### UNIT 25070

Tutor’s Copy

### Properties of conductors, insulators, and semiconductors and their effect on electrical circuits

# This workbook is intended for “SELF-PACED STUDY”.

# The assessment for this Unit is not included in this Workbook.



You will need:

Calculator – Casio fx-82

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1 – Conductors, Insulators & Semiconductors

The Theory of Electricity

The Ancient Greeks knew that rubbing amber with wool caused the amber to attract lint and feathers, and other lightweight particles. The Greek word for amber was *elektron*, and this process is today known as **electrification by friction.**



It wasn't until the early seventeenth century that it was found that glass rubbed with silk, and, ebonite rubbed with fur caused the same thing to happen.

The interesting thing about these two new materials (glass and ebonite), was that two rubbed glass rods, when suspended next to each other by two separate threads, would repel each other. The same thing occurred when two rubbed ebonite rods were strung next to each other. When a glass rod and an ebonite rod were suspended next to each other however, they attracted one another.



This discovery led to the conclusion that there were two types of electricity, and, those materials charged with the same type of electricity repelled each other, while those charged with different types of electricity attracted each other; this is known as the **fundamental law of charged bodies**:

**LIKE CHARGES REPEL - UNLIKE CHARGES ATTRACT**

It wasn't until around 150 years later that Benjamin Franklin suggested that when glass was rubbed with silk, that some kind of *electric fluid* passed from the silk to the glass, giving the glass an excess of electricity (a positive charge). He concluded, also, that when the ebonite was rubbed with fur, the electric fluid passed from the ebonite to the fur leaving the ebonite with a reduced amount of electricity (a negative charge).

OPTIONAL –

Carry out the Electrification by friction experiment now.

EQUIPMENT –

Glass/Plastic/Ebonite Rods, Pith balls; or Styrofoam cups, a water tap, a piece of foil on a string and a full head of hair.

Atomic Theory

The modern explanation, for the outcome of the electrification by friction experiments, deals with atomic theory. So to get a fuller understanding of this, we must get a better understanding of the atom.

n n

Molecule

If we were to take a grain of table salt to pieces (for example), the smallest piece we could have, without changing the nature of the substance, would be a **molecule**. If we continued taking this salt molecule to pieces, some of the pieces would form a soft shiny metal and other pieces a poisonous gas; one molecule of salt contains one **atom** of the metal sodium and one **atom** of the gas chlorine.



**1 Molecule of Table Salt**

1 Chlorine

atom

1 Sodium

atom

**Cl**

**Na**

Elements, Atoms and the Periodic Table

Elements consist of atoms of only one type (e.g. pure lead is made up of lead atoms only). The most important thing about any atom is the number of protons in the nucleus (the centre of the atom where both the protons and neutrons exist), as this determines not only the number of **electrons**, but also it is the number that decides what it is an atom of.

This number of protons per atom is called the **atomic number**. Atoms having nearly every atomic number from 1 to 92 have been discovered in nature; the few missing ones and also several above 92 have been made artificially.

**Periodic Table**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Group** | **1**  **I** | **2**  **II** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13**  **III** | **14**  **IV** | **15**  **V** | **16**  **VI** | **17**  **VII** | **18**  **0** |
| **Period**  **1** | H  1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | He  2 |
| **2** | Li  3 | Be  4 |  |  |  |  |  |  |  |  |  |  | B  5 | C  6 | N  7 | O  8 | F  9 | Ne  10 |
| **3** | Na  11 | Mg  12 |  |  |  |  |  |  |  |  |  |  | Al  13 | Si  14 | P  15 | S  16 | Cl  17 | Ar  18 |
| **4** | K  19 | Ca  20 | Sc  21 | Ti  22 | V  23 | Cr  24 | Mn  25 | Fe  26 | Co  27 | Ni  28 | Cu  29 | Zn  30 | Ga  31 | Ge  32 | As  33 | Se  34 | Br  35 | Kr  36 |
| **5** | Rb  37 | Sr  38 | Y  39 | Zr  40 | Nb  41 | Mo  42 | Tc  43 | Ru  44 | Rh  45 | Pd  46 | Ag  47 | Cd  48 | In  49 | Sn  50 | Sb  51 | Te  52 | I  53 | Xe  54 |
| **6** | Cs  55 | Ba  56 | \* | Hf  72 | Ta  73 | W  74 | Re  75 | Os  76 | Ir  77 | Pt  78 | Au  79 | Hg  80 | Tl  81 | Pb  82 | Bi  83 | Po  84 | At  85 | Rn  86 |
| **7** | Fa  87 | Ra  88 | \*\* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | \* | La  57 | Ce  58 | Pr  59 | Nd  60 | Pm  61 | Sm  62 | Eu  63 | Gd  64 | Tb  65 | Dy  66 | Ho  67 | Er  68 | Tm  69 | Yb  70 | Lu  71 |  |
|  |  | \*\* | Ac  89 | Th  90 | Pa  91 | U  92 | Np  93 | Pu  94 | Am  95 | Cm  96 | Bk  97 | Cf  98 | E  99 | Fm  100 | Mv  101 |  |  |  |

**H Hydrogen He Helium Li Lithium Be Beryllium B Boron C Carbon**

**N Nitrogen O Oxygen F Fluorine Ne Neon Na Sodium Mg Magnesium**

**Al Aluminium Si Silicon P Phosphorous S Sulfur Cl Chlorine Ar Argon**

**K Potassium Ca Calcium Sc Scandium Ti Titanium V Vandium Cr Chromium**

**Mn Manganese Fe Iron Co Cobalt Ni Nickel Cu Copper Zn Zinc**

**Ga Gallium Ge Germanium As Arsenic Se Selenium Br Bromine Kr Krypton**

**Rb Rubidium Sr Strontium Y Yttrium Zr Zirconium Nb Niobium Mo Molybdenum**

**Tc Technitium Ru Ruthenium Rh Rhodium Pd Palladium Ag Silver Cd Cadmium**

**In Indium Sn Tin Sb Antimony Te Tellurium I Iodine Xe Xenon**

**Cs Cesium Ba Barium La Lu Rare Earths Hf Hafnium Ta Tantalum W Tungsten**

**Re Rhenium Os Osmium Ir Iridium Pt Platinum Au Gold Hg Mercury**

**Tl Thallium Pb Lead Bi Bismuth Po Polonium At Astatine Rn Radon**

**Fa Francium Ra Radium**

The periodic table groups elements according to their atomic numbers. The "**Group**" the element is in is determined by the number of electrons in the atoms outermost energy level (often referred to as the valence energy level or the valence shell).

The "**Period**" is determined by the number of energy levels or shells that the atoms of these elements have.

Protons, Neutrons and Electrons



The Helium atom above has an Atomic Number of 2. That means 2 protons, 2 electrons - Helium also has 2 neutrons. The **protons have a positive charge, and the electrons have a negative charge equal and opposite to that of the protons.**

The **neutrons have no charge** - neutrons are believed to consist of a proton and an electron (the weight of one neutron one proton + one electron and a little bit more) and as they have no "nett charge" they can virtually be neglected for the purpose of this assignment. The number of neutrons in the nucleus can be found by subtracting the atomic number from the atomic weight.

If opposite charges attract as was discovered in the "glass and silk - ebonite and fur experiment", it must be fair to assume the electrons and the protons would mass together forming a neutralised clump and thus the collapse of the atom.

This does not happen because the electrons are moving and therefore must have a **certain energy level**, which does not -

decrease (enabling the electron to be drawn to the nucleus), or

increase (enabling the electron to free itself from it's orbit),

**unless a very specific amount of energy is removed or introduced.**

Energy Levels

The atom and its electrons can be represented in a diagram that consists of a spherical nucleus while the electrons are shown as particles "orbiting" the nucleus:



The electrons require a discrete amount of energy to remain attached to their respective atoms, and can only exist in discrete energy levels. An electron will not move from one energy level to another unless a certain amount of energy is removed or applied.



**Electron Populations in the different Energy Levels**

Valence Electrons, Free Electrons and Electron Movement

An atom containing a single loosely bound valence electron (ie. only one electron in the outermost energy level) is considered to be the atomic structure of most "good" conductors.

**Valence Electron**

When an electron leaves the valence energy level of an atom, and becomes a "free electron", it vacates a position that can be filled by another electron from somewhere else.

The vacant position the electron leaves behind is called a "hole", and people often refer to a hole as having a positive charge (due to the absence of a negatively charged electron).

**Free Electron**

**Hole – (Positively Charged)**

Atomic Theory and Electrons are discussed in "Electrotechnology..” Pages 1-11

Conductors and Conductance

**Periodic Table - Conductors** (provide very little opposition to current flow)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Group** | **I** | **II** |  |  |  |  |  |  |  |  |  |  | **III** | **IV** | **V** | **VI** | **VII** | **0** |
| **Period** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **1** | **H**  **1** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | **He**  **2** |
| **2** | **Li**  **3** | **Be**  **4** |  |  |  |  |  |  |  |  |  |  | **B**  **5** | **C**  **6** | **N**  **7** | **O**  **8** | **F**  **9** | **Ne**  **10** |
| **3** | **Na**  **11** | **Mg**  **12** |  |  |  |  |  |  |  |  |  |  | **Al**  **13** | **Si**  **14** | **P**  **15** | **S**  **16** | **Cl**  **17** | **Ar**  **18** |
| **4** | **K**  **19** | **Ca**  **20** | **Sc**  **21** | **Ti**  **22** | **V**  **23** | **Cr**  **24** | **Mn**  **25** | **Fe**  **26** | **Co**  **27** | **Ni**  **28** | **Cu**  **29** | **Zn**  **30** | **Ga**  **31** | **Ge**  **32** | **As**  **33** | **Se**  **34** | **Br**  **35** | **Kr**  **36** |
| **5** | **Rb**  **37** | **Sr**  **38** | **Y**  **39** | **Zr**  **40** | **Nb**  **41** | **Mo**  **42** | **Tc**  **43** | **Ru**  **44** | **Rh**  **45** | **Pd**  **46** | **Ag**  **47** | **Cd**  **48** | **In**  **49** | **Sn**  **50** | **Sb**  **51** | **Te**  **52** | **I**  **53** | **Xe**  **54** |
| **6** | **Cs**  **55** | **Ba**  **56** | **\*** | **Hf**  **72** | **Ta**  **73** | **W**  **74** | **Re**  **75** | **Os**  **76** | **Ir**  **77** | **Pt**  **78** | **Au**  **79** | **Hg**  **80** | **Tl**  **81** | **Pb**  **82** | **Bi**  **83** | **Po**  **84** | **At**  **85** | **Rn**  **86** |

|  |  |
| --- | --- |
|  | **Conductor - Has a resistivity between 10 and 100 x 10-8m** |
|  |  |
|  | **Good Conductor - Has a resistivity between 5 and 10 x 10-8m** |
|  |  |
|  | **Very Good Conductor - Has a resistivity of less than 5 x 10-8m** |

The *atomic number* associated with elements with the **least resistivity** on the **conductor periodic table** (i.e.the best conductors):

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Silver | Ag | 47 | Copper | Cu | 29 | Gold | Au | 79 | Aluminium | Al | 13 |

If we look at the maximum population of electrons in each shell with regard to the atomic numbers of these elements we can see that the number of electrons in the valence shell (the outermost shell) of an atom of each element, we can see:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ELEMENT** |  |  | **1st Energy Level**  **MAX. POP (2)** | **2nd Energy Level**  **MAX. POP (8)** | **3rd Energy Level**  **MAX. POP (18)** | **4th Energy Level**  **MAX. POP (32)** | **5th Energy Level**  **MAX. POP (50)** | **6th Energy Level**  **MAX. POP (72)** |
| Silver | Ag | 47 | 2 | 8 | 18 | 18 | 1 |  |
| Copper | Cu | 29 | 2 | 8 | 18 | 1 |  |  |
| Gold | Au | 79 | 2 | 8 | 18 | 32 | 18 | 1 |
| Aluminium | Al | 13 | 2 | 8 | 3 |  |  |  |

Conductors have (in most cases) only one or two electrons in the valence shell. If electric current flow is due to electron movement, from silver and copper (the best and next best conductors respectively), we must be able to safely assume:

*a single electron existing just outside a full energy level must be only very loosely bound to its atom; and must be able to move as the movement of free electrons constitutes electric current flow.*

The actual motion of the free electrons in a conducting wire is quite complicated. When there is no electric field applied to a conducting wire, these electrons move in random directions with relatively large speeds due to their thermal energy. Their “thermal energy” is created by the ambient temperature of the surroundings being greater than 0K (absolute zero at which temperature their is no electron movement).

Random electron movement due to thermal energy is the main cause for electron movement under all circumstances. This random electron movement is in any direction, until that electron collides with a fixed ion in the conductor, and then continues in another undefined direction, so the nett velocity of electrons in a conductor is zero.



**RANDOM ELECTRON MOVEMENT IN A CONDUCTOR**

When an emf is applied to the conductor however, the emf forces the electrons to accelerate and gain a small velocity in a direction opposite to that of the electric field (ie. the electrons will begin to accelerate toward the positive terminal).

This acceleration does not continue however, because the faster the electron moves the faster it will have collisions with the fixed ions. The result of the interaction between the electron movement due to thermal energy and the applied emf, is random electron movement throughout the conductor with a small **drift velocity** toward the positive terminal.

Think about this:

When a magnet induces an emf in a conductor it is not creating electron movement. The magnet is only directing electron movement - so - this means the electrons must have already been moving. The laws of probability would tell us that the same number of electrons would be moving in one direction as those moving in the other direction. This would mean that no emf was present before the introduction of the magnet; either way there must be an awful lot of random electron movement in a conductor.

The following diagram represents random and directed electron flow in a conducting material. The difference in the final position of the electron illustrates a drift toward the positive terminal.



In a conductor at room temperature, the random electron movement velocity is at about half the speed of light - the drift velocity however is typically in the only 36 metres an hour. The reason a light appears to come on as soon as the switch is thrown (and not half an hour later), can be likened to water in a hose. When you turn the water on to an empty hose, it takes a few seconds before water comes out of the other end - if you turn the water on to a hose that is already full of water, as soon as water goes into the faucet end, the same volume of water will come out of the other end.

The passage of electric current through a conductor is not due to a few electrons moving rapidly through the conductor, but more due to a very large number of electrons drifting slowly through the conductor.

Loosely bound electrons must be able to move randomly, and in their multitudes particularly when an emf (electromotive force) is applied across a piece of conducting material. The "free electrons" which are attracted away from their atoms by the application of an emf will not necessarily take up a position vacated by another valence electron that has left its valence energy level, but may move directly toward the positive material without reuniting with an ionised conductor atom.

Electrons will flow from a piece of negatively charged material, to a piece of material with a deficiency of electrons (positively charged), or to a piece of uncharged material, or to a piece of material that has a lesser negative charge. The movement of 6.24 billion electrons constitutes a 1 ampere current flow.

When a conductor is connected between these two differently charged materials the loosely bound electrons will travel toward the material with a deficiency of electrons, while excess electrons will be introduced into the conductor from the negatively charged material.

By convention, the direction of current is considered to be the direction of flow of the positive charge - This convention was established before it was known that free electrons, which are negatively charged, are the particles that are actually moving.

The motion of the negatively charged electrons in one direction is **equivalent** to a flow of positive charge (holes) in the opposite direction. Thus, the electrons move in the direction opposite to the direction of conventional current flow.

positive

negative

|  |  |  |  |
| --- | --- | --- | --- |
| Electron flow is from: | ................................. | to | ................................. |
| Hole flow is from: | ................................. | to | ................................. |
| Current flow is from: | ................................. | to | ................................. |

(positive or negative)





A good conductor will provide very little resistance to the electron flow; hence:

 , and like wise 

QUESTIONS

Answer the following questions with regard to atomic theory:

|  |  |
| --- | --- |
| 1. | What is a valence electron? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  An electron that exists in the outermost energy level of an atom or compound | |
| 2. | What is the name given to a copper atom that is missing 1 electron? |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  A copper ion (it is a positive ion) | |
| 3. | What causes the majority of the movement of an electron, and what is a typical speed (velocity) of this electron movement? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  Thermal agitation due to the ambient temperature – the speed of electron movement is half the speed of light | |
| 4. | Describe the conduction process, with regard to electrons, when a conductor connected to an electrical load is supplied with electricity. |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  There is major electron movement in a conductor all of the time due to thermal agitation caused by the temperature of the surroundings. When an EMF is applied to either end of a conductor, negatively charged electrons will gain a certain drift momentum toward the positive terminal. This drift movement of electrons constitutes electric current flow (although electron movement is in the opposite direction to what is said to be the direction of electric current flow). | |

The Properties of Conductors

The quality of a conductor (or how good that conductor is) is known as that materials conductance. On the previous page we stated that the conductance of a conductor is the inverse of that conductor's resistance (or the "resistivity" of a material). **Conductance** has the symbol **G**, and is measured in **Siemens** (**S**).

The resistivity of a material is measured using an ohmmeter across opposite faces of a metre cubed of that material (probably taken at 0C or 20C). **Resistivity** has the symbol ("rho"), and is measured in **ohm metres** (**.m**).

Complete the following Table:

|  |  |  |  |
| --- | --- | --- | --- |
| **1=BEST**  **13=LAST**  (conductance) | **CONDUCTOR**  Material | **RESISTIVITY** (20C)  Resistivity refers to a specific amount of a given material | **CONDUCTIVITY**  A high conductance means a good conductor (G=1/ρ) |
| **13** | **Nichrome** | 112 10-8.m | 892.9 103 S |
| 1 | **Silver** | 1.63 10-8.m | 61.35 106 S |
| 11 | **Constantan** | 49 10-8.m | ***2.041*** 106 S |
| 2 | **Copper** | 1.72 10-8.m | 58.14 106 S |
| 10 | **Manganin** | 48 10-8.m | 2.083 106 S |
| 3 | **Gold** | 2.44 10-8.m | 40.98 106 S |
| 4 | **Aluminium** | 2.83 10-8.m | 35.34 106 S |
| **5** | **Tungsten** | 5.50 10-8.m | 18.18 106 S |
| 9 | **Mild Steel** | 16.9 10-8.m | 5.917 106 S |
| 8 | **Phosphor Bronze** | ***9.39*** 10-8.m | 10.65 106 S |
| 7 | **Nickel** | 7.8 10-8.m | 12.82 106 S |
| 6 | **Brass** | ***7*** 10-8.m | 14.29 106 S |
| **12** | **Stainless Steel** | 70 10-8.m | 1.429 106 S |

The following table lists the properties and common electrical uses for some commonly used conducting materials:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Material** | **Resistivity**  **(m 20C)** | **Cost**  **($/kg)** | **Weight**  **(kg/m3)** | **Temp. coeff. α0** | **Melting point C** | **Additional Qualities** |
| **Copper** | **1.72 x 10-8** | **3-23** | **8,890** | **0.00427** | **1083** | Conductivity second only to silver, but much cheaper. Easy to solder, and corrosion resistant, but special precautions must be taken when joining copper to aluminium. Ductile but reasonably strong. Has a high melting point and is used in M.I.M.S. cable. |
| **Aluminium** | **2.8 x 10-8** | **2-19** | **2,670** | **0.00423** | **660** | Cost-wise aluminium is the best conductor. Corrosion resistant but special precautions must be taken when terminating to other metals (eg. special lugs or paste must be used). Light weight but relatively soft and weak, work-hardens. Not for use at high temperatures used in heatsinks. |
| **Tungsten** | **5.51 x 10-8** |  | **18,800** | **0.005** | **3410** | Highest melting point of all the metals, and is used a lot as an alloy in high-speed steels because of its hardness at high temperatures. It is this ability to withstand high temperatures that leads to its wide use as lamp filaments. Magnetic properties. |
| **Carbon amorphous** | **4.0 x 10-8** |  | **1,850** | **-0.0005** | **3500** | Very lightweight with a high melting point. Pure carbon is a very good insulator, but alloys can make it a good conductor; and is used a lot as brushes for electrical contacts in rotating machinery and in commonly used resistors In the semiconductor group. |
| **Nichrome** | **112 x 10-8** |  | **8,250** | **0.0002** | **1350** | Low temp. coefficient. These alloys are particularly suitable for high temperature working. These alloys are used in heater elements, toasters etc. High resistance to oxidation. |
| **Brass** | **7.0 x 10-8** |  | **8,400** | **0.002** | **880** | Copper-zinc alloy. Ductile, corrosion resistant. Used a lot in electrical circuits mainly for its mechanical strength, although it gets brittle when it heats up. |
| **Phosphor-Bronze** | **9.39 x 10-8** |  | **8,660** | **0.0039** |  | Non-magnetic, corrosion free, fatigue-resistant and is used in springs and electrical contacting mechanisms. |
| **Bi-metals** |  | | | | | A conductor which changes its shape when heated, often used as a switch (e.g. the starter in fluorescent lighting, or a toaster latch mechanism). |
| **Gold** | **2.44 x 10-8** | **21,408** | **19,320** | **0.00368** | **1063** | The most malleable and one of the most ductile of all metals. Will not corrode. Used in electronic circuitry. Very expensive. |
| **Silver** | **1.58 x 10-8** | **20,552** | **10,490** | **0.004** | **960.8** | Having highest conductivity (lowest resistivity) of all the metals and high thermal conductivity leads to use in electrical contacts and HRC fuses, particularly where high currents and voltages are involved. Used in lighting for its light reflecting qualities. High melting point. Expensive. Mechanically weak. Will tarnish. |

Which Conductor do I use?



**Things to look at when selecting a conductor are:**

|  |  |
| --- | --- |
|  | The current that will flow (and the resistivity) |
|  | Any secondary task requirements (carbon brushes, mercury, etc) |
|  | The environment (e.g. heat, weather, oils, gases) |
|  | The surrounding metals (e.g. copper/aluminium) |
|  | Cost |
|  | Voltage (insulation requirements) |
|  | The physical properties of the conductor (malleability; ductility) |
|  | Weight/volume ratio (suitability for overhead lines) |

QUESTIONS

Answer the following questions with regard to conductor selection:

|  |  |
| --- | --- |
| 5. | Why is copper used instead of aluminium in small cables (at least 3 factors)? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  conductivity, less electrolytic problems, does not work harden | |
| 6. | The circuit you are constructing requires that a contact is made when the surrounding temperature reaches 80C.  The temperature sensor that you choose to install to make this contact may include this type of conducting material - what is it, and how does it work? |
| ……………………………………………………………………………………………………………………………………………………………………………………  bi-metal strip | |
| 7. | What material would be best suited for use in the construction of switch contacts that must retain their springiness throughout their useful working life, because this springiness is required to ensure a good electrical contact is made? |
| ……………………………………………………………………………………………………………………………………………………………………………………  phosphor-bronze - springy | |
| 8. | You want to construct a heater element - what conductor are you going to use and why? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  Nichrome - α and high melting point | |
| 9. | Why is tungsten used in lamp filaments? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  High conductivity, does not oxidise readily, high melting point | |

|  |  |
| --- | --- |
| 10. | Aluminium (that is protected against the weather) is often used in conductors on overhead lines, why? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  conductivity, light weight | |
| 11. | Why are the brushes in electric motors made of carbon? |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  Doped so as to be conductive with copper or silver (up to 90%), they are also mechanically soft and will wear-out first. | |
| 12. | Brass and Copper will react electrolytically with each other, why then are brass nuts and bolts (and brass busbars), often used for the termination of copper conductors? |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  Conductivity and mechanical strength | |
| 13. | Which is the best conductor and where is it used? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  silver, HRC fuse elements, switch contacts | |
| 14. | Electronic componentry generally deals with very small currents at extra-low voltages, it is important therefore, that the resistance between sliding or switch contacts is kept to a minimum as this may reduce current flow to such a low level that the circuit may not operate correctly. What conductor suits this application best, and why? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  High conductivity, does not tarnish as does silver which will reduce the conductivity of a low current contact | |

|  |  |
| --- | --- |
| 15. | Complete the following table listing one advantage and one disadvantage of each of these conductors: |

|  |  |  |
| --- | --- | --- |
| **MATERIAL** | **ADVANTAGE** | **DISADVANTAGE** |
| **Copper** | Cheap, maleable, V.Good conductor | Mechanically soft |
| **Aluminium** | Light, best conductivity to weight ratio, inexpensive | Work hardens, reacts with other metals |
| **Tungsten** | Mechanically strong, high melting point, will not oxidise readily | Expensive |
| **Carbon**  (compound incl.copper/silver) | Soft | Needs to be doped for conductivity, soft, brittle |
| **Nichrome** | High melting point | Relatively high resistance |
| **Brass** | Mechanically strong, most brasses are corrosion resistant | Relatively expensive when compared to copper |
| **Phosphor-Bronze** | Springy, non-sparking |  |
| **Bi-metals** | Bend when heated |  |
| **Gold** | Good conductor | Expensive, soft |
| **Silver** | Best conductor | Expensive, tarnishes |



INSULATORS

|  |  |
| --- | --- |
| 16. | Copy the first paragraph from “Electrotechnology..” Chapter 1.7 "Electrical insulators” from Page 5 into the space below: |

.............................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................................

**A good insulator has a high opposition to electric current flow.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 17. | | List the FOUR most common insulating materials used for the insulation of cables: | | |
| a. | | .............................................................................………. | Plastics | |
| b. | | .............................................................................………. | Rubber | |
| c. | | .............................................................................………. | MgO2 | |
| d. | | .............................................................................………. | Paper | |

**Typically Insulators are not elements, as these may not suit the practical applications. It is more likely that a typical insulator is a compound.**

Magnesium Oxide is one such compound that finds practical application as an insulator in electrical cables:



**Ionic Bonded Insulator (not the most common type of insulator bond)**

Note that in the diagram above, the Magnesium has lost its 2 valence electrons to the oxygen, forming a Magnesium (+ve) ion and an Oxygen (-ve) ion.

This is called **"ionic bonding**". The Magnesium (+ve) ion and the Oxygen (-ve) ion have a mutual electrostatic attraction to each other that binds them together.

Magnesium Oxide has what can be considered a full compliment of valence electrons, and no free electrons and would therefore not assist in the flow of electric current.

Magnesium oxide in the crystalline form acts as an insulator because:

|  |  |
| --- | --- |
| a. | ionic bonding leaves both atoms with "full" valence shells; and |
|  |  |
| b. | the crystalline structure prevents the ions moving and thus the electrons must remain attached to their adopted atoms. |

The electronic structure of an atom is relatively stable if there are eight valence electrons occupying its outermost energy level (or only two for the first energy level). Sometimes an atom may acquire these eight electrons by sharing electrons with an adjacent atom in a process known as covalent bonding.

The bond formed by 2 Hydrogen atoms is a covalent bond - in which a sharing of electrons takes place:



Ethylene is probably more typical of the structure of an insulating compound. In this type of compound neighbouring atoms share the electrons.

**Covalent Bonded Insulator (the most common type of insulator bond)**

In Ethylene the covalent bond occurs because the valence shell of each carbon atom shares an electron with each of two hydrogen atoms (giving them a full compliment of electrons, and shares 2 electrons with the other carbon atom.

|  |  |
| --- | --- |
| An easier method of illustrating the covalent bonding for ethylene, is: |  |

Covalent bonded insulators, which are by far the majority - plastic, rubber, polymers, porcelain and glass - will not carry an electric current because there are no ions and thus no free electrons.

Practical Insulators

**Insulators** protect against leakage short-circuiting of conductors; electric shock to persons; and as a heat barrier.

**Insulators - practical applications and reasons for use**

|  |  |
| --- | --- |
| **rubber-** | 90C, All rubbers are effected to some degree by solvents but some resist the action of particular solvents really well. Vulnerable to oxidation resulting in brittleness. **Uses:** moulded plugs and connectors especially for outdoor and rough usage, hand held portable equipment, flexible cords.  **Resistivity = 10 1012.m - 10 1015.m** |
| **mica-** | 130C+, Strong in 2 directions - weak in a third, and splits readily into sheets (which may be extremely thin). Most "good" mica comes from India. The best mica is transparent. **Uses:** microwave windows, interlayer insulation in Class H transformers, insulators between commutator segments, formers for toaster element windings and as the main insulation of high voltage generator stator windings.  **Resistivity = 90 1012.m** |
| **magnesium oxide-** | Melting Point (2800C), Absorbs moisture (hygroscopic), A good conductor of heat. **Uses:** used in powder form in tubular heaters for domestic stoves and industrial heating and in MIMS cable (Mineral-Insulated Metal-Sheathed).  **Resistivity = 1 106.m** |
| **glass-** | 130C+, excellent insulator, strong and rigid but easily broken. **Uses:** lamps and valve bulbs (because of its sealing qualities), High Voltage insulators on transmission lines.  **Resistivity = 5 109.m - 100 1012.m** |
| **porcelain-** | 130C+, must be glazed to discourage the formation of surface films of dirt or moisture. **Uses:** insulators on power distribution lines, formers for heating elements and resistors.  **Resistivity = 20 1012.m** |
| **plastics (PVC, Polycarbonate, Polyethylene, nylon)-** | 75C - 105C, PVC (Polyvinyl Chloride) is relatively cheap and has a good resistance to water, petrol, oil and sunlight, but it is not mechanically strong. **Uses:** Cable and conductor insulation.  **Resistivity = 100 109.m - 100 1012.m** |
| **transformer oils-** | Suitably refined mineral oils and some synthetic oils. PCBs and fluorocarbons have lost favour. Fluid at all climatic and operating temperatures, not readily flammable, will not sludge or oxidise.  **Resistivity = 1 1012.m - 100 1012.m** |

Practical Insulation for Cords and Cables

**KEY**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Water resistant |  | Oil resistant |  | High resistance |
|  | Chemical resistant |  | Heat resistant |  | Mechanically strong |
|  | Cold resistant |  | UV resistant |  | Fire retarding |
|  | Expensive |  | **See also “Electrotechnology…” TABLE 9.5** | | |

**INSULATION TYPE**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **PVC - Polyvinyl Chloride - TPS (cable and cords)** |  |  |  |  |  |  |  |  |
| **XLPE - Xylene - x-linked polyethylene** |  |  |  |  |  |  |  |  |
| **PCP - Polychloroprene, (flexible cords)** |  |  |  |  |  |  |  |  |
| **HO-FR - Heat & Oil resisting , flame retardant** |  |  |  |  |  |  |  |  |
| **Cotton Braid - secondary insulation** |  |  |  |  |  |  |  |  |
| **Natural Rubber - flexible cords** |  |  |  |  |  |  |  |  |
| **Synthetic Rubber -** Butyl, Ethylene Propylene rubber & Chlorosulphanated Polyethylenes |  |  |  |  |  |  |  |  |
| **Silicone Rubber - flexible cords** |  |  |  |  |  |  |  |  |
| **Magnesium Oxide - (MIMS)** |  |  |  |  |  |  |  |  |

Practical Insulation for Rigid Use.

|  |  |  |
| --- | --- | --- |
| INSULATION | PROPERTIES | APPLICATION |
| **Glass** | Hard and brittle, easily cleaned. Very high resistivity. Stronger than glazed porcelain. Glass shatters if over-voltage fault occurs - so is easily visible.  **Dielectric Strength - 13kV/mm at 10mm** | HV transmission line insulators. Lamps and valve bulbs due to its sealing qualities (and the fact that its transparent!). |
| **Mica** | Not affected by high temperatures, can be wafer thin, very high resistivity. Strong in two directions -weak in a third. Transparent.  **Dielectric Strength - 160kV/mm at 10mm** | Toaster element former, microwave oven window, between commutator segments on dc motors. HV generator stator winding insulation. |
| **Polycarbonate & plastics** | High resistivity, cheap - no resistance to high temperatures.  **Dielectric Strength - 50kV/mm at 10mm** | Many electrical applications where heat is not expected. |
| **Porcelain** | Hard and brittle, heat resistant, hygroscopic (moisture absorbent), will gather dirt which may cause insulation breakdown.  **Dielectric Strength - 4kV/mm at 10mm** | Fuse carriers, stand-offs inside appliances - particularly with heating elements - not in areas where moisture may be present. |
| **Glazed Porcelain** | Hard and brittle, easily cleaned. Glazed porcelain cracks if over-voltage fault occurs - not easily visible. Will heat up due to sunshine.  **Dielectric Strength - 4kV/mm at 10mm** | Overhead line insulators |
| **Transformer Oil** | Suitably refined oils and some synthetic oils. Fluid at all climatic temperatures. Will not sludge or oxidise.  **Dielectric Strength - 12kV/mm at 10mm** | Insulation and cooling in power transformers and fuse switches. |

**MOISTURE**

Moisture will, in many cases, have an adverse effect on the **dielectric strength** of an insulator. This dielectric strength refers to the maximum potential difference that can be applied to opposite faces of an insulating material before it "breaks down" (eg., **Dielectric Strength:** 14kV/mm at 10mm.). Moisture will usually worsen all electrical, and often mechanical, properties of insulators.

 **HEAT**

Most insulators have negative temperature coefficients of resistance (NTC). This means that as the temperature of the conductor, and thus its insulation, increases - the lower its resistance becomes; understandably this is not a good thing.

 **DIRT **

Dirt on an insulator will provide a lower resistance path for leakage currents than that provided by the insulator. This can create an opportunity for electric current to track across that insulator - this is undesirable. Salt spray causes havoc on power line insulators even many miles from the sea, and these must be regularly cleaned.

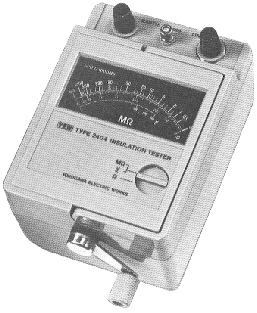
More about Insulators

Insulators protect us from accidental contact with live conductors. They prevent short circuits occurring between conductors, and they prevent leakage currents to earth.

**Insulation restricts current flow to the path of least resistance.**

**Insulation Resistance**

The resistance of the insulation is a good indicator of an insulators' condition. An insulation resistance test is usually carried out between conductors that should not have any electrical connection between them at all; and thus a "good reading" is in the order of many million ohms (Megohms). An insulation resistance tester supplies a voltage of 500V in most cases (twice the circuits normal working voltage so as to stress the insulation), to two conductors that should not have any contact with each other, and from the leakage current - displays the resistance between these two conductors.



An **Insulation Resistance Tester** is often called by the trade name "Megger", and as with the ohmmeter should never be used on a "live" circuit. An insulation resistance test will pick up any weaknesses in the insulation, any moisture or dirt - it will prove the integrity of the insulation and let you know to a large extent whether a circuit is safe.

**Storing and handling insulating materials.**

You should store insulating materials in dry, well-ventilated areas out of direct sunlight and safe from extreme temperatures (hot or cold). This will protect the insulating material from moisture absorption, perishing and breaking down due to excessive temperature and condensation forming temperature change.

**The correct choice of materials, adequate protection and regular maintenance and correct storage of conductors and insulators will restrict the deterioration of those conductors and insulators.**

|  |  |
| --- | --- |
| 18. | What does an electrical insulator do? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  Restricts current flow to the most conductive path, this prevents inadvertent contact and electric shock | |
| 19. | What is the typical atomic structure of an insulator? |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  A covalently bonded compound with no free electrons. | |
| 20. | List the two main reasons that rubber (as opposed to other insulating material) mats and gloves are worn/used to prevent electric shock by linesmen carrying out live line work on high voltage transmission lines: |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  Very high resistance and flexibility | |
| 21. | What benefits does PVC have over rubber as an insulator for cords and cables? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  Will not oxidise, better resistance to solvents, stronger, fire retarding, water resistant, cheap | |
| 22. | What is the insulation on a TPS (Tough Plastic Sheath) cable made from? |
| …………………………………………………………………………………………………………………………………………………………………………………….  PVC – Polyvinyl chloride | |
| 23. | What is the major problem associated with the installation of MIMS (pyro) cables? |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  It is hygroscopic (absorbs water readily) | |

|  |  |
| --- | --- |
| 24. | Why is glazed porcelain used for line insulators as opposed to ordinary porcelain? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  Not susceptible to dirt and moisture | |
| 25. | Why would a failed glass insulator on a High Voltage line be easier to spot than a failed glazed porcelain insulator? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  The glass shatters under over voltage, porcelain cracks | |
| 26. | Why is mica used in microwave oven windows? |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  It is an excellent insulator and it is transparent | |
| 27. | What is “Dielectric Strength”? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  max p.d. applied across opp. faces of insulator before breakdown | |
| 28. | How can insulators be best stored? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  Dry, ventilated, mod. temp, no sun | |

Semiconductors

Materials with conductivity’s too small to be regarded as conductors (<105S), and resistivity too small to be regarded as insulators (<1003m) are known as semiconductors. Silicon and germanium are known as semiconductor materials because they possess the properties of both insulators and conductors.

**Periodic Table - Semiconductor Materials**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |  |  | **GROUP 4** | | | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Group** | **I** | **II** |  |  |  |  |  |  |  |  |  |  | **III** | **IV** | **V** | **VI** | **VII** | **0** |
| **Period**  **1** | **H**  **1** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | **He**  **2** |
| **2** | **Li**  **3** | **Be**  **4** |  |  |  |  |  |  |  |  |  |  | **B**  **5** | **C**  **6** | **N**  **7** | **O**  **8** | **F**  **9** | **Ne**  **10** |
| **3** | **Na**  **11** | **Mg**  **12** |  |  |  |  |  |  |  |  |  |  | **Al**  **13** | **Si**  **14** | **P**  **15** | **S**  **16** | **Cl**  **17** | **Ar**  **18** |
| **4** | **K**  **19** | **Ca**  **20** | **Sc**  **21** | **Ti**  **22** | **V**  **23** | **Cr**  **24** | **Mn**  **25** | **Fe**  **26** | **Co**  **27** | **Ni**  **28** | **Cu**  **29** | **Zn**  **30** | **Ga**  **31** | **Ge**  **32** | **As**  **33** | **Se**  **34** | **Br**  **35** | **Kr**  **36** |

It can be seen in the table above that carbon (C), silicon (Si), germanium (Ge), are all in group 4 - that is; an atom of each of these materials will have 4 electrons in its outermost energy level.



The semiconductor Silicon is more commonly used than Germanium due to its abundance and temperature handling characteristics - but these are the two main semiconductor materials in use today.

Covalent Bonding of Semiconductor Atoms

Silicon and germanium atoms have only 4 valence electrons. A silicon atom (like a germanium atom) will form covalent bonds with 4 neighbouring atoms of the same type:



This can also be shown:



The atomic structure of a block of silicon must then be:



The majority of atoms in a block of silicon must form covalent bonds with neighbouring atoms of silicon - and therefore there are very few free electrons.

Doping

It is not until a very small quantity of another element (e.g. one atom) is added to the silicon or germanium (e.g. 12 000 000 atoms) that they take on the properties of both conductors and insulators, i.e. they become semiconductors.

(1:12 000 000 ≈ 2 000 000 000 000 000 impurity atoms per gram of silicon).

If we add an atom of Boron to another piece of silicon



closer inspection would reveal:



This piece of Silicon doped with an element having only three valence electrons would end up with a more positive charge than a non-doped piece of Silicon, because of the "positively charged hole" - this is known as P-TYPE MATERIAL.

Now if we add an atom of Phosphorous to yet another piece of silicon:



closer inspection would reveal:



This piece of Silicon doped with an element having five valence electrons would end up with a more negative charge than a non-doped piece of Silicon, because of the extra negatively charged electron - this is known as N -TYPE MATERIAL.

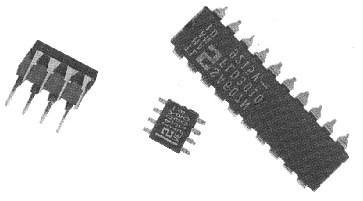
An electron would attempt to flow from N-TYPE material to P-TYPE material - "holes" and thus current, would appear to flow in the opposite direction.

The Applications of a Semiconductor

The simplest semiconductor in use is the diode. The requirements of a diode are that it will only allow current to flow in one direction.

1. For this to happen the diode must provide very little opposition to current flow in one direction, and thus have the characteristics of a good conductor;
2. That diode must also have the characteristics of a good insulator in order to ensure that only negligible current can flow in the opposite direction.
3. Just like any good conductor, too much current flow will cause heating which will damage the semiconductor; and
4. Just like any good insulator, too much voltage applied across the diode in the reverse direction will cause that diode to breakdown.

Semiconductor material is used in diodes, transistors, integrated circuits (silicon chips) and all sorts of electronic devices.



|  |  |
| --- | --- |
| 29. | Is pure semiconductor material a conductor or an insulator (include the resistivity of silicon and germanium in your answer)? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  Neither - Si=30-80010-3m, Ge=46-89010-3m | |
| 30. | What is a typical atomic structure of a piece of pure semiconductor material? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  Covalent bonded atoms (4 valence electrons)- no free electrons | |
| 31. | What is the difference between a covalent bond and an ionic bond? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  An ionic bond consists of ions (+ve or -ve) bonded due to their dissimilar charges, a covalent bond (no charge) is a sharing of electrons | |
| 32. | How would a piece of semiconductor material end up with an excess of electrons? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  Dope it with a very small quantity (1 part in 12 million), of an element with 5 valence electrons. | |
| 33. | A diode is a typical use of semiconductor material. What are the electrical properties of a diode? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  It acts as a resistor to current flow in one direction, and as a conductor to current flow in the other direction. | |

|  |  |
| --- | --- |
| 34. | Draw a piece of silicon showing at least 5 atoms, their electrons and the way in which the atoms bond: |

|  |  |
| --- | --- |
| 35. | Answer all of the Questions in “Electrotechnology..” on Page 12 here: |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………   1. a. negative   b. positive  c. neutral (no-charge)   1. it loses or gains an electron   if it has lost an electron it will have a positive charge   1. A conductor has one electron (or a few electrons) loosely bound in the outermost energy level whereas an insulator has a full outermost energy level and is typically a compound 2. The directed movement of electrons constitutes electric current flow – current flow is in the opposite direction to electron flow (current flow is from positive to negative). 3. N-Type material has an excess of electrons – these are the majority carriers 4. N-Type semiconductor has no charge because the number of electrons still equals the number of protons 5. BIG PAL – P-Type - Boron, Indium, Galium, Aluminium (acceptor)   & JAPAN – N-Type – Antimony, Phosphorous, Arsenic (donor) | |

2 – Resistance, Resistivity & Resistors

Ohm's Law

**In any closed loop d.c. circuit the current is**

**directly proportional to the applied voltage**

**and inversely proportional to the resistance.**

This is best illustrated by the “Water Analogy” below:

Electrical Pressure –

Voltage

Electrical Pressure –

Voltage

Electrical Pressure –

Voltage

Resistance

Resistance

Resistance

Current Flow

From Ohm’s Law, and the Water Analogy on the previous page, we can safely conclude that:

**As the voltage increases current flow will increase; and**

**If the resistance is decreased the current will increase.**

e.g., **V= I R;** and **V = I R**

* Voltage [symbol – E or V, measured in volts]
* Current [symbol – I, measured in amperes (A)]
* Resistance [symbol – R, measured in ohms (Ω)

|  |  |
| --- | --- |
| 36. | Transpose this formula V = I × R to find R and I: |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  R = V/I and I = V/R | |
| 37. | If the voltage across a 10Ω resistance is 24V, how much current will be flowing through that resistance? |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  I = V/R = 24V/10Ω = 2.4A | |
| 38. | The voltage across a resistor is 100V, and the current flowing through that resistor is 3A, what is the value of that resistor? (use the correct symbol) |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  R = V/I = 100V/3A = 33.33Ω | |

??? HELPFUL HINT ???

***In the Electrical/Electronic Industry we use “Engineering Notation”. This is just so that we all speak the same mathematical language. See below:***

|  |  |
| --- | --- |
| ***Instead of saying “11 thousand volts” we say “11kV”*** | ***11,000V ⇒ 11×103V*** |
| ***“1 million Ohms” becomes “1 Megohm” (1MΩ)*** | ***1,000,000Ω ⇒ 1×106Ω*** |
| ***“0.012 amperes” becomes “12 milliamps” (12mA); and*** | ***0.012A ⇒ 12×10-3A*** |
| ***“0.000 036 amperes” becomes “36 microamps” (36μA).*** | ***0.000 036A ⇒ 36×10-6A*** |

***We also use “nano” (×10-9), and “pico” (× 10-12).***

**To enter 11 000 into your calculator push:**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **11** |  | **EXP** |  | **3** |  |  |  |

**To enter 1 000 000 into your calculator push:**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **1** |  | **EXP** |  | **6** |  |  |  |

**To enter 0.012 into your calculator push:**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **12** |  | **EXP** |  | **(-)** |  | **3** |  |

**To enter 0.000 036 into your calculator push:**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **36** |  | **EXP** |  | **(-)** |  | **6** |  |

Factors affecting resistance

Every conductor will have some resistance to electrical current flow.

|  |  |
| --- | --- |
| **M**aterial | Specific materials have specific resistivities to current flow |
| **A**rea | The greater the cross-sectional area of conductor, the lower its resistance |
| **L**ength | The longer the conductor, the greater its resistance |
| **T**emperature | Both Conductors & Insulators have different responses to temperature |

Material & Resistivity

In a material (copper etc.,) this specific resistance is measured across opposite faces of a metre cube of that material. Each different material will have a different resistance across that metre cube. The resistance specific to this material is known as its **resistivity**.

The Symbol for resistivity is:

**ρ**(rho)

and the unit is:

**Ωm**

(ohm metres)

**RESISTIVITY IS MEASURED ACROSS OPPOSITE FACES OF A METRE CUBE OF THE MATERIAL**

**RESISTIVITYS OF DIFFERENT MATERIALS**

|  |  |  |
| --- | --- | --- |
| **Element** | **Temperature (C)** | **ρ (resistivity) (m)** |
| Antimony | 0 | 39 10-8 |
| Arsenic | 20 | 33.3 10-8 |
| Boron | 0 | 1800000000000 10-8 |
| Brass | 20 | 7 10-8 |
| Carbon | 0 | 1375 10-8 |
| Indium | 20 | 5.3 10-8 |
| Magnesium | 20 | 4.45 10-8 |
| Mercury | 50 | 98.4 10-8 |
| Molybdenum | 0 | 5.2 10-8 |
| Nichrome\* | 0 | 112 10-8 |
| Nickel | 20 | 6.84 10-8 |
| Phosphorus | 11 | 1000000000 |
| Platinum | 20 | 10.6 10-8 |
| Steel | 20 | 81 10-8 |
| Sulphur | 20 | 2000000000 106 |
| Titanium | 20 | 42 10-8 |
| Tungsten | 27 | 5.65 10-8 |
| Zinc | 20 | 5.916 10-8 |

Nichrome\* - the resistivity of Nichrome is wrongly listed in Electrotechnology Principles and Practice as 1.090nΩm

Area and Length

Area is measured in metres square (m2), and length is measured in metres (m). The metre is a standard international unit (SI unit) for distance. An International System of Units is used so that people from different countries will all be able to use the same measurements.

There are seven “base” units, and all other units are derived from these:

|  |  |  |
| --- | --- | --- |
| **QUANTITY** | **UNIT** | **SYMBOL** |
| length | metre | m |
| mass | kilogram | kg |
| time | second | s |
| electric current | ampere | A |
| temperature | kelvin | K |
| luminous intensity | candela | cd |
| amount of substance | mole | mol |

|  |  |
| --- | --- |
| **NOTE:** | A commonly used derivative of the kilogram is the gram - many calculations use the gram. |
|  | A change in temperature of 1K is equivalent to a change of 1°C (Celsius). |

|  |  |
| --- | --- |
| 39. | Quite often you will find that a cable size is given in square millimetres (mm2). What is 16mm2 in metres2? |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  16×10-6 m2 | |

**4mm**

**16mm2**

**16mm2**

**4mm**

**0.004m**

**× 0.004m**

**0.000 016m2**

**0.004m**

**0.004m**

**0.000 016m2 = 16×10-6m2**

|  |  |
| --- | --- |
| 40. | What is the cross sectional area of 8cm2 in m2? (use engineering notation) |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  800×10-6m2 | |
| 41. | What is the area of a circle that has a diameter of 23mm? Use  give your answer in engineering notation and m2. |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  415.5×10-6m2 | |

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| --- | --- |
| 42. | What is the equation used to determine the resistance of a conductor from its physical properties (the materials resistivity, length and area)? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  R= ρ × l / A (R equals “rho” l over A) | |
| 43. | The resistivity of Copper is 1.72× 10-8Ωm, w hat is the resistance of 200m of 1.0mm2 copper conductor? |
| ……………………………………………………………………………………………………………………………………………………………………………………  3.44Ω | |
| 44. | The diameter of a solid aluminium conductor is 4.51mm. What is the resistance of 3km of this conductor? (ρAl = 2.8×10-8Ωm) |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  5.26Ω | |
| 45. | How long must a piece of 0.4mm2 nichrome wire be if the resistance of that wire is 11.2Ω? ρNiCh = 112 × 10-8 Ωm |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  4m | |
| 46. | A 2.5mm2 TPS/copper cable is used to supply 20A to a resistive load that is 33m away from the supply. How much power is dissipated by the cable as heat? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  181.6W | |

Temperature

Conductors have a “positive temperature coefficient” – that means that as the temperature goes up, the resistance goes up as well.

Insulators and semiconductors have a “negative temperature coefficient”, the hotter an insulator gets the lower its resistance becomes.

In both cases this is generally a bad thing.

Temperature coefficients are specific to different materials at specific temperatures.

The Symbol for the temperature coefficient is:

**α**(alpha) and the unit is: **Ω/°C** (ohms per degrees Celcius)

|  |  |
| --- | --- |
| 47. | Read “Electrotechnology..” Section 9.2.  Answer Question 2 from “Electrotechnology..” Page 249 |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….   1. 233Ω | |

The equations for calculating resistance change relative to temperature change are:

**Where α is given for one of the temperatures in the equation**:



**Where α is not given for either temperature in the equation:**



|  |  |  |
| --- | --- | --- |
| **Temperature Coefficients for Metals** | | |
| MATERIAL | α at 0°C | α at 20°C |
| Silver | 0.00412 | 0.00400 |
| Copper | 0.00427 | 0.00393 |
| Gold | 0.00365 | 0.00340 |
| Aluminium | 0.00424 | 0.00390 |
| Tungsten | 0.00510 | 0.00450 |

NOTE: Some of the α20 figures in this Table were adjusted to align with “Electrotechnology – Principles and Practice” UNITEC takes no responsibility for any inaccuracy due to these figures

|  |  |  |
| --- | --- | --- |
| 48. | The resistance of a copper conductor is 30Ω at 0°C. What is the resistance of this conductor at 250°C? | |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  62Ω✓ 59.5🗶 | | |
| 49. | The resistance of an aluminium conductor is 50Ω at 20°C. Which equation can be used to calculate the resistance of this conductor at 200°C?  d) 85.1Ω | |
| **a)** | | **b)** |
| **c)** | | **d)** |
| 50. | The resistance of a silver conductor is 15Ω at 20°C. What is the resistance of this conductor at 100°C? | |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  19.8Ω | | |
| 51. | The resistance of an aluminium conductor is 100Ω at 50°C. What is the resistance of this conductor at 0°C? | |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  82.5Ω | | |

|  |  |
| --- | --- |
| 52. | The resistance of a motor’s copper windings is 25Ω when measured at 12°C. The motor was run for an hour, switched off, and the resistance was measured again. The resistance of the windings had increased to 33.43Ω.  What was the running temperature of the windings? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  95°C | |
| 53. | The cold (16°C) resistance of lamp is measured at 46.8Ω, however when connected to a 230V supply the current drawn by the lamp is only 435mA.  What is the operating temperature of the lamps tungsten filament? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  2200°C | |

Resistors

In many electrical/electronic circuits we use specific values of resistance to limit current flows to certain values. Also if we required a certain lesser voltage than the supply voltage we can use predetermined values of resistance to arrive at those values.

A “resistor” is the name given to a resistance of a certain value.

|  |  |  |  |
| --- | --- | --- | --- |
| 54. | What is the difference between a “linear” resistor and a “non-linear” resistor? | | |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  The resistance of a “linear resistor” does not differ much with temperature or applied voltage | | | |
| TYPE | | ILLUSTRATION | CIRCUIT DIAGRAM |
| Carbon Compound | | metal  carbon  Spiral cut  Carbon compound |  |
| Metal Film | |  |  |
| Wire Wound | |  |  |
| Slider Potentiometer | |  |  |
| Rotary Carbon Potentiometer& Rotary Rheostat | |  |  |

Non-linear Resistors

“Non-linear” resistors such as Voltage Dependant Resistors, Light Dependant Resistors, Resistive Humidity Sensors, Thermistors, and Strain Gauges are included in the text in “Electrotechnology...”. The current through a non-linear resistor is not always directly proportional to the voltage across that resistor as it will also be dependant on other factors (light, humidity etc.).

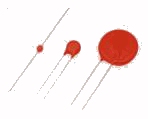
VDR – Voltage Dependant Resistor

Another example of a non-linear resistor is a “Voltage Dependant Resistor” (VDR).

A VDR has a high resistance to current flow at low voltages, but a very low resistance at high voltages.

VDR’s are used to protect sensitive electronic circuitry. They are installed in parallel with circuits susceptible to damage due to high voltage spikes. A high voltage will short-circuit the VDR and no voltage will appear “across” the electronic components.

Also known as a “Varistor”.



LDR – Light Dependant Resistor



A Light Dependant Resistor has a high resistance in the dark (the LDR shown has a resistance of 1MΩ in the dark), and a low resistance in bright light (this one has a resistance of 400Ω at 1000 lux).

Often used in security lighting circuits.

Tolerance

Resistors are mass-produced, and it is a greater expense to manufacture a large number of resistors with an exact resistance – than it is to manufacture the resistors with a resistance that is close to the value required. Because of this lower cost of manufacture resistors are manufactured with tolerances (errors) between 0.1% → 20% of the “Preferred Value”. This tolerance is indicated on the resistor as a coloured band.

Preferred Values

We will concern ourselves with the “E12 Series” of preferred resistor values. This series has only 12 values that can be multiplied/divided by 10.

|  |  |  |  |
| --- | --- | --- | --- |
| 10 | 12 | 15 | 18 |
| 22 | 27 | 33 | 39 |
| 47 | 56 | 68 | 82 |

e.g. A resistor that is 1Ω is also available in the E12 Series

e.g. a resistor that is 4.7MΩ is also available in the E12 Series

Stability

|  |  |
| --- | --- |
| 55. | What type of metals would be suited to applications where an increase in temperature has little effect on the value of resistance? Should the temperature coefficient of resistance (α) be high or low to achieve temperature stability? |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  α should be low | |

Power Rating

The Power Rating of a resistor is an indication of how much heat the resistor can handle continuously. If this power rating is exceeded the resistor will overheat and probably open-circuit. *See “Electrotechnology…” Page 96 Calculating Power.*

The power can be calculated by dividing the Voltage across the resistor by the value of that resistor in ohms or I2R (Ohm’s Law).

Resistor Colour Coding

|  |  |
| --- | --- |
| 56. | Use the Table in Section 4.14 of “Electrotechnology..” to complete Question 12 on Page 94. |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  See Electrotech Page 541 | |

The resistance values as listed in the E12 Series are the “nominal” (named) values.

The actual resistance of a resistor as measured with an ohmmeter is known as its “ohmic” value.

3 – Resistance & Power Calculations

|  |  |
| --- | --- |
| 57. | Read Chapter 4 of “Electrotechnology – Principles and Practice” ISBN 0-909009-16-3 (this ISBN number will help a bookshop locate this textbook) and complete all of the Questions from Page 93.  Resistor problems are easier solved when you draw a clear circuit diagram to direct your focus on the problem. |
| …………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  See Electrotech Page 541 | |
| 57. | Contd. |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  See Electrotech Page 541 | |

Kirchhoff's Laws

|  |  |
| --- | --- |
| 58. | Write Kirchhoff’s voltage and current laws in the spaces provided below: |

|  |
| --- |
| **KIRCHHOFF'S VOLTAGE LAW:** |
|  |
|  |

|  |
| --- |
| **KIRCHHOFF'S CURRENT LAW:** |
|  |
|  |

Insulation Resistance

As the length of a conductor increases, the resistance of the conductor will also increase. If a conductor was to double in length its resistance would double - but - the resistance of the insulation would halve!!

E.g., A 100m piece of 2.5mm2 cable having two conductors insulated from each other by PVC may have a resistance of 0.688Ω in each conductor, and a resistance between those conductors of 50MΩ. The equivalent circuit for this cable would be:

**Circuit diagram for 100m cable..**

0.688Ω

0.688Ω

50MΩ

Insulation

Conductor 2

Conductor 1

**the circuit diagram for a cable twice this long..**

Conductor 1

Conductor 2

50MΩ

Insulation

0.688Ω

0.688Ω

0.688Ω

0.688Ω

50MΩ

Insulation

Conductor 2

Conductor 1

100m

100m

**Since the resistance between the two conductors is now two 50MΩ resistors in parallel the total insulation resistance is 25MΩ.**

|  |  |
| --- | --- |
| 59. | A 40m length of insulated copper conductor has a resistance of 0.05Ω and an insulation resistance to earth of 63MΩ. What will the conductor resistance and insulation resistance of 80m of this conductor be? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  R= 0.1Ω RINSULATION = 31.5MΩ | |
| 60. | A 50m length of twin insulated copper conductors has a resistance of 0.2Ω per conductor and an insulation resistance of 100MΩ between conductors. What will the conductor resistance and insulation resistance of 150m of this cable be? |
| ………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………  R= 0.6Ω RINSULATION = 33.33MΩ | |
| 61. | A 1km length of insulated copper conductor has a resistance of 8Ω and an insulation resistance to earth of 20MΩ. What will the conductor resistance and insulation resistance of 23km of this conductor be? |
| ……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………….  R= 184Ω RINSULATION = 870kΩ | |

You will be required to calculate and measure values of resistance, voltage, current and power in the assessment for this unit.

4 – Work, Power & Energy

Simply put…

1. Energy (Q) can be in one of two forms (kinetic [moving], or potential [will have kinetic energy if released]). Energy is measured in Joules (J).
2. Work (W) is done when energy is converted from one form to another (e.g. heat creates steam). Work is also measured in Joules (J).
3. Power (P) is the rate at which work is done. Power is measured in Watts (W).

**1 Joule = 1 watt × 1 second**

When it comes to calculating Power in electrical calculations, Power is simply the product of voltage and current:

**P = V × I**

It can also be calculated from: **P = I2R**. Or **P = V2/R**.

|  |  |
| --- | --- |
| 62. | Another point to be remembered is that “1 unit” of electricity is 1 kilowatt-hour (which is a convenient quantity of electrical energy). How many “Joules” are there in a kilowatt-hour? |
| …………………………………………………………………………………………………………………………………………………………………………………….  3.6MJ | |
| 63. | One horsepower (Hp) = 0.746kW. How many Hp in a 2.2kW motor? |
| …………………………………………………………………………………………………………………………………………………………………………………….  2.95Hp | |

ANSWERS

|  |  |
| --- | --- |
| 1. | An electron that exists in the outermost energy level of an atom or compound |
| 3. | Thermal agitation due to the ambient temperature – the speed of electron movement is half the speed of light |
| 5. | conductivity, less electrolytic problems, does not work harden |
| 7. | phosphor-bronze - springy |
| 9. | High conductivity, does not oxidise readily, high melting point |
| 11. | Doped so as to be conductive with copper or silver (up to 90%), they are also mechanically soft and will wear-out first. |
| 13. | silver, HRC fuse elements, switch contacts |
| 17. | Plastics, Rubber, Magnesium-Oxide, Paper |
| 19. | A covalently bonded compound with no free electrons. |
| 19. | Very high resistance and flexibility |
| 21. | Will not oxidise, better resistance to solvents, stronger, fire retarding, water resistant, cheap |
| 23. | It is hygroscopic (absorbs water readily) |
| 25. | The glass shatters under over voltage, porcelain cracks |
| 27. | max p.d. applied across opp. faces of insulator before breakdown |
| 29. | Neither - Si=30-80010-3m, Ge=46-89010-3m |
| 31. | An ionic bond consists of ions (+ve or -ve) bonded due to their dissimilar charges, a covalent bond (no charge) is a sharing of electrons |
| 33. | It acts as a resistor to current flow in one direction, and as a conductor to current flow in the other direction. |
| 35. | See Answers Electrotechnology Page 540 |
| 37. | I = V/R = 24V/10Ω = 2.4A |
| 39. | 16×10-6 m2 |
| 41. | 415.5×10-6m2 |
| 43. | 3.44Ω |
| 45. | 4m |
| 47. | See Answers Electrotechnology Page 544 |
| 49. | D) |
| 51. | 82.5Ω |
| 53. | 2200°C |
| 55. | α = 0.00001 Manganin is used where high temperature stability is required. Carbon would be next best on the Table on Page 190 as it has the next lowest temperature coefficient of resistance. The lower the temp. coeff. the less effect a rise in temperature would have and hence better stability. |
| 57. | See Answers Electrotechnology Page 541 |
| 59. | R= 0.1Ω RINSULATION = 31.5MΩ |
| 61. | R= 184Ω RINSULATION = 870kΩ |
| 63. | 2.95Hp |
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FORMULAE

