wire (flowing electrons are called **current**).
- The number of electrons that are moving is called the **amperage** or the current, and it is measured in ampere.
- Conventional current in a wire or resistor always flows from higher voltage to lower voltage.
- French term for current is intensity. It is alphabetically expressed as I.

Types of Current:

- Types of current are determined by the directions the current flows through a conductor.
- There are 2 types of current:
  - **Direct Current** (**DC**)
    - It is a flow of electrons moving steadily and continually in the same direction along a conductor from a point of high potential to one of lower potential. It is produced by a battery, generator, or rectifier.
    - It flows in only one direction from negative toward positive pole of source
  - **Alternating Current** (**AC**)

- It is a flow of electrons which reverses its direction of flow at regular intervals in a conductor.
- It flows back and forth because the poles of the source alternate between positive and negative.
- Alternating current does not have a constant voltage: the AC voltage builds to a maximum value, decline to zero, builds to maximum value in the other direction, and returns to zero.

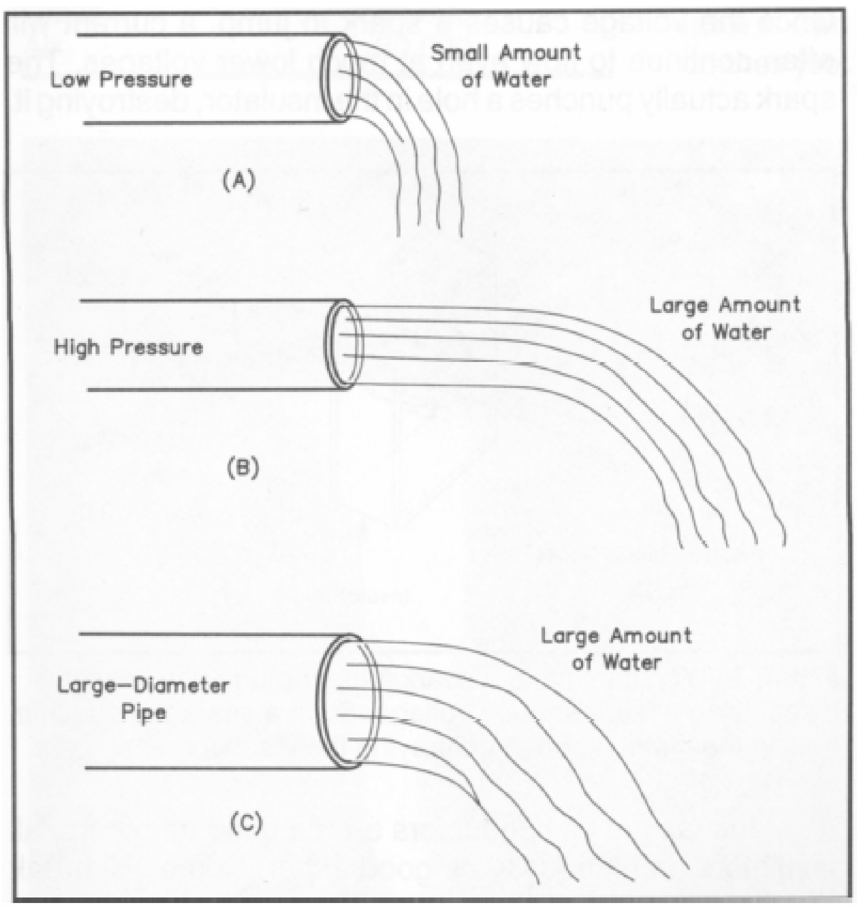
Voltage/ Electromotive Force (EMF):

- The "pressure" that causes electrons to flow is called the **voltage**, that is, Voltage is a driving force that causes **current** to flow.
- It can be compared to water pressure which causes water to flow in a pipe. As **pressure** is the force pushing water through a hose – **Voltage** is the force pushing electrons through a wire.
- Voltage is always relative between two points. The voltage between two ends of a path is the total energy required to move a small electric charge along that path, divided by the magnitude of the charge.
- **Voltage increases, current increases.**
- Voltage can be generated by means other than rubbing certain types of materials against each other: Chemical reactions, radiant energy, and the influence of magnetism on conductors are a few ways in which voltage may be produced. Respective examples of these three sources of voltage are batteries, solar cells, and generators.

Hydraulic Analogy of Voltage and Current

- The water flow analogy is a useful way of understanding several electrical concepts.
- Water flowing through a hose is a good way to imagine electricity. Here **water** is like **electrons** in a wire (flowing electrons are called **current**).
- As **pressure** is the force pushing water through a hose – **voltage** is the force pushing electrons through a wire.
- Potential difference between two points corresponds to the water pressure difference between two points.

- If there is a water pressure difference between two points along a pipe (due to the pump), then water flowing from the first point to the second will be able to do work, such as driving a turbine. In a similar way, work can be done by current driven by the potential difference due to an electric battery: for example, the current generated by an automobile battery can drive the starter motor in an automobile.
- If the water pump isn't working, it produces no pressure difference, and the turbine will not rotate. Equally, if the automobile's battery is flat, then it will not turn the starter motor.



Voltage drop:

- It is the reduction in voltage in the passive elements (not containing sources) of an electrical circuit.
- Voltage drops across conductors, contacts, connectors and source internal resistances are undesired as they reduce the supplied voltage while voltage drops across loads and other electrical and electronic elements are useful and desired.

Voltage Source and Current Source:

- The most important active elements of a network or circuit are voltage or current sources that generally deliver power to the circuit connected to them.
- The voltage sources push current through the circuit.
- In electric circuit theory, an ideal voltage source is a circuit element where the voltage across it is independent of the current through it.
- A voltage source supplies a constant DC or AC potential between its terminals for any current flow through it.
- Some real-world voltage sources are batteries, generators, or power systems.
- A schematic diagram of an ideal voltage source, V, driving a resistor, R, and creating a current I is shown below.

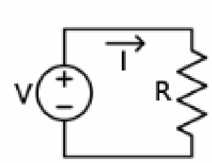


Figure: Schematic diagram of a voltage source

- A current source is the dual of a voltage source and vice versa.
- There are two basic types of source:

  1) Independent source:

  - A source that is not affected by changes in the connected circuit variables is an independent source.
  - Figure below shows the symbol of an independent source.

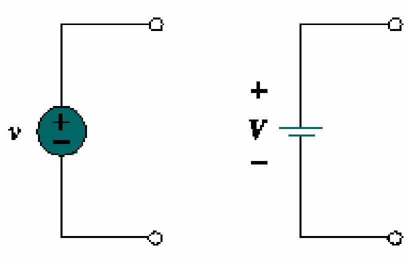


Figure: Independent voltage source

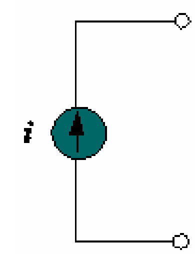


Figure: Independent current source

2) Dependent source:

- A dependent source is affected by changes in some described manner with the conditions on the connected circuit. That is, the source quantity is controlled by another voltage or current.
- Figure below shows the symbol of a dependent source.

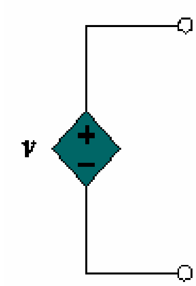


Figure: dependent voltage source

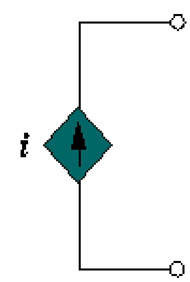


Figure: dependent voltage source

There are a total of four variations of sources, namely:

1) A voltage –controlled voltage source (VCVS)
2) A current –controlled voltage source (CCVS)
3) A voltage –controlled current source (VCCS)
4) A current –controlled current source (CCCS)

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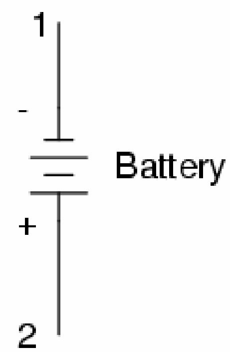
Note:

- 2 or more voltage sources with different value are not permissible to be connected in parallel
- 2 or more current sources with different value are not permissible to be connected in series
- Voltage sources connected in series is equivalent to one voltage source
- Current sources connected in parallel is equivalent to one current source
- A voltage source connected to any branch in parallel is equivalent to itself
- A current source connected to any branch in series is equivalent to itself

Symbol of Battery as a Voltage Source:



- Any source of voltage, including batteries, has two points for electrical contact. In this case, we have point 1 and point 2 in the above diagram.
- The negative (-) end of the battery is always the end with the shortest dash, and the positive (+) end of the battery is always the end with the longest dash.
- The negative end of a battery is that end which tries to push electrons out of it. Likewise, the positive end is that end which tries to attract electrons.

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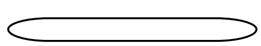
Resistance:

- It is defined as the property of a substance due to which it opposes (or restricts) the flow of electricity (i.e. electrons) through it.
- It can be compared to the friction experienced by water when flowing in a pipe: The friction against the pipe's walls slows the flow of water – **Resistance** is an impediment that slows the flow of electrons.
- It is measured in ohms, Ω.
- All materials have electrical resistance. A conductor is said to have a resistance of 1 Ω if it permits 1 A current to flow through it when 1 V is impressed across its terminal. R=V/I
- The two most important characteristics of resistance are:
    1) Heat is generated when electricity flows through a resistant material.
    2) The voltage is decreased (hence current) when electricity flows through a resistant material. Therefore, resistance increases, current or voltage decreases.

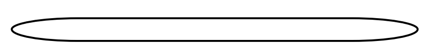
Law of Resistance:

The resistance R offered by a conductor depends on the following factors:

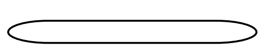
- It varies directly as its length, *l.*
- It varies inversely as the cross-section A of the conductor.
- It depends on the nature of the material.
- It depends on the temperature of the conductor.



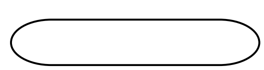
Smaller l, lower R



Larger l, greater R



Smaller A, larger R



Larger A, smaller R

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Resistivity/ Specific Resistance

- Neglecting the last factor above for the time being, we can say that-

  R∞ l/A, or

  $$R = \rho \frac{l}{A}$$

  where ρ is a constant depending on the nature of the material of the conductor and is known as its specific resistance or resistivity.
- If we set *l*= 1 meter, *A*= 1 meter^2, then R=ρ
- Hence resistivity of a material may be defined as the resistance between the opposite faces of a meter cube of that material.
- Unit of resistivity is ohm-meter.
- Both the resistance and resistivity of a conductor increases with the rise in temperature.

Conductance and Conductivity:

- Conductance is reciprocal of resistance.
- Whereas resistance of a conductor measures the hindrance which it offers to the flow of current, the conductance measures the inducement which it offers to its flow. Conductance is the ease at which an electric current passes.
- Unit of conductance is siemens (S, earlier it was called *mho*) and is expressed alphabetically as G, where G=1/R. G=I/V

$$R = \rho \frac{l}{A}$$

$$G = \frac{1}{\rho} \cdot \frac{A}{l} = \frac{\sigma A}{l}$$

where σ =1/ ρ, is called the conductivity or specific conductance of a conductor.

- The unit of conductivity is simens/meter.

Effect of Temperature on Resistance:

The effect of rise in temperature is:

- to increase the resistance of pure metals. Metals have a positive temperature-coefficient of resistance.
- to increase the resistance of alloys
- to decrease the resistance of electrolytes, insulators, and partial conductor such as carbon. Insulators are said to posses a negative temperature-coefficient of resistance.

Power:

- The rate of use of energy is termed as power. In electricity, energy is produced by moving current through a load. Power used over a period of time yields energy.
- Power is measured in watt (W) where $W = V \cdot I$

Energy:

- It is the amount of power used over a period of time. This energy can take many forms, such as heat (from a space heater), light, or work that might be done by an electric motor.
- It is measured in watt-hour (Wh) or kilowatt-hour (kWh).

Load:

- Anything which consumes electrical energy is called a load. Examples include lights, appliances, heaters and electric motor.

Ground:

- It is a conducting path between an electrical circuit or equipment and the earth.
- In alternating current (AC) systems, the purpose of grounding is for safety. If proper grounding is not maintained, risk of electrical shock, fires, and damage to appliances and motors greatly increases.
- A ground is often established using a conducting rod driven into the earth.

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Electrical Quantities and their SI Units:

- The SI Units (International System of Units) for various electrical quantities and their symbols commonly used in electrical circuit analysis are listed in the table below:

Quantity	Symbol	SI Unit	Abbreviation	Description
Voltage	V or E	Volt	V (e.g. 5 V)	Unit of Electrical Potential $\mathbf{V = I \times R}$
Current	I or i	Ampere	A (e.g. 2 A)	Unit of Electrical Current $\mathbf{I = V \div R}$
Resistance	R	Ohm	Ω (e.g. 6 Ω)	Unit of DC Resistance $\mathbf{R = V \div I}$
Conductance	G	Siemens	S (e.g. 0.5 S)	Reciprocal of Resistance $\mathbf{G = 1 \div R}$
Capacitance	C	Farad	F (e.g. 6 F)	Unit of Capacitance $\mathbf{C = Q \div V}$
Electric Charge	Q or q	Coulomb	C (e.g. 7C)	Unit of Electrical Charge $\mathbf{Q = C \times V}$
Inductance	L	Henry	H (e.g. 7 H)	Unit of Inductance $\mathbf{V_L = -L(di/dt)}$
Power	P or p	Watts	W (e.g. 6 W)	Unit of Power $\mathbf{P = V \times I}$ or $\mathbf{I^2 \times R}$
Impedance	Z	Ohm	Ω (e.g. 6 Ω)	Unit of AC Resistance $\mathbf{Z^2 = R^2 + X^2}$
Frequency	f	Hertz	Hz (e.g. 7 Hz)	Unit of Frequency $\mathbf{f = 1 \div T}$

Table-1: SI Units of various electrical quantities

Multiples and Sub-multiples of SI Units:

- Sometimes in electrical or electronic circuit analysis, it is necessary to use multiples or sub-multiples (fractions) of SI units of the above quantities when the quantities being measured are very large or very small.
- For example, resistance can be lower than 0.01 Ω or higher than 1,000,000 Ω.
- By using multiples and submultiples of the standard unit, we can avoid having to write too many zero's to define the position of the decimal point.

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- The table below gives their names and abbreviations.

Prefix	Symbol	Multiplication Factor
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}