FOUNDATION COURSE 101

A free educational course for vehicle enhancement installation technicians

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OHM’S LAW

INTRODUCTION

In this course, we are deliberately limiting ourselves to:

- a basic description of electricity
- Ohm's Law and its calculations

The topics discussed are relevant to the Vehicle Enhancement Certification Programme (VECP) and only applicable to the installation of aftermarket devices to vehicles. The VECP is not concerned with factory fitted electrics or electronics except for safely interconnecting aftermarket power, ground and signalling wiring.
For instance, the use of Ohm's Law will determine the correct fuse rating needed to protect aftermarket wiring.

More advanced detail can be found in the MESF Study Guides that lead to qualifications and accreditation.

This course is not a certificated qualification but is an introduction to the MESF qualifications which are part of the Vehicle Enhancement Certification Programme leading to accreditation for installation technicians.

A qualified and accredited technician is in control of the installation

Comparisons between the flows of electricity and water are used to aid understanding.
Water can be seen which makes it easier to visualise what is happening with electricity.

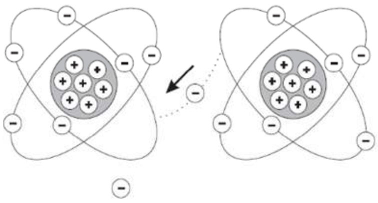
DESCRIPTION and TERMS

ELECTRICITY

This is energy in the form of either **moving** or **stationary** charged particles
These particles are called **electrons** and are parts of an **atom.**
Electrons that move from one atom to another are called **free** electrons
Free electrons enable us to use electricity.

Stationary charged particles are stored in a battery or other storage device; (an electrical or electronic circuit that is connected to a battery but switched off would also contain stationary charged particles).

Moving charged particles (free electrons) **flow** along a circuit and allow **work** such as powering a **device** (i.e. radio or electric windows). (See **CURRENT**)



Free electron moving between atoms (flow along a circuit)

ELECTRICAL CHARGE

An electrical charge is the flow of free **electrons** and can only exist in one of two conditions, **positive** or **negative**. The charge will flow out of the battery when a connection is made with a device.

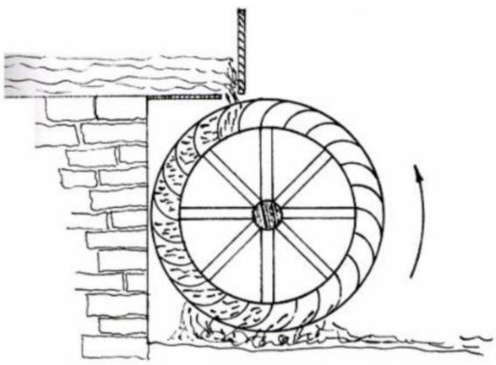
POLARITY

The **+** (positive) and **–** (negative) you see on the terminal posts of **batteries** indicates the **electrical polarity**. It refers to the direction of electron flow in a connected circuit. The electrons move from positive to negative.

POTENTIAL ENERGY

This is the amount of electrical charge, stored in a device (the number of free electrons in a battery) and is referred to as **voltage**.

A **battery** stores electricity (charge) in a similar way to a tank holding water.
Imagine a water wheel (device) below a tank (battery) that contains a quantity of water (charge).



There is a tap (switch) in the tank controlling the flow of water that empties on to and turns (work) the water wheel.

When the tap is turned off, no water is flowing, therefore the wheel does not turn.

The water held in the tank contains the *potential energy* that can turn the water wheel when the tap is opened. The more water the tank holds, the more potential energy it contains.

ELECTROMOTIVE FORCE

A voltage source such as a battery is a provider of potential energy. When a charged battery is not connected, it is not delivering power. However, as it contains charged particles available to provide power (work), it contains potential energy. The amount of this available potential energy is expressed as electromotive force (emf) and known as the capacity of a battery measured in **amp/hrs**.

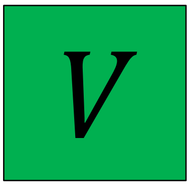
Now imagine our tank filled with water is a charged battery and the water wheel, a lamp. As the circuit is switched off, so is the lamp. Unlike the water in the tank, we cannot see electricity, however the battery is full of charge and contains the potential energy to perform work (power the lamp in this example) when the circuit has been completed (switched on).

When analysing electronic circuits, you'll encounter four basic terms:

1. **Voltage (V) (Can also be written as (E) - both are correct)**
2. **Current (I)**
3. **Resistance (R)**
4. **Power (P)**

These terms are known as **Elements**

VOLTAGE



Voltage is the electrical force that moves electrons
Measured in *volts*
Symbol V

Voltage is the amount of electricity (<u>not</u> power) and is measured in **volts**.

Voltage provides movement to electrons (the **charge**) and is the driving force that causes current to flow in a circuit.
Go back to our tank of water and see that the amount of water can be likened to the amount of voltage available to perform work. Insufficient water and it will be quickly drained, only providing flow for a short time, too much water (voltage) and it will swamp and damage our water wheel.

Too much voltage will damage and destroy devices and components within a circuit.

To simplify things a little, voltage is the amount of potential energy. Just like the volume of water available in our tank to turn the water wheel, it is not the rate at which it is used, (that is current).
Water in a stream can be compared to generated electricity, unlimited while the source is available, water stored in a tank can be likened to electricity stored in a battery, the smaller the consumption then the longer the power supply will last.

The most common vehicle voltage for vehicle enhancement purposes is referred to as 12 Volt.

This, however, needs more explanation.

Vehicle voltage will vary like this:

- 12.6 VDC voltage with the engine switched off
- 14.4 VDC voltage with the engine at tick over.
- 11.6 VDC voltage of an old battery with the engine switched off.

CURRENT

Current is the rate of electron flow through a given point
Measured in *amps*
Symbol I

Current is the force behind electricity and is measured in amperes (**amps**)
The movement of electrons in the same direction is current, this enables work to be performed (light a lamp).

Think water again but this time, a river. Imagine standing in a wide, *very* slow-moving river (say 1 metre deep), you would have no problem in standing, because the water movement is slow.
Suppose the same river had a fast flow, you would then have trouble standing. The amount of water passing you is the same, it is the speed at which the water is flowing that has changed.
This water flow, the current, can only exist because of the water. No water, no flow

Let's compare our river to an electrical current.
The amount of water represents voltage and the flow, current (the rate of movement of the electrons).
Electrical current cannot exist without voltage.
When standing in the fast-moving river it was the speed of the flowing water (also called current) that was trying to move you.

Our tank over the water wheel will hold exactly 10 litres of water. Open the tap and water will start to flow out. If at the same time, a tap is filling the tank with the same amount of water that is draining out, then the tank will still always contain 10 litres of water. There is a difference, instead of 10 litres of still water the tank contains 10 litres of moving water. Providing the inlet and outlet flows are matched then there will always be 10 litres of water in the tank, irrespective of the speed of the flow.
A charging circuit will maintain the voltage in a battery when current is flowing to power a device.

RESISTANCE

Electrical resistance describes the electrical conductivity that various materials possess
Measured in *Ohms* W
Symbol R

A **resistor** restricts or limits the movement of electricity (**current**).
The lower the resistance of a material, such as a length of wire (this is known as a **conductor**), then the more gaps that exist between its atoms, enabling the current to move easily along the wire. When passing along the wire, electrons collide with atoms in the wire, loosing energy and slowing down. It follows then that higher resistance materials have more atoms to restrict the movement of electrons slowing down, restricting, the current. The longer the length a connecting wire has, the more atoms it has and the greater is its resistance. Which is why cable sizes are so important in mobile electronics installations.

In our river again. Water enters a pipe but at its entrance is a debris-trap (an iron grid to prevent large objects entering). If the grid is clear, it will cause very little obstruction to the flow of water, but if there is a lot of debris blocking the grid, the water will find it more difficult to pass through. This will create a build-up of water on the inlet side, together with a reduction in the water flowing on the outlet side. The river is experiencing **resistance** to its flow.

Imagine that a conductor has open spaces (between atoms) for the current to move along, rather like a pipe. The higher the resistance of a conductor (lots of atoms) then the less the open spaces that exist, making it more difficult for the current to flow, this leads to a build-up of electrons, like the water at the blocked pipe grid. Similarly, too much current in a conductor or any component with resistance will create a build-up of electrons, this will generate heat that could lead to either failure or fire. If a wire is bent sharply, this will also increase its resistance by reducing the spaces between its atoms, rather like inserting a grid in the middle of a pipe.

A basic physical law says you cannot create or destroy energy you can only change or convert it into another form. Electricity is a form of **energy**. Resistance in electricity converts it into **heat**. Resistance applied correctly will limit the flow of current within a circuit but if carelessly used can cause a wide range of problems to the vehicle and equipment.

Potential causes of high resistance include:

- Bad wiring connections
- Connecting wires bent sharply
- Wire too long or not large enough for the intended current

Some problems caused by high resistance:

- Insufficient voltage/current reaching component
- Overheating
- Too much current in circuit to overcome high resistance

Controlled, intentional resistance is essential to convert electricity into another form of energy.

EFFECTIVE RESISTANCE

This is the term used to describe the resistance that a load imposes on an operating circuit.

It is not practical to measure resistance in a live circuit, so it is essential to be able to calculate the resistance from voltage and current measurements.

CONDUCTOR

A **conductor** permits the movement of electricity

This is a material that contains many free electrons that can travel relatively freely. Most metals are good conductors with gold and silver being the best.
Copper is the usual choice for wiring due its low price, but gold is preferred for connectors as it does not corrode and maintains low resistance between the contacts.

POWER

Power is the conversion of energy into work in a unit of time
Measured in *Watts*
Symbol *P*

Electrical devices are usually rated by their voltage and power. With a lamp, the specified power (**wattage**) determines the amount of light that will be produced at the rated voltage. With an electric drill the specified watts show how powerful it is.

The tank and water wheel will also help to understand power. We already know that water stored in the tank has potential energy. When the outlet tap is opened the water flows onto the water wheel, causing it to rotate. What has happened is that the stored energy has been converted into actual energy (per second, as time is also involved). This energy has been converted into work and is measured in watts.

Switching on our lamp creates the same conversion of energy into work.
A watt represents the rate over time that the energy is converted.
1 volt will move 1 amp through 1 ohm of resistance at a work rate of 1 watt per second.

In the Ohm's Law part of this course, you will see how voltage, current, resistance and power are all linked together.

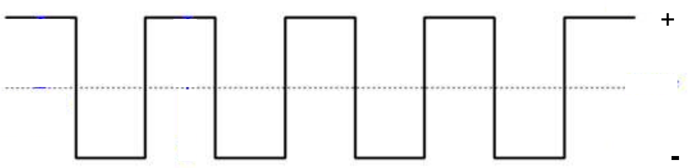
You need to know about the two types of electrical current you will be working with in the vehicle enhancement environment - AC and DC.

ALTERNATING CURRENT

Alternating current is an electrical current that periodically changes polarity
Symbol *AC*

Alternating current behaves exactly as its name implies, rapidly alternating or changing direction, from positive polarity to negative polarity at a constant rate of cycles per second (**Hertz**). The advantage of AC is that a high current supply can be carried over long distances without losing voltage or requiring oversized wires (domestic mains supply is 240 volts AC at a frequency of 50 Hertz).
AC has both an **amplitude** component (how much) and a **frequency** component (how often).

On an **oscilloscope**, AC could look like this:



The AC an installation technician is concerned with is the audio signal that flows from a radio head unit through signal processors and then amplified to drive loudspeakers. That audio signal contains many varied frequencies and amplitudes that make up the tempo and pitch of individual sounds in music.

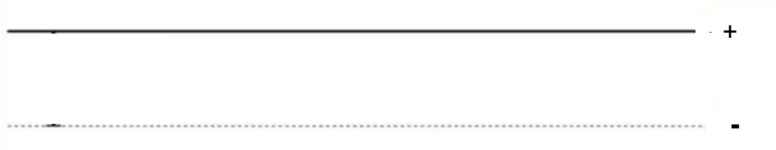
This is a short description of AC electricity, but it is all you need to know for this course.

DIRECT CURRENT

Direct current is an electrical current that flows in one direction only
Symbol *DC*

Direct current is the opposite of AC as it flows in one direction only and produces a flat, straight line on an oscilloscope. The biggest drawback to DC is that it suffers from loss of voltage. This is known as **voltage drop**. The only effective way of conducting DC along anything other than short distances is to use cable with a large diameter conductor. The longer the distance, the larger the conductor. Unfortunately, this is a very inefficient and expensive exercise, but we must use it as a battery will only supply DC

DC has only an amplitude component (called potential) and a frequency of zero.
On an oscilloscope, positive DC could look like this:



Most non-audio aftermarket electrical devices are DC.

This is a short description of DC electricity, but it is all you need to know for this course.

LOAD

A load is the resistive element within a circuit

A **load** is what causes the electrons to flow around a circuit. Without a load, a completed circuit is known as a **short circuit**. A load can consist of any resistive component, and ranges from a simple resistor or lamp to a complex electrical device.

If it consumes electricity it is a load

INSULATOR

An **insulator** resists (prevents) the movement of electricity

Insulators are poor conductors of electricity, having very few free electrons. *Most plastics, wood and glass are good insulators.* As all materials have free electrons, the perfect insulator does not exist.

OHM'S LAW and CALCULATIONS

MATHS GUIDANCE NOTES

This part introduces the basic mathematics you will need for using Ohm's Law. Many of you will have learned them already at school but others may not have or may have forgotten them. Everyone should read this section carefully; it will help you in your job and when studying for VECP qualifications. Even though this is basic maths, it may look difficult but by following the instructions and using a calculator, you will soon get to grips with the maths.

Some of this is algebra, mathematical shorthand that allows the instructions for a calculation to be written down without including any actual numbers.

SYMBOLS

It is important to recognise the following symbols and what they mean:

Multiplication can be shown as:

Symbol	Example	
x	2x4	
*	2*4	
•	2•4	**I•R** (used in Ohm's Law formulas)

Division can be shown as:

Symbol	Example	
÷	4÷2	
/	4/2	
–	$\frac{4}{2}$	$\frac{\mathbf{V}}{\mathbf{R}}$ (used in Ohm's Law formulas, you need to divide the upper number by the lower number)
$\overline{)\ \ }$	$4\overline{)2}$	

Whichever symbols are used the actual calculation remains the same.

POWERS

A **power** is mathematical shorthand that tells you to multiply a number by itself a specific number of times.

Whenever you see a number written like this:

$\mathbf{5^4}$

then you know that it is a number with a power, that is **5 to the power of 4** (5 x 5 x 5 x 5).

It is much easier to write 5^4 than 5 x 5 x 5 x 5.

Ohm's law only requires us to perform calculations to the power of **2** (this is also known as **squared**, or to square the number)

5^2 this is the same as writing 5 x 5.

To recap a **power** is simply an instruction to multiply a value (a number) by itself the stated number of times.

As an example:

$\mathbf{I^2}$ is the shorthand instruction to multiply the value of the current by itself

If **I** (current) is 2 amps

$\mathbf{I^2}$ is the same as 2 (amps) multiplied by 2 which is 2 x 2 = 4 amps

SQUARE ROOTS

The **square root** of a number is a number that when it is multiplied by itself gives the first number as the answer. This odd statement is explained by example below, but fortunately almost all calculators have a square root facility (button), only requiring you to enter the number, press the square root button and the calculator display will show the correct answer.

A square root has its own symbol:

√ which will contain a number like this:

$\sqrt{16}$ **or** √ 16

16 being the number you want to find the square root of.
The square root of 16 is 4 (which is the same as 4 x 4 = 16), the number (4) that when multiplied by itself results in the first number (16) as the answer.

DECIMAL PLACES (ROUNDING)

Not every number is a whole number.
1, 2 and 16 are examples of whole numbers but sometimes our calculations will result in an answer that is not a whole number. An answer that is between 1 and 2 or 16 and 17 are examples.
We must show these non-whole numbers somehow, so we use the
Decimal System.
The decimal system has its own symbol called the **decimal point**:

.

A non-whole number using this system looks like this:
1.5 or **16.75**
These non-whole numbers are **decimal** numbers.

When working with **decimals** you will calculate answers with a lot of figures behind the decimal point, for example 6.34562, (6 is a whole number with 5 figures behind the decimal point. This is also called five decimal places). As you move right from the decimal point, each place is divided by 10.

.3 is three **tenths**, .34 is thirty-four **hundredths**, .345 is three hundred and forty-five **thousandths** and so on.

6.34562 is a correct answer but it is too accurate for our purposes, so we need to shorten the answer to two decimal places, that is hundredths. Just like the pounds and pence we use every day.

To shorten the answer, we cannot simply remove the surplus figures (decimal places), as that would result in an inaccurate answer. Instead we use a technique called **rounding**.
This shortens an answer but keeps it accurate. As surplus figures are removed an adjustment is made to compensate for the value of the decimal places being removed.
Starting with the last (right hand) figure, if it is 5 or higher then add 1 to the figure immediately on its left. If the right-hand figure is below 5 i.e. 4 or lower, then leave the figure to its left alone.

In our example 6.34562 the last figure is 2. As this is lower than 5 you can simply cross it off and move along (left) to the next figure 6. We now have the number 6.3456
Now look at the last figure (this time it is 6) as this is higher than 5 we have to round up the figure (add 1) immediately to the its left (which happens to be 5) so 5 + 1 = 6
We now have the number 6.346

Repeat the process again and you will end up with a finished answer of 6.35 that is two decimal places to the right of the decimal point.

If one of the figures you are rounding is a 9 you need to alter two decimal places.
Say our number is 6.34952
First stage: 6.3495 we have rounded the 2, but the 5 is unchanged since 2 is lower than 5
Second stage: 6.35 when we rounded the 5, we had to increase the number to its left by 1, but as
9 + 1 = 10
we also had to add 1 to the 4 at the same time.

IMPORTANT

It is only the final answer that must be to two decimal places, **do not** round any other answers in your working below four decimal places otherwise your final answer may be incorrect. If you were to round down the intermediate calculations, the final answer may be 10% inaccurate, which when combined with any component tolerances can alter the result significantly

<table>
<tr><td rowspan="2">Try this example:
You need to work out the value of a component, and you have calculated the three following values that are to be added together.
Let's see the difference to the final answer, working to four decimal places, rounding to two decimal places and cutting to two decimal places has.</td><td>Four decimal places

0.0454
0.0454
0.0045
a 0.0953</td><td>Rounded to two decimal places
0.05
0.05
0.00
b 0.10</td><td>Cut at two decimal places
0.04
0.04
0.00
c 0.08</td></tr>
<tr><td colspan="3">a) With the answer to four decimal places
b) With the answer rounded to two decimal places, we are .0047 out
c) With the answer cut at two decimal places, we are .0153 out
The numbers used in the three calculations represent component values.
The end result of a and b is the same (round up answer a).
If we were to be using the answer within another calculation, then the error increases.</td></tr>
</table>

OHM'S LAW

Ohm's Law describes a specific and measurable relationship between the elements:

- **current**
- **voltage**
- **resistance**
- **power**

An understanding of Ohm's Law is an essential for working with vehicle electrical systems. Georg Ohm (1787-1854) discovered that there is a constant link between current, voltage, resistance and power. It is this link that makes **Ohm's Law the most important law of physics for the automotive technician working with electrical systems.**

With Ohm's Law we can, for example:

- Determine the correct size fuse and cable to use in a specific application.
- Calculate the current consumption of an alarm system in standby condition - estimating how long the vehicle can be left before engine starting becomes impossible.
- Work out how many speakers can be connected to an amplifier.

There are many more applications for Ohm's Law.

RELATIONSHIP BETWEEN RESISTANCE AND VOLTAGE

Ohm's Law states that:
Current is directly proportional to voltage and inversely proportional to resistance.
In plainer English,

- If resistance stays constant and voltage is increased - more current will flow,
- If voltage is decreased - less current will flow
- If voltage stays constant and resistance is increased - less current will flow,
- If resistance is decreased - more current will flow.

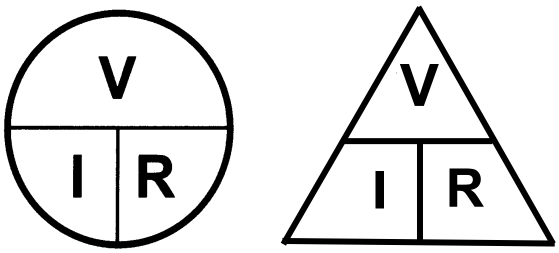
This needs some more explanation.
Ohm's Law comprises of four separate elements of electricity:

- **voltage**
- **current**
- **resistance**
- **power**

The three most important are: voltage, current and resistance; an electrical circuit can only work when all three factors are present.
All three are linked, change any one and the other two must also change, in an exactly predictable way. This means that you can easily calculate what effect changing, for example, resistance will have on a circuit. Once you understand the way that voltage, current and resistance interact, then the value of Ohm's Law becomes clear.

BASIC OHM'S LAW CHARTS AND FORMULAS

As we have said, the basic version of Ohm's Law contains three elements: voltage, current and resistance. When we have any two element values, we can calculate the third value.
Ohm's Law fits neatly into an easily remembered formula chart that automatically provides the correct formulas ready to use, totally avoiding the need to calculate mathematical formulas.



To find **voltage**: cover up the **V** and multiply current **I** and resistance **R** values together.
To find **current**: cover up **I** and divide resistance **R** value into the voltage **V** value
To find **resistance**: cover up the **R** and divide current **I** value into the voltage **V** value.

Use either style of chart - both give the same answer.
Use this simple way to remember the Ohms Law chart.
The V (volts) is an arrowhead pointing down, so it goes at the top.
I is before R in the alphabet, so I is to the left

Remember:

- **V** **Voltage** is expressed as **Volts**
- **I** **Current** is expressed as **Amps**
- **R** **Resistance** is expressed as **Ohms - symbol Ω**

SYMBOL	PARAMETER	UNIT OF MEASURE
V	**Voltage**	**Volts**
I	**Current**	**Amps or Amperes**
R	**Resistance**	**Ohms Ω**

Using the same values and performing the three different Ohm's Law calculations will prove the direct relationship that exists between voltage, current, and resistance.
Calculate the following examples using the values of 12 volts, 3 amps and 4 ohms.

To find voltage (V)
Multiply Current by Resistance:

Current ×	**Resistance** =	**Volts**
3 amps x	4Ω =	? volts
3 x	4 =	**12 volts**

To find current (I)
Divide Resistance into Volts:

Volts ÷	**Resistance** =	**Amps**
12 volts ÷	4Ω =	? amps
12 ÷	4 =	**3 amps**

To find resistance (Ohms Ω)
Divide Amps into Volts:

Volts ÷	**Current** =	**Resistance**
12 volts ÷	3 amps =	? Ohms
12 ÷	3 =	4 Ω

If you check, all three values (volts, amps and ohms) remain the same whichever way the calculations are performed, proving the direct relationship between the three.

FULL OHM'S LAW CHART AND FORMULAS

Ohm's Law has another useful element for us, **Power**. Power has the same direct relationship as the other three elements.

Electrical **POWER** is the *conversion* of energy into work over a certain period of time, and a **watt** represents the rate over time that the energy is converted. It's the result of the collective work of current, voltage and resistance. The last parameter, 'P', allows you to determine how much a system can produce, how many amps it will draw, and therefore what size of cable and fuse is needed. Power determines supply and demand.

SYMBOL	PARAMETER	UNIT OF MEASURE
P	**Power**	**Watts**

There are different forms of power:

- Mechanical power usually measured in ***Horsepower.***
- Heat measured in ***BTU's*** (British Thermal Units).
- Nuclear power measured in ***Roentgens.***
- Electrical power measured in ***Watts****.*

The law *of conservation of energy* states that energy cannot be created or destroyed only changed into some other form of energy. The same law is valid in audio circuits, where electrical energy is being converted into heat and sound.
Resistors convert electrical energy into heat.

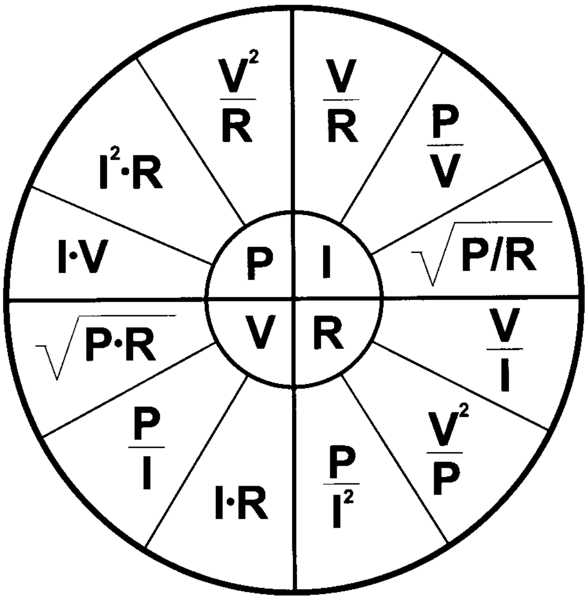
Getting back to Ohm's Law, electrical power is equal to volts times amperes,
or **P = I x V**
One volt will move **one amp** through **one ohm** of resistance, at a work rate of **one watt**.

Since power is equal to V x I, and we know from Ohm's Law that
V = I x R and P = I x R x I
We can see that; P is the same as V but multiplied by I again which is the same as:
$P = I^2 R$.

This is the formula we will use to work out the power (wattage) for most of our DC applications.

As a vehicle enhancement installer, it is important for you to understand not only Ohm's Law as a concept, but also its application in everyday installations. Ohm's Law can work out complex answers to installation questions by using the building blocks of current, voltage, resistance and power.

Power calculations are slightly more difficult and the Ohm's Law formula calculator that includes power, is more complex.



1) In the centre segment identify which value you are calculating.

2) In the outer segment determine which two values you already have; this will provide the correct formula to use.

3) Substitute the symbols for your existing values.

4) Calculate the missing value.

Once you have established how to use the wheel, it becomes more useful than the basic version

As an alternative to the wheel, Ohm's Law can be put into table format with each element having its own table.

To calculate Power P	
Known values	Formula to use
Current and Voltage	I x V
Current and Resistance	I^2 x R
Voltage and Resistance	$V^2 \div R$

To calculate Current I	
Known values	Formula to use
Voltage and Resistance	V ÷ R
Power and Voltage	P ÷ V
Power and Resistance	√ (P ÷ R)

To calculate Resistance R	
Known values	Formula to use
Voltage and Power	$V^2 \div P$
Power and Current	$P \div I^2$
Voltage and Current	V ÷ I

To calculate Voltage V	
Known values	Formula to use
Power and Current	P ÷ I
Current and Resistance	I x R
Power and Resistance	√ (P x R)

Try using the Ohm's Law wheel and the table, then use whichever you find easiest. The result is the same.

Another method is this Ohm's Law list:

If you want to find…	**and you know…**	**then the formula is…**
Current (I)	Voltage (V) and Resistance (R)	$V \div R = \mathbf{I}$
Current (I)	Power (P) and Voltage (V)	$P \div V = \mathbf{I}$
Current (I)	Power (P) and Resistance (R)	$\sqrt{(P \div R)} = \mathbf{I}$
Voltage (V)	Power (P) and Resistance (R)	$\sqrt{(P \times R)} = V$
Voltage (V)	Current (I) and Resistance (R)	$I \times R = V$
Voltage (V)	Power (P) and Current (I)	$P \div I = V$
Resistance (R)	Voltage (V) and Current (I)	$V \div I = R$
Resistance (R)	Power (P) and Current (I)	$P \div I^2 = R$
Resistance (R)	Voltage (V) and Power (P)	$V^2 \div P = R$
Power (P)	Voltage (V) and Current (I)	$V \times I = P$
Power (P)	Resistance (R) and Current (I)	$R \times I^2 = P$
Power (P)	Voltage (V) and Resistance (R)	$V^2 \div R = P$

When a square root formula has a calculation in brackets like this $\sqrt{(P \times R)}$, work out the calculation in brackets first and then find the square root.

It is important to your use of electricity in vehicles that you understand Ohm's Law and its calculations.

This is the end of the Foundation Course.

There is a free on-line test accompanying this Foundation Course.
Go to www.mesf.org.uk

No registration or password is needed.

The test can be retaken.

Your next step is to get your MESF Basic Installation qualification that is part of the Vehicle Enhancement Certification Programme.
Go to www.mesf.org.uk

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