Unit notes for 25070 E2 & E3
"Resistance, Resistivity and Resistors"

Version 1   9.2.09   Chris Meehan

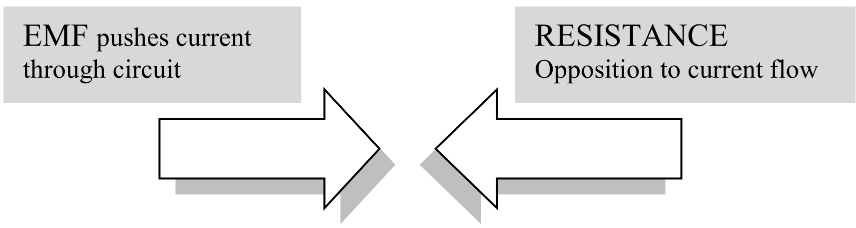
Introduction

Resistance is the opposition to the flow of electrons or current in a circuit.
The resistance in a given part of a circuit or a whole circuit is measured in **ohms** and given the symbol **Ω**

Resistivity or specific resistance is the resistance of a known block of material to enable us to compare the resistive behaviour of different conductors or insulators.

Ohms law

Practically, resistance means little in isolation. We need to consider what current is being "resisted" and how much pressure is being exerted on the current in opposition to the resistance.



Ohms law, the most fundamental electrical law and possibly the most used electrical law bonds these three quantities together mathematically.

"In a DC circuit at a constant temperature, current is directly proportional to voltage and inversely proportional to resistance"

In equation form this is $I = \frac{V}{R}$

Resistive Factors

There are 5 factors for us to consider that will affect a resistors value.

1. The resistors length
2. The cross sectional area
3. The resistivity of the material used
4. The temperature of the resistor
5. Positive or negative gain in resistance with temperature rise

Length (l)

The longer the resistor is, the higher the resistance value in ohms becomes.

$\therefore$ **R** α l

Cross sectional area (A)

The greater the cross sectional area is, the lower the resistance value in ohms becomes.

$\therefore$ **R** α $\frac{1}{A}$

Resistivity ρ (rho)

This factor relates directly to the material used.
If we consider copper and aluminium as 2 options for a cables conductor material we find that a smaller cross sectional area copper cable can be selected for the same resistance value.
Copper is a better conducting material than aluminium and has a smaller specific resistance value.
The lower the value of resistivity the lower the value of resistance.

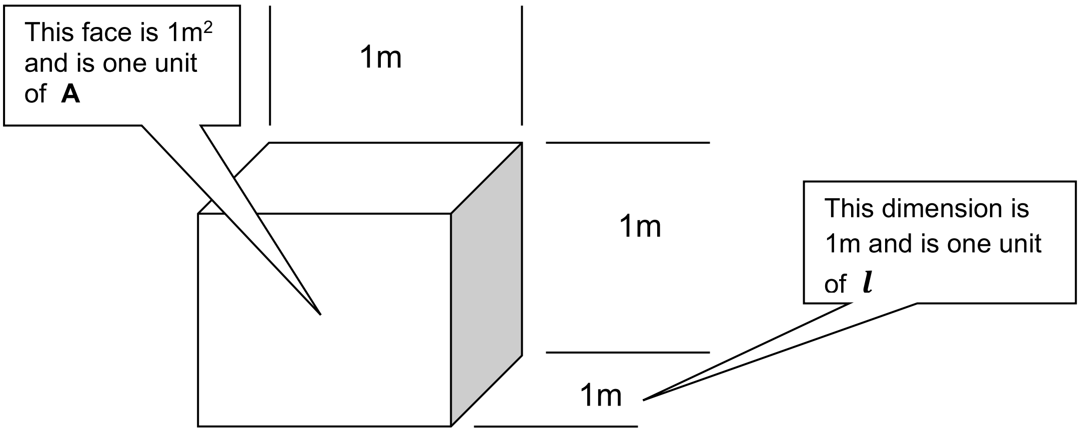
$\therefore$ **R** α ρ

If we now combine these first 3 factors, assuming the temperature is constant at room temperature, we find that ;

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

Explaining ρ

To compare the value of resistivity for different materials a standard size of each material needs to be tested.
The size chosen was a block of $1m^3$
The dimensions of the cube being 1m x 1m x 1m



<u>Sample block of material to measure resistivity value</u>

If we measure across any 2 opposing faces we will have a value of ρ for that material.

This value is called specific resistance. Specific to that material, and to that dimensioned block. The temperature is usually specified at 20℃.

The unit of resistivity in this case is ohms per metre or Ωm.
This is because the unit of resistance is ohms and the sample is 1 metre long.

For a good conductor we would see a value of around 0.00000002 Ωm,
and to keep the number a bit tidier we would convert to engineering format .
This would be 20×10^{-9} Ωm.

A close look at conductors, insulators and semiconductors shows the resistivity relative to each other.

Resistivity table

Silver	1.6×10^{-8} Ωm	good conductor
Copper	1.7×10^{-8} Ωm	
Gold	2.4×10^{-8} Ωm	
Aluminium	2.8×10^{-8} Ωm	
Brass	4.6×10^{-8} Ωm	
Steel (tungsten)	5.5×10^{-8} Ωm	
Tin	1.1×10^{-7} Ωm	
Lead	20.7×10^{-8} Ωm	
Nichrome	1.1×10^{-6} Ωm	
Carbon	3.5×10^{-5} Ωm	
Silicon	0.8 Ωm	semi-conductor
Germanium	0.9 Ωm	
Ceramic	10^{10} Ωm	
Rubber	10^{13} Ωm	
PVC	10^{14} Ωm	good insulator
Glass	10^{10} to 10^{14} Ωm	
Mica	10^{13} to 10^{17} Ωm	

Looking at a practical resistivity calculation.

Calculate the resistance of a 16mm^2 mains cable 100m long.
Assume ρ for copper is 0.017 $\mu\Omega\text{m}$

Starting with the basic formula $R = \dfrac{\rho\, l}{A}$

Inserting the given values $R = \dfrac{0.017\mu\Omega\text{m} \times 100\text{m}}{16\text{mm}^2}$

Changing the units to Ω and metres $R = \dfrac{0.017 \times 10^{-6}\ \Omega\text{m} \times 100\text{m}}{16 \times 10^{-6}\ \text{m}^2}$

Cancelling exponents top and bottom $R = \dfrac{0.017 \times \cancel{10^{-6}}\ \Omega\text{m} \times 100\text{m}}{16 \times \cancel{10^{-6}}\ \text{m}^2}$

Calculating values and units $R = \dfrac{0.017 \times \Omega\text{m} \times 100\text{m}}{16 \times \text{m}^2}$

$R = \dfrac{1.7\ \Omega\ \cancel{\text{m}^2}}{16\ \cancel{\text{m}^2}}$

Cable resistance equals <u>0.106 Ω</u>

Temperature

Resistance is affected by heat

Most conductors increase their resistance slightly with a rise in temperature.
This is termed a *positive temperature coefficient of resistance*.

Carbon is one of the exceptions which decreases with a rise in temperature and is deemed to have a *negative temperature coefficient*.

The temperature coefficient of resistance is defined as
“ *The change in resistance of each ohm for each degree celcius change in temperature”*

This long winded term is often shortened to Tempco.

The symbol for Tempco is $\propto$ and is usually taken at either $0℃$ or $20℃$.

Tempco formula

Knowing the resistance at 0℃ we can calculate the resistance at any temperature given using the tempco formula below.

$R_T = R_o (1 + \propto_o t)$

Where R_T is the resistance in ohms at the increased temperature

R_o is the resistance in ohms at 0℃

$\propto_o$ is the temperature coefficient for that material taken at 0℃
(note: this is a number or multiplier having no attached units)

t is the temperature rise in degrees celcius above zero

Resistivity and tempco tables

The values for ρ and $\propto$ are given in tables for different materials.
Below is an example of 5 common metals prevalent in the electrical industry.

Material	Resistivity ρ $\mu\Omega$m	Tempco $\propto$
brass	0.066	+ 0.00100
aluminium	0.028	+ 0.00423
copper	0.017	+ 0.00427
silver	0.016	+ 0.00400
nichrome	1.122	+ 0.00017

The first 4 materials are considered conductors with similar low resistivity values

Nichrome has a higher resistivity value so a little of the material will resist the flow of current more. About 70 times more.

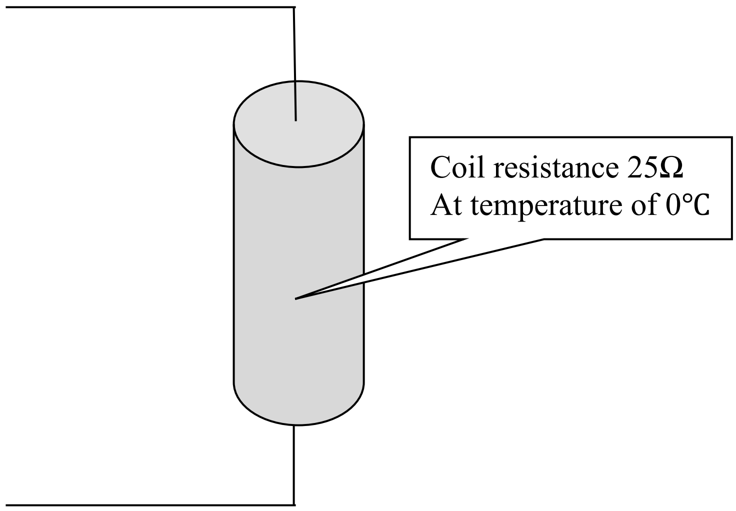
Nichrome has a much smaller tempco value making it 20 times more stable than the conductors shown in the table.

These attributes make nichrome ideal for a heater element, small and stable from cold to red hot.

Looking at a practical tempco calculation

Given:
A copper contactor coil heats up to 50℃ after it has been energised for a few hours.

Q. What will be its final resistance?



Using the tempco formula

$R_T = R_o (1 + \alpha_o t)$

$R_T = 25\Omega (1 + \alpha_o t)$

$R_T = 25\Omega (1 + 0.00427 \times t)$

$R_T = 25\Omega (1 + 0.00427 \times 50)$

The new resistance

Resistance At 0℃

Tempco of copper at 0℃ from table

Temperature rise in degrees

$R_T = 25\Omega (1 + 0.00427 \times 50)$

$R_T = 25\Omega (1 + 0.2135)$

$R_T = 25\Omega \times 1.2135$

$\underline{R_T = 30.3375\ \Omega}$ or a rise in resistance of 5.34 Ω

Tempco formula variation for WS22A

Knowing the resistance at 0℃ is not always practical.
Room temperature is often more usable.

Consider the situation below.

A motor is sitting in a room at 20℃.
We can measure the resistance of the windings with a multimeter.
We then run the motor at full load until it stops getting any hotter, and measure the resistance again before it loses heat.

Using the readings of resistance in both situations we can calculate the running temperature without having to have a thermocouple in the windings.

The varied formula below is used to do this.

$$\frac{R_2}{R_1} = \frac{1 + \propto_0 t_2}{1 + \propto_0 t_1}$$

where R_2 is the final resistance

R_1 is the initial resistance

t_2 is the final temperature

t_1 is the initial temperature

$\propto_0$ is the tempco constant for copper

Work Sheet 22A. Resistance / Resistivity / Tempco.

Show workings.

Material	Resistivity ($\mu\,\Omega$m at 20^0C)	Temperature Co-efficient (at 0^0C).
Brass	0.066	+0.001
Copper	0.017	+0.00427
Silver	0.016	+0.004
Nichrome	1.122	+0.00017
Aluminium	0.028	+0.00423

1. A cable is made of copper and measures 45m long, the conductor CSA is 10mm^2. Calculate the resistance of the cable.

2. Find the difference in Ohms between a bar 15m long and measuring 3mm x 10mm if it was made from Copper or Brass.

3. Find the Voltage drop that occurs on a 120mm^2 Aluminium cable, 2 km long and carrying 50 A.

4. Calc. the length of 0.75mm^2 Nichrome wire required to make an element of 12 Ohms resistance.

5. For any conductor, an increase in LENGTH, _______________ resistance and a decrease in AREA. ______________ resistance.

   For a conductor with a positive Tempco, resistance ____________ as Temperature increases.

   For a conductor with a negative Tempco, resistance ____________ as Temperature increases.

6. The working temperature of a heater element using nichrome wire is 600^0C. Find the resistance at this temperature if the resistance at 0^0C is 5 Ohms.

7. A copper cable has a resistance of 0.2 Ohms at 0^0C. When a short circuit occurs, 3 kV are dropped across the cable as 8 kA flows. Find the temperature the cable reaches during the short circuit - is this good for the insulation?? - Hint: Find the R during the short circuit using Ohms Law then apply the Resistivity formulae.

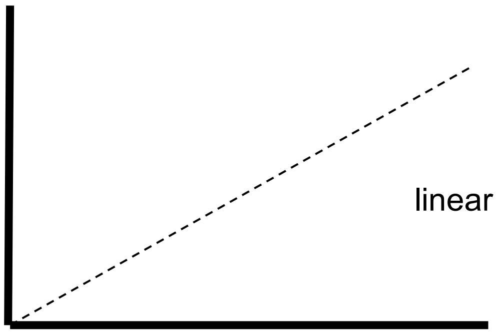
8. A special motor with silver conductors for windings, has a resistance of 2.7 Ohms at room temperature of 18^0C and when run fully loaded for 30 minutes has a resistance of 3.37 Ohms. Find the average temperature of the conductors at full load.

Resistors

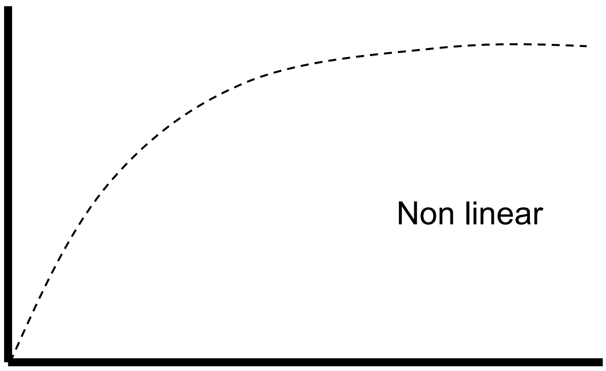
A resistor can be considered as a conductor with a resistance fit for its purpose.

Resistors fall into two main groups **Linear** or **non linear**

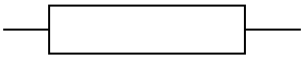
Linear resistors give a direct proportional change and produce a straight line graph

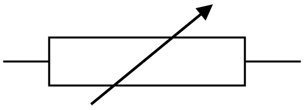
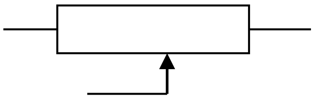


Non linear resistors give a disproportionate change producing a curved graph



Linear resistors can also be manufactured as **fixed** value or **variable** value (adjustable) resistors.

The symbol for a fixed resistor is 

The symbol for a variable resistor is  or 

Resistor types

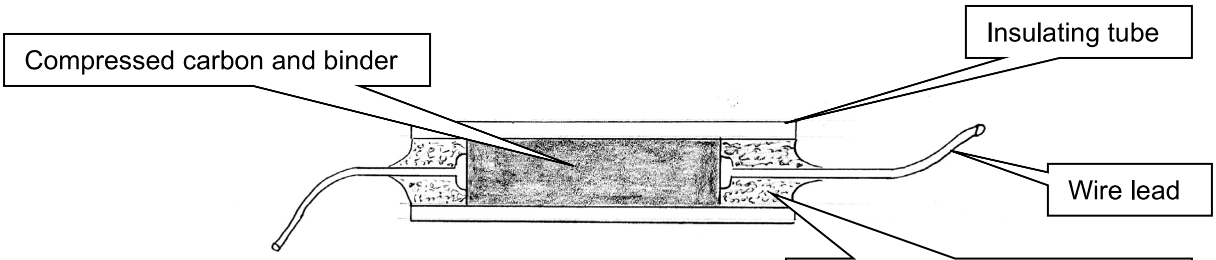
We will study the following types of resistors divided into groups as shown in the table

linear		Non linear
fixed	Carbon film	NTC thermistor
	Metal film	PTC thermistor
	Wire wound	Voltage dependant resistor
	Carbon composition	Light dependant resistor
variable	Slider potentiometer	
	Rotary carbon potentiometer	
	rheostat	

<u>Resistor construction </u>(linear)

Carbon composition

Very finely ground carbon particles are mixed with a ceramic binder.
This is moulded into small cylinders, heat treated and encased in plastic or ceramic tubes. A wire lead is attached to each end.

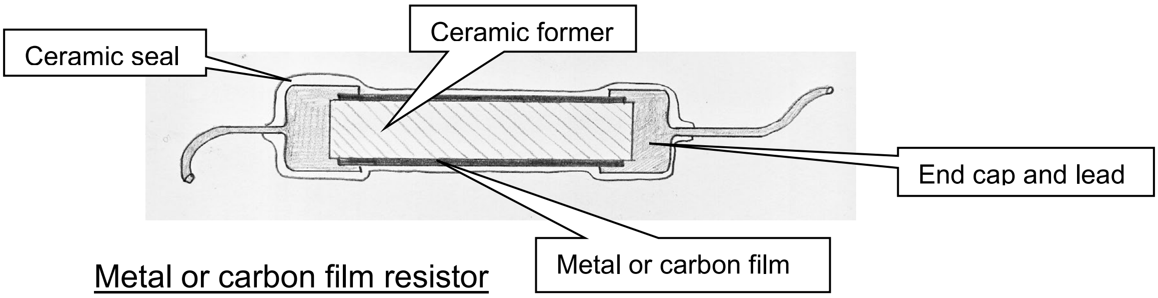


<u>Carbon composition resistor</u>

This resistor has a negative temperature characteristic.
The resistance decreases as the temperature rises, risking thermal runaway.
This is a relatively unstable resistor prone to failure.

Carbon film and metal film

A high temperature insulator, usually ceramic or mica, is coated with either a metal oxide film or a carbon film.
The thickness and composition are adjusted for various values.

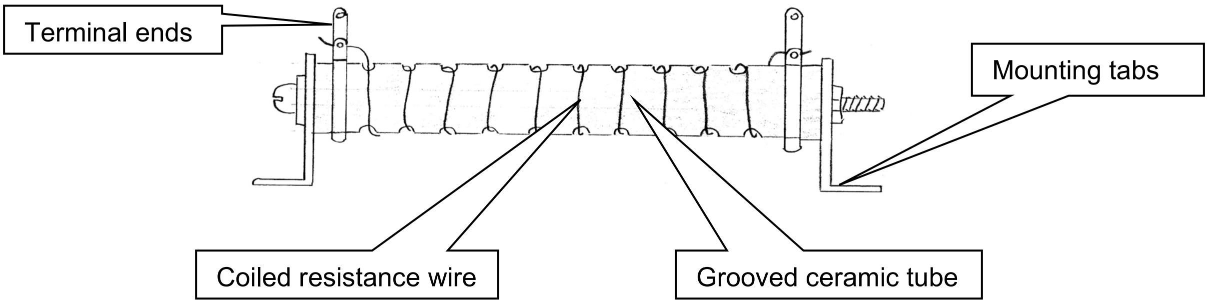


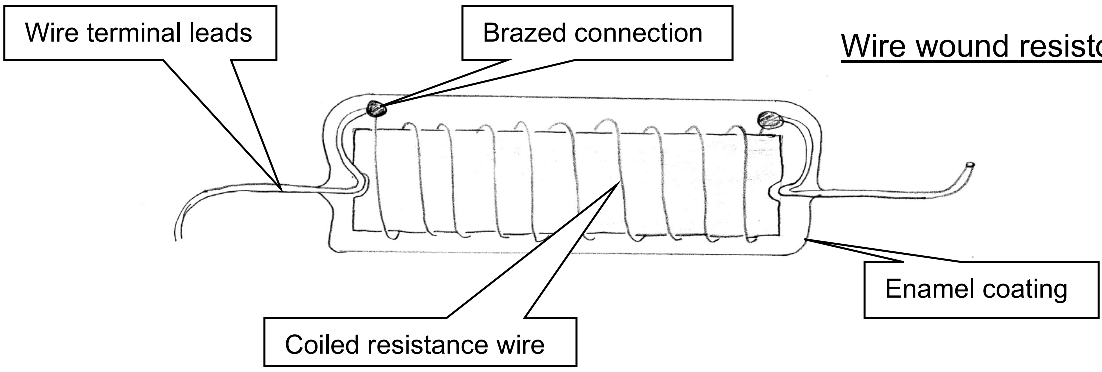
Metal or carbon film resistor

This type is more stable and manufactured to closer tolerances.
Positive temperature coefficient.

Wire wound

Nichrome or constantin resistance wire is wound around a ceramic former.
This wire has a high resistivity and a low temperature coefficient.
This gives a stable ohmic value across a large temperature range.
Used prevalently for higher wattage applications where small resistances and high currents are employed.



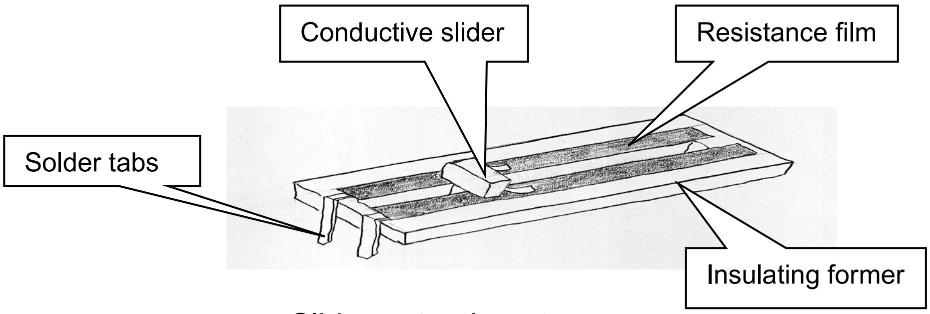


Wire wound resistors

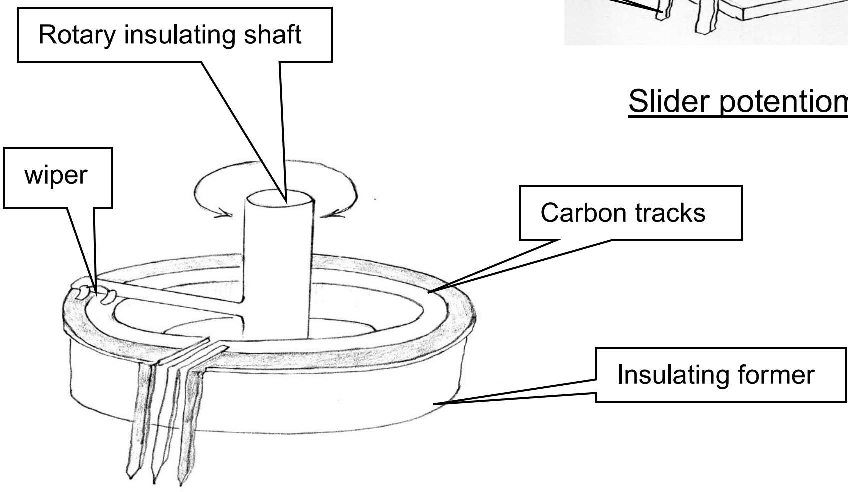
Variable resistors

A variable resistor is known also as a potentiometer.
Two main types are the **slider potentiometer** and the **rotary carbon potentiometer**.

These variable resistors are constructed in a case with an adjustable wiper to vary the resistance by length.
They are used in low power applications and are usually soldered into position bb solder tabs onto circuit boards.



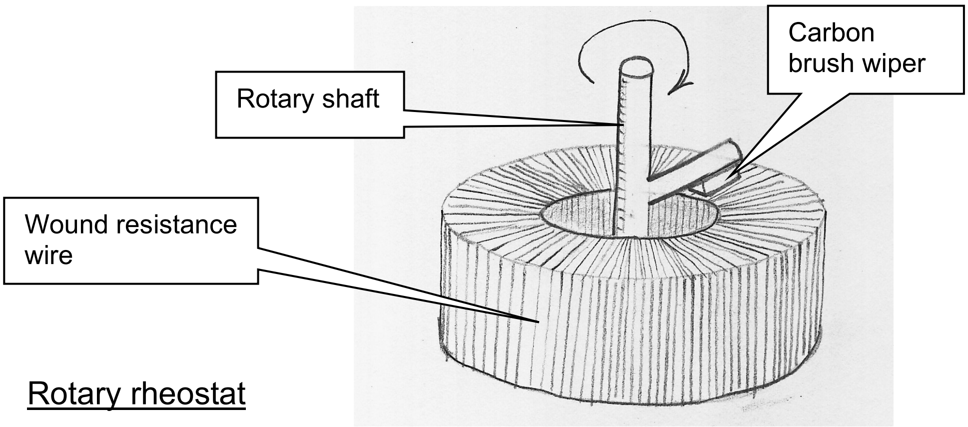
Slider potentiometer



Rotary carbon potentiometer

Rheostat

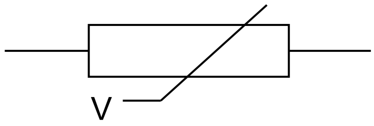
Similar in function to the rotary potentiometer but with wire wound tracks for a higher wattage use. Motor speed control a typical use.



Rotary rheostat

<u>Resistor construction</u> (Non linear)

VDR (voltage dependant resistor)



A solid state package with 2 leads.
Also referred to as a surge suppressor or surge diverter.
When a sudden spike in voltage arrives, the resistance in the VDR decreases allowing the extra current to divert to earth.
In these applications the VDR is wired phase to earth to arrest voltage spikes

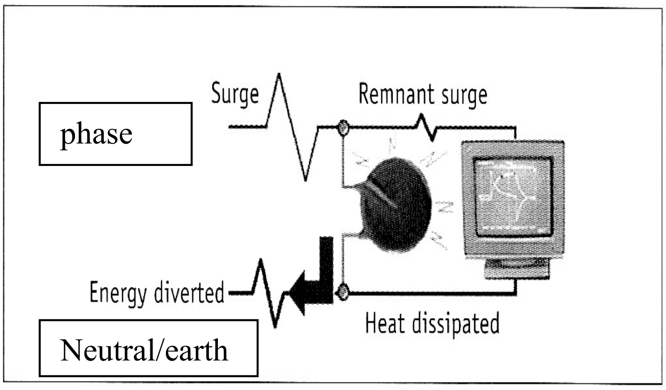


Figure 2.21 Surge suppression

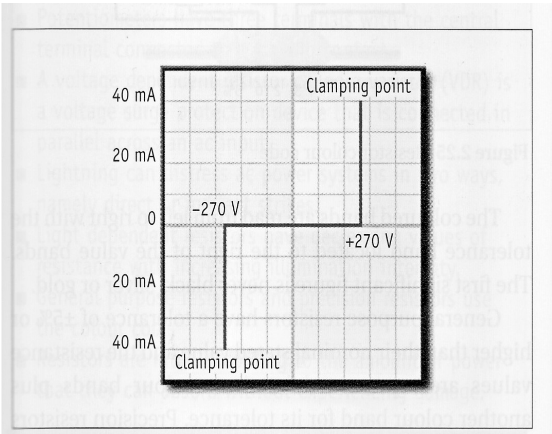
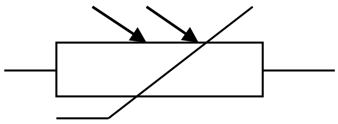
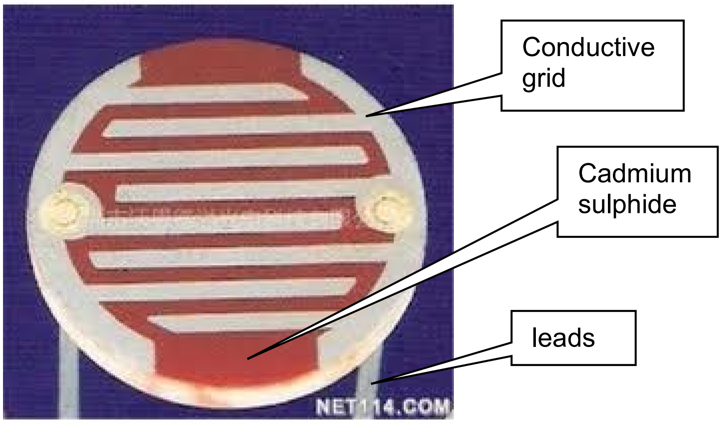


Figure 2.20 Metal oxide varistor conduction characteristic

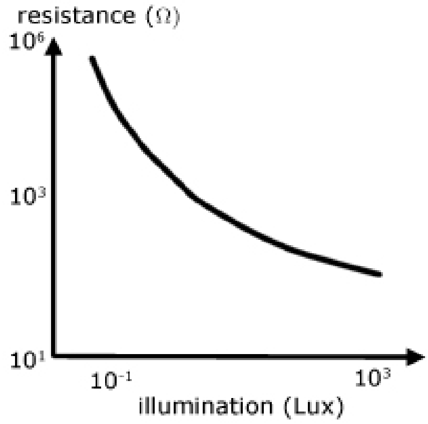
LDR (light dependant resistor)



A photoconductive device or light sensitive switch.
Also referred to as a daylight switch.
As light falls on the surface the device, the falling resistance allows the LDR to conduct.
A semi conductor layer of cadmium-sulphide on a former is encased in a glass envelope

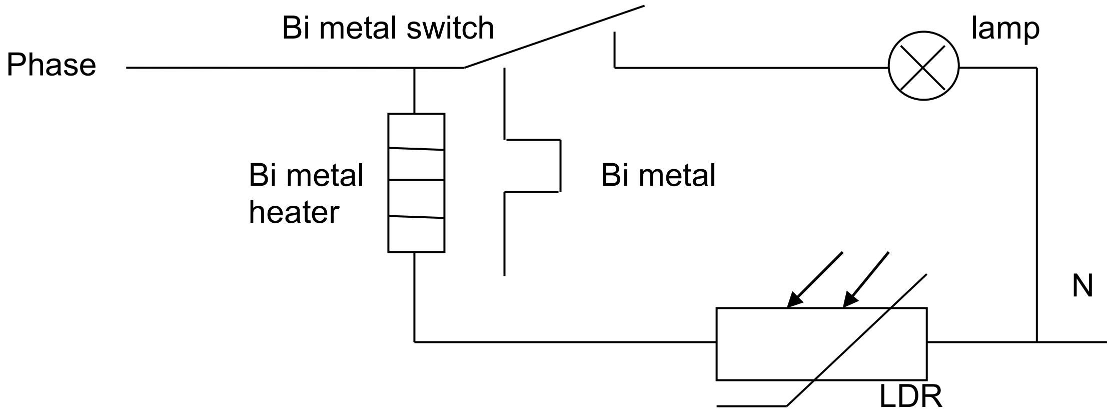


LDR construction



LDR characteristics

The LDR responds gradually to changes in light levels suiting the device to daylight switch applications. Automatic outside lights or security lighting.

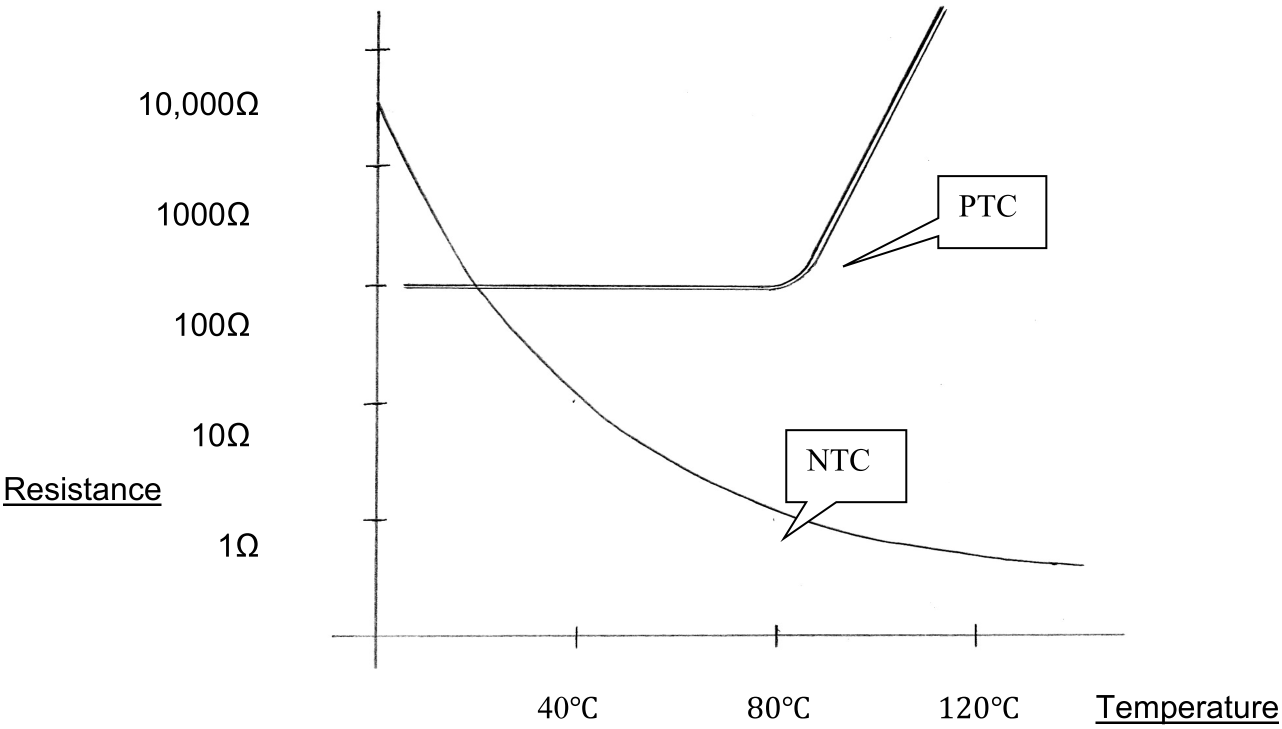


Circuit for daylight switch

In full daylight the LDR is low resistance.
This allows a high current to flow through the bi-metal via the LDR bending open the bi-metal switch contact.
As the light fades the LDR becomes higher in resistance reducing the current flowing through the bi-metal.
The cooling bi-metal bends and closes the switch, turning on the light.
The gradual change allows for light fluctuations.

Thermistors (temperature dependant resistors)

A solid state package with 2 leads, this device has a non linear output to a change in temperature. Semi conducting ceramic oxide is used in construction.
A positive and negative temperature coefficient version is available.
Resistance rises with temperature increase for PTC.
Resistance lowers with temperature increase for NTC.



Temperature Vs Resistance for thermistors

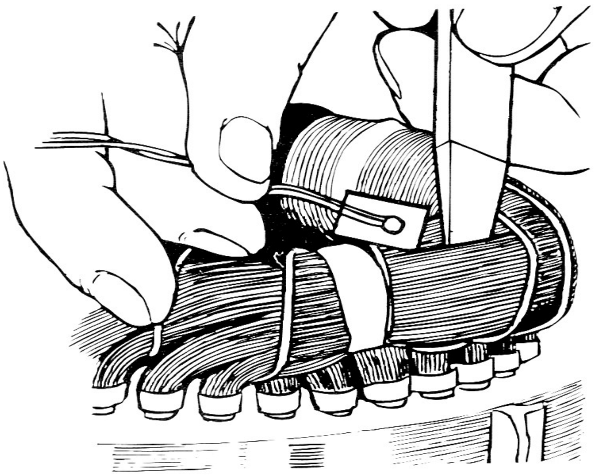
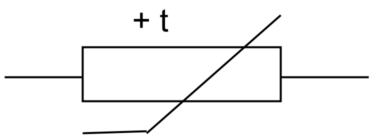
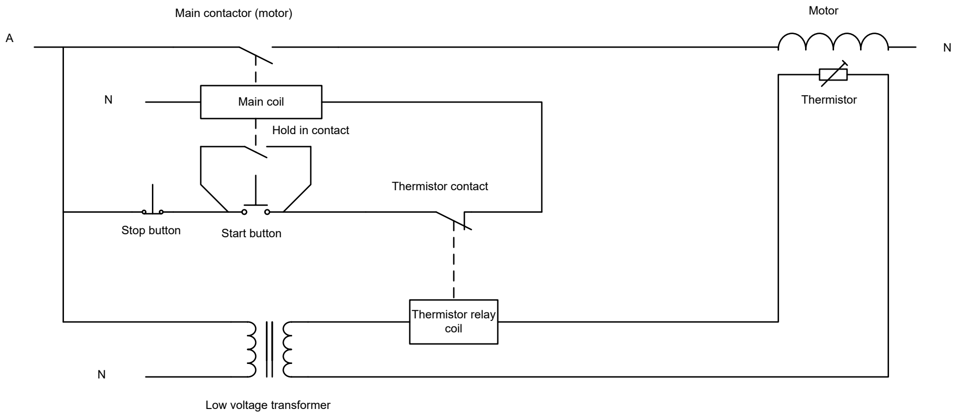


Fig. 10.24 A thermistor being inserted in a small motor during manufacture

PTC thermistor

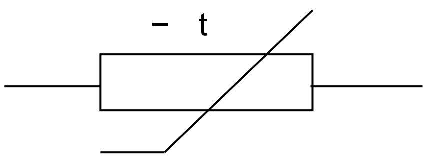


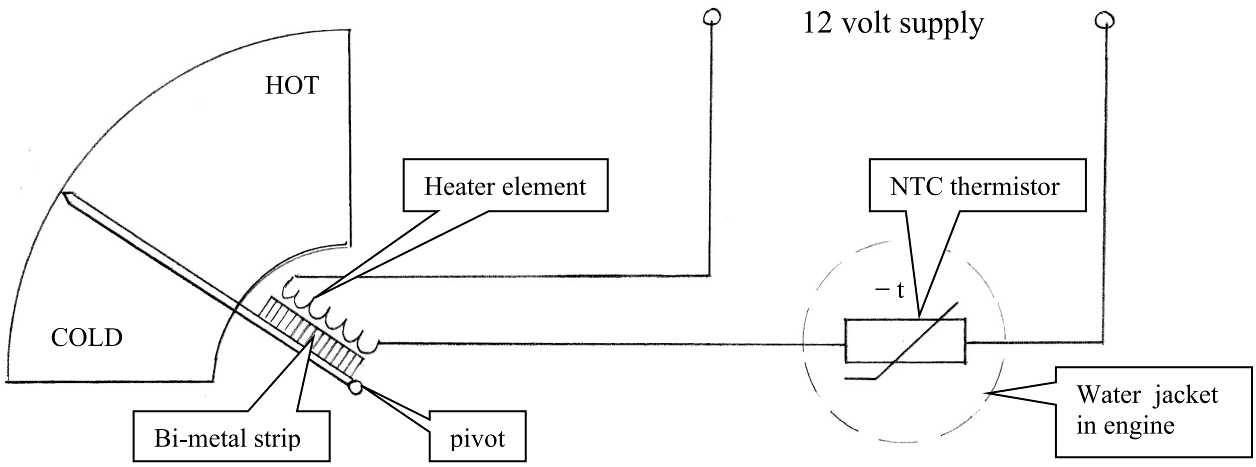
This thermistor is typically employed in transformer or motor windings where the sudden change in resistance at a defined temperature triggers the protection.
This stops damage from overheated or burnt out windings in expensive equipment.



Motor winding thermistor protection circuit

NTC thermistor

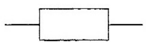
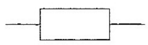
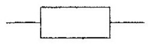
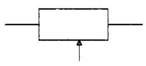
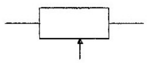
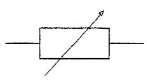
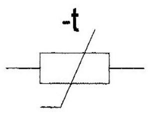
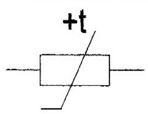
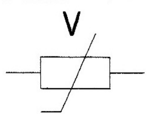
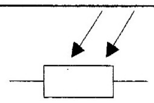




Car temperature gauge

A NTC thermistor could be found in the water jacket in a car to indicate the water temperature.
As the water heats up the thermistor resistance goes down.
The rising current causes the heater element to become hotter.
The bi-metal strip bends the pointer indicating the temperature value on the scale.

Resistor characteristics, symbols, connections and applications

	Characteristics	Symbol	Connection	Applications
Carbon	Low cost Poor stability Poor temp co-efficient		Two wire	General purpose Mostly obsolete
Metal film	High stability resistant to most environmental conditions and close tolerance		Two wire	General purpose and semi precision
Wire wound	High power ratings in small body sizes and high operating temperatures		Two wire	High power
Slider potentiometer	Variable output		Three wire	Volume control
Rotary carbon potentiometer	Variable output		Three wire	Speed control
Rotary rheostat	Variable output		Two wire	Timing circuit
NTC thermistor	As temp increases resistance decreases		Two wire	Temp measurement
PTC thermistor	As temp increases resistance increases		Two wire	Warning and trip circuits
VDR	As voltage increases resistance decreases		Two wire	Reducing transient voltage spikes
LDR	As light increases resistance decreases		Two wire	Daylight switches

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Resistor terms

Tolerance
All components differ from their marked value by some amount. Tolerance specifies the maximum allowed deviation from the specified value. Tolerances are normally expressed as a percentage of the nominal value
As an example, a component with a marked value of 100 and a tolerance of 5%, could actually be any value between 5% below the marked value (95) and 5% above the marked value (105)

Preferred value
The system of preferred values which is used for resistors, capacitors, and inductors, was developed to provide a logical progression from one value to the next, where each value represents an increase by an approximately constant percentage. Depending on the tolerance of the particular components, there can be between 3 and 192 preferred values in each decade. The more common series are shown below. Values given for each series are repeated in each decade

3 per decade (50% tolerance)
10 22 47

12 per decade (10% tolerance)
10 12 15 18 22 27 33 39 47 56 68 82

24 per decade (5% tolerance)
10 11 12 13 15 16 18 20 22 24 27 30 33 36 39 43 47 51 56 62 68 75 82 91

Stability
The ability of a component to maintain its value under varying circuit and environmental conditions

Power rating
The maximum power in watts that can be dissipated, usually quoted at a temperature of 70°

Power dissipation
Power (Vx I) generated as heat in watts in a device

Voltage rating
The maximum continuous voltage that can be applied across the device

Current rating
The maximum current the device can carry continuously

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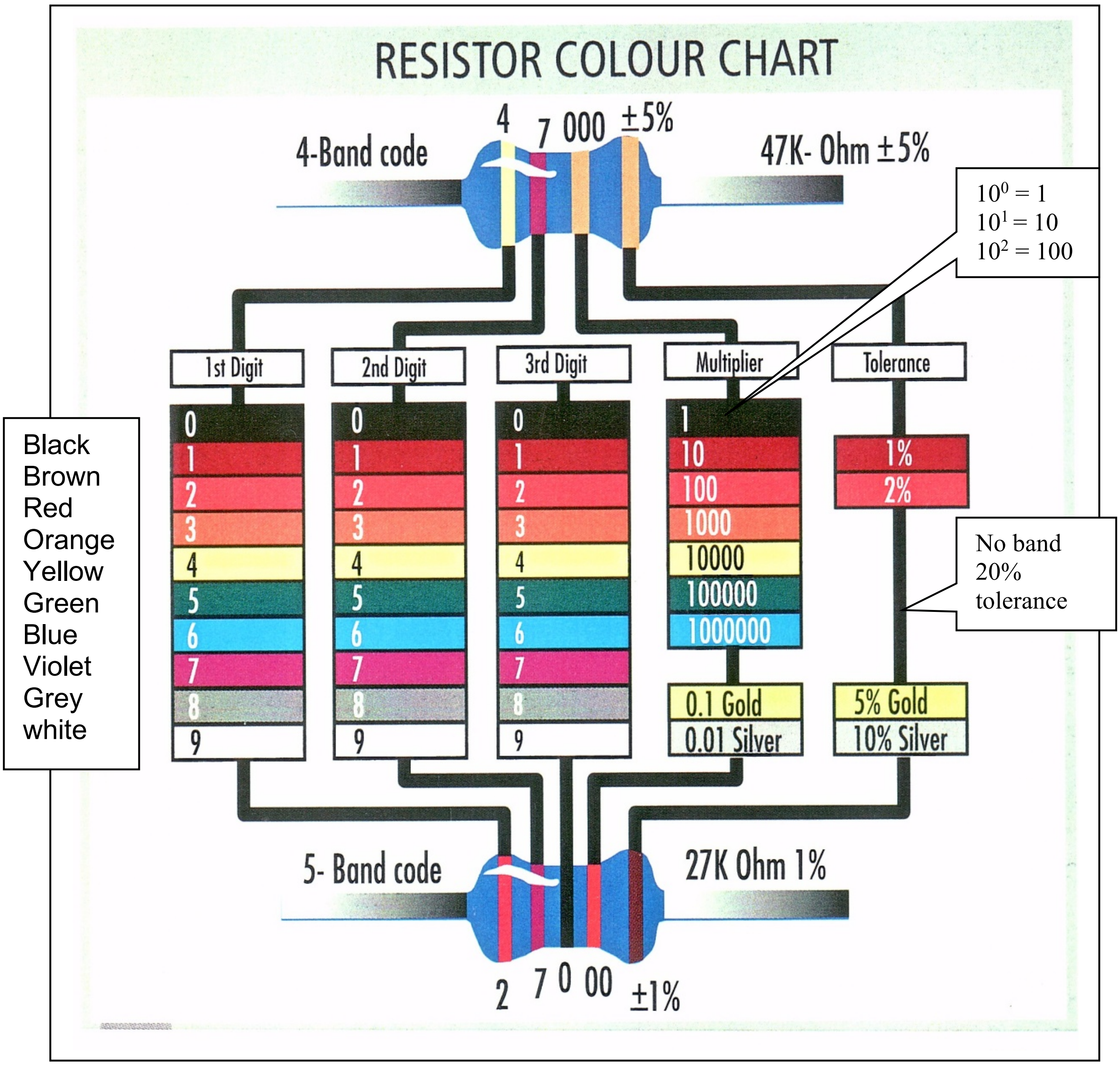
RESISTOR COLOUR CHART HANDOUT



INTERPRETING RESISTOR COLOUR CODES

Resistors

Most resistors are so small that it is impractical to print their values on them using normal numeric characters. Instead, they are marked using a code of coloured bands.

Resistors made to tolerance of 5% and 10% are marked with 4 bands while higher precision types, such as 2%, 1% or better, may be marked with 5 bands to allow for an extra digit of precision.

How to read 4 - band codes:

At one end of the resistor there will be a gold, silver or brown tolerance band. This band is usually spaced apart from the other three bands. Start with the band nearest to the other end. Its colour represents the first digit of the resistor's value, as shown in the colour code chart. The next band represents the second digit of the resistor's value. The third band represents the decimal multiplier, that is, the number of zeroes that we have to put after the first two digits to arrive at the resistor's value. The final band gives us the tolerance of the resistor, silver for 10% types, gold for 5% types, brown for 1% types.

Let's take the resistor shown at the top of the colour chart as an example. It's first band is yellow, representing "4" and the second band is violet, representing "7". The third band, the multiplier, is orange which tells us to add 3 zeroes to the number we already have. This is the same as multiplying it by 1,000. Thus the value of the resistor is 47,000, forty-seven thousand ohms or 47k-ohms. Finally, the fourth band, being gold, indicates that the resistor has a 5% tolerance, that is, its actual value will be somewhere between 44,650 ohms and 49,350 ohms.

Some special high-voltage resistors use a yellow tolerance band in lieu of gold. This is simply because the metal particles in the gold paint might compromise the resistor's voltage rating.

What they mean:

Band one - first figure of value
Band two - second figure of value
Band three - number of zeroes/multiplier
Band four - tolerance

Tolerance band colours: brown 1%, red 2%, gold 5%, silver 10%, none 20%.

Reading 5-band resistors:

Because the final band on these resistors is usually brown or red, it can be a bit more difficult to know which end to start from. In most cases the first four bands are grouped a bit closer together than the fourth and fifth bands. The first two bands are read the same as they are on the 4 - band types. The third band supplies the third digit of the value. The fourth band now becomes the multiplier and the fifth represents the tolerance.

For example, if the 5 bands are, from first to fifth, red/yellow/white/gold/brown, then the three significant digits of the value would be "249", the multiplier would be 0.1, and the tolerance 1%. Hence, this is the code for a 24.9 ohm, 1% resistor.

What they mean:

Band one - first figure of value
Band two - second figure of value
Band three - third figure of value
Band four - number of zeroes/multiplier
Band five - tolerance

HOMEWORK RESISTOR COLOUR CODE

Name..............................

1. Give the colour codes for the following values of resistors

680 ohm ....

470k ohm ....

4M7 ohm ....

470K ohm ....

0.22 ohm ....

8.2 ohm ....

180 ohm ....

150K ohm ....

8K2 ohm ....

3.3 ohm ....

2. State the resistance values of the following colour coded resistors, answers to be in appropriate S.I. unit, eg 150KΩ not 150,000Ω

orange orange brown ....

brown red yellow ....

brown green brown ....

orange white blue ....

brown black green ....

brown grey orange ....

green blue gold ....

blue grey silver ....

red violet green ....

yellow violet orange ....

Insulation resistance

Insulation on cables is designed to keep the electricity contained within the conductor beneath its surface. Ideally no electricity will leak out, but in practice a small amount will and is still acceptable within limits.
If the insulation is old, faulty or damaged the current escaping may be unacceptable.

Insulation resistance testing is mandatory under the NZ wiring rules.
This is to ensure the insulation resistance is high enough between all live conductors and earth to ensure the integrity of the insulation.

This is done to prevent

a) Electric shock hazards from inadvertent contact
b) Fire hazards from short circuits
c) Equipment damage

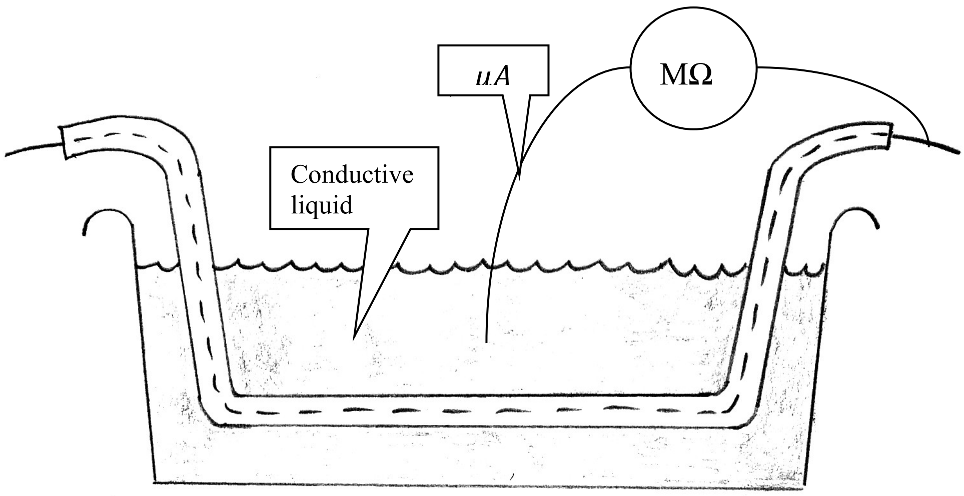
500 volts DC is applied with an insulation resistance tester, also known as a megger.
Live parts (active and neutral) to earth must be not less than 1MΩ.

500 volts is used on a 230v ac system to stress the insulation above the working voltage. The insulation breaks down exponentially as the voltage is increased so that problems are revealed before they would in service.

DC is applied as capacitors appear as a leakage if AC is used.

Insulators have great difficulty conducting electricity, but they will conduct small currents. By ohms law at 230v a cable with 1MΩ of insulation resistance
will leak 23 micro amps through the insulation.

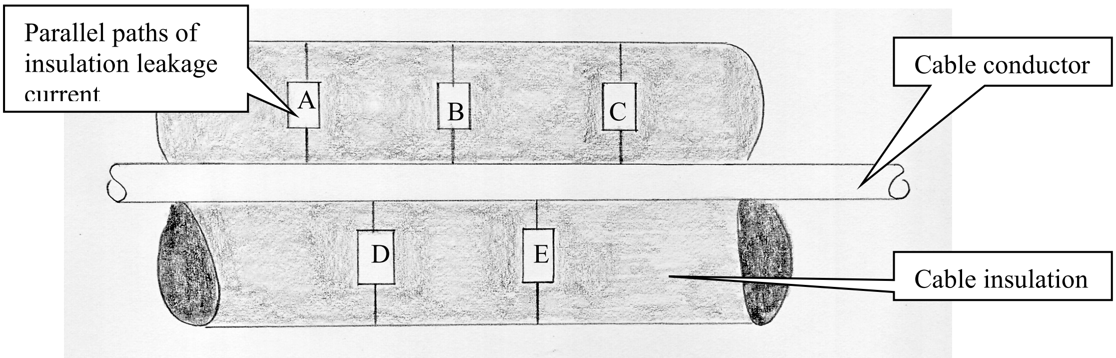
Looking at how cables are tested in a cable manufacturing plant will illustrate how insulation resistance works.



Factory insulation resistance testing of new cables

The cable is immersed in a conductive liquid to give total contact with the outer surface of the insulation. A tester measures the current from the inner conductor leaking through the insulation into the conductive liquid.

Looking closely at the cable in the diagram below we see that the resistances A,B,C,D and E represent the insulation resistance of the cable.



Cable insulation parallel leakage paths

It follows that the thicker the insulation the longer the resistance paths, increasing the insulation resistance.
The longer the cable, the more parallel paths of leakage, lowering the cables insulation resistance.
Therefore the cables insulation resistance is *directly* proportional to the thickness of the insulation and *inversely* proportional to the cables length.

Calculation example.

4km of cable has 40MΩ insulation resistance.
What is the insulation resistance of the same cable type at 5km of length.

$IR_{new} \times length_{new} = IR_{old} \times length_{old}$

And transformed to find newIR

$$IR_{new} = \frac{IR_{old} \times length_{old}}{length_{new}}$$

$$IR_{new} = \frac{40M\Omega \times 4km}{5km}$$

$IR_{new} = \underline{32M\Omega}$

Insulation Resistance (IR).
Work Sheet 18A.
Basic theory and basic calculations.

1. Insulation Resistance (abbreviated to IR in the rest of this work sheet) can be considered as a number of resistors connected in_______________ ,consequently, as the length of a cable is increased the IR will _______________________, and conversely as the length of a cable decreases the IR will ____________________ .

2. List 5 factors that will affect the IR of a cable:

______________________________ ______________________________

______________________________ ______________________________

____

3. IR is measured with an _______________________________________ (the term MEGGER is a trade name and should not be used in exam answers). This type of device tests IR with an average voltage of ________Volts d.c., which is designed to stress the insulation above that normally applied by the mains voltage to see if the insulation will breakdown with the additional stress. The normal unit for values of IR is the _______.

4. A cable which is 50m long has an IR test result of 10MΩ . What is the IR of 200m of the same cable ?.

5. A 1m long length of cable has an IR test result of 150MΩ. What would be the IR of
a) 0.5m &
b) 100m
of the same cable ?.

6. A 100m drum of cable has an IR of 400MΩ. What is the IR of 75m ?.

Insulation Resistance (IR).
Work Sheet 18AX.
Basic theory and basic calculations.

1. Write below a formulae that will enable you to complete Insulation Resistance calculations. Check it against your notes or with your tutor before you continue with the problems.

2. As the length of a cable increases the Insulation Resistance ________________________.

   As the length of a cable decreases the Insulation Resistance ___________________.

   Remember to check the above statements with your answers to the following problems.

   IR is the abbreviation used for Insulation Resistance in these work sheets.

3. A cable that is 35m long has an IR of 420 MΩ What is the IR of the following lengths of the same cable ?: - remember to check your answers with the statements above.

   a) 5m:

   b) 20m:

   c) 50m:

   d) 100m:

   e) 1km:

4. A cable that is 10km long has an IR of 10MΩ Calculate the IR of the following lengths of the same cable:

   a) 1km: b) 1m:

5. A cable is tested as having an IR of 250MΩ when it is 100m long. What is the IR of 35m ?

Insulation Resistance (IR).
Work Sheet 18B.
Harder theory and calculations.

1. When testing an installation or an appliance, the IR tester is connected between phase / neutral (clamped together) and _______________. An important testing consideration is that all switches must be in the _____ position and all circuitry must be tested as being ___________________.

2. The minimum IR test result for an installation or an appliance is _________.
When this minimum IR test result is recorded, what is the current that will flow in the earthing conductor of an appliance or the protective earthng conductors for an installation, when 230V ac is connected? _____________.

3. A normal test result for a new appliance/installation could be expected to be _________________.
A test result less than the minimum would indicate:_____________________________________
____

4. Why should the main earthing conductor for an installation be connected to the protective earthing conductor being tested when an IR test is being performed ? ____________________________
____
____.

5. A cable has an IR test of 77MΩ and is 85m long. What is the IR of 22m of this cable ?.

6. A cable is 45m long. You test a 1m off-cut and and get an IR test result of 12 MΩ. At that point in time your IR tester goes faulty. What could you reasonably expect the IR of the 45m length to be ?

7. An old cable has an IR of 0.35MΩ and is measured at 45m long. What length of this cable would give a test result of 2MΩ.

8. A cable on a drum is of unknown length. You cut 1m off it and the IR test result for this off cut is 180 MΩ. You then test the remaining cable on the drum and record 2 MΩ. What is the length of cable on the drum ?.

<u>Factors that can cause a reduction in a cables insulation resistance</u>

A) Poor insulation material
B) Very long conductor
C) Very thin insulation
D) Poorly constructed cable (eg varying insulation)
E) High surface contact area
F) High ambient temperature
G) Excessive voltage
H) Insulation deterioration due to
   1) Moisture
   2) Mechanical damage
   3) UV deterioration
   4) Chemical damage
   5) Heat damage