{Introduction}

Welcome to the Electronics Fundamentals Course. Throughout this course you will learn the building blocks of electronic devices that you use everyday. Devices such as computers, smart phones, calculators, video games and more.

Please note – this course is not complete! I had intended on making it a complete course however it was a little too time consuming. But hopefully the information in these pages comes in very handy nonetheless.

{Introduction}

{About Me}

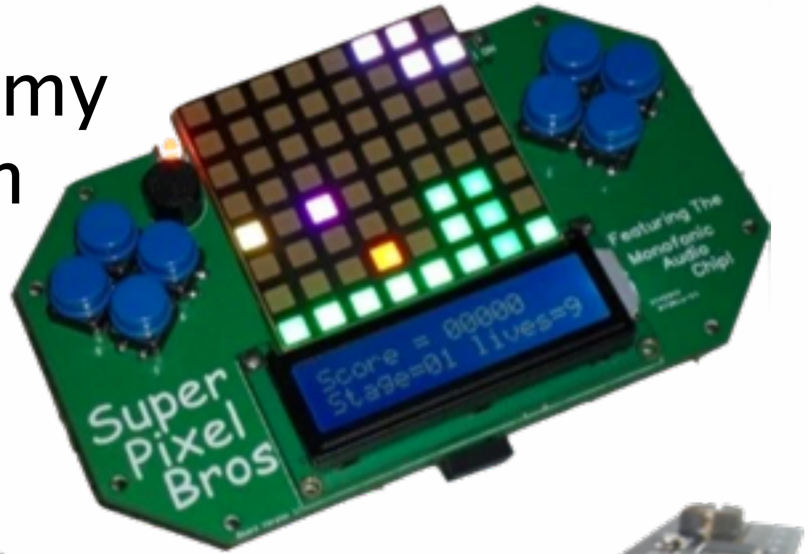
My name is Brad and I have been a full time electronics teacher since 2007. Electronics is not only an incredibly interesting hobby to get in to, but can also make for an exciting career.

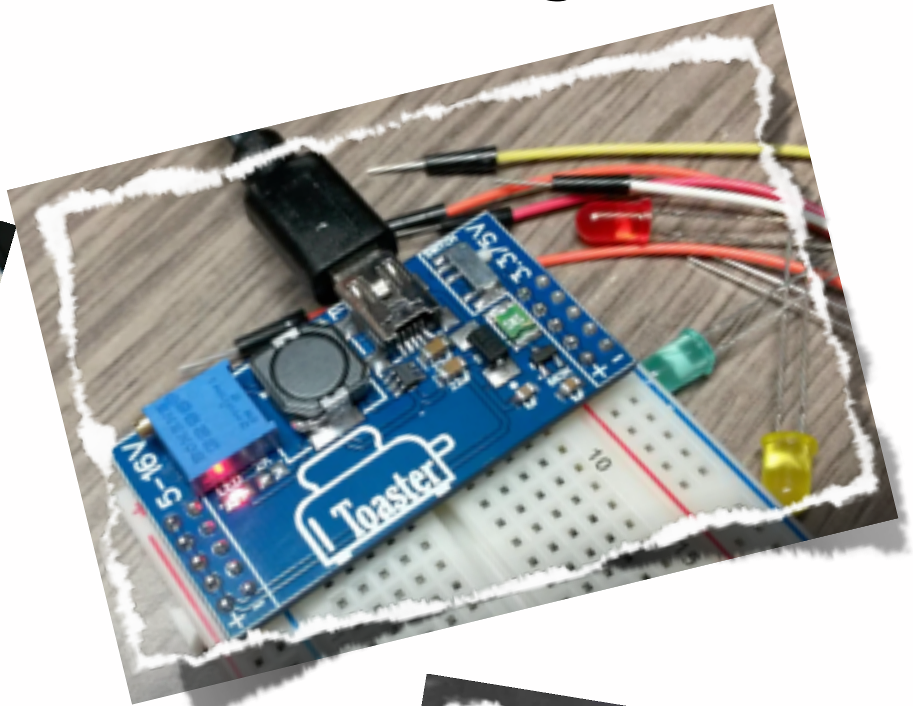
Throughout years of teaching electronics subjects I been able to tweak my teaching style in such a way to make the content no only informative, but have it delivered in a fun easy to understand fashion.

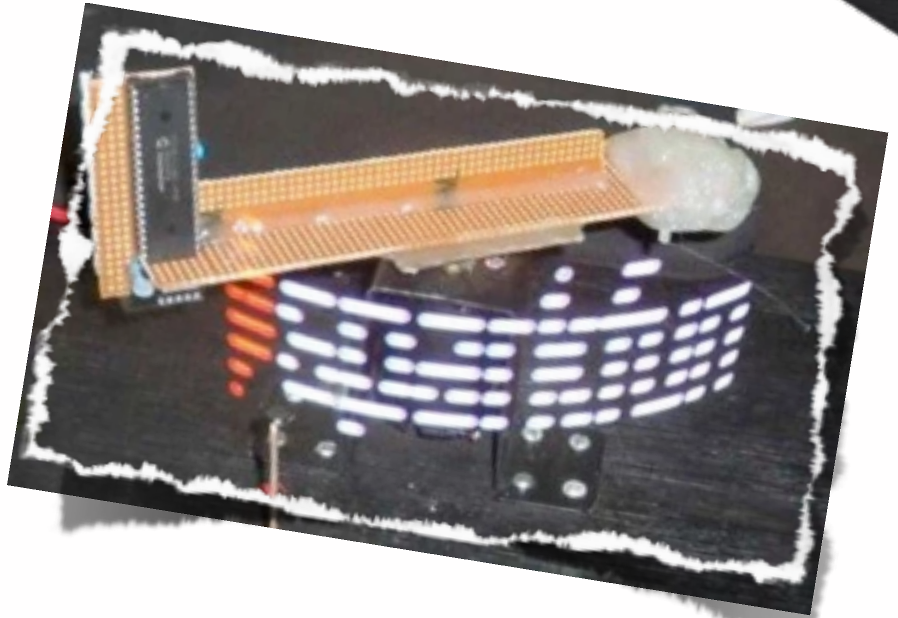
{Introduction}

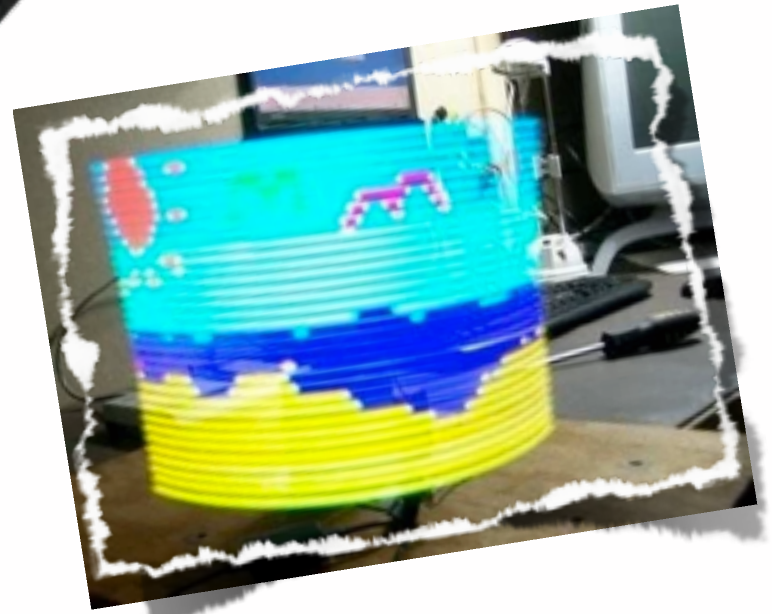
{About Me}

I have designed and built dozens of projects which you can find on my website www.bradsprojects.com – Some of these projects have been successfully funded on Kickstarter together raising over $110000.









{Introduction}

{My Projects – Retroball}

Retroball is a classic bat and ball style game in the likeness of PONG which was popular back in the 1970’s and 80’s. My version can be played by up to four players and with up to four balls on the screen at once.

{Introduction}

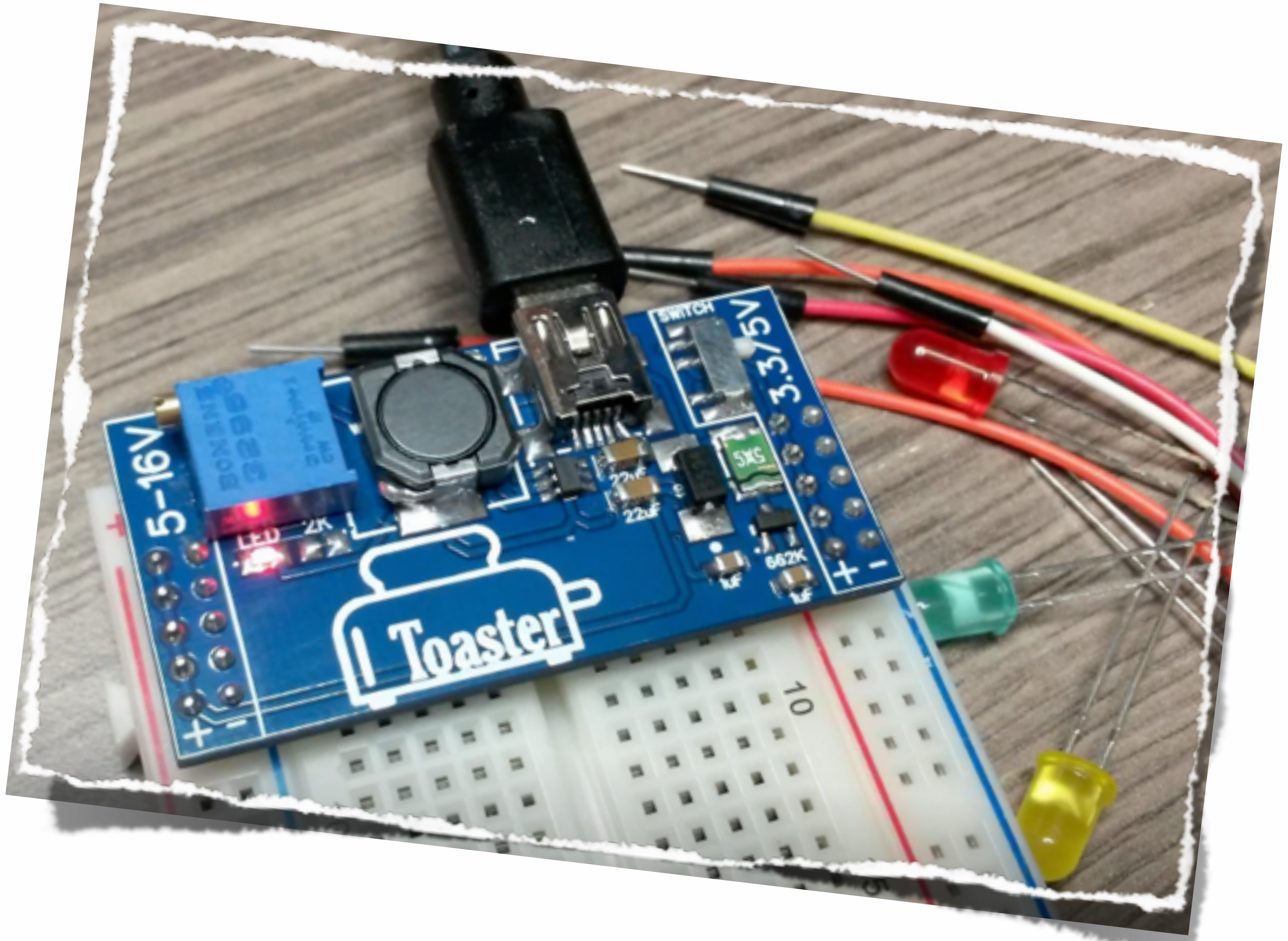
{My Projects - USB Meter Pro}

The USB Meter Pro is a small device which gives you information about the power output of your USB ports as well as telling you how fast your mobile phone or tablet is charging. It contains a built in feature to boost your charging speed as well.

{Introduction}

{My Projects – Toaster}

Toaster is a mini breadboard power supply which allows you to power up all sorts of different projects with all sorts of different power requirements, all from a single USB port.



{Introduction}

{My Projects – Conclusion}

These project examples serve to show you what you could build when you are armed with the knowledge of how electronic circuits work. Electronics is a wonderful hobby to get in to and even after over ten years of being a full time electronics teacher, I still find it fascinating!

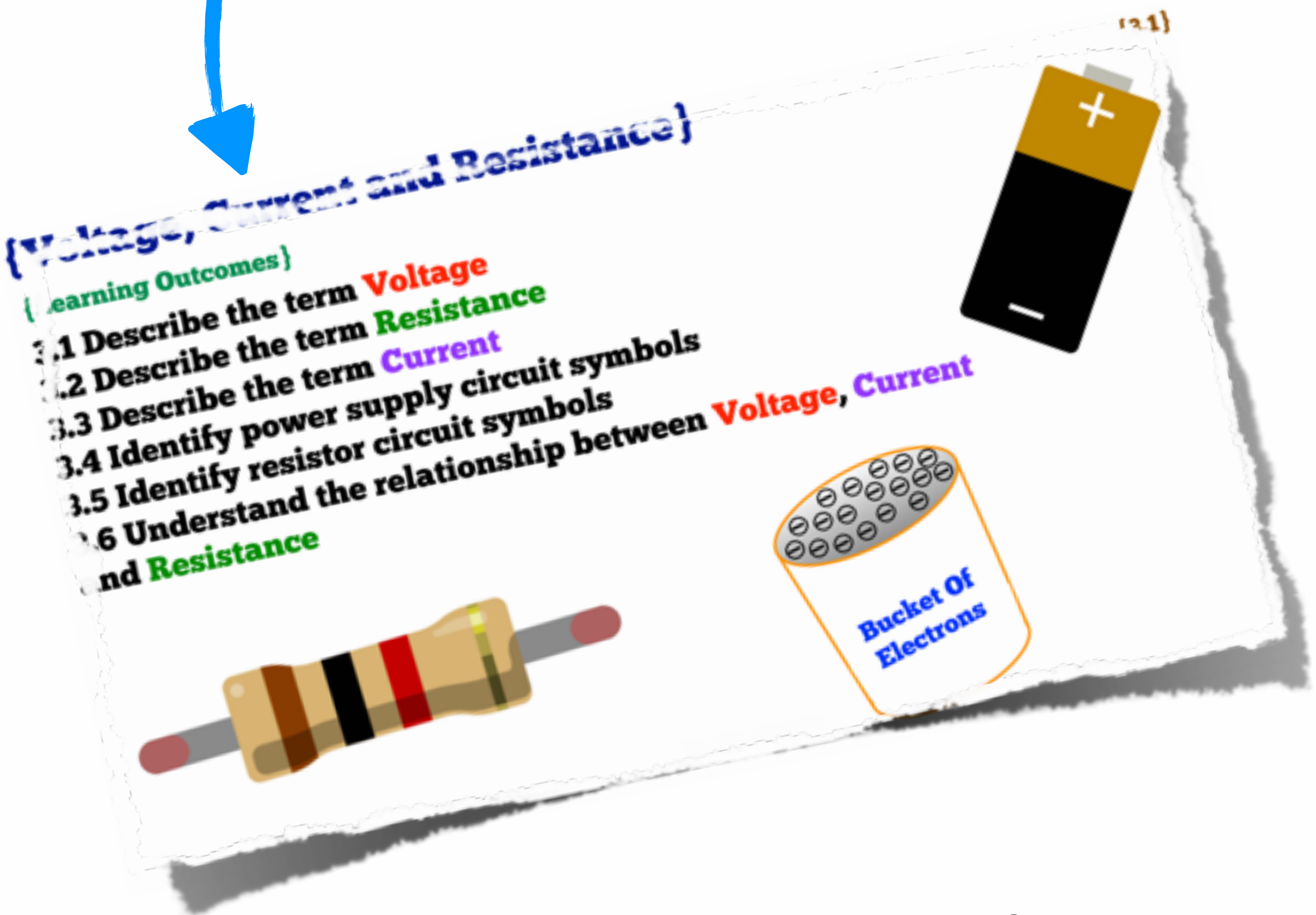
This course is the result of years of tweaking my teaching style to not only help you understand electronics theory, but to deliver it in a fun easy to read fashion.

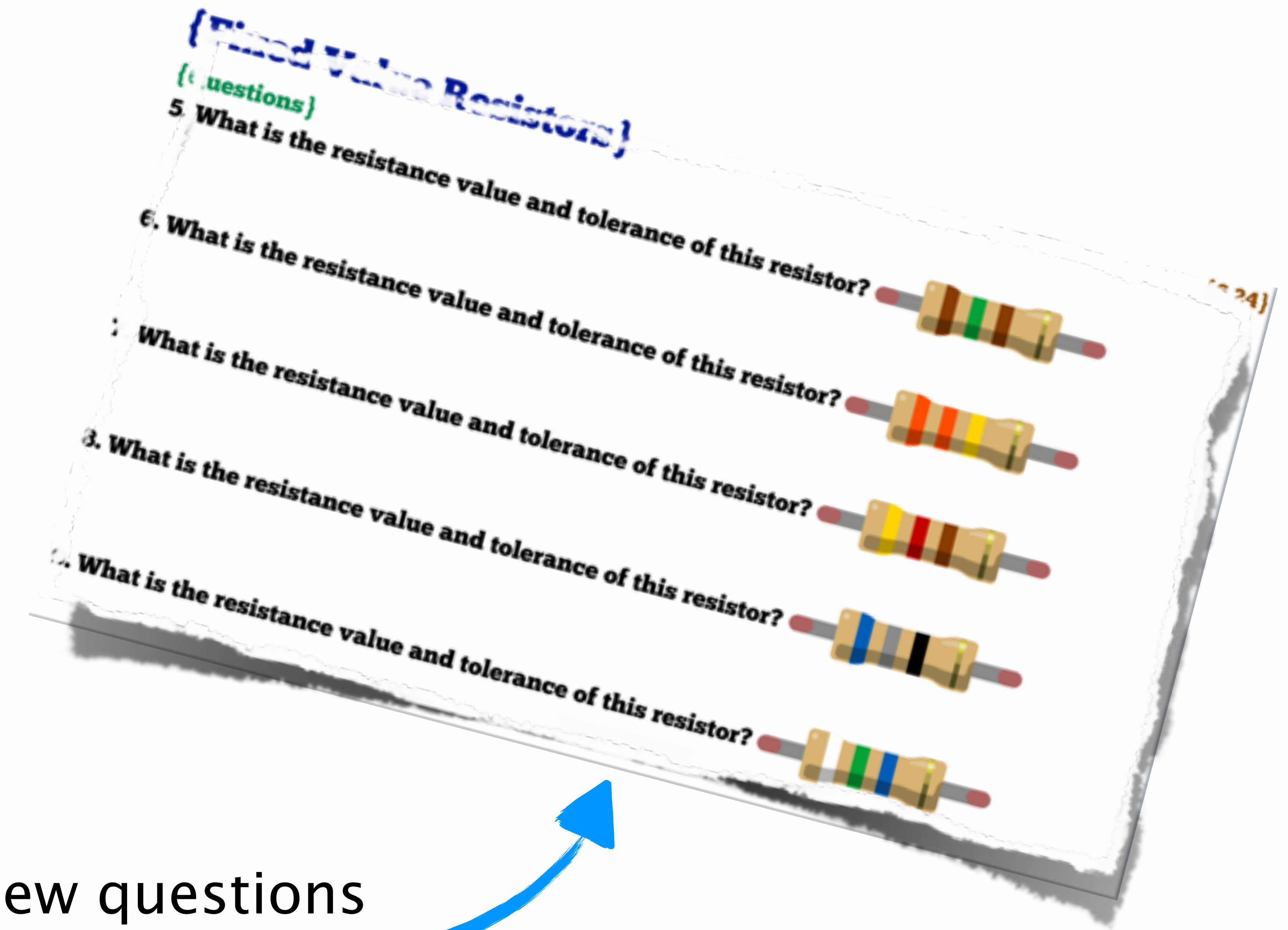
There will be plenty of practical exercises for you to perform so that you will ‘learn by doing’. This is a great way to get theoretical concepts to actually stick in your brain.

{Introduction}

{Course Structure}

To help you along the way, each chapter starts with a learning outcomes page. Once you finish each chapter, if you can answer yes to understanding each of those learning outcomes, then you have achieved what you needed to for that chapter.



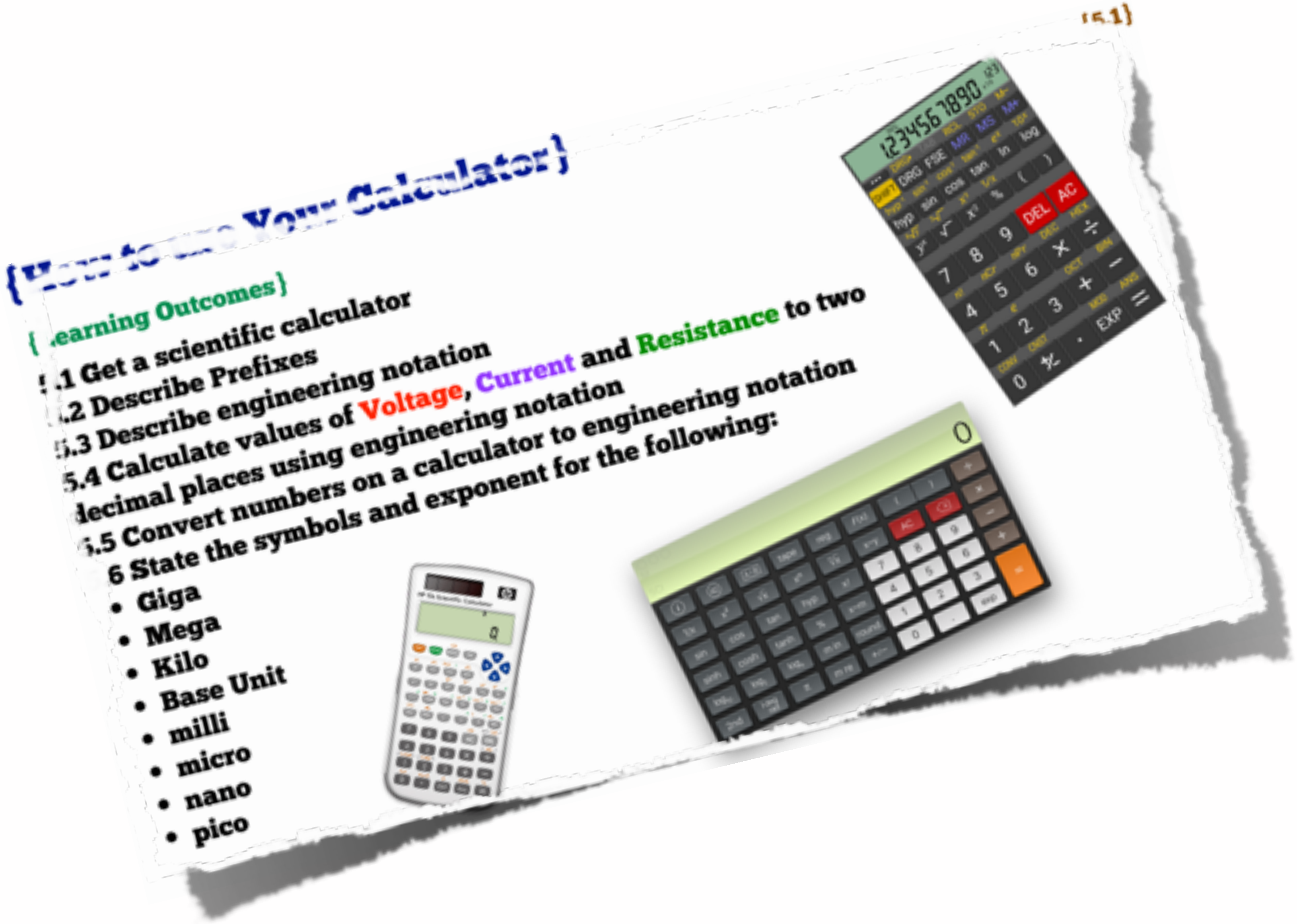


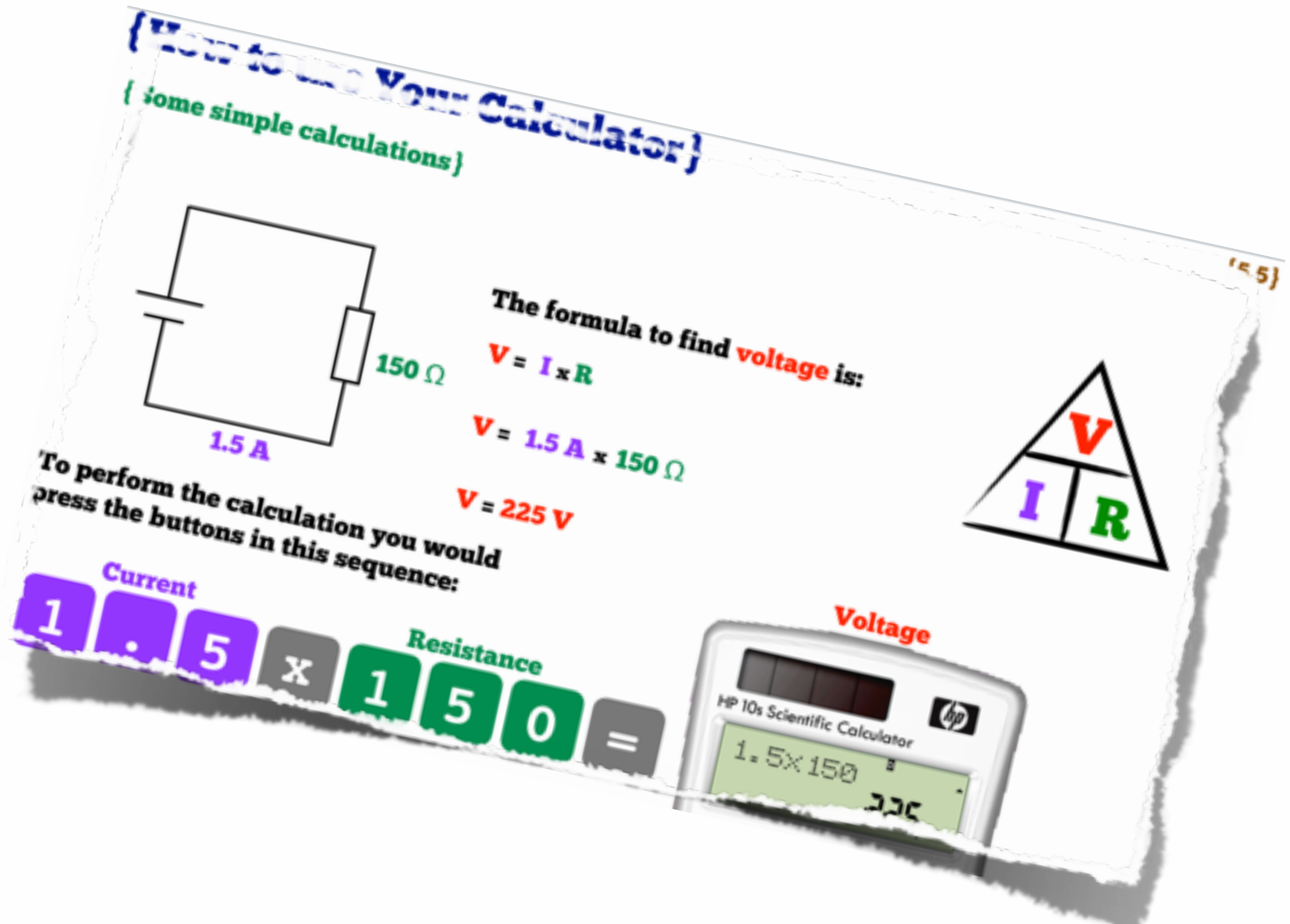
There are also end of chapter review questions for you to do, to self check your knowledge.

{Introduction}

{Course Structure}

At the heart of electronic circuits are calculations! But don't worry because there is a whole chapter dedicated to teach you how to use your calculator.

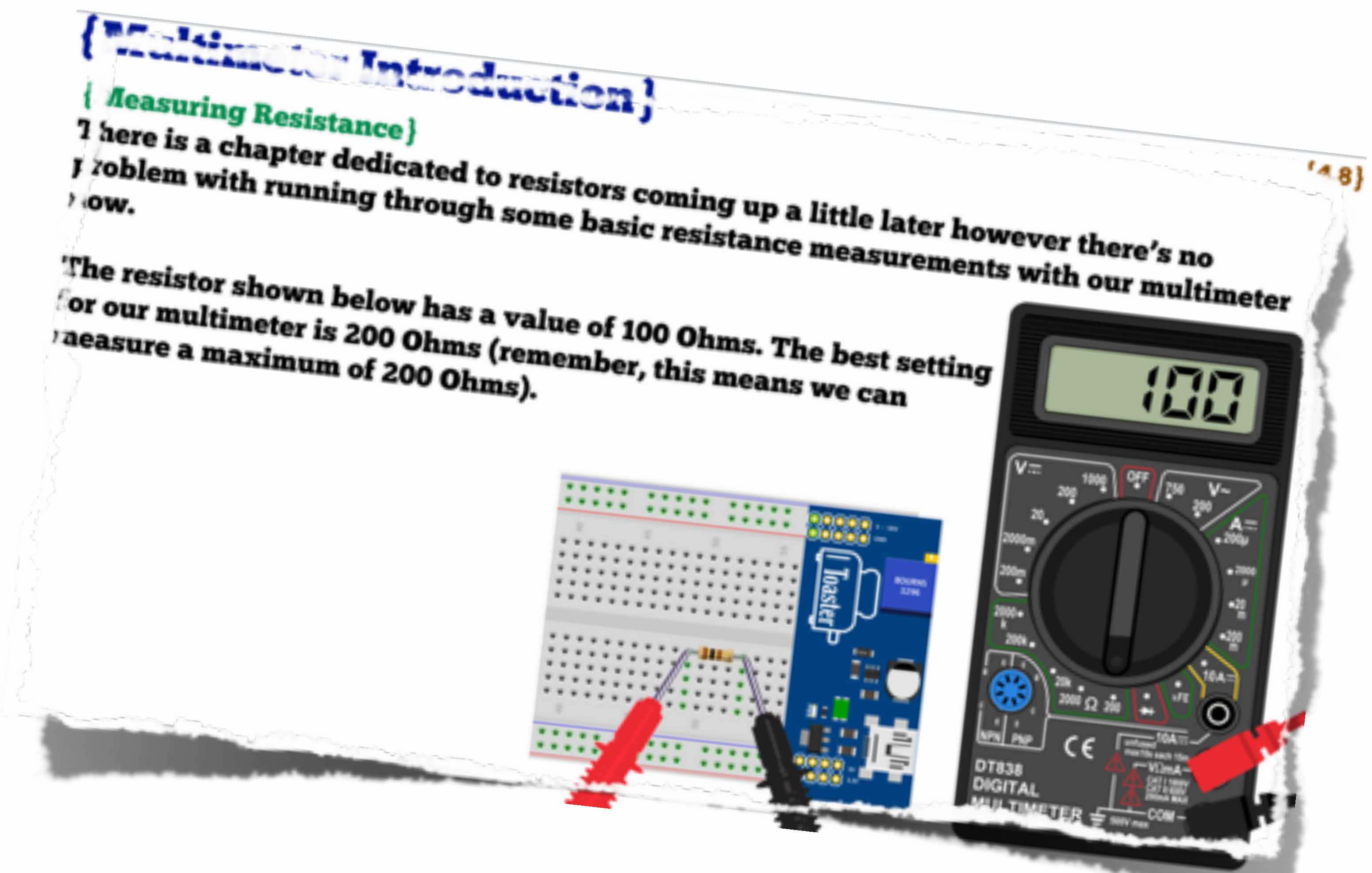




{Introduction}

{Course Structure}

Practical activities are perhaps the best way to gain an understanding of how electronic components and circuits work. As you progress through the course you will be given plenty of practical exercises to perform.

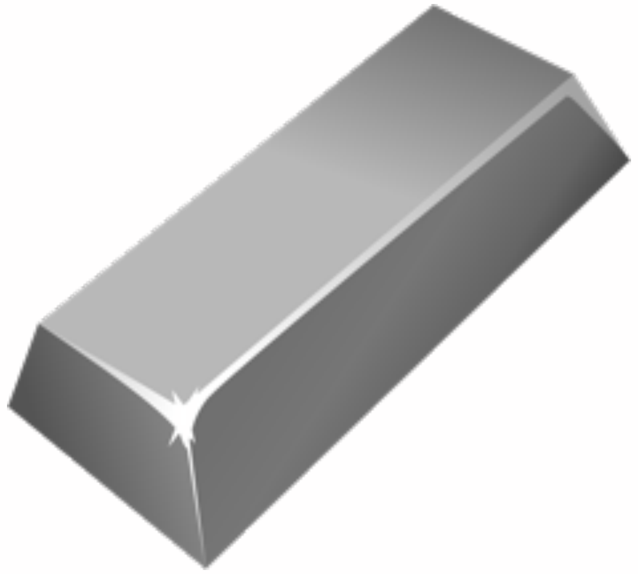


{Introduction}

{Conclusion}

So make sure your brain is switched on, because the first chapter (basic Atomic Theory) is coming up on the next page!

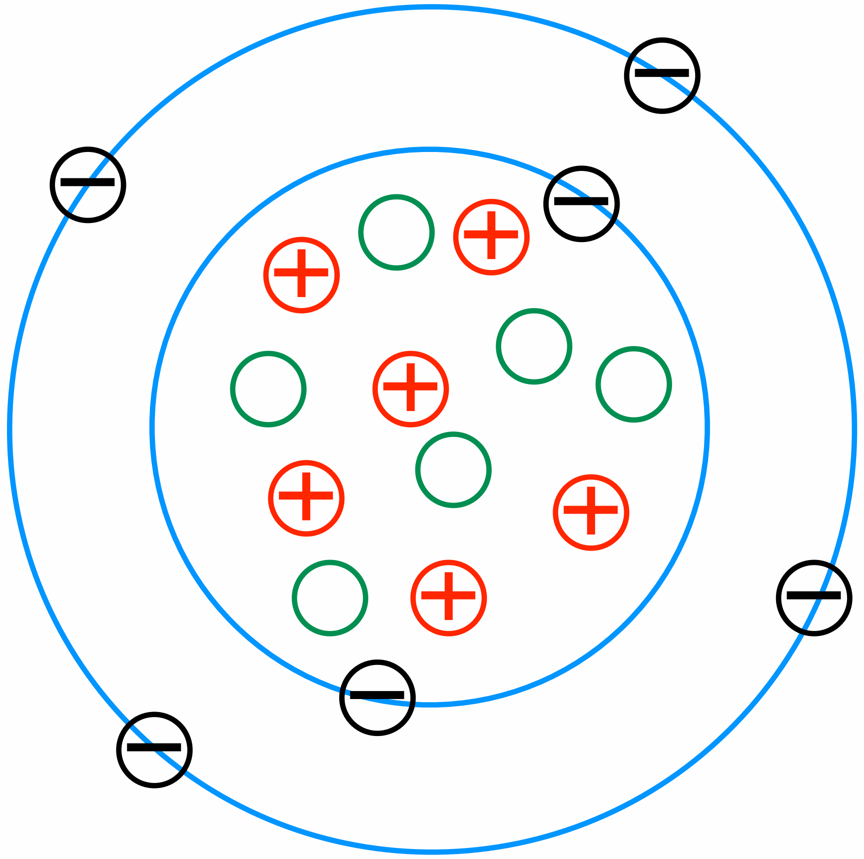
{Basic Atomic Theory}



{Learning Outcomes}

1.1 Describe the make up of an atom
1.2 Describe what makes an element a conductor
1.3 Describe what makes an element a semiconductor
1.4 Describe what makes an element an insulator
1.5 Describe the significance of an atoms valence shell
1.6 Describe what happens when an electron gains energy
1.7 Describe what a coulomb of charge is
1.8 Define neutral atoms, positive ions and negative ions
1.9 Identify conductors, semiconductors and insulators from the periodic table of elements

Atomic number	Symbol	Name	Electron shells
13	Al	Aluminium	2, 8, 3
29	Cu	Copper	2, 8, 18, 1
7	N	Nitrogen	2, 5
18	Ar	Argon	2, 8, 8
79	Au	Gold	2, 8, 18, 32, 18, 1
32	Ge	Germanium	2, 8, 18, 4
14	Si	Silicon	2, 8, 4

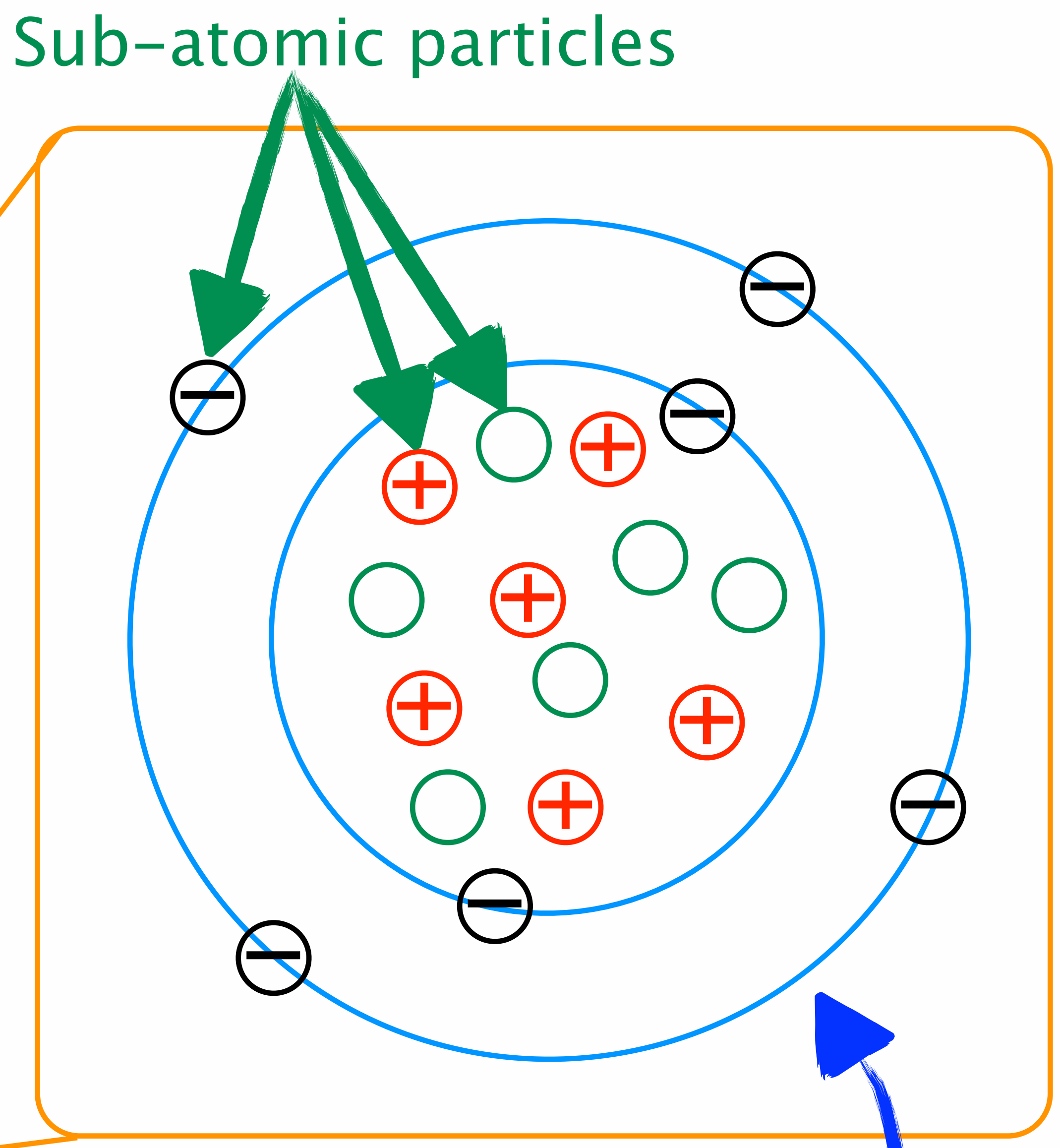


{Basic Atomic Theory}

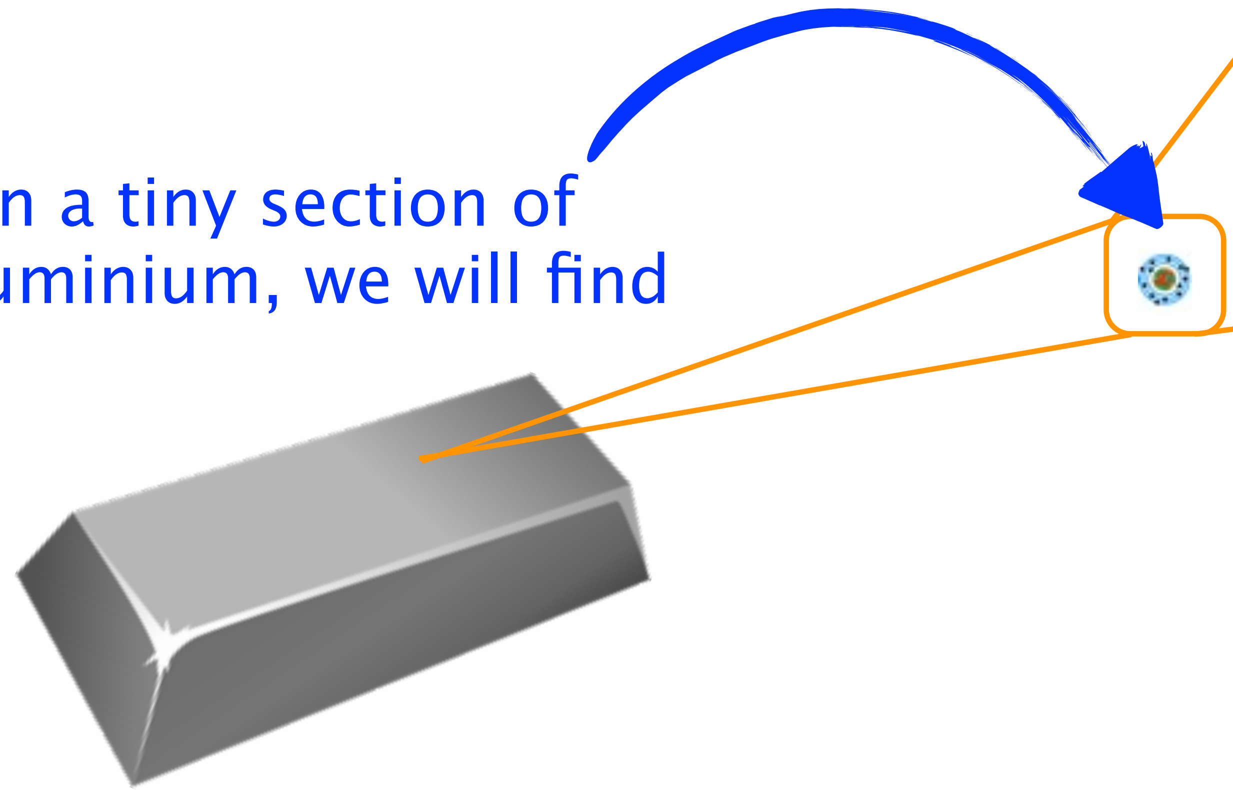
{Introduction}

Matter (otherwise known as ‘stuff’) is made up of billions of tiny atoms and each atom is made up of a number of smaller particles known as sub-atomic particles. We need to talk about the make up of an atom to get some idea about how electronic circuits actually work.

To help us on our way, we will have a look into the atoms that make up this bar of aluminium.



If we zoom in on a tiny section of this block of aluminium, we will find a single atom.



If we zoom in even further we will see that an atom is made up of even smaller things!

{Basic Atomic Theory}

{Aluminium Atom Features}

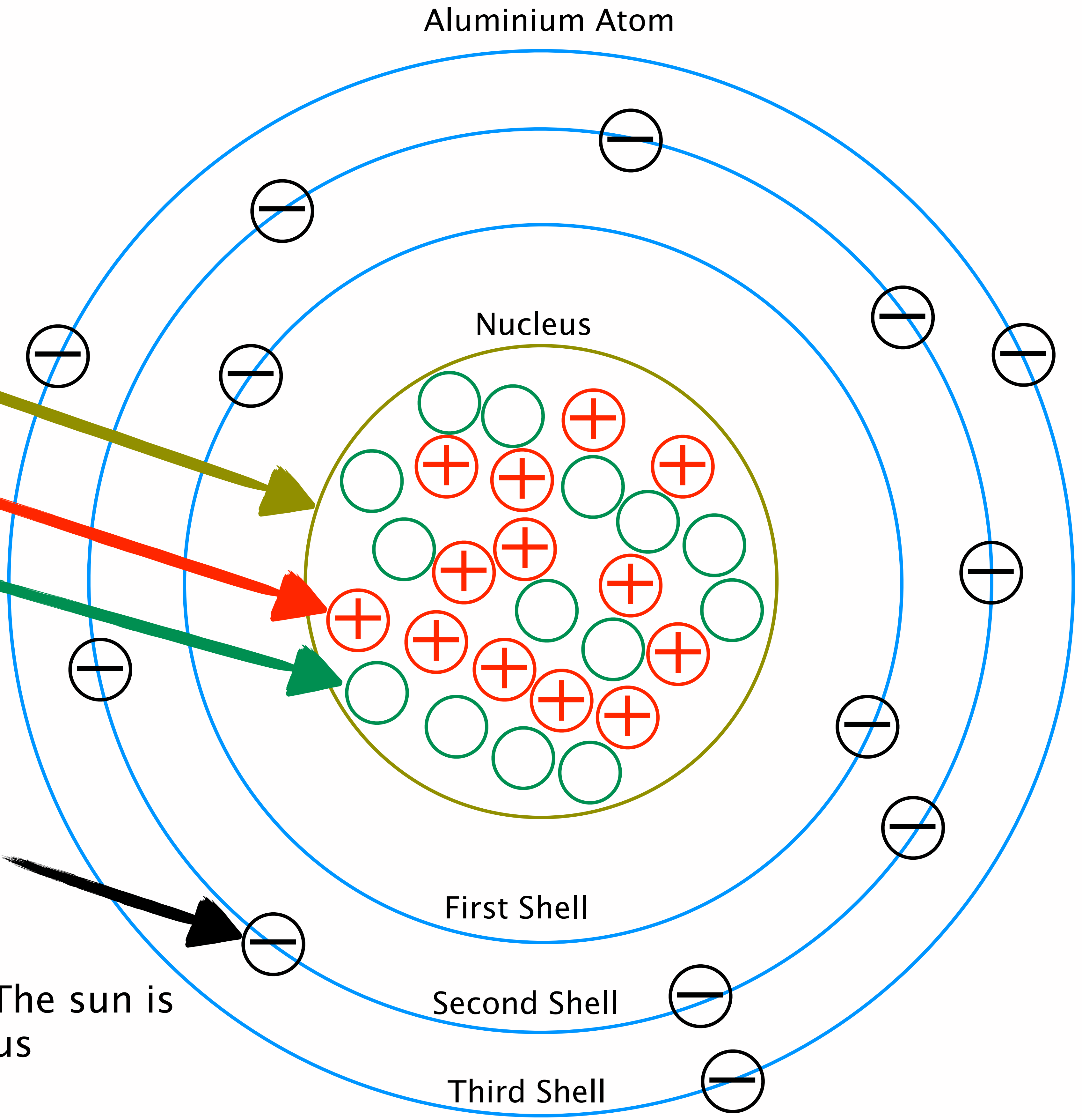
- 14 Neutrons (No charge / Neutral)
- 13 Protons (Positive charge)
- 13 Electrons (Negative Charge)

The nucleus is at the centre of the atom and houses the protons and neutrons.

Protons are in the nucleus and have a positive charge

Neutrons are in the nucleus and have no charge (they are neutral)

Electrons orbit around the nucleus in what are known as shells or energy levels. Electrons will fill these shells starting from the inner shell and then moving out. The inner most shell can have a maximum of 2 electrons, the next shell can have a maximum of 8 and the list goes on. Electrons have a negative charge.



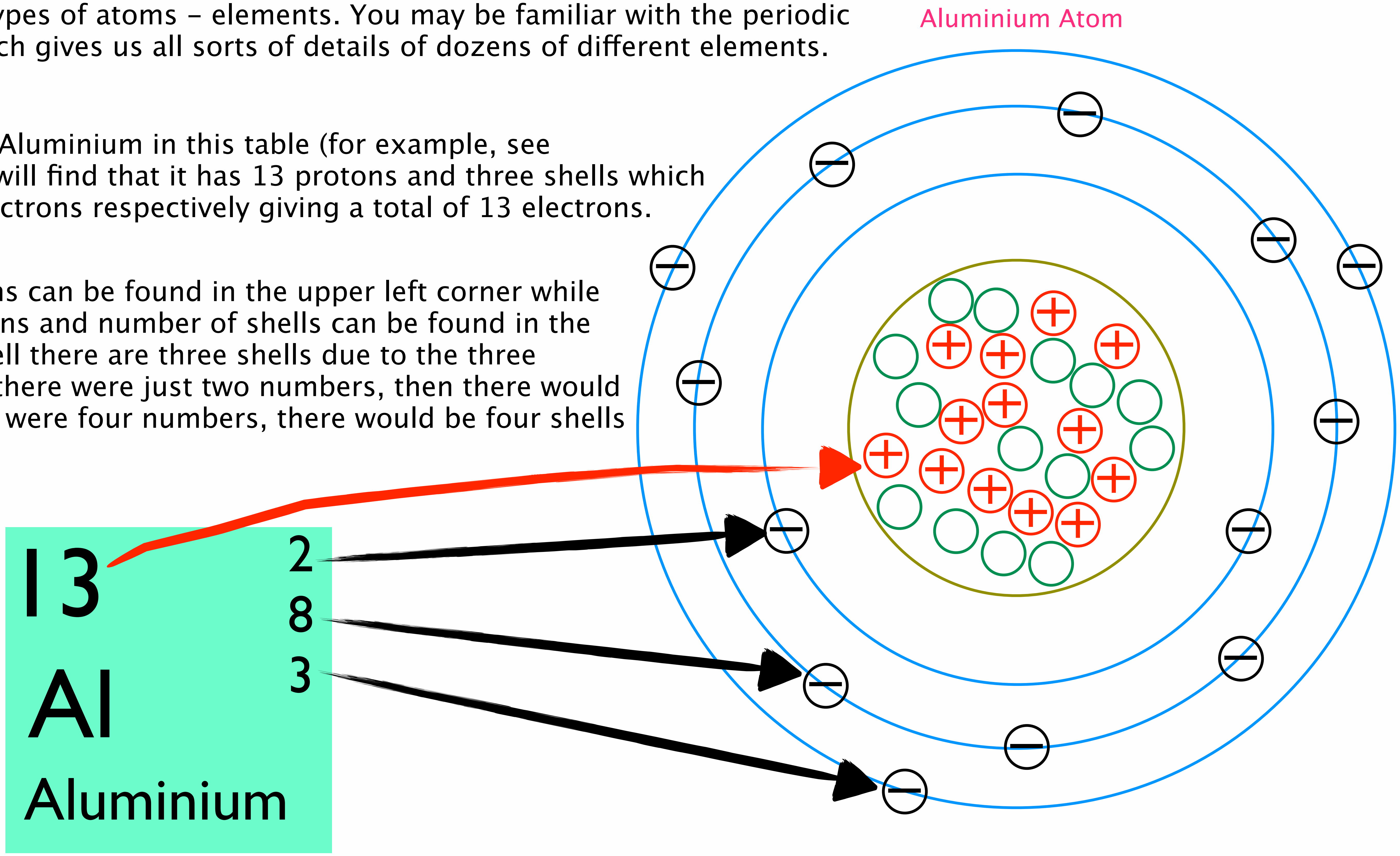
It can be useful to think of an atom like our solar system. The sun is at the centre and the planets orbit around the sun at various distances from it.

{Basic Atomic Theory}

There are all sorts of different atoms which make up all of the matter that we have today. We often call types of atoms – elements. You may be familiar with the periodic table of elements which gives us all sorts of details of dozens of different elements.

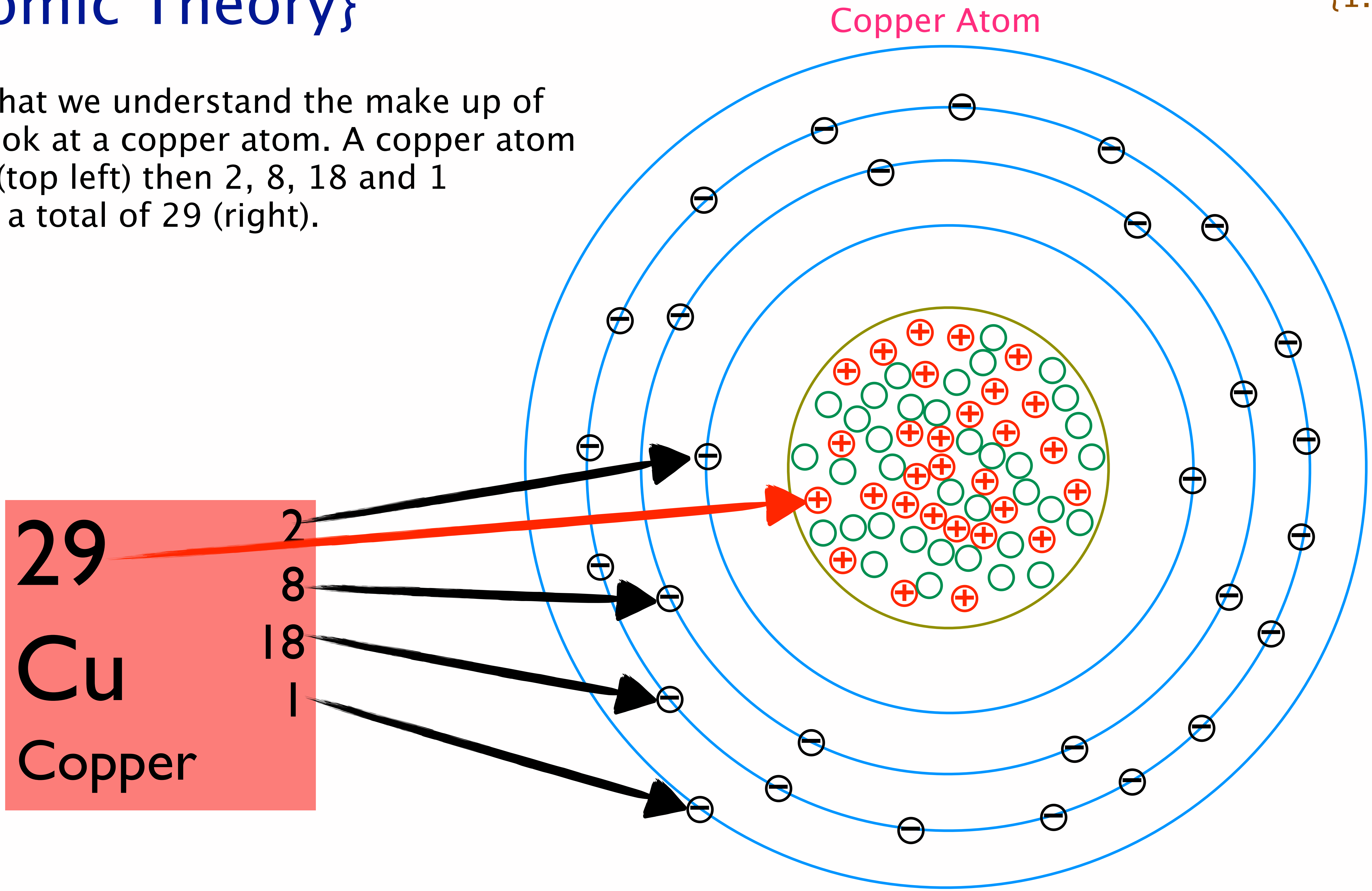
If we were to look up Aluminium in this table (for example, see www.ptable.com) we will find that it has 13 protons and three shells which contain 2, 8 and 3 electrons respectively giving a total of 13 electrons.

The number of protons can be found in the upper left corner while the number of electrons and number of shells can be found in the upper right. We can tell there are three shells due to the three different numbers. If there were just two numbers, then there would be two shells. If there were four numbers, there would be four shells and so on.



{Basic Atomic Theory}

Just to be sure that we understand the make up of an atom, let's look at a copper atom. A copper atom has 29 protons (top left) then 2, 8, 18 and 1 electrons giving a total of 29 (right).



{Basic Atomic Theory}

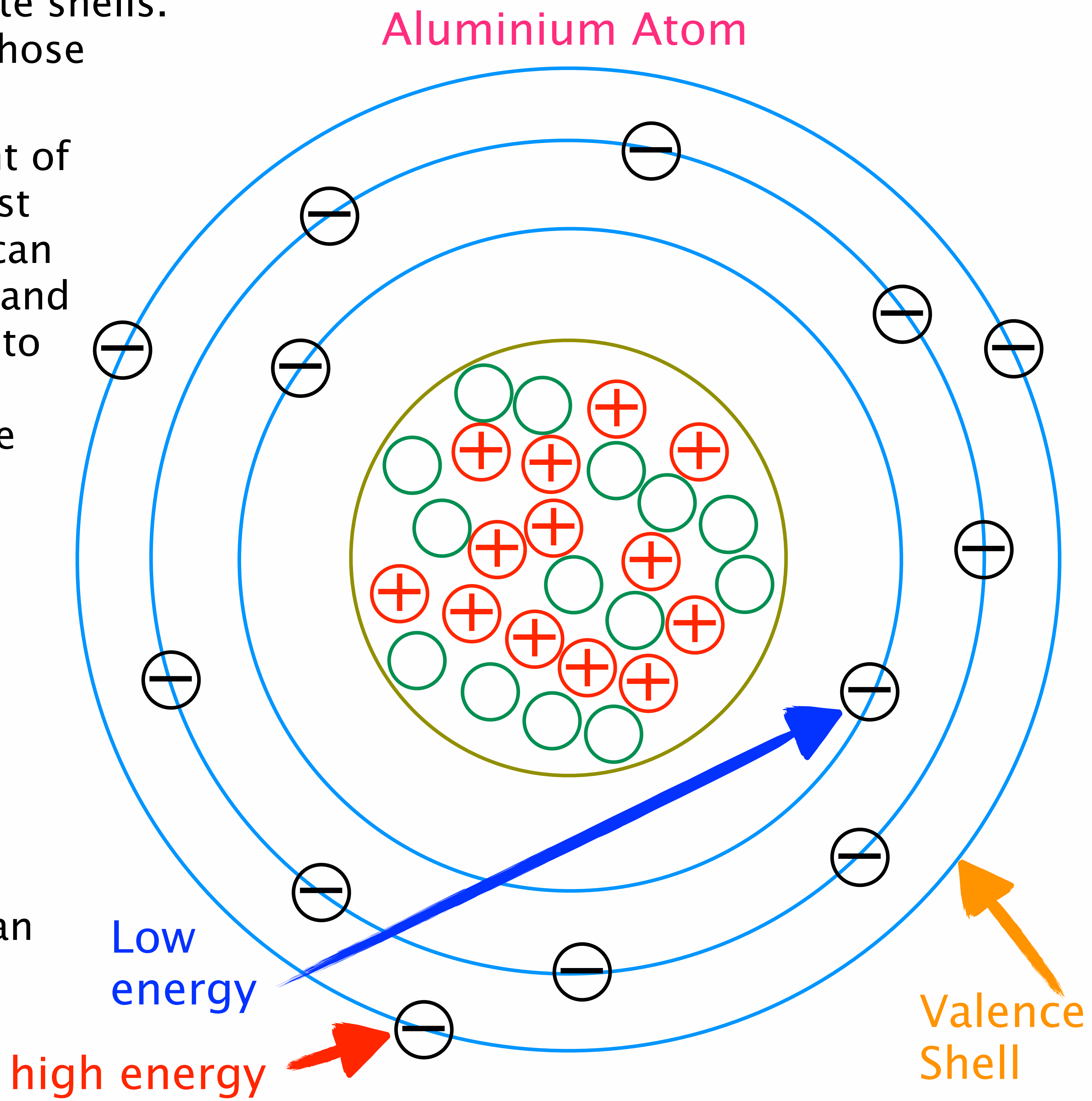
Notice how with the aluminium atom there are three separate shells. These different shells represent different energy levels for those electrons.

The electrons closest to the nucleus have the lowest amount of energy while the electrons in the outer shell have the highest amount of energy. If we add energy to these electrons, we can make them jump to a shell that is further from the nucleus and we can even make them jump right out of the atom and go to a different atom! This is going to be the most important concept with respect to making electronic circuits work. The movement of electrons through our circuit.

So where do the electrons get their extra energy from?

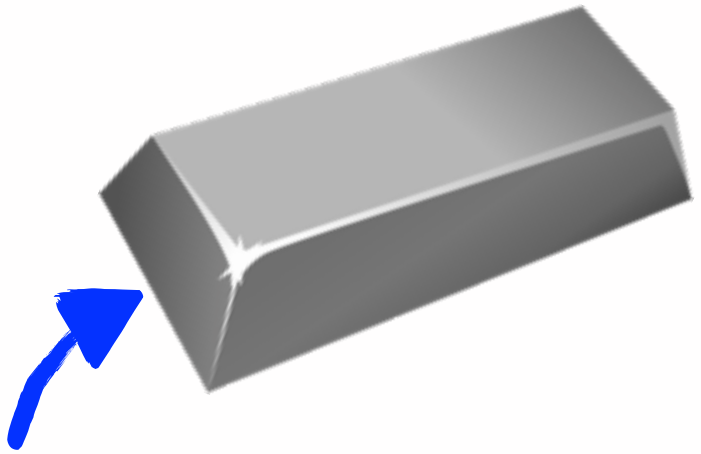
Well, they can get energy from all sorts of sources such as heat, light or more commonly from some form of electric power supply like a battery.

One last thing before we move on. The outer most shell of an electron has a special name. It is called the Valence shell.



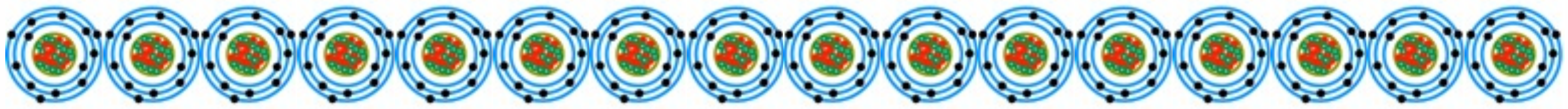
{Basic Atomic Theory}

{Conductors, Insulators and Semiconductors}



So you may be wondering 'well why do we care about all of this theory about atoms anyway?' Well that is a good question!

As stated previously, matter is made up of multiple billions of atoms (like the block of aluminium). If we add energy to the electrons in these atoms we can cause the electrons to move from atom to atom. It is these electrons flowing through the 'string' of atoms that causes electronic devices to actually work.



The number of electrons in an atoms valance shell determines how easily electrons can move from one atom to another. From this we have three categories based on the number of electrons in an atoms valance shell:

{Number of Valance Shell Electrons}

- 1,2 or 3 = Conductor
- 4 = Semiconductor
- 5,6,7 or 8 = Insulator

If you have a look at www.ptable.com once again, you will find that all the elements listed there will fall under one of these three classifications. A conductor allows electrons to move quite easily from atom to atom. An insulator makes it extremely hard for electrons to move from atom to atom and then in between these two are semiconductors.

{Basic Atomic Theory}

Here are six elements from the three classifications. Let's run through them.

Aluminium, Copper and Gold are good conductors because they have 3, 1 and 1 valance shell electrons respectively. Copper and Gold are the best conductors since they each have just one valance shell electron.

Atomic number	Symbol	Name	Shells
13	Al	Aluminium	2, 8, 3
29	Cu	Copper	2, 8, 18, 1
79	Au	Gold	2, 8, 18, 32, 18, 1

Nitrogen and Argon are good insulators since they have 5 and 8 valance shell electrons respectively. Argon is the best insulator since it has eight valance shell electrons.

Atomic number	Symbol	Name	Shells
7	N	Nitrogen	2, 5
18	Ar	Argon	2, 8, 8

Finally, we have Germanium and Silicon which are semiconductors containing four valance shell electrons each.

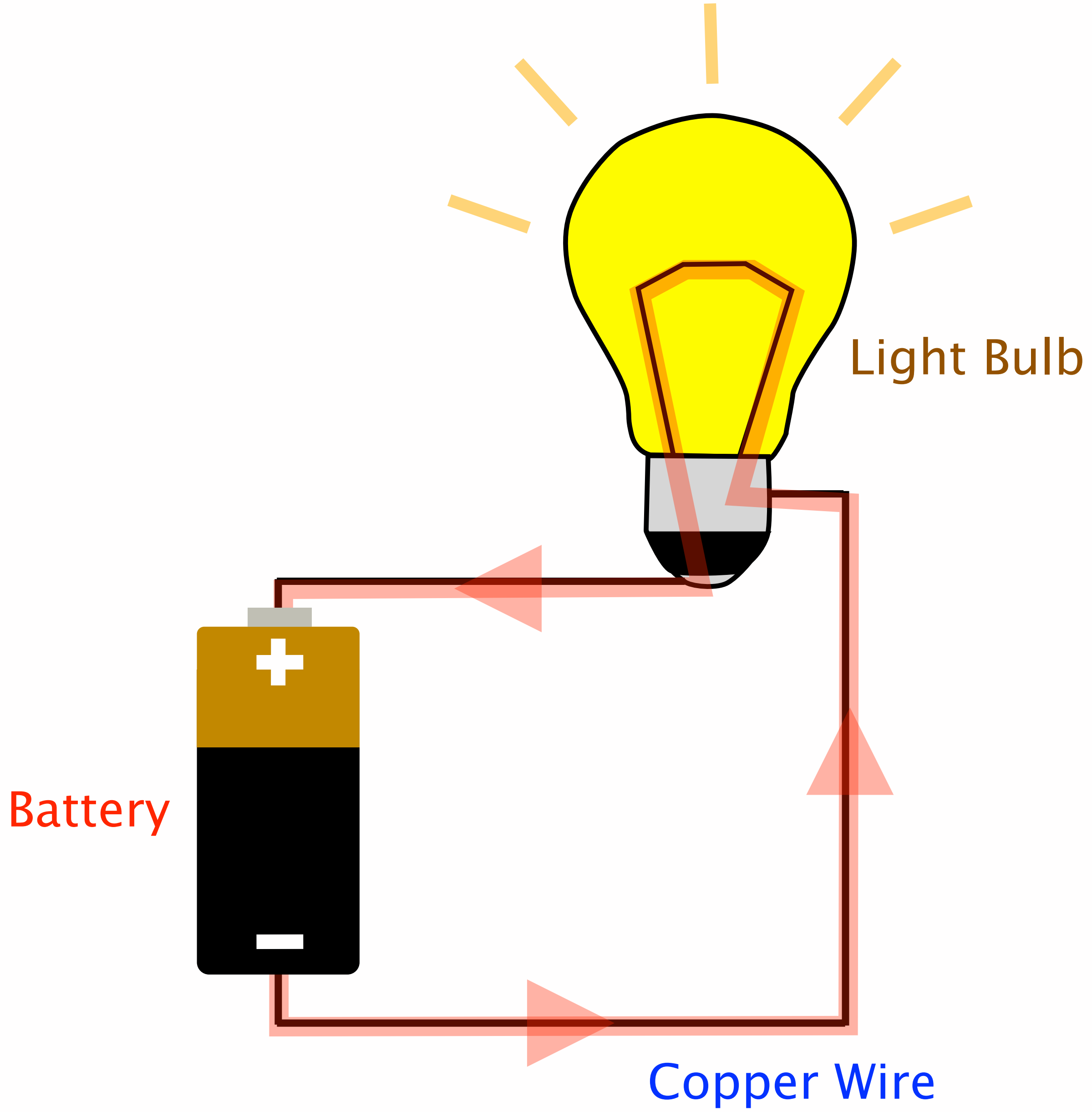
Atomic number	Symbol	Name	Shells
32	Ge	Germanium	2, 8, 18, 4
14	Si	Silicon	2, 8, 4

{Basic Atomic Theory}

{Where do we use conductors?}

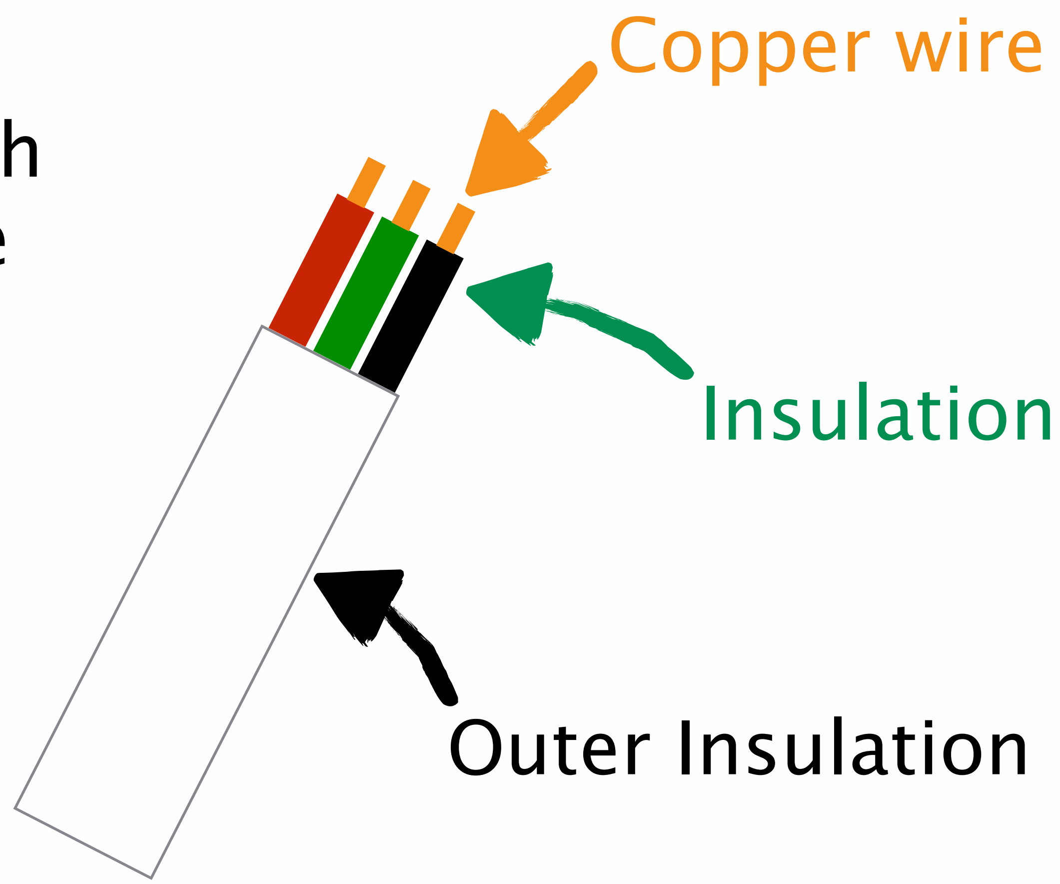
Conductors are extremely important within electronic circuits since it is quite easy for electrons to travel through a conductor. If we wanted to connect a light bulb to a battery for example, we would use some sort of conductor such as copper wire.

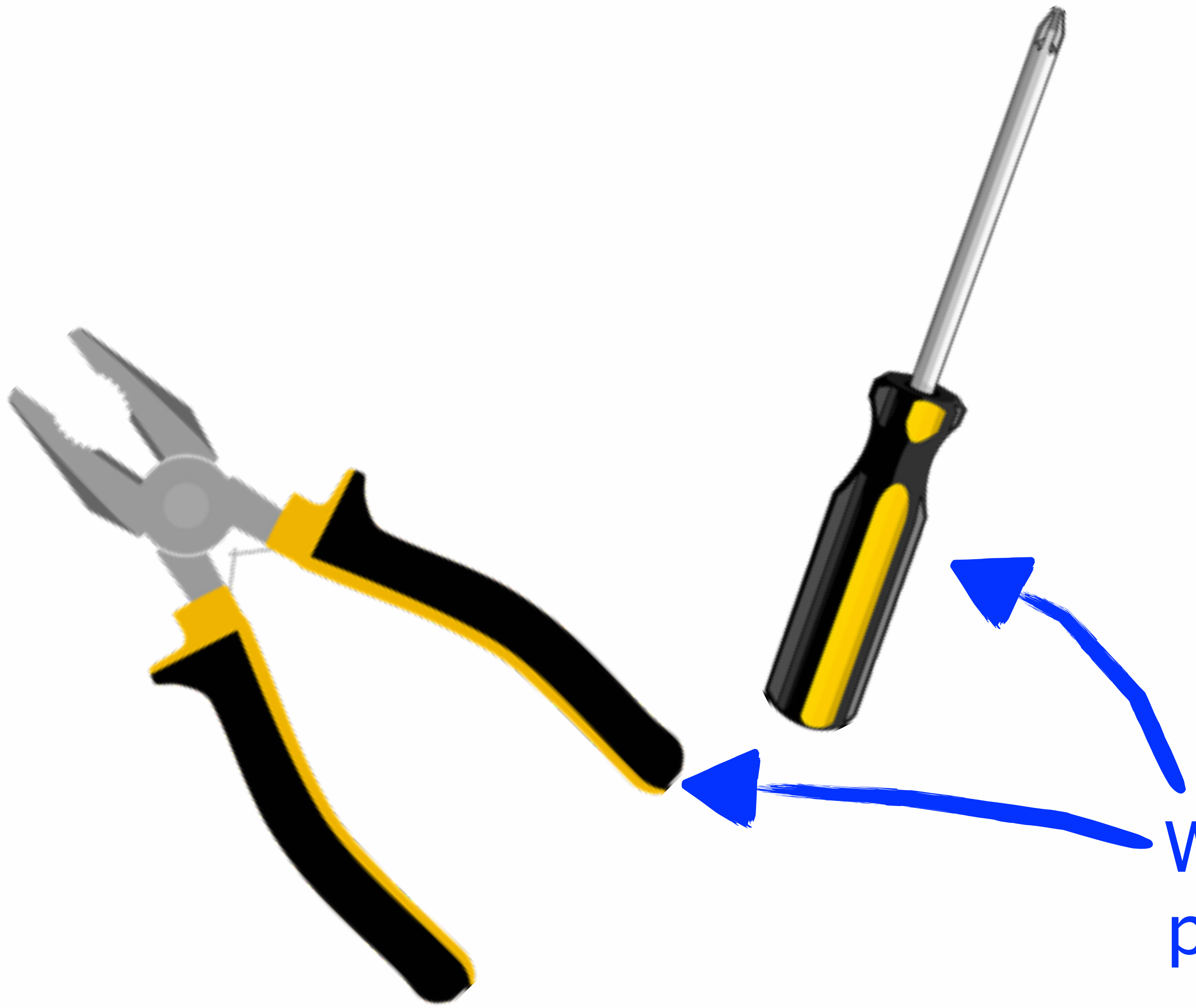
The battery is a source of electrical energy that is able to 'push' electrons through the copper wire by adding energy to them. This movement of electrons through our 'circuit' causes the light bulb to glow.



{Where do we use insulators?}

In order to prevent copper wires from touching each other when they shouldn't we encase them in some sort of insulator such as plastic.



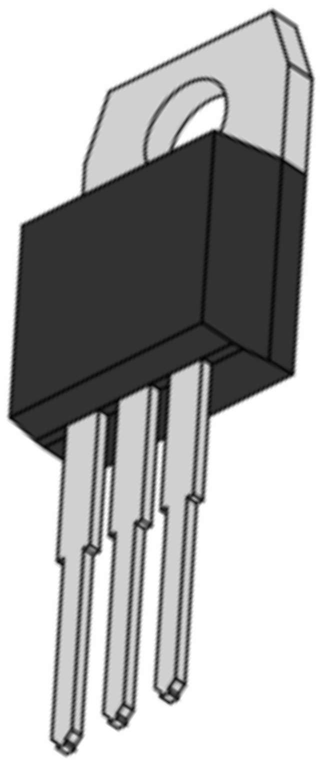


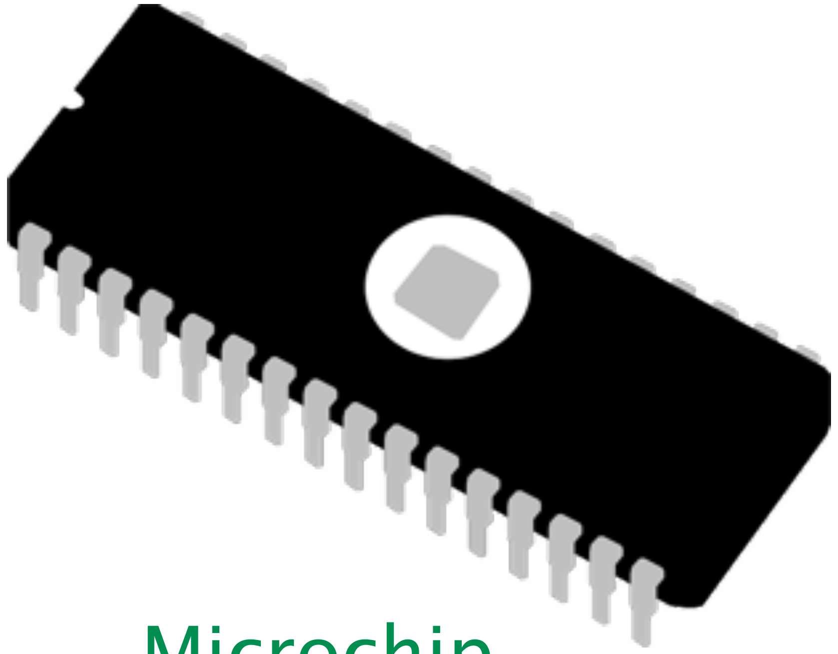
We also use insulation on the handles of tools such as pliers and screwdrivers.

{Basic Atomic Theory}

{Where do we use Semiconductors?}

Semiconductors are used to make special electronic components such as LED lights, microchips and transistors.

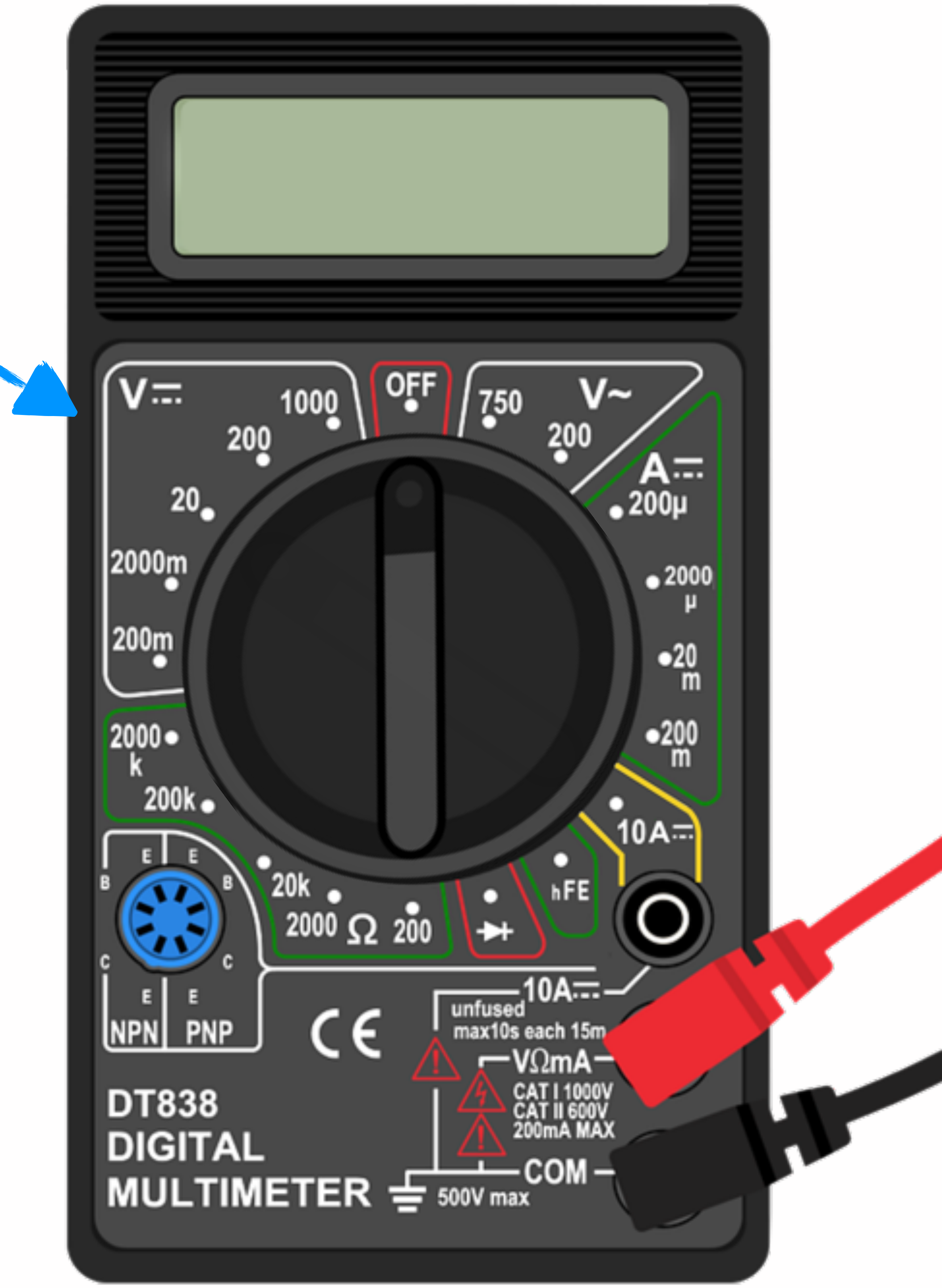




{Basic Atomic Theory}

{Something for you to try…}

If you purchased the kit, you will have a little device that looks just like this one. This is a ‘Digital Multimeter’ and is perhaps the most useful piece of electronic test equipment you could own.



There will be a whole heap of multimeter theory in later chapters however you can do a simple experiment with yours right now without knowing exactly what a multimeter does.

Your task is to connect your multimeter to random objects around the home to see if the object is a conductor or an insulator.

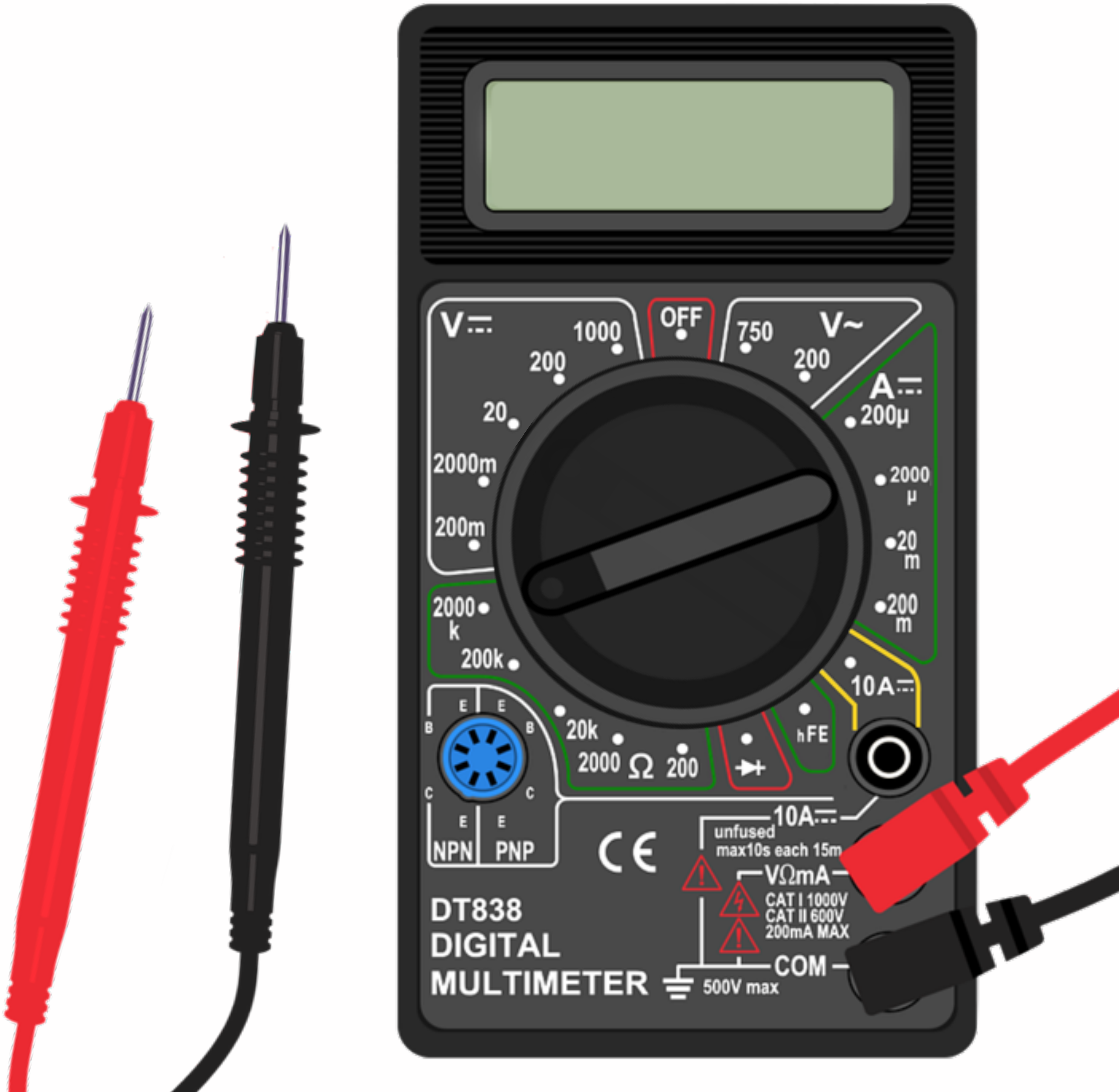
{Basic Atomic Theory}

{Something for you to try…}

To set up your multimeter, just connect the BLACK lead to the bottom connection and the RED lead to the middle connection.

Then rotate the function switch to the 2000k setting as shown in the photo.

You will then connect the RED and BLACK probes to various objects to determine whether they are a conductor or an insulator.

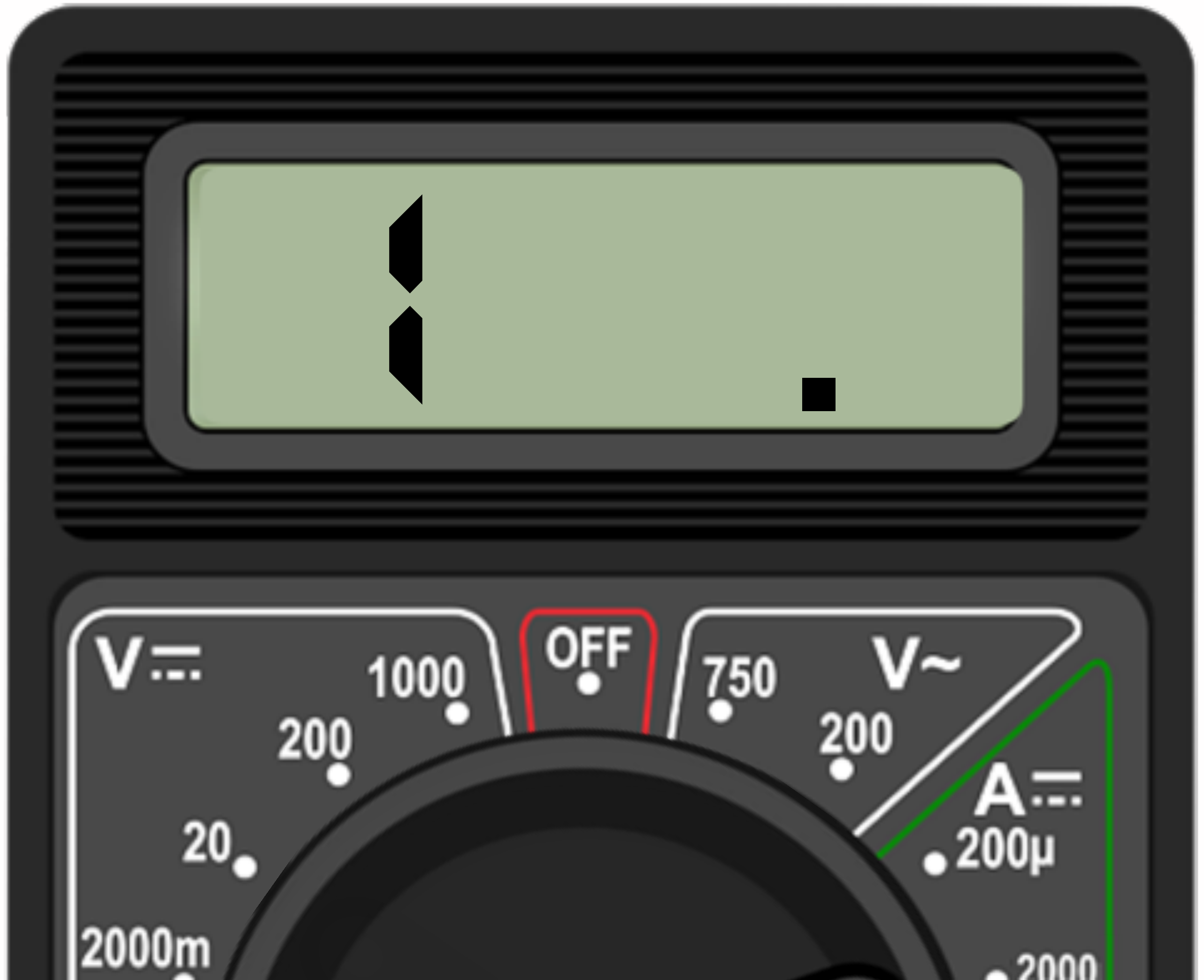


{Basic Atomic Theory}

{Something for you to try…}

When using your multimeter to test objects, if the display shows a single ‘1’ to the left of screen it is telling you that the object is an insulator. If the display shows ‘000’ or something close to that such as ‘001’ or ‘002’ then it is telling you the object is a conductor.

This means the object is an insulator



This means the object is a conductor

{Basic Atomic Theory}

{Something for you to try…}

So give it a try! Connect the RED and BLACK probe’s to a metal fork, knife or spoon. What reading do you get? Is it an insulator or a conductor?

{Basic Atomic Theory}

{Something for you to try…}

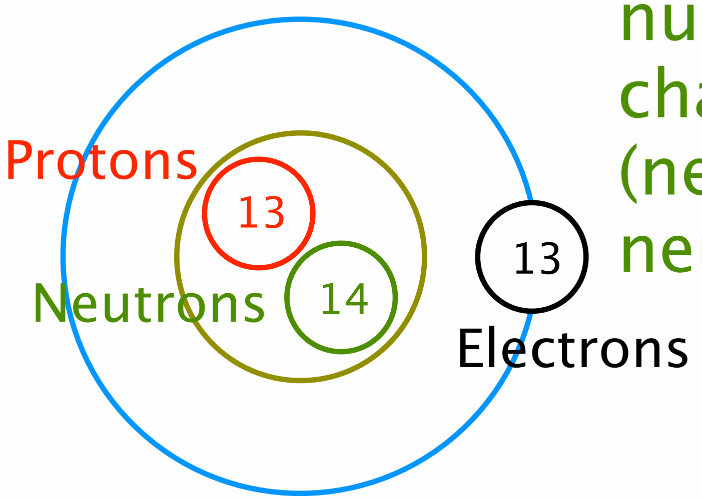
How about a permanent marker? Does this come up as a conductor or an insulator?

Make sure you try all sorts of other objects to get more of an idea of what objects are insulators and what objects are conductors.

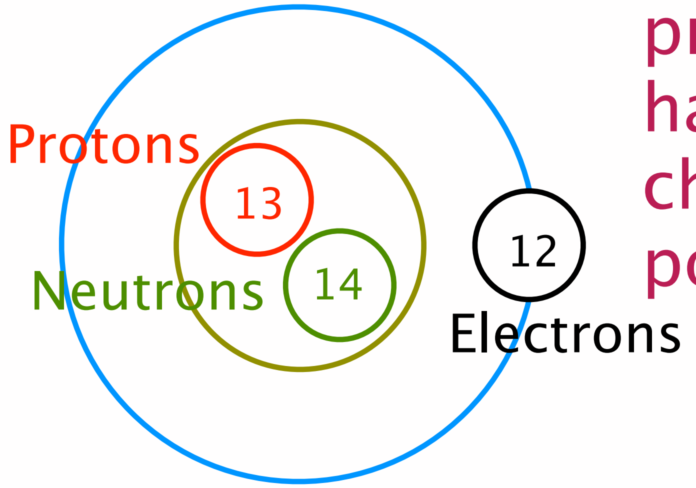
{Basic Atomic Theory}

{Neutral Atoms, Positive Ions and Negative Ions}

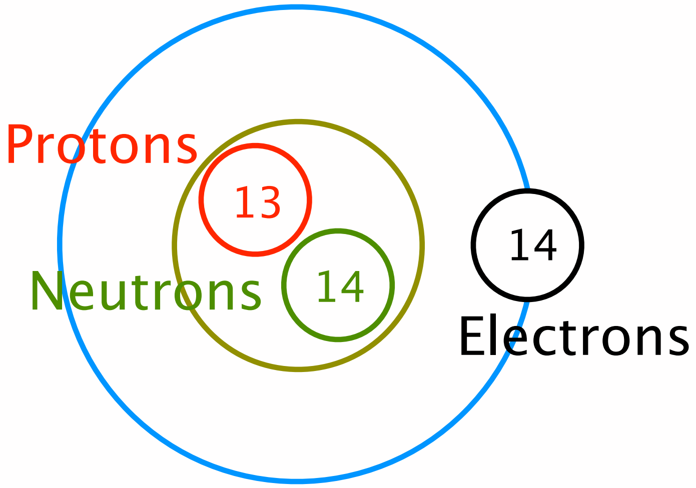
We have spoken about the possibility of moving electrons from one atom to another. This can cause an atom to become positively charged or negatively charged depending on whether we give electrons to the atom, or take electrons away from it. This will come in handy later for when we talk about batteries, solar panels and other methods of generating electricity.



If an atom contains an equal number of protons (positive charges) and electrons (negative charges) we call it a neutral atom.



If an atom contains more protons than electrons, it will have an overall positive charge and we call it a positive ion.



If an atom contains more electrons than protons, it will have an overa negative charge and we call it a negative ion.

{Basic Atomic Theory}

{Summary}

- Matter is made of atoms
- Atoms are made up of a nucleus containing protons and neutrons and then there are electrons orbiting around the nucleus Different atoms have different amounts of protons, neutrons, electrons and shells
- The outer shell is always called the valence shell and it can only ever have a maximum of eight electrons in it
- 1 to 3 electrons in a valence shell make the material a good conductor
- 5 to 8 electrons in the valence shell make the material a good insulator
- 4 electrons in the valence shell make the material a semi-conductor
- adding energy (normally in the form of a battery or power supply) to a conductor, will cause the electrons to break free from the valence shell and travel through the material. This is how we can make electronic appliances work – simply moving electrons from one place to another!

{Basic Atomic Theory}

{Questions}

Please visit www.ptable.com for help with answering these questions.

1. How many valance shell electrons does Iron have and does this make it a conductor, semiconductor or insulator?

2. How many valance shell electrons does Silicon have and does this make it a conductor, semiconductor or insulator?

3. How many valance shell electrons does Xenon have and does this make it a conductor, semiconductor or insulator?

4. How many valance shell electrons does Silver have and does this make it a conductor, semiconductor or insulator?

5. If a neutral atom were to lose an electron what would it now be known as and what sort of charge would it now have?

{Basic Atomic Theory}

{Questions}

6. If a neutral atom were to gain an electron what would it now be known as and what sort of charge would it now have?

7. If a negative ion with one more electron than protons were to lose an electron, what would it now be known as and what sort of charge would it now have?

8. Where are protons located within an atom and what sort of charge do they have?

9. Where are electrons located within an atom and what sort of charge do they have?

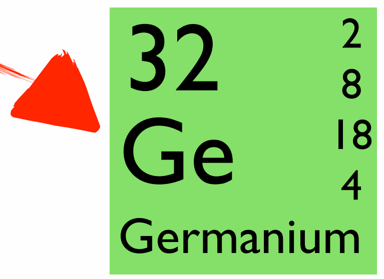
10. Where are neutrons located within an atom and what sort of charge do they have?

{Basic Atomic Theory}

{Questions}

11. Where are the electrons located which have the greatest amount of energy?

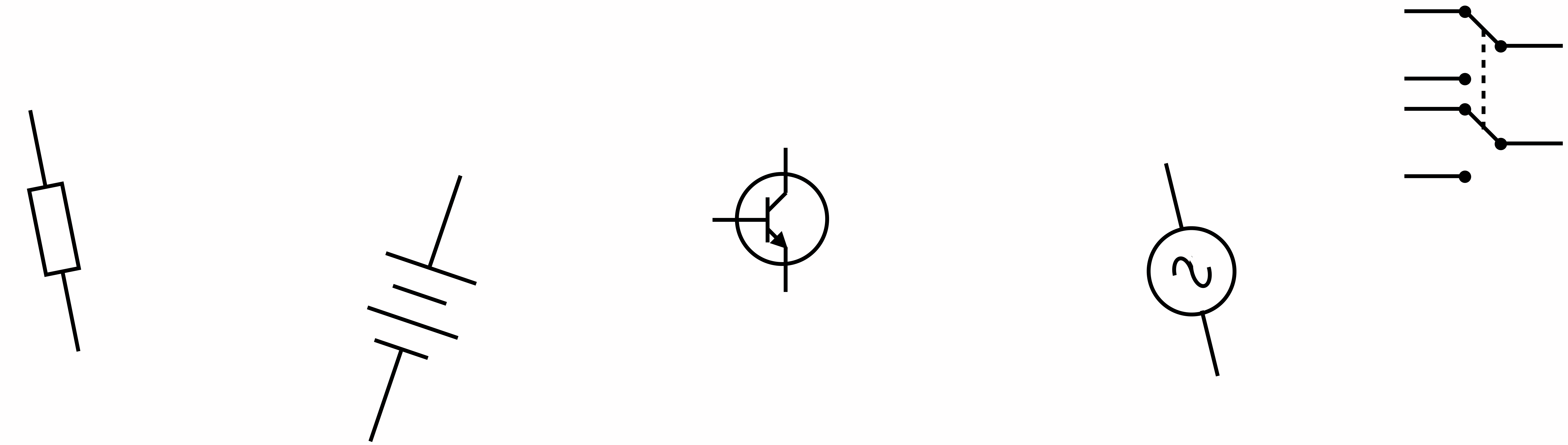
12. Referring to the germanium atom:
- How many protons does it have?
- How many shells does it have?
- How many electrons does it have?
- Is it a conductor, Insulator or Semiconductor?



{Electronic Circuit Symbols}

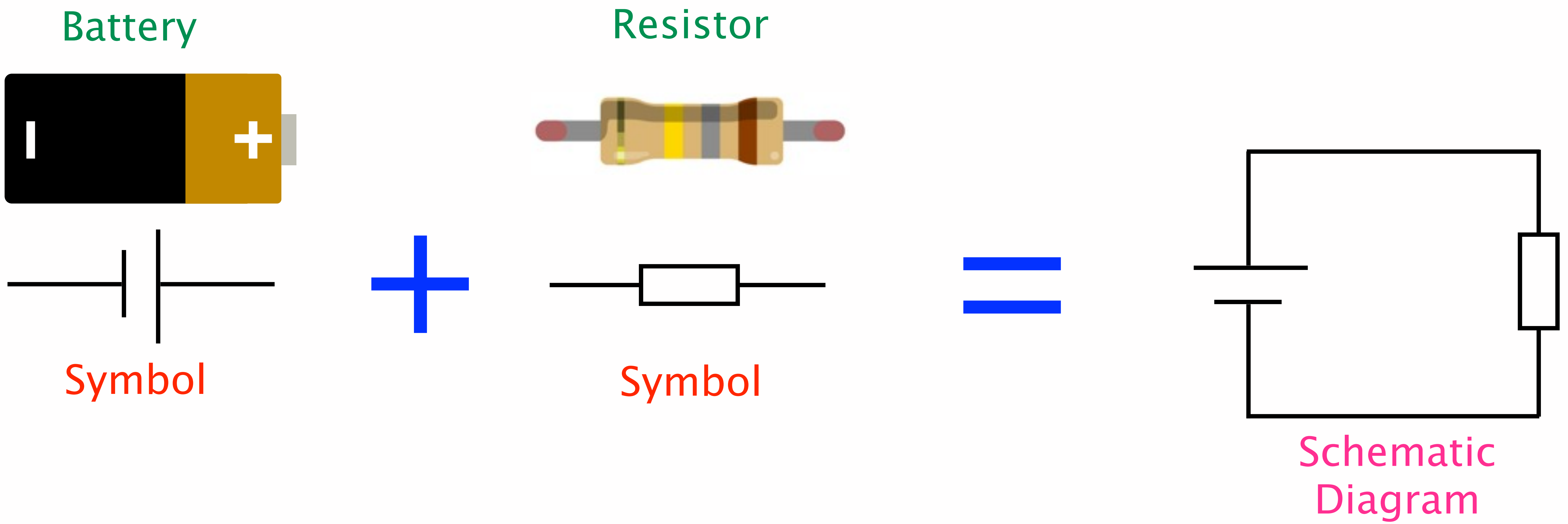
{Learning Outcomes}

2.1 Identify basic electronic circuit symbols
2.2 Understand circuit symbols are basic images of electronic components
2.3 Understand there can be different symbols for the same component
2.4 Understand that circuit symbols are combined to produce schematic diagrams



{Electronic Circuit Symbols}

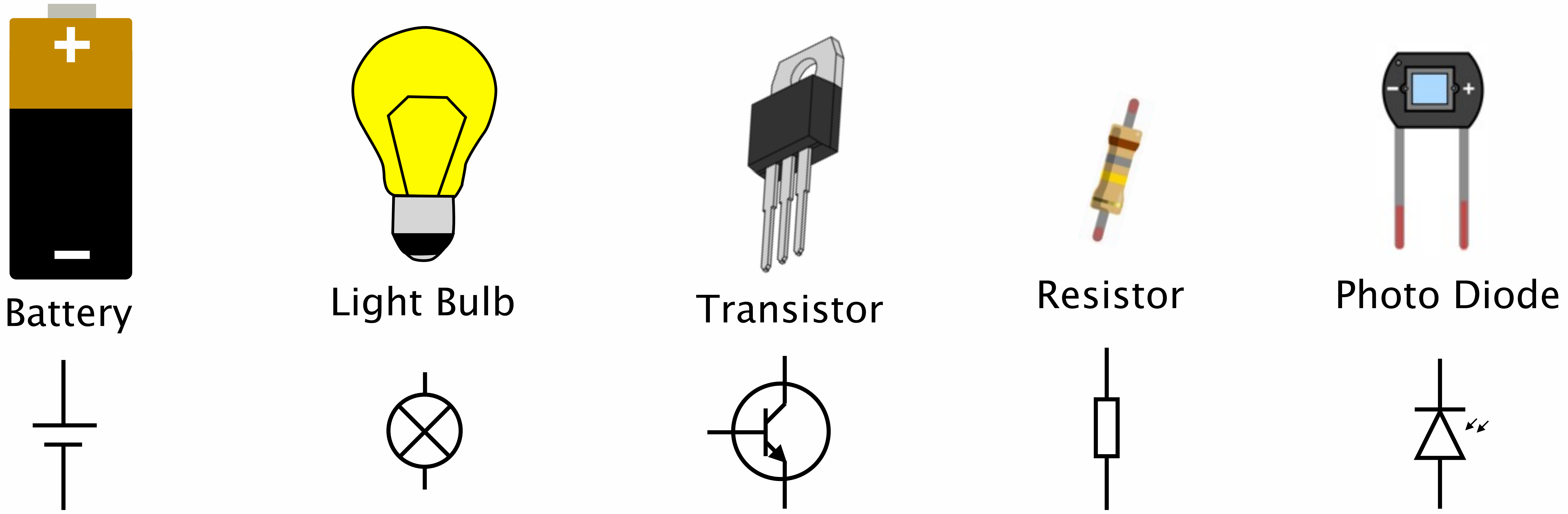
Electronic circuit symbols are basic images that represent electronic components. These symbols are often grouped together and connected with lines (wires) to form complete electronic circuits known as schematic diagrams.



{Electronic Circuit Symbols}

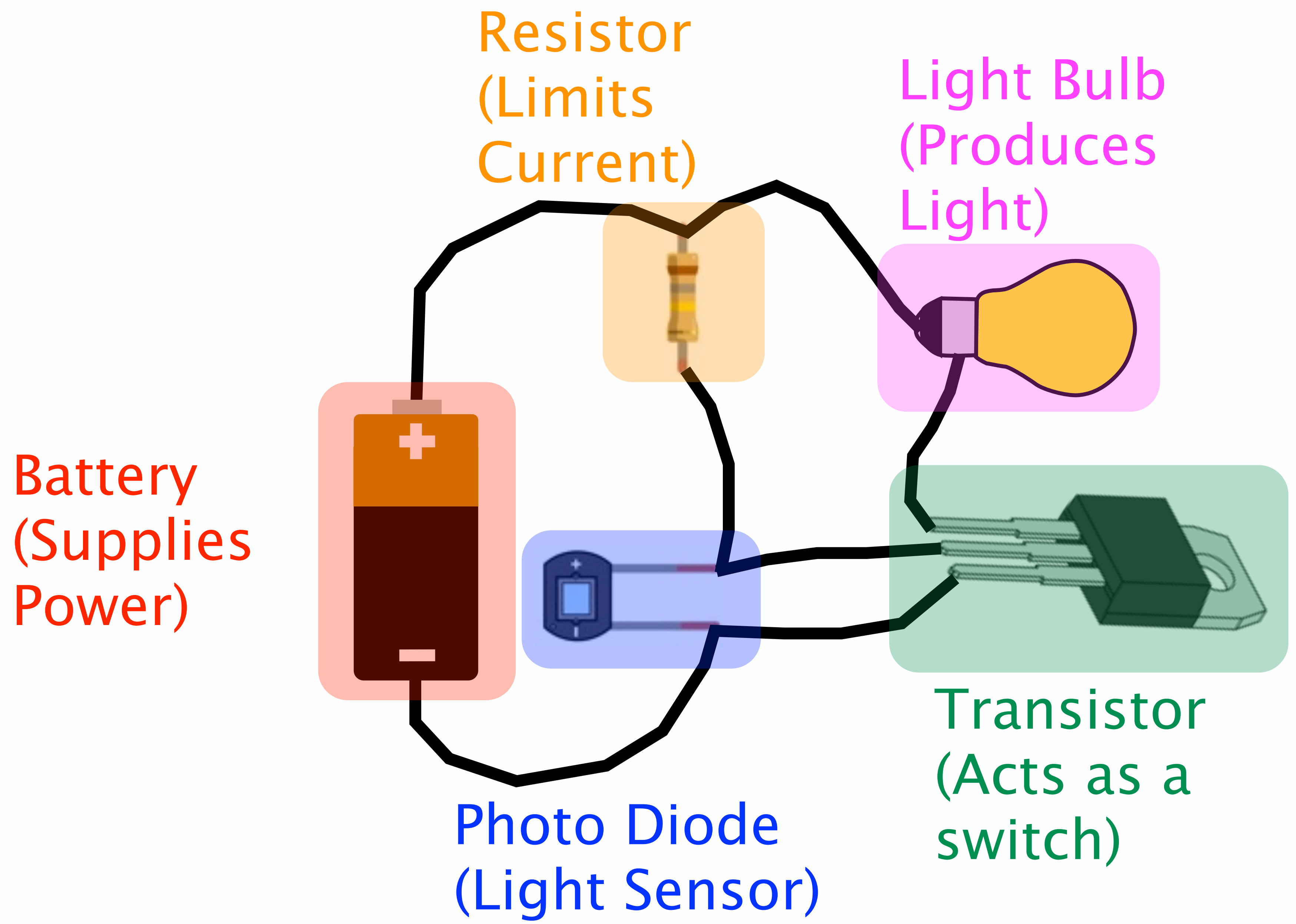
The purpose of this chapter is to get you familiar with some commonly used symbols, as well as how these symbols come together to form a complete circuit in the form of a schematic diagram. To help us on our way, let’s design a night light that will automatically turn on when the room is dark.

Here are our components along with their symbols:



{Electronic Circuit Symbols}

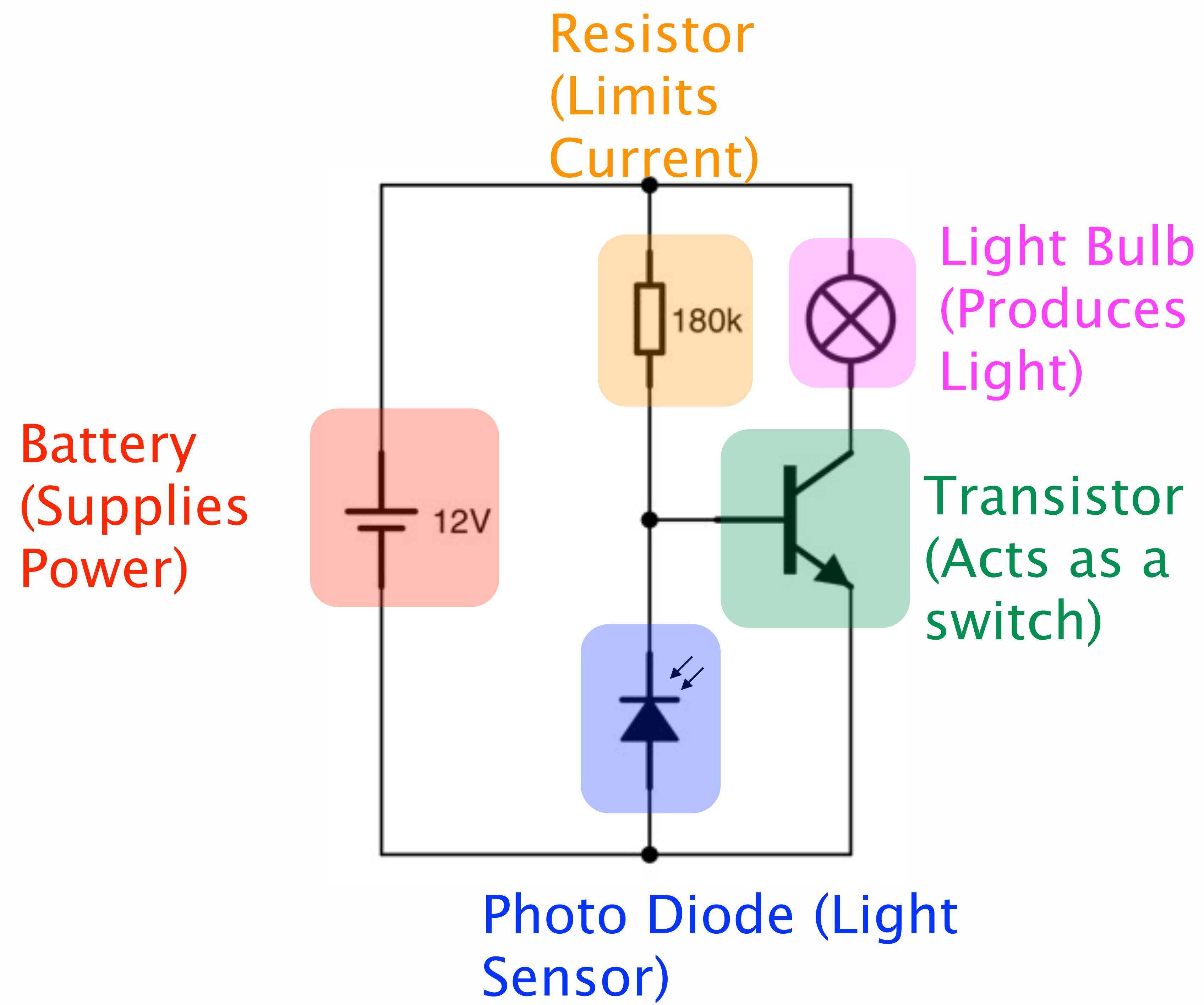
First up let's have a look at what the circuit might look like by drawing the components along with the interconnecting wires:



While this method does work, we can make it easier to read by using the circuit symbols for each component instead. Let's have a look at that on the next page.

{Electronic Circuit Symbols}

Now this looks better!



This is the schematic diagram version of the night light circuit. You may notice it is much easier to read compared to the design on the previous page.

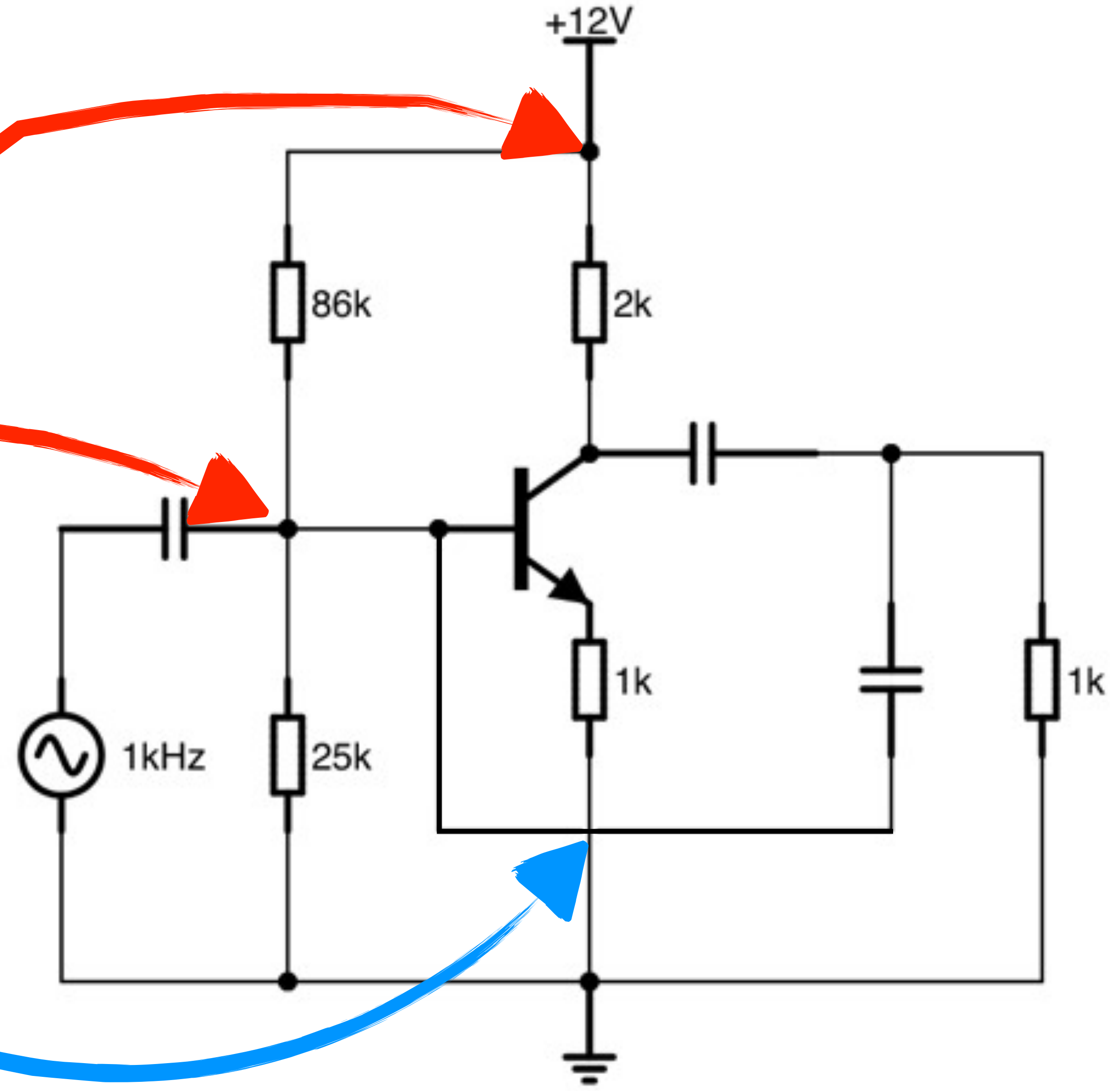
It is important to remember that we have not gone into circuit theory just yet so you don't need to understand how this circuit works or even what all the symbols mean. This section is here to prepare you for the circuit theory that is to come, since all circuits will be drawn using symbols.

{Electronic Circuit Symbols}

{Interconnecting wires}

Schematic diagrams can certainly become quite detailed. While the previous example contained only a few components, some schematics contain tens, hundreds if not thousands of components. In these cases you will most certainly find interconnecting lines going all over the diagram. So how do we know when a wire should and should not be joined?

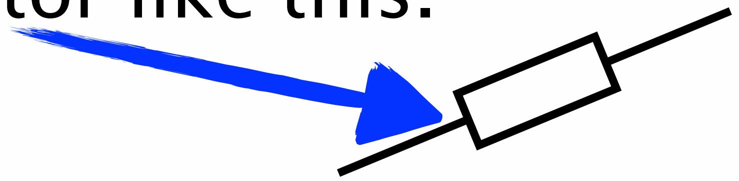
We simply have little dots to represent a join, like these ones.



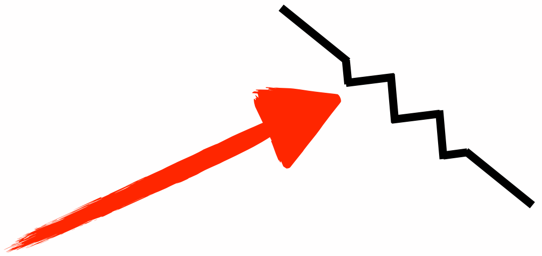
Where a join is not intended, the lines simply cross over one another with the dot left out. Like this.

{Electronic Circuit Symbols}

Now to add a little confusion to the mix, there can often be more than one circuit symbol to represent a component. For example, here in Australia we would often represent a resistor like this.

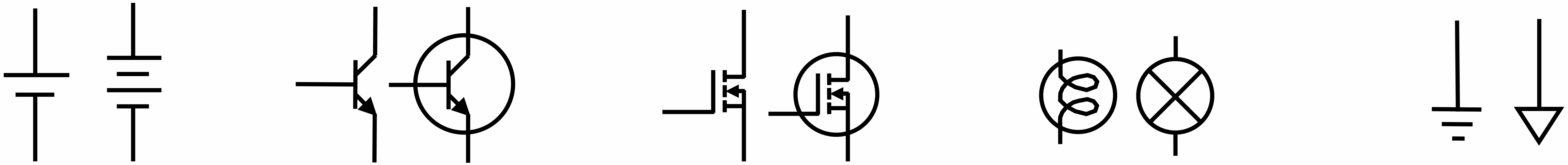


However in America, resistors are often represented like this.



There is a humorous quote about standards by Andrew Tanenbaum – “The nice thing about standards is that you have so many to choose from.”

Here are some more components with more than one design style. You may very well notice there is not a great deal of difference between them.



DC Power Supply

NPN Transistor

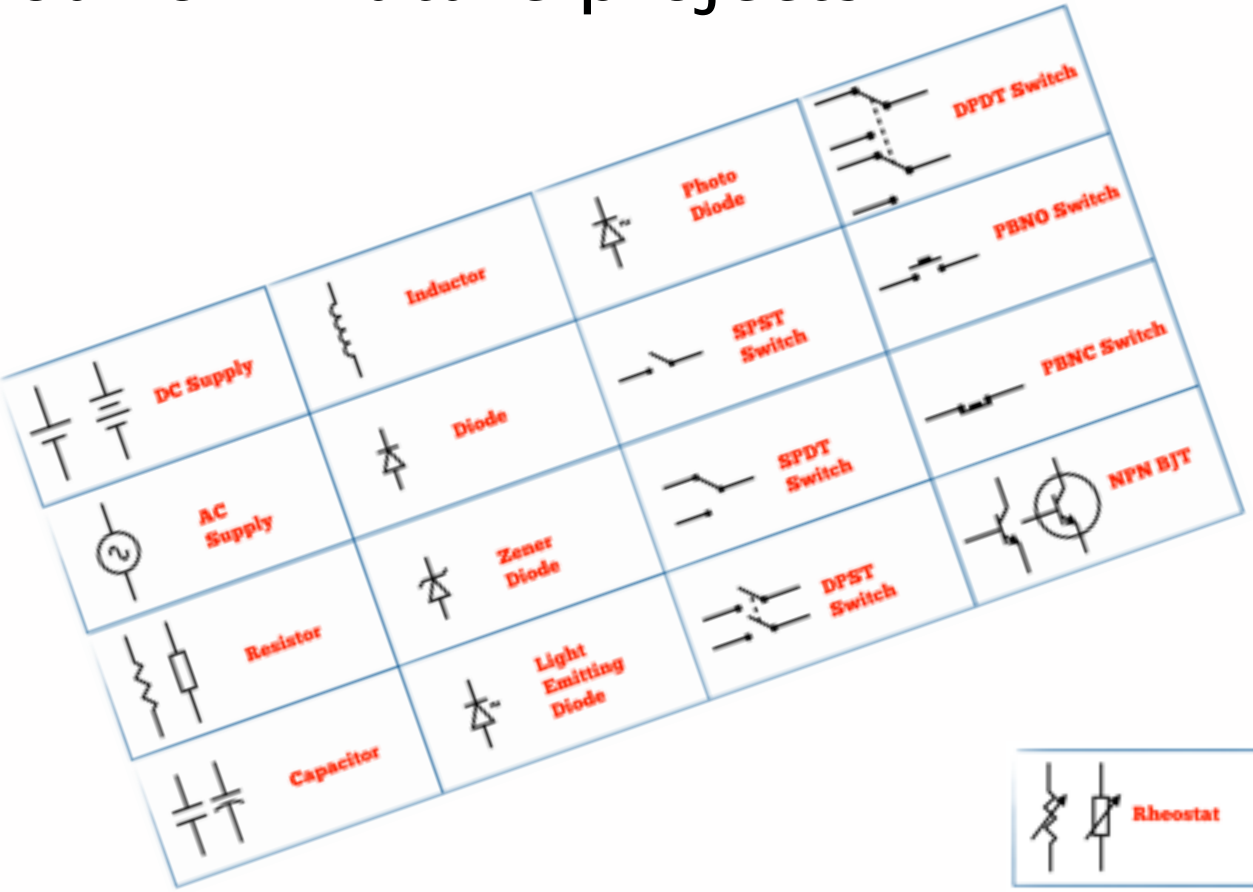
N MOSFET

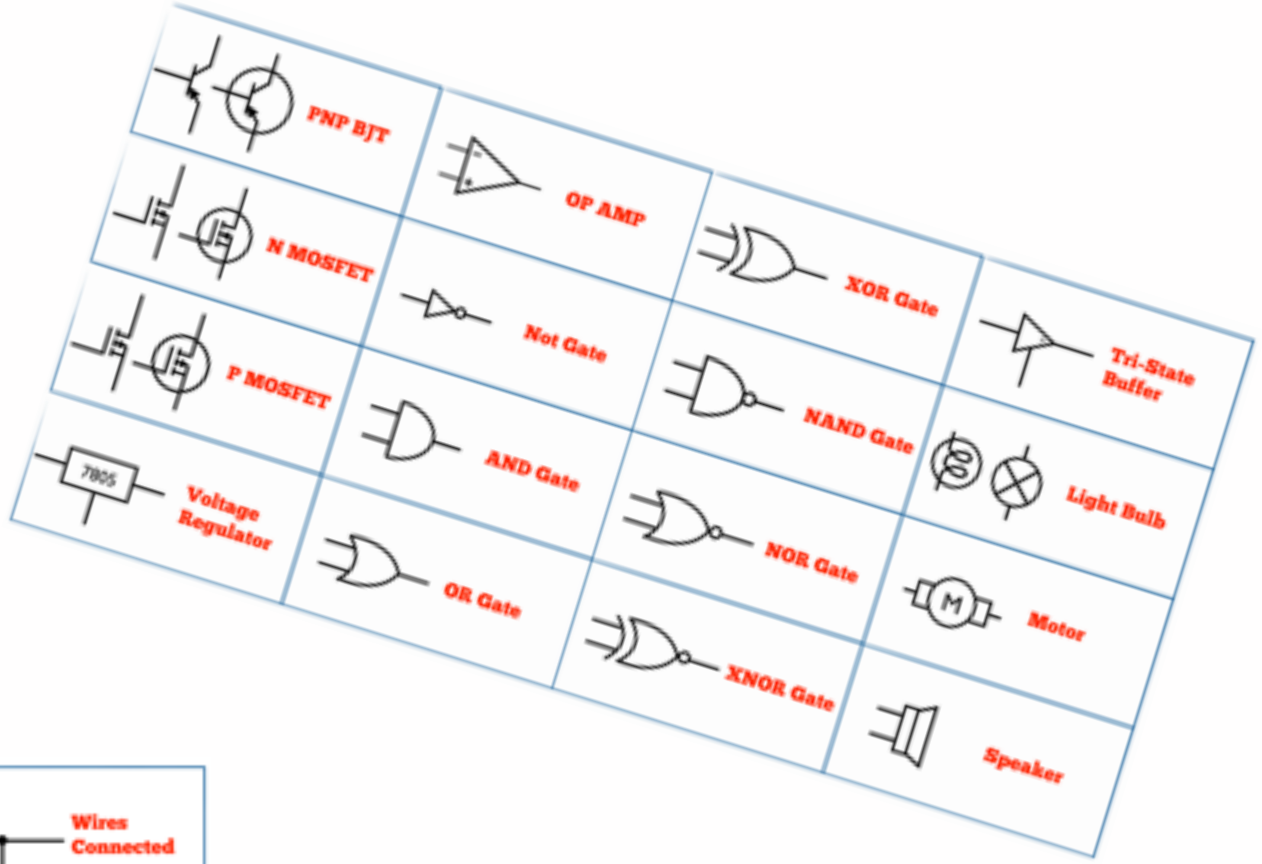
Lamp

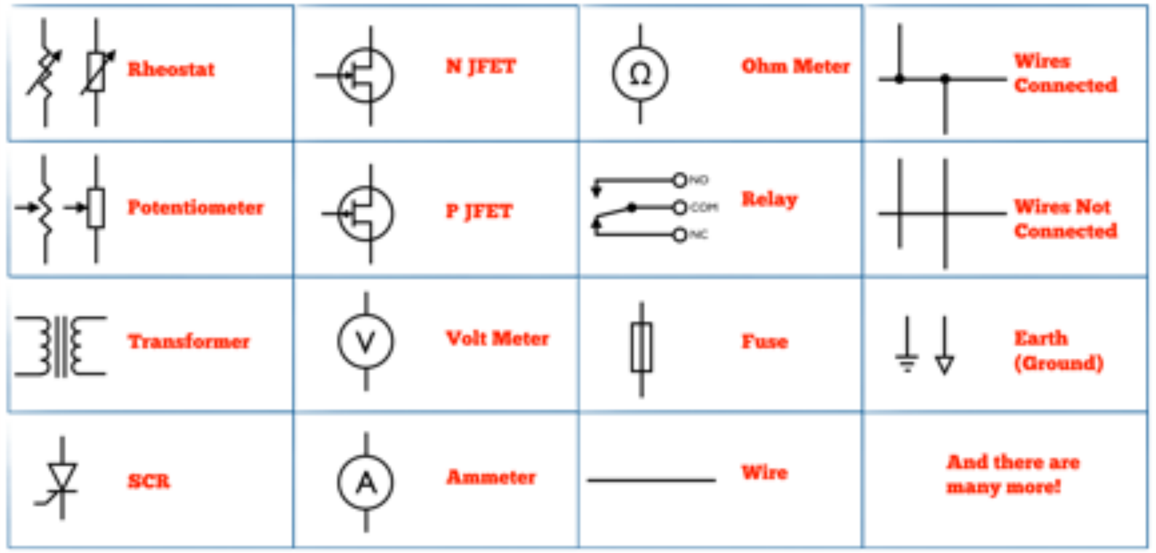
Earth

{Electronic Circuit Symbols}

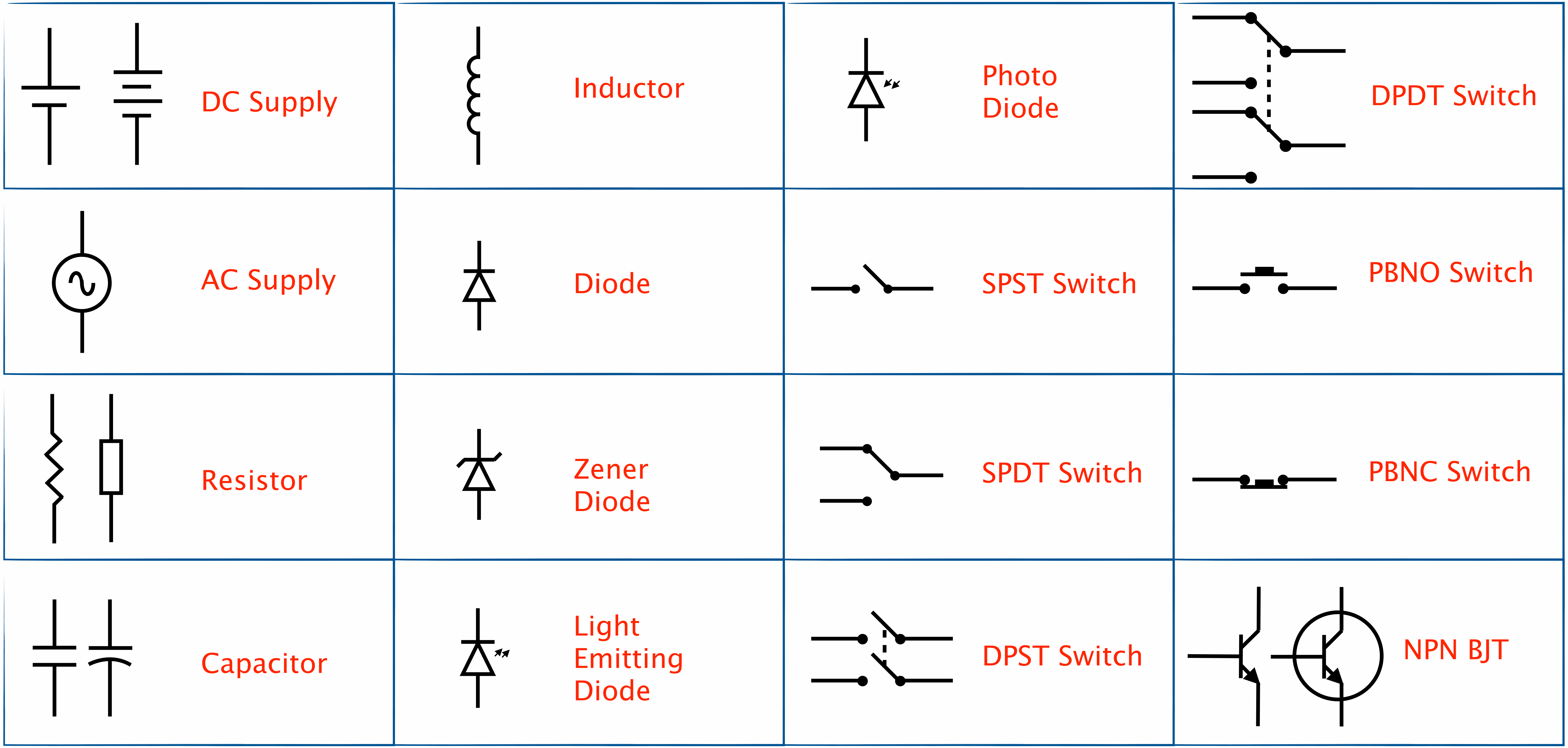
The next three pages contain a good range of electronic circuit symbols that will serve as a handy reference guide as you continue through this course as well as helping for your own future projects.



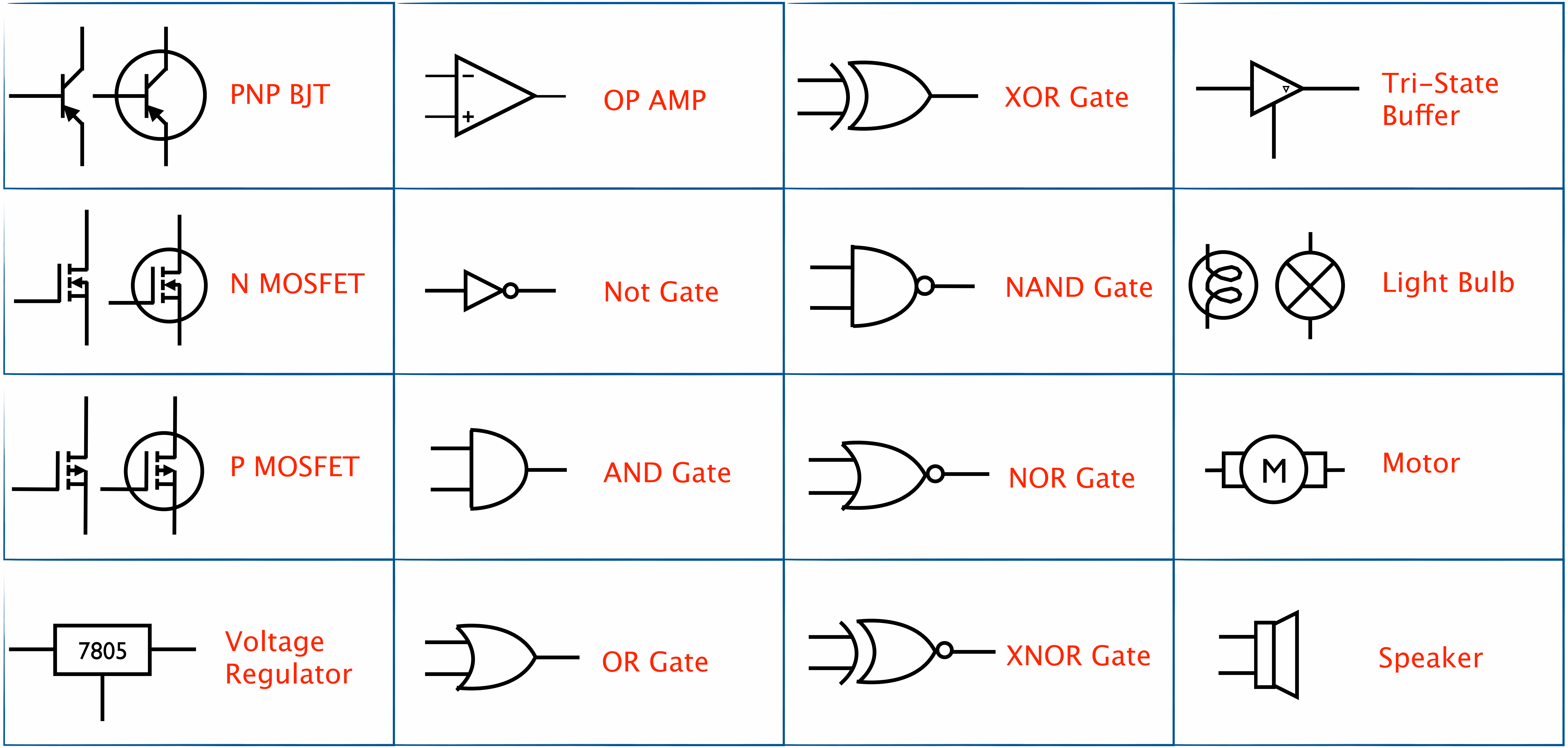




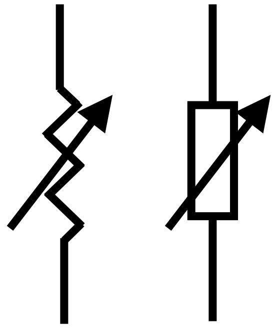
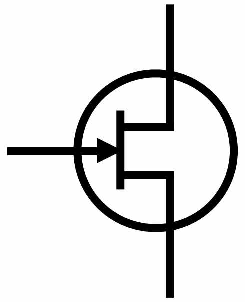
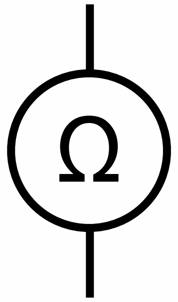
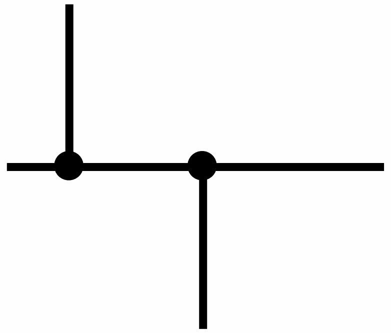
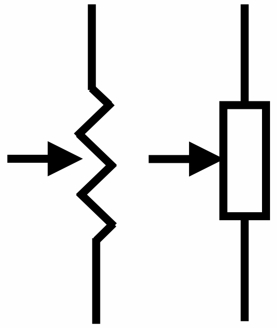
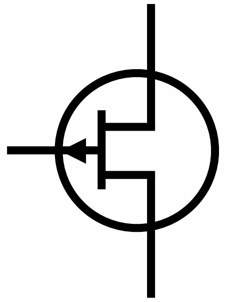
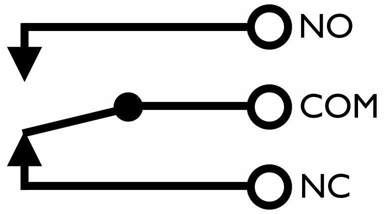
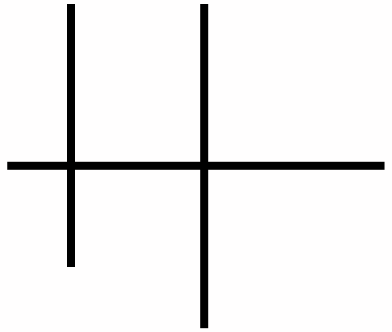
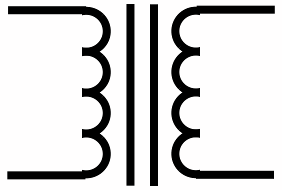
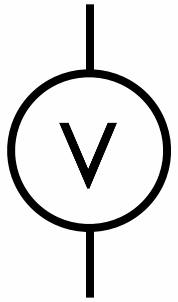
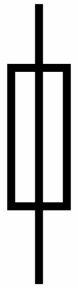
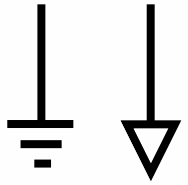
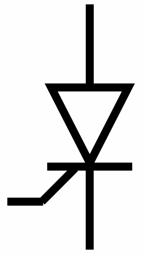
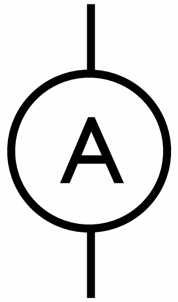
{Electronic Circuit Symbols}



{Electronic Circuit Symbols}



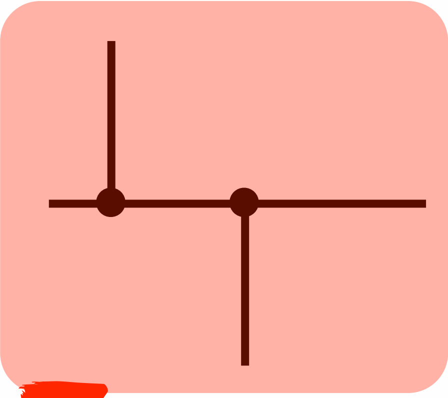
{Electronic Circuit Symbols}

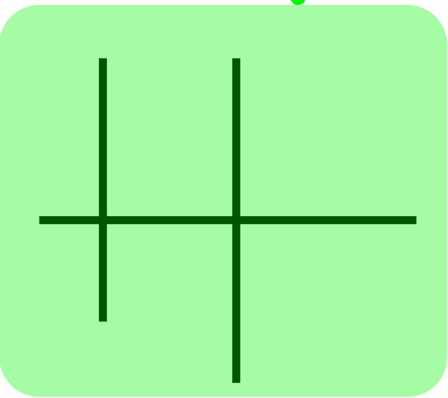
 Rheostat	 N JFET	 Ohm Meter	 Wires Connected
 Potentiometer	 P JFET	 Relay	 Wires Not Connected
 Transformer	 Volt Meter	 Fuse	 Earth (Ground)
 SCR	 Ammeter	Wire	And there are many more!

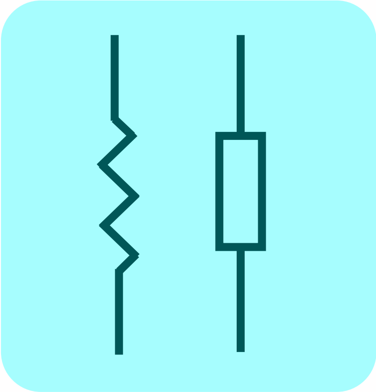
{Electronic Circuit Symbols}

{Summary}

- Electronic circuit symbols are simple images which represent electronic components.
- Schematic diagrams are formed when multiple symbols are connected together into a complete circuit
- Interconnecting lines (wires) are joined with a dot like this
- Wires that are not connecting are simply drawn passing by each other, like this
- There can be different symbols for the same component, like these resistors







{Electronic Circuit Symbols}

{Questions}

1. What is the purpose of electronic circuit symbols?

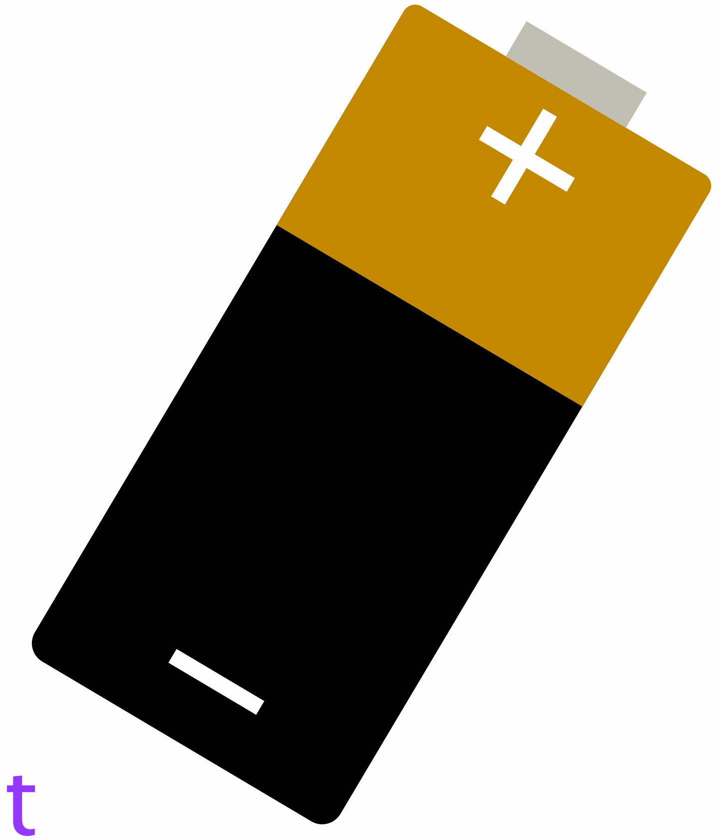
2. Is it possible for a component to have more than one circuit symbol?

3. Draw the circuit symbol for a resistor (tip – refer to the list of symbols in the previous pages).

4. Draw the circuit symbol for a light bulb (tip – refer to the list of symbols in the previous pages).

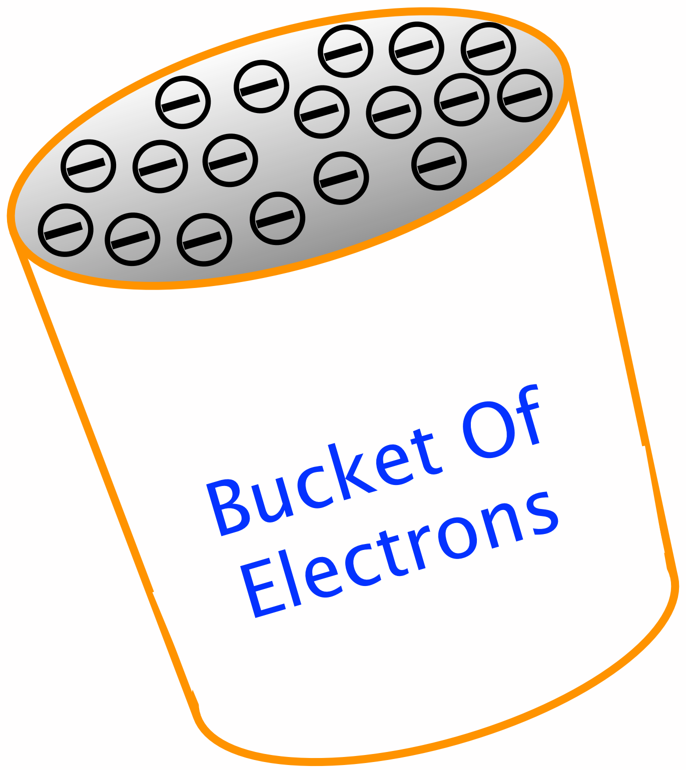
5. What is it called when multiple symbols are connected together to represent a complete circuit?

{Voltage, Current and Resistance}



{Learning Outcomes}

3.1 Describe the term Voltage
3.2 Describe the term Resistance
3.3 Describe the term Current
3.4 Identify power supply circuit symbols
3.5 Identify resistor circuit symbols
3.6 Understand the relationship between Voltage, Current and Resistance



{Voltage, Current and Resistance}

{Introduction}

Throughout this chapter we will be looking at the three fundamental aspects of any electronic circuit. These being:

- Voltage
- Current
- Resistance

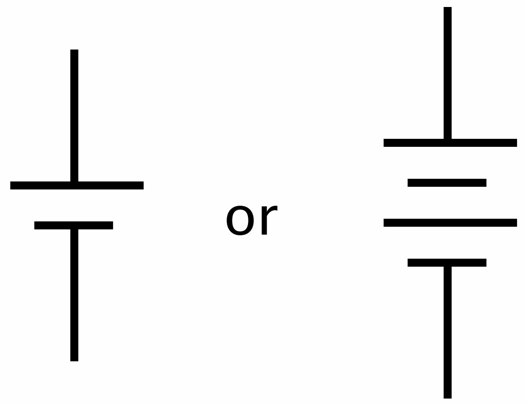
We will first look at them individually then bring them together while using an analogy to help drive the theory home.

{Voltage, Current and Resistance}

{Voltage}

Voltage is the ‘pushing force’ which pushes the electrons through the circuit. Voltage is also known as ‘potential difference’ or ‘electromotive force’ and these terms will make more sense as we progress through the course. Batteries provide us with a potential difference between the top and bottom connections. Voltage is measured in Volts and is given the letter V.

Battery

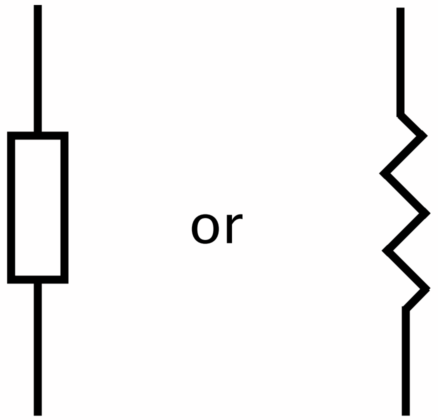


Circuit Symbols

{Resistance}

While voltage is pushing the electrons through the circuit, Resistance is the opposing (or restricting) force that is trying to slow them down. Resistance is given the letter R and is measured in ohms Ω.

Resistor



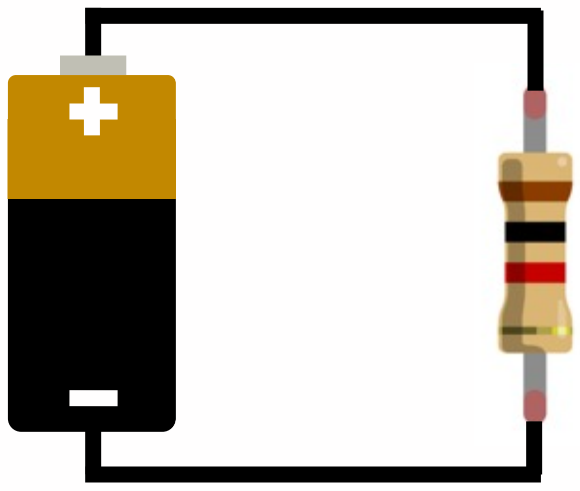
Circuit Symbols

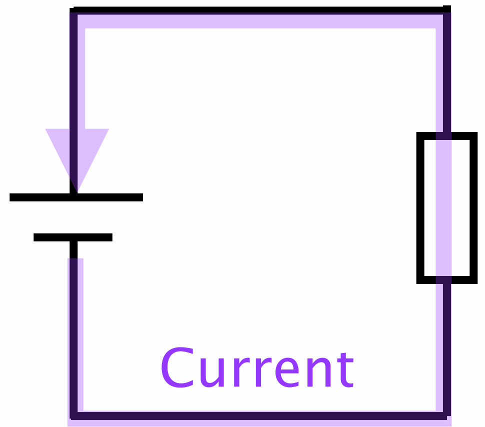
{Current}

Current is all about how many electrons are passing through our circuit per second. The combination of the pushing force (Voltage) and the opposing force (Resistance) results in a certain amount of Current. Current is measured in Amperes (or Amps) and is given the letter I.

More Voltage = more Current

More Resistance = less Current





{Voltage, Current and Resistance}

{Voltage Explanation}

Generating electricity (also known as potential difference or electromotive force) will be covered in more detail later however a brief preview will be covered here.

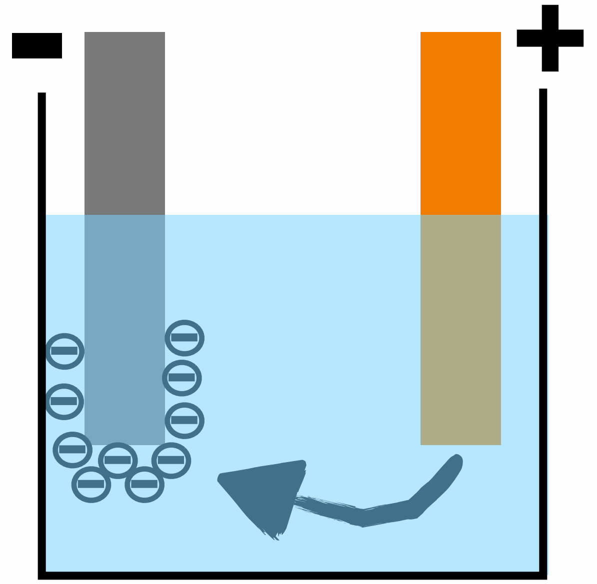
Let's take a look at a simple battery for example.

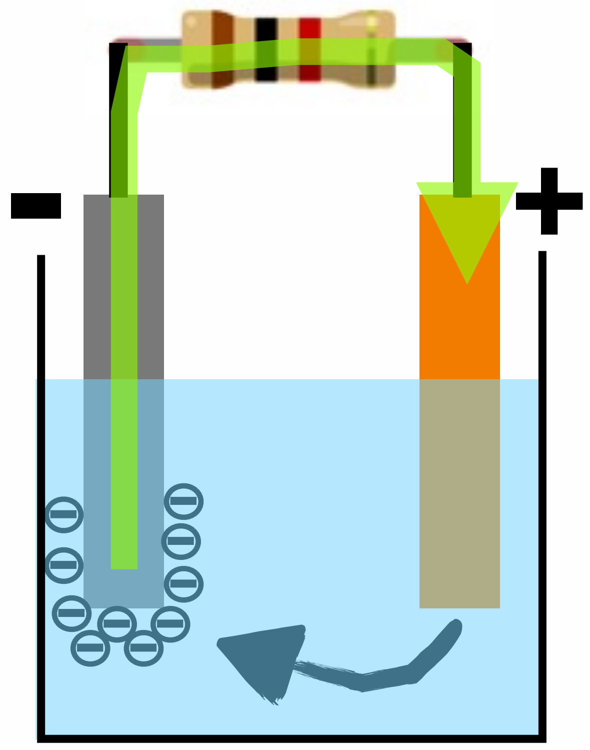
Inside the battery are some chemicals and two different types of metal (the two metals give you your two ends or terminals of the battery). The chemicals will eat away at one terminal of the battery, taking electrons from it. The electrons will then travel through the battery to the other terminal.

This leaves us with a difference in charge between the two terminals. The terminal that lost electrons will have a positive charge while the terminal that gained the electrons will have a negative charge. We commonly call the difference between the two a 'potential difference' which is measured in Volts.

It is this potential difference that causes electrons to flow in an electronic circuit when the battery is connected to it.

Chemical reaction causes electrons to travel away from one terminal and are deposited on the other. This gives us a positive and negative terminal.





If an electrical circuit were connected, the electrons would continue to travel through the circuit from negative to positive.

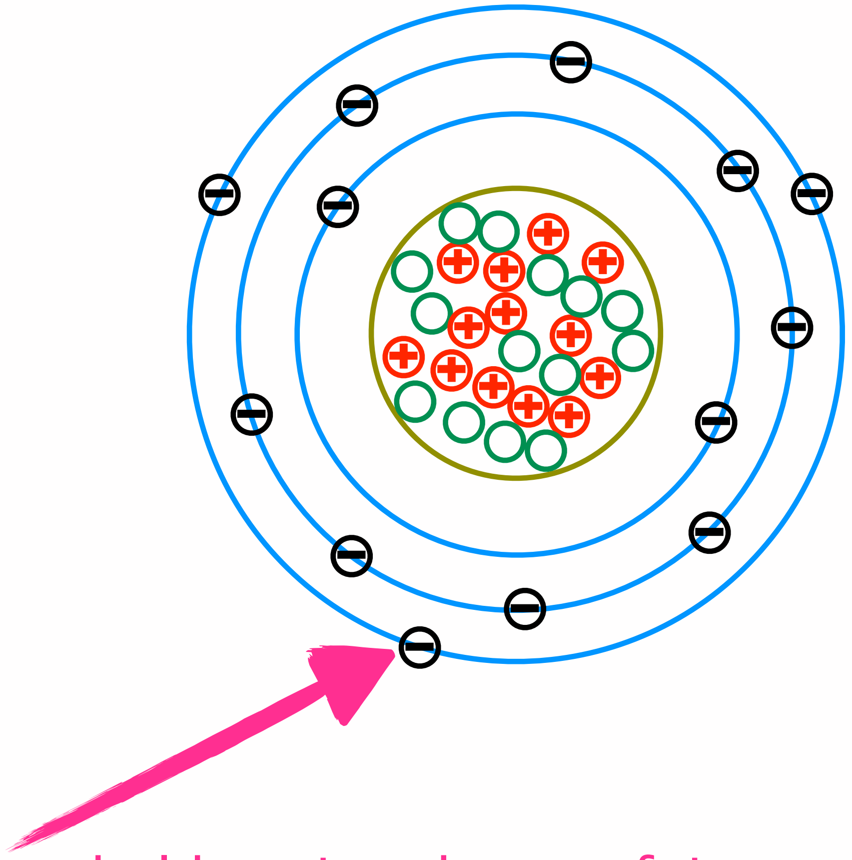
{Voltage, Current and Resistance}

{Current Explanation}

We have mentioned that current is measured in Amperes (or Amps), but what exactly is an Amp?

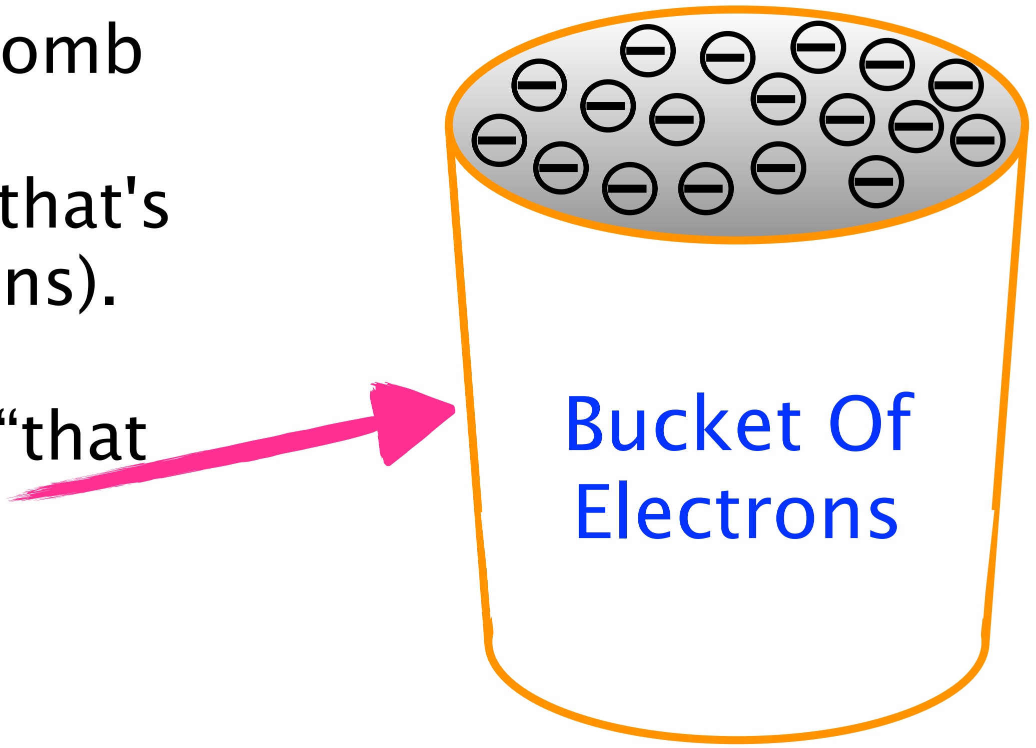
An Amp is when we have 1 Coulomb of charge moving through a circuit per second. Now this may cause you to want to ask another question. What is 1 Coulomb of charge?

Remember back to atomic theory when we dealt with electrons. Each one of those electrons has a certain amount of charge and charge is measured in Coulombs. In fact, each electron has a tiny little charge of 0.000,000,000,000,000,000,160,2 Coulombs. Now that is tiny!

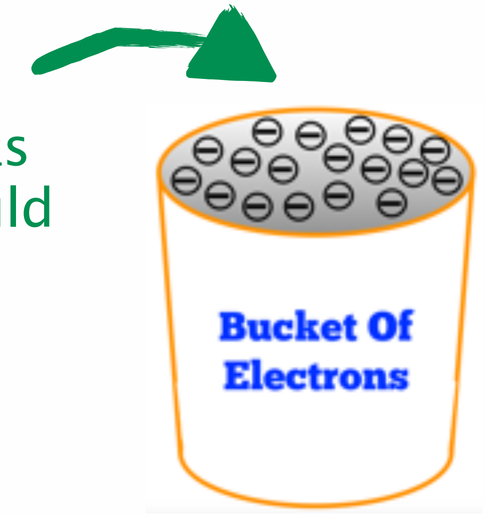


Each electron holds a tiny charge of just 0.000,000,000,000,000,000,160,2 Coulombs

In order to make up one single Coulomb of charge, we would need to bunch together 6.24 Quintillion electrons (that's 6,240,000,000,000,000,000 electrons). So if you imagine a bucket of 6.24 Quintillion electrons, you could say “that bucket contains a charge of one coulomb.”



A bucket with half as many electrons would be half a coulomb.

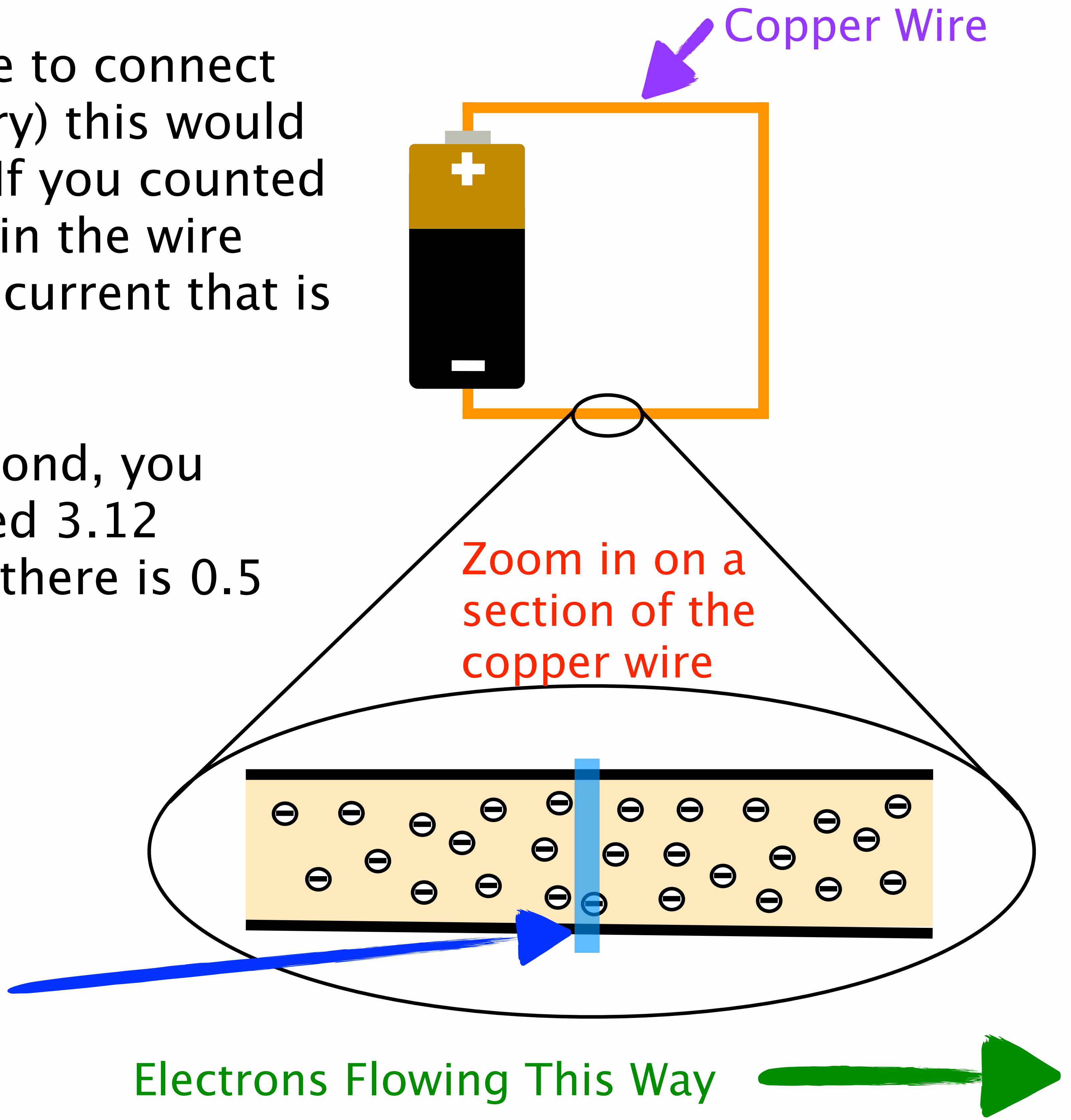


{Voltage, Current and Resistance}

{Current Explanation Continued...}

So let's piece all this theory together. If you were to connect your copper wire to a power source (like a battery) this would cause the electrons to move through your wire. If you counted the number of electrons passing a certain point in the wire every second you could work out the amount of current that is flowing.

If you counted 6.24 Quintillion electrons per second, you would say "there is 1 Amp flowing" if you counted 3.12 Quintillion electrons per second you would say "there is 0.5 Amps flowing".

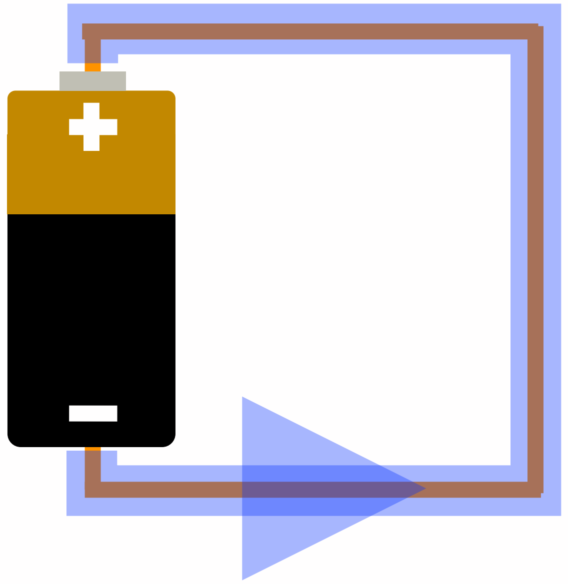


Count the number of electrons passing the blue line per second. If you counted 6.24 Quintillion in one second, then there is 1 Amp of current.

{Voltage, Current and Resistance}

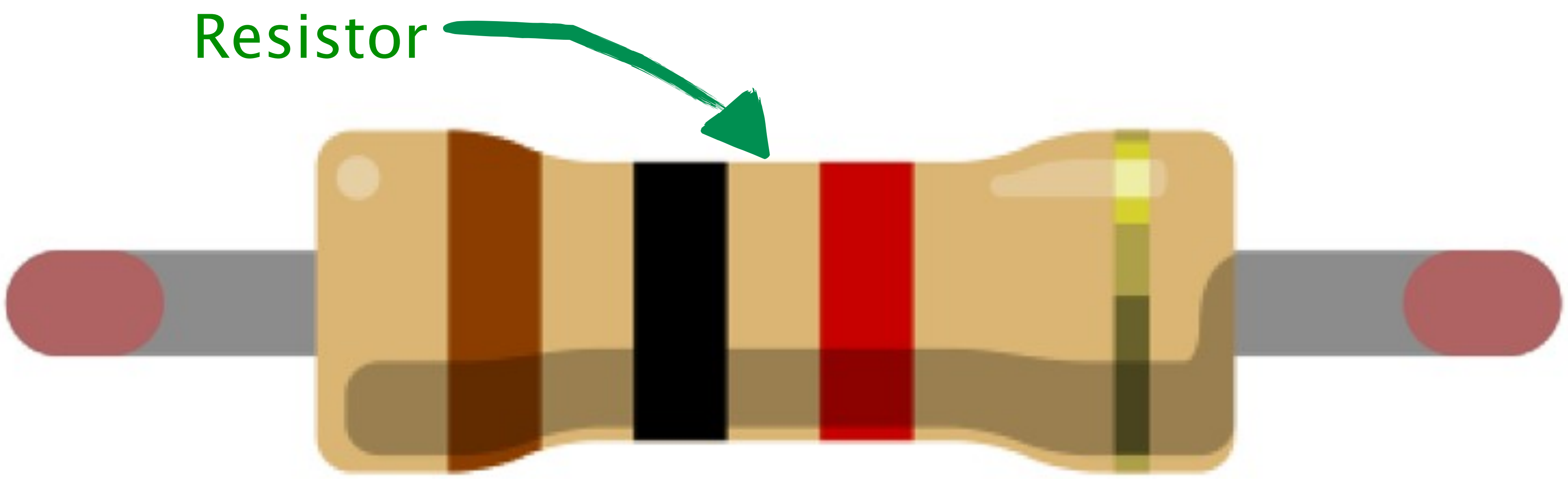
{Resistance Explanation}

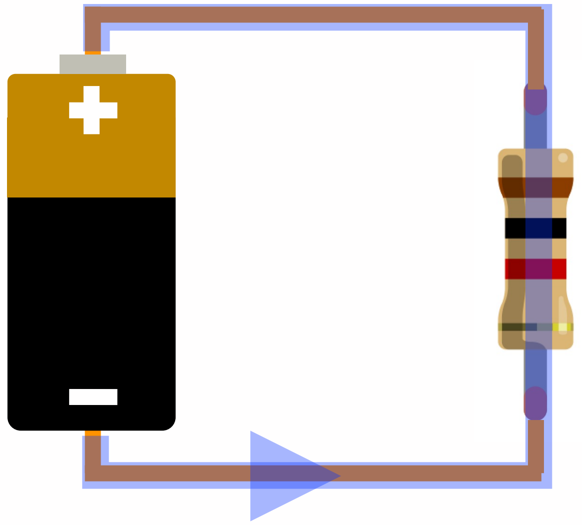
We have just learned that voltage is the 'pushing force' which will push electrons through a conductor such as a piece of copper wire. Then, if we were to count the number of electrons passing through that wire every second we can figure out the amount of current flowing.



Without Resistor = Lots of Current

Resistance can then be added into the circuit to slow down these electrons. Resistors are components which are given the specific task of slowing the electrons down in order to reduce the amount of current in a circuit.





With Resistor = Less Current

{Voltage, Current and Resistance}

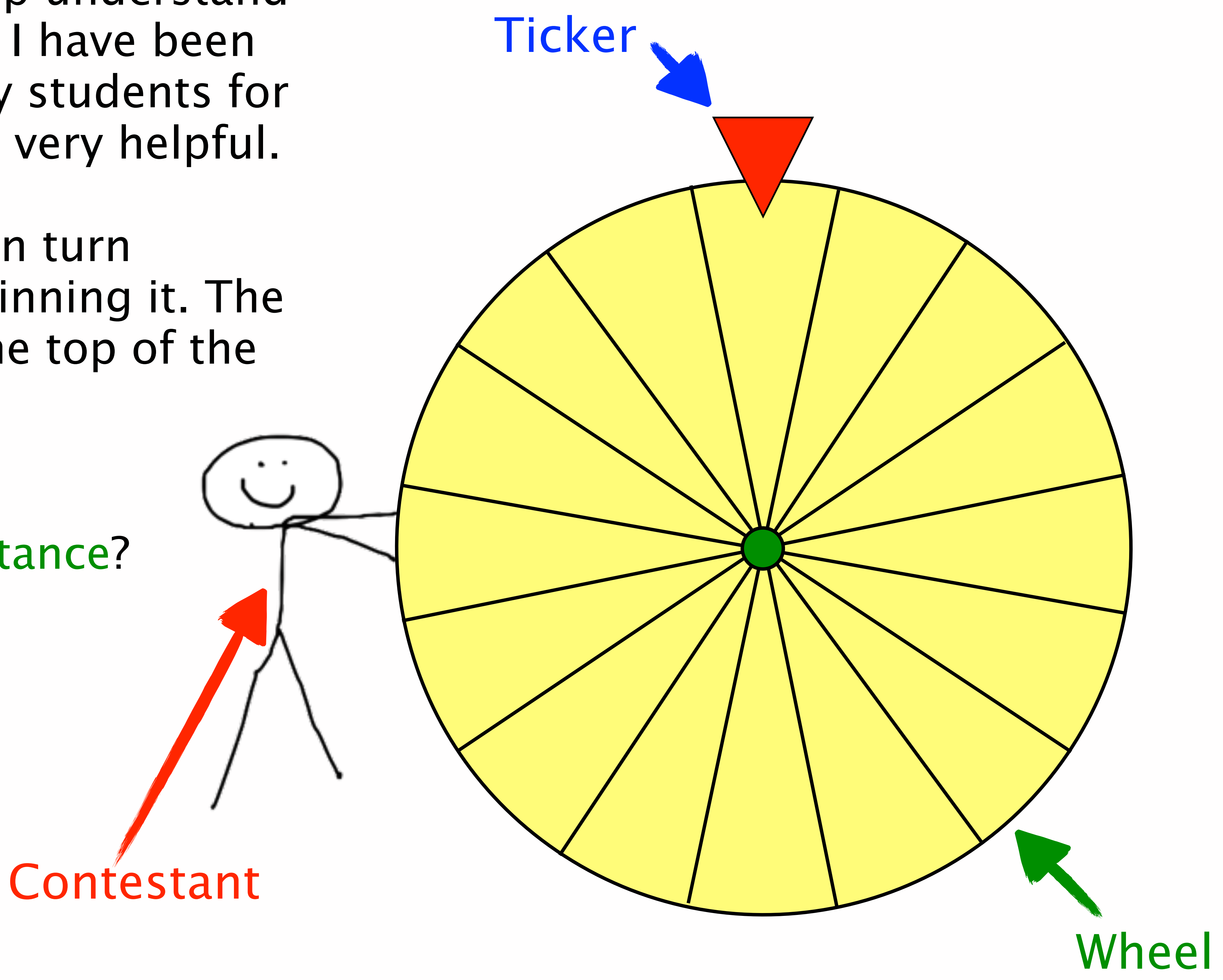
{Wheel of Fortune Analogy}

Often times a water analogy is used to help understand Voltage, Current and Resistance. However I have been using a 'wheel of fortune' analogy with my students for a number of years which has proven to be very helpful.

In wheel of fortune, players are to take it in turn grabbing hold of a big prize wheel and spinning it. The wheel eventually stops and the ticker at the top of the wheel indicates their prize.

So how on earth is this going to help with understanding Voltage, Current and Resistance?

Well, let's continue reading to find out!



{Voltage, Current and Resistance}

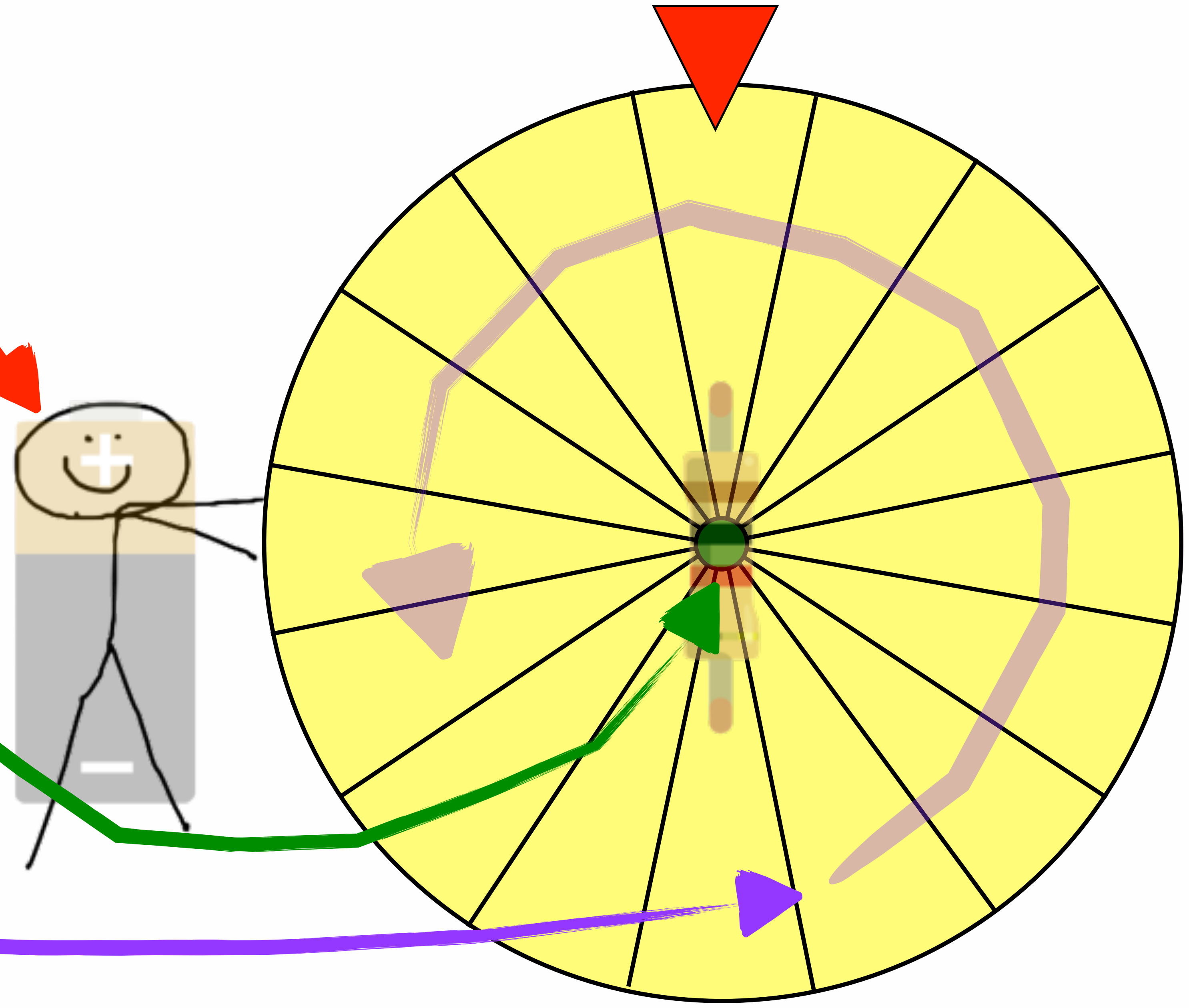
{Wheel of Fortune Analogy – Continued...}

Let’s relate the analogy to to our electrical properties:

{Voltage}
The contestant is the ‘pushing force’ for the wheel, much like voltage is the pushing force in an electronic circuit. As the contestant pushes the wheel, it spins and the contestant can either push with a lot of force to make it spin fast or not so much force to make it spin slower.

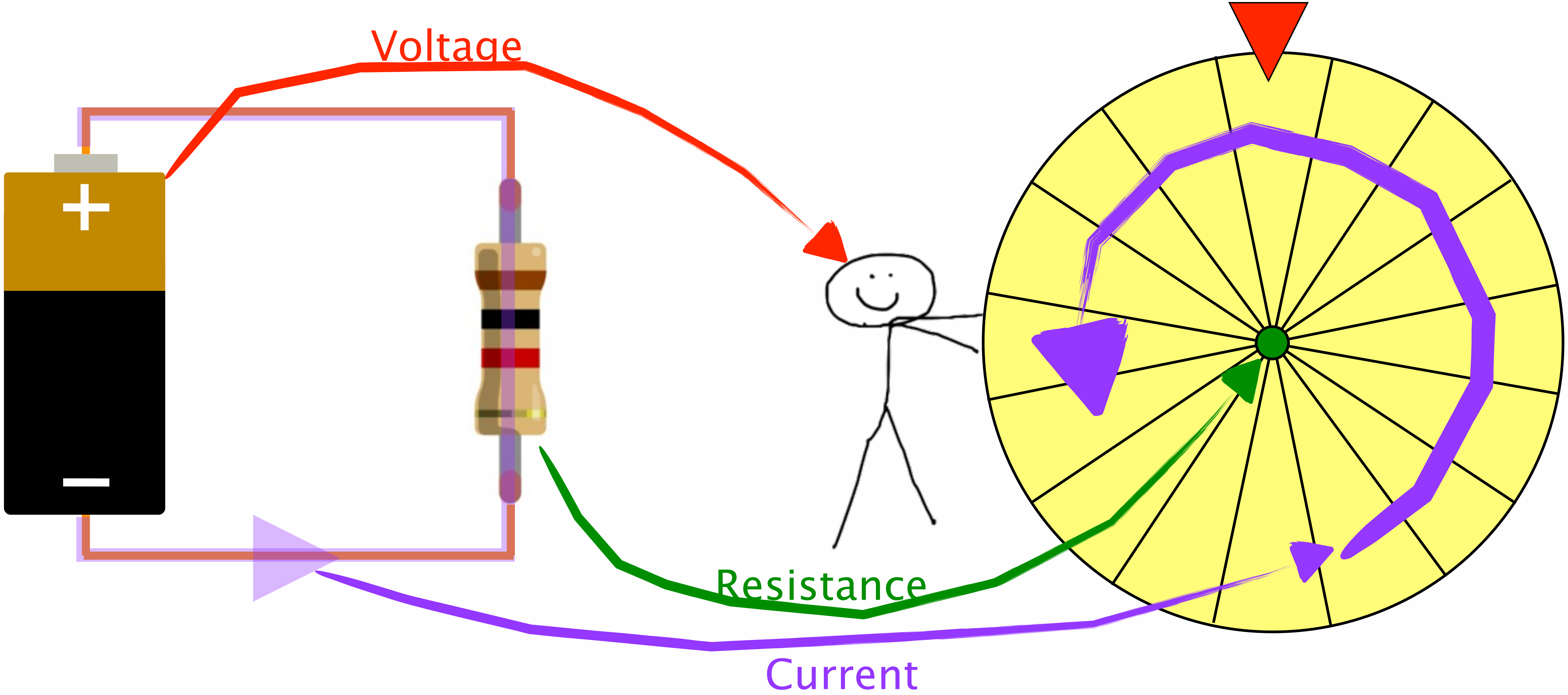
{Resistance}
The bearings the wheel is mounted on will provide some sort of resistance. The bearings could be very well oiled which means they will allow the wheel to spin freely (low resistance). Or, the bearings may be old and rusted which will restrict the wheel spinning (high resistance).

{Current}
As the wheel spins, a certain number of wheel segments will pass by the ticker each second. This represents our current. The faster the wheel is spinning, the more segments will pass by the ticker each second and therefore the more current we have. (just like counting electrons passing through wire).



{Voltage, Current and Resistance}

{Wheel of Fortune Analogy – Continued...}



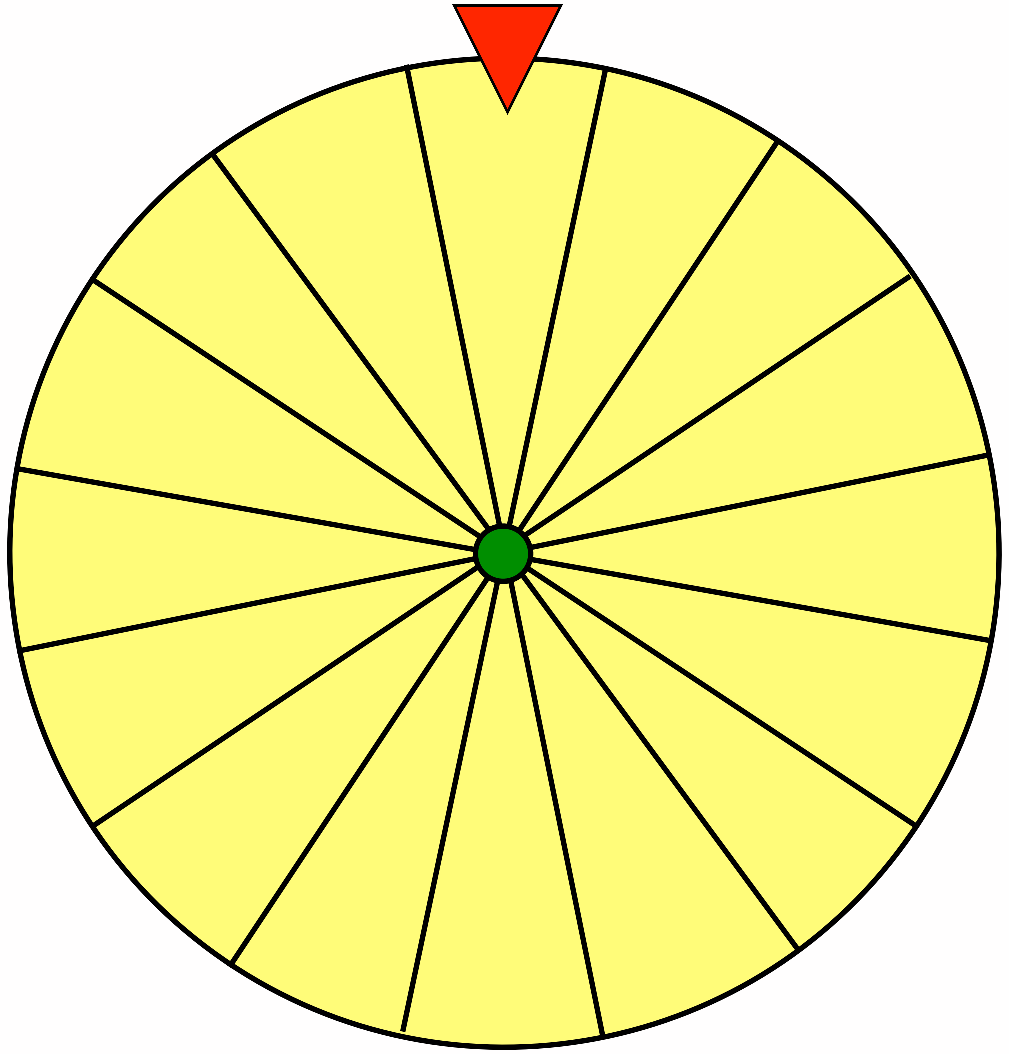
{Voltage, Current and Resistance}

{Wheel of Fortune Analogy – Continued...}

So let's run through some scenario's to figure out the relationship between Voltage, Current and Resistance.

{Scenario 1 – No Current Flow}

This scenario is very simple, we have no contestant to spin the wheel and we have no battery to push electrons through the circuit. Therefore just as the wheel will not spin, neither will current flow.

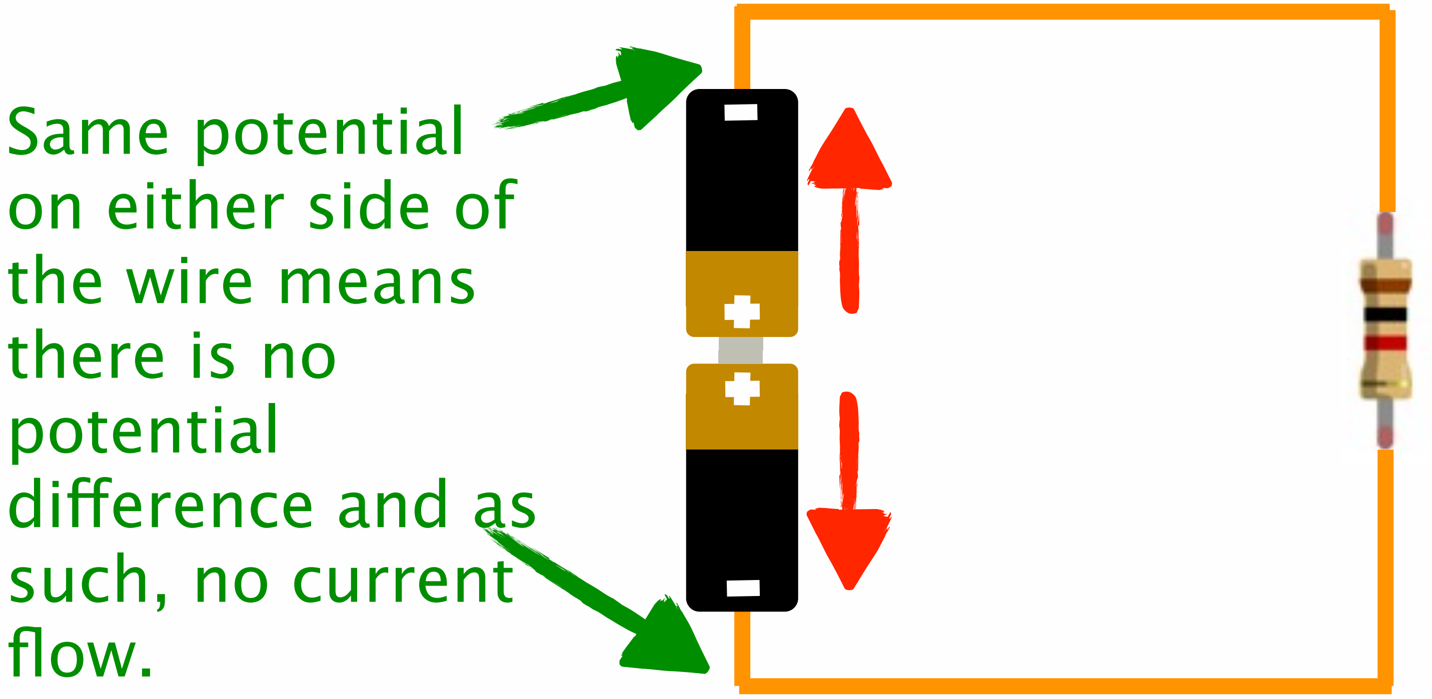


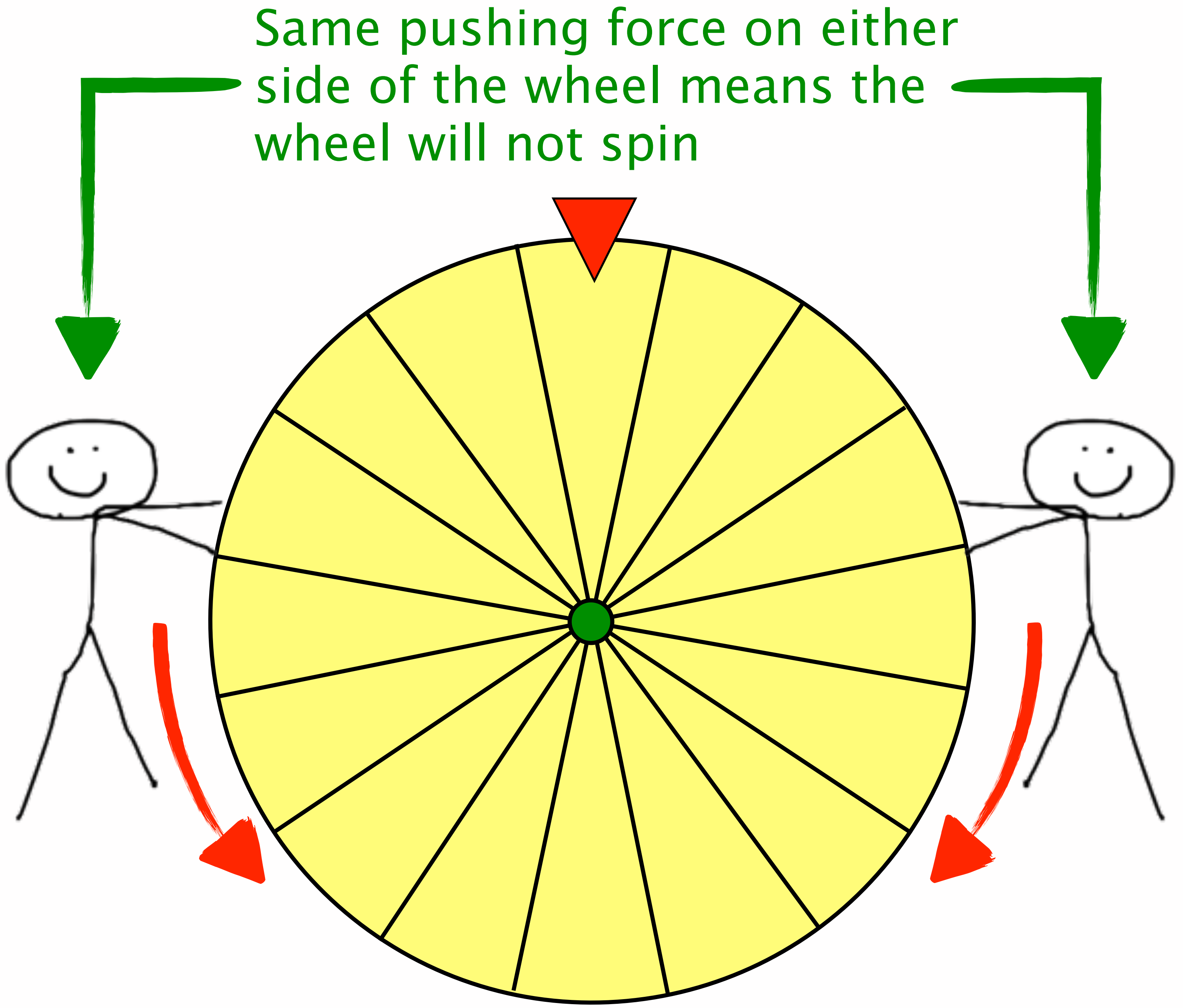
{Voltage, Current and Resistance}

{Wheel of Fortune Analogy – Continued...}

{Scenario 2 – No Current Flow}

Having two batteries in a circuit connected the opposite way to each other is exactly the same as having two people on either side of the wheel pushing against each other. As long as they are both pushing with exactly the same amount of force, the wheel will not move. And as long as the batteries have the same potential difference I.E. have the same voltage, no current will flow.





{Voltage, Current and Resistance}

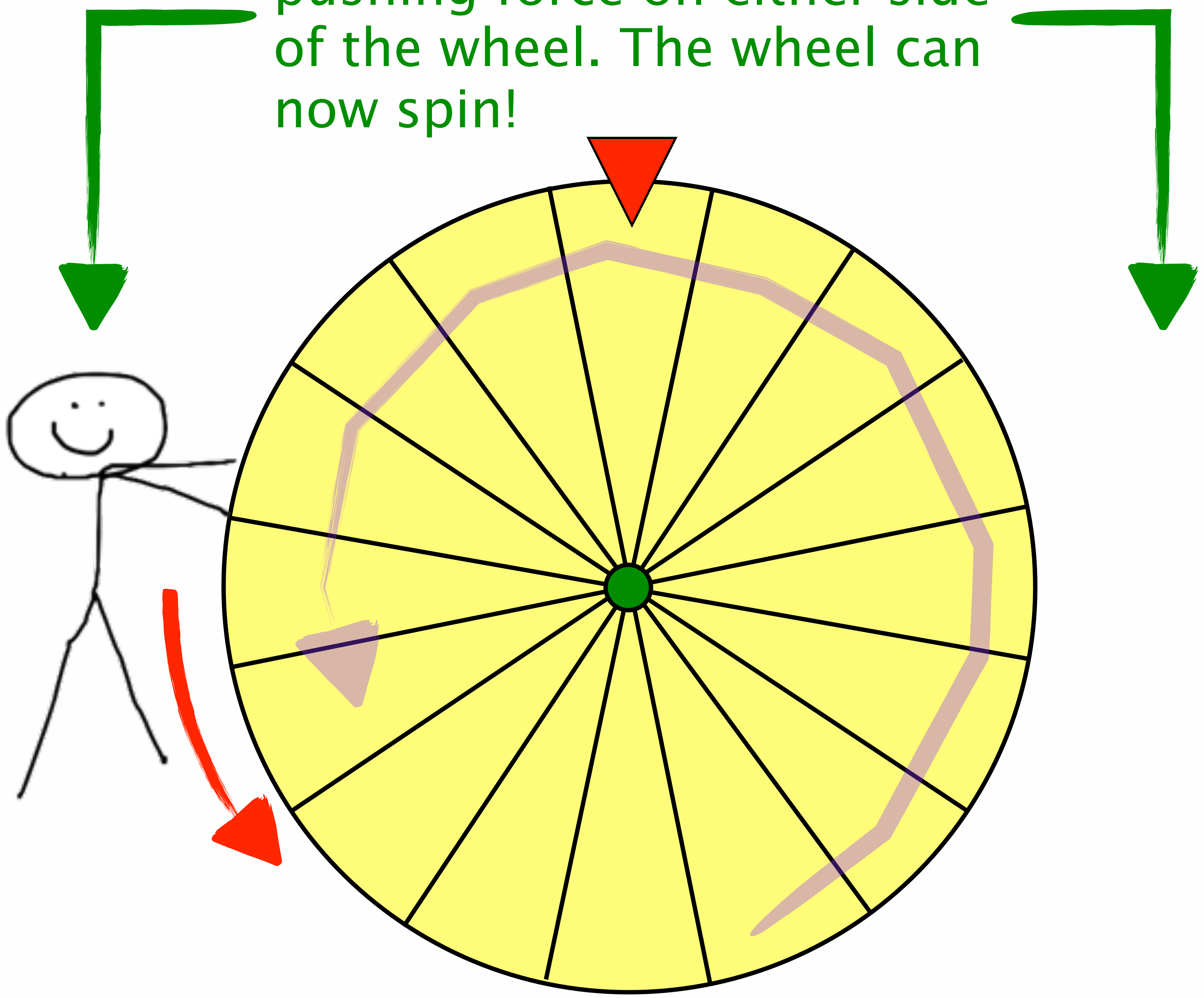
{Wheel of Fortune Analogy – Continued...}

{Scenario 3 – Current Is Now Flowing}

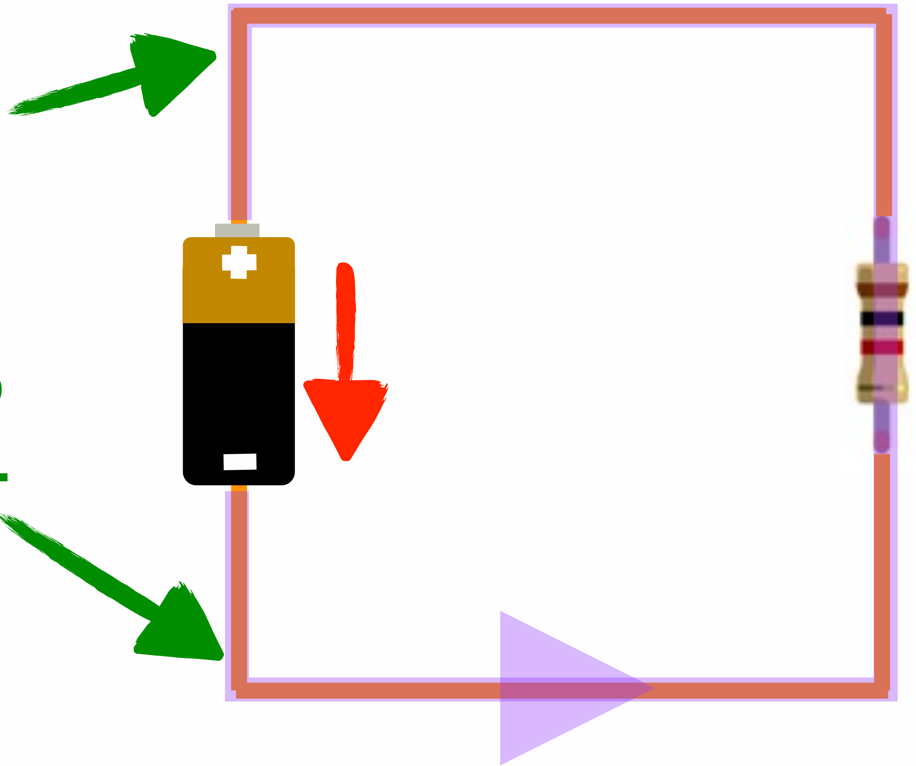
As soon as we remove the extra contestant, the wheel will actually spin. Since it is spinning we can count the number of segments passing the ticker each second.

Relating this to the electronic circuit, we have removed the extra battery working against us. This means electrons will flow through the circuit and if we count the number of electrons passing a certain point per second – we can then say how much current there is.

There is now a difference in pushing force on either side of the wheel. The wheel can now spin!



There is now a potential difference between the two ends of the wire. Current is now flowing!



{Voltage, Current and Resistance}

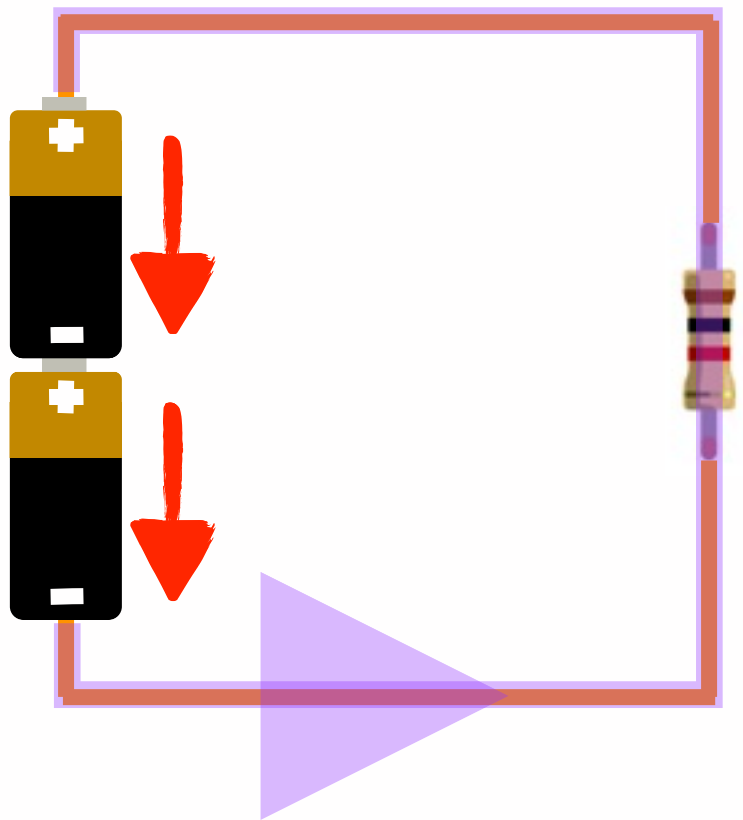
{Wheel of Fortune Analogy – Continued...}

{Scenario 4 – Increasing the voltage}

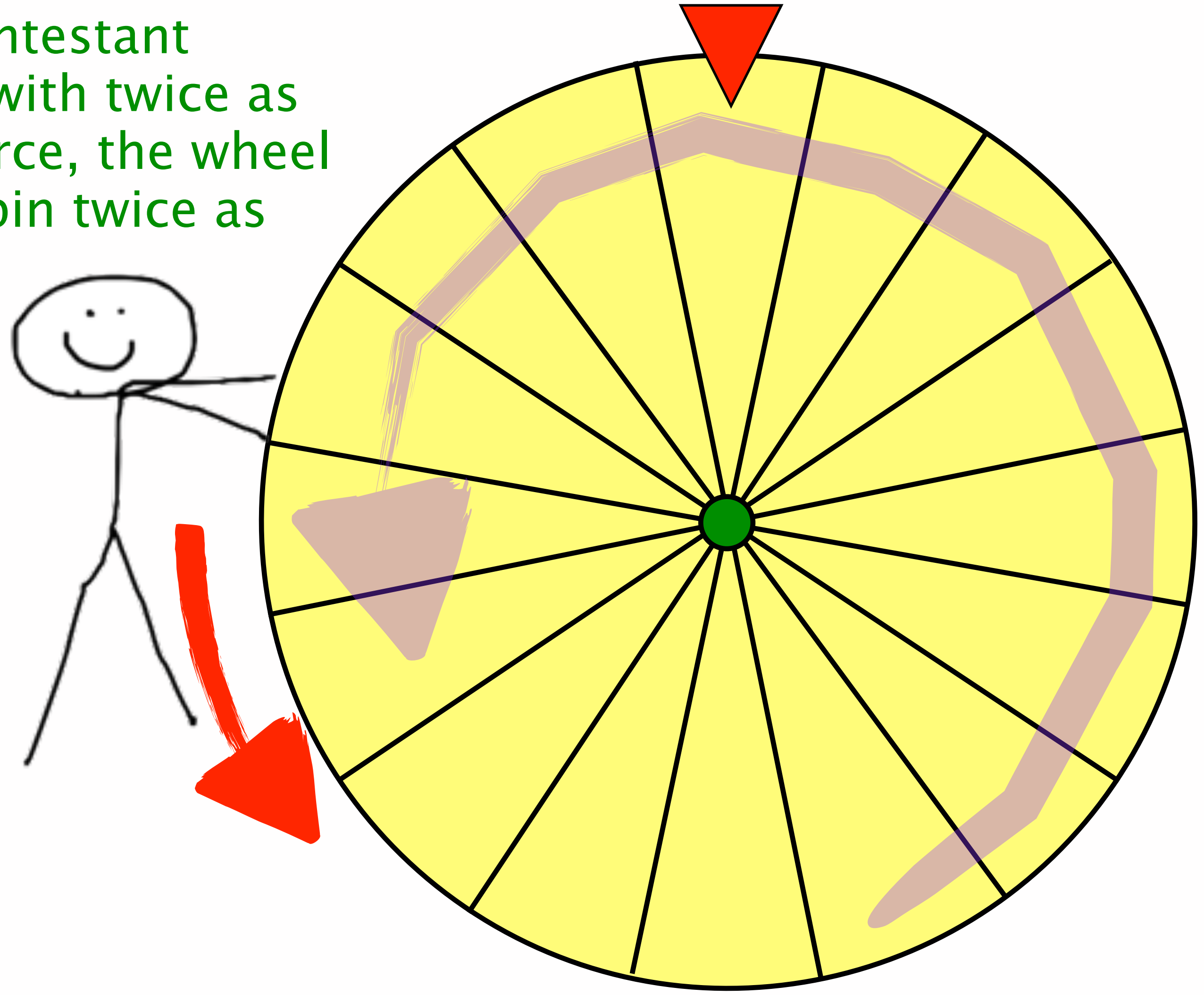
If we double the circuit voltage, we will double the number of electrons passing through each second which means we have twice as much current. To do this we could add an extra battery which is helping the previous one.

This is just like having the contestant push the wheel with twice as much force as before, resulting in the wheel spinning twice as fast and therefore twice as many segments passing the ticker each second.

Both batteries are pushing in the same direction. Therefore we will get twice as much current flowing



If the contestant pushed with twice as much force, the wheel would spin twice as fast.



{Voltage, Current and Resistance}

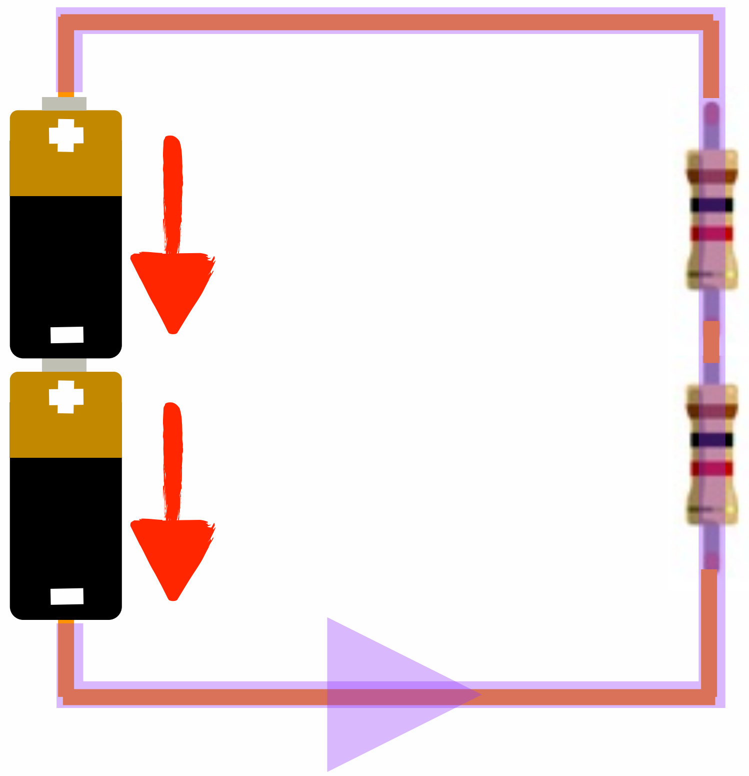
{Wheel of Fortune Analogy – Continued...}

{Scenario 4 – Increasing the Resistance}

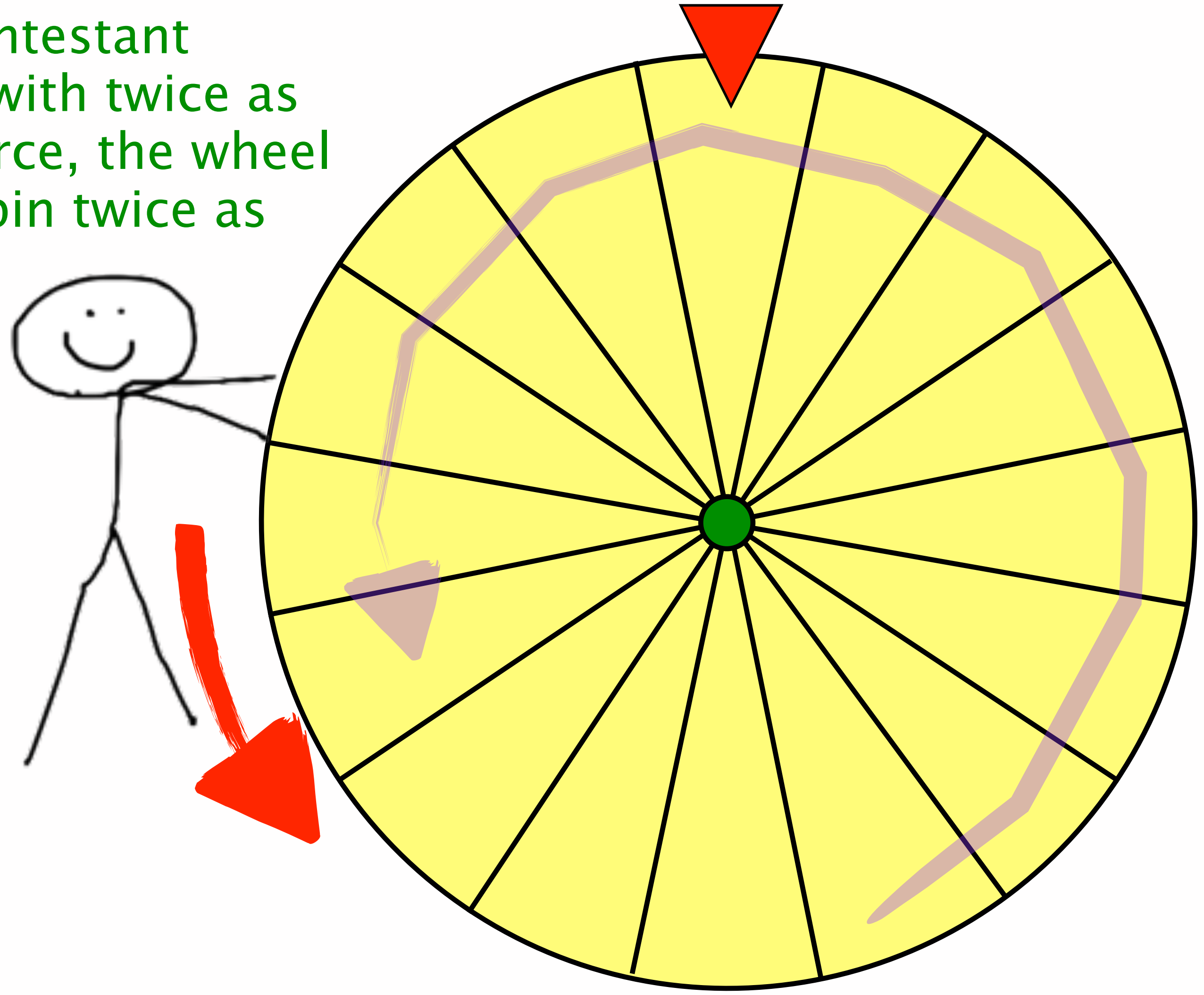
If we double the resistance in the circuit we will now slow down the electrons. This means we would count less electrons per second and therefore our current would be less.

This would be like adding rust to the wheel of fortune bearings. The rust adds more resistance causing the wheel to spin slower. Since it is spinning slower we would count less segments passing the ticker each second.

Both batteries are pushing in the same direction. Therefore we will get twice as much current flowing



If the contestant pushed with twice as much force, the wheel would spin twice as fast.



{Voltage, Current and Resistance}

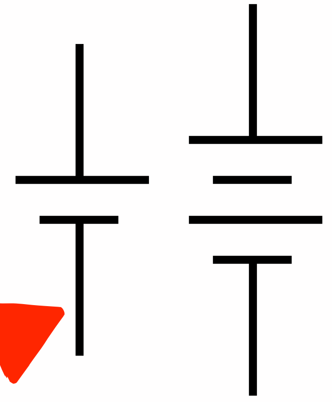
Hopefully the analogy has helped you understand the relationship between Voltage, Current and Resistance. To finish off this section, here’s a handy little reference table to show what happens to current as voltage or resistance increase and decrease.

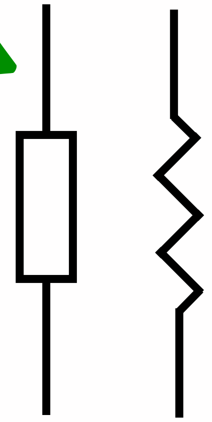
	Current
Voltage ↑	↑
Voltage ↓	↓
Resistance ↑	↓
Resistance ↓	↑

{Voltage, Current and Resistance}

{Summary}

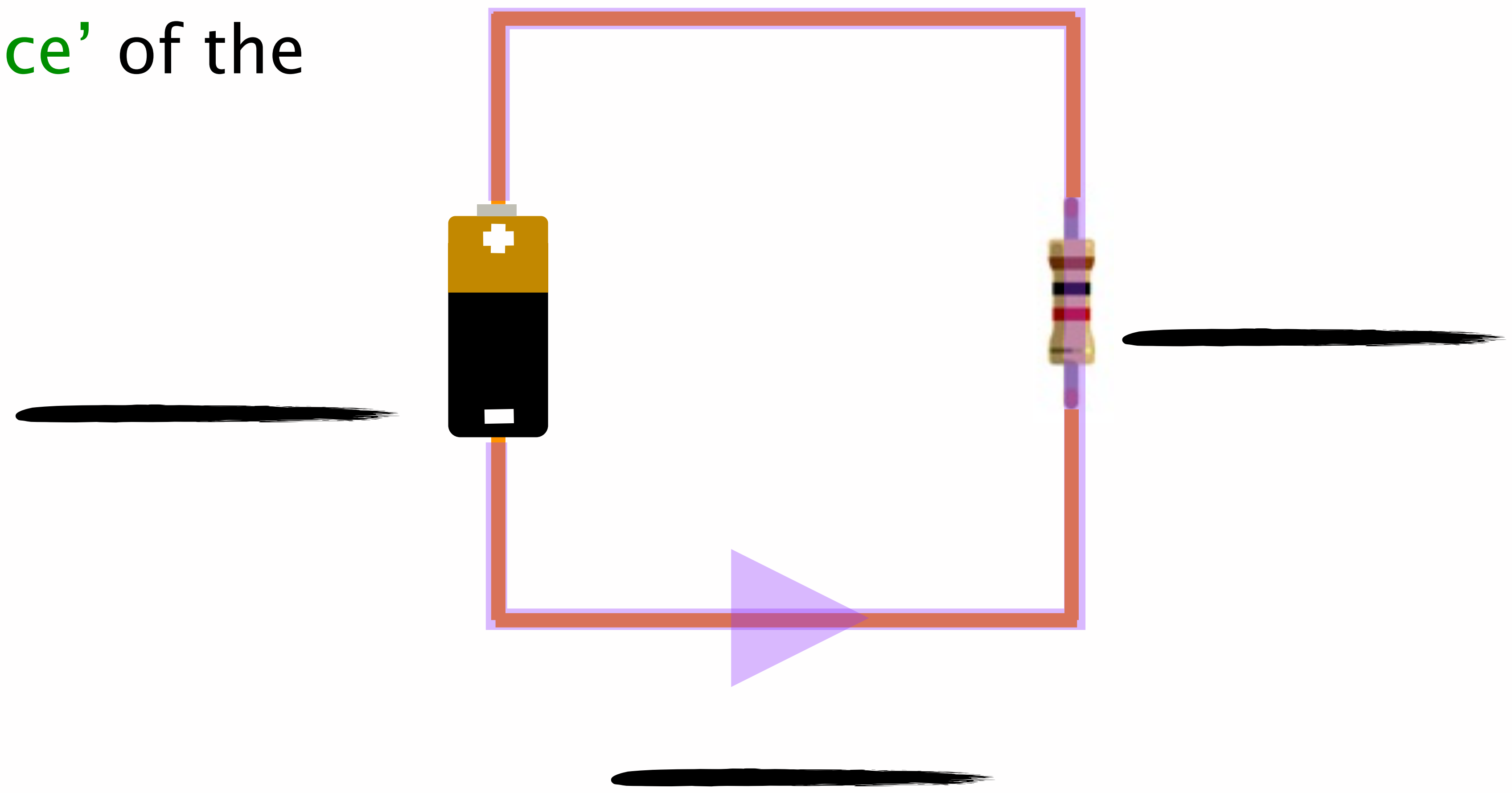
- Voltage is the potential difference or electromotive force that ‘pushes’ electrons through an electronic circuit. Voltage is measured in Volts and is given the letter V.
- Current is the amount of electrons passing a certain point in our circuit each second. Current is given the letter I and is measured in Amps.
- Resistance is the opposition to current flow. Resistance is given the letter R and is measured in ohms Ω.
- These are the circuit symbols for a power supply (which represents Voltage)
- These are the circuit symbols for resistors (which represents Resistance)
- Current is directly proportional to Voltage (which means it will increase as voltage increases and decrease as voltage decreases)
- Current is inversely proportional to resistance (which means it will decrease and resistance increases and increase as resistance decreases)





{Voltage, Current and Resistance}

1. Label The 'Voltage', 'Current' and 'Resistance' of the following circuit:



2. What does 'voltage' do in an electronic circuit?

3. What does 'current' do in an electronic circuit?

{Voltage, Current and Resistance}

4. What does ‘resistance’ do in an electronic circuit?

5. Draw the two different symbols that represents a power supply.

6. Draw the two different symbol that represents a resistor.

7. What would happen to current in a circuit if the resistance increased?

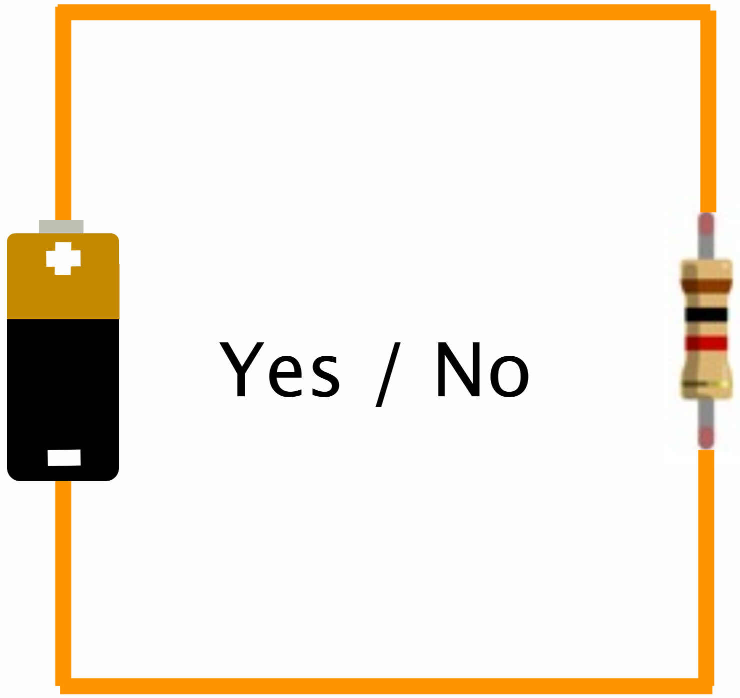
8. What would happen to current in a circuit if the resistance decreased?

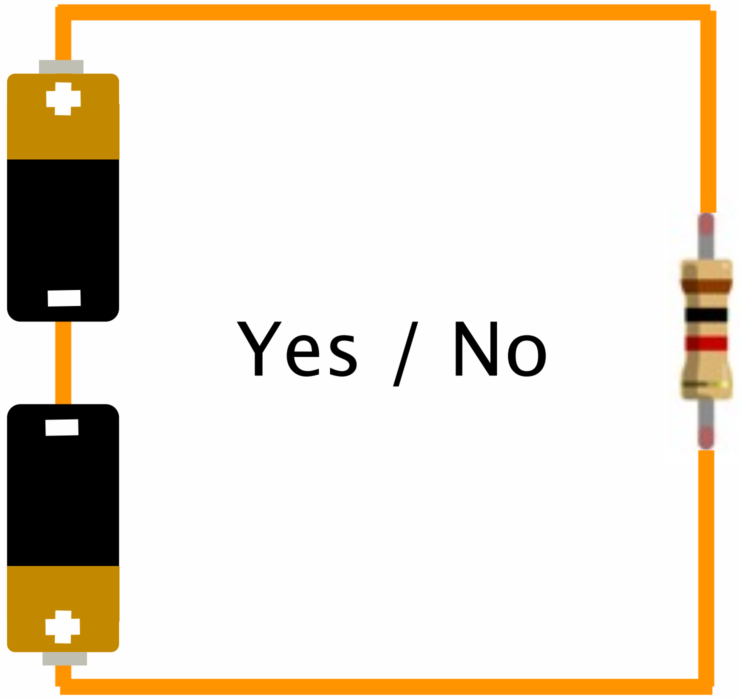
{Voltage, Current and Resistance}

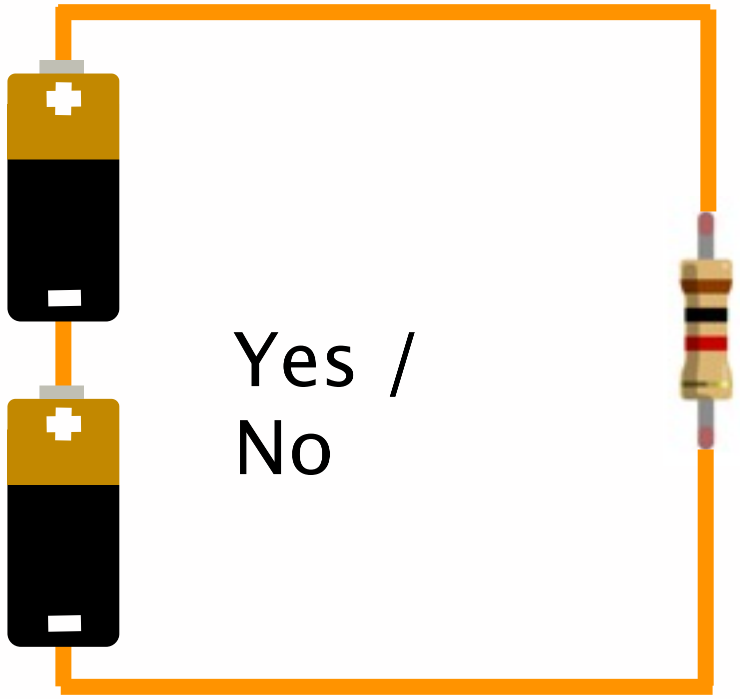
9. What would happen to current in a circuit if the Voltage decreased?

10. What would happen to current in a circuit if the Voltage increased?

11. Answer yes or no for whether current will flow in the following circuits:







{Multimeter Introduction}

{Learning Outcomes}

4.1 Perform a pre-use check on a multimeter
4.2 Understand the different connections available on a multimeter
4.2 Understand the different selections available on a multimeter
4.3 Measure Voltage, Current and Resistance with a multimeter
4.4 Understand the difference between a manual range multimeter and an auto range multimeter

{Multimeter Introduction}

{Introduction}

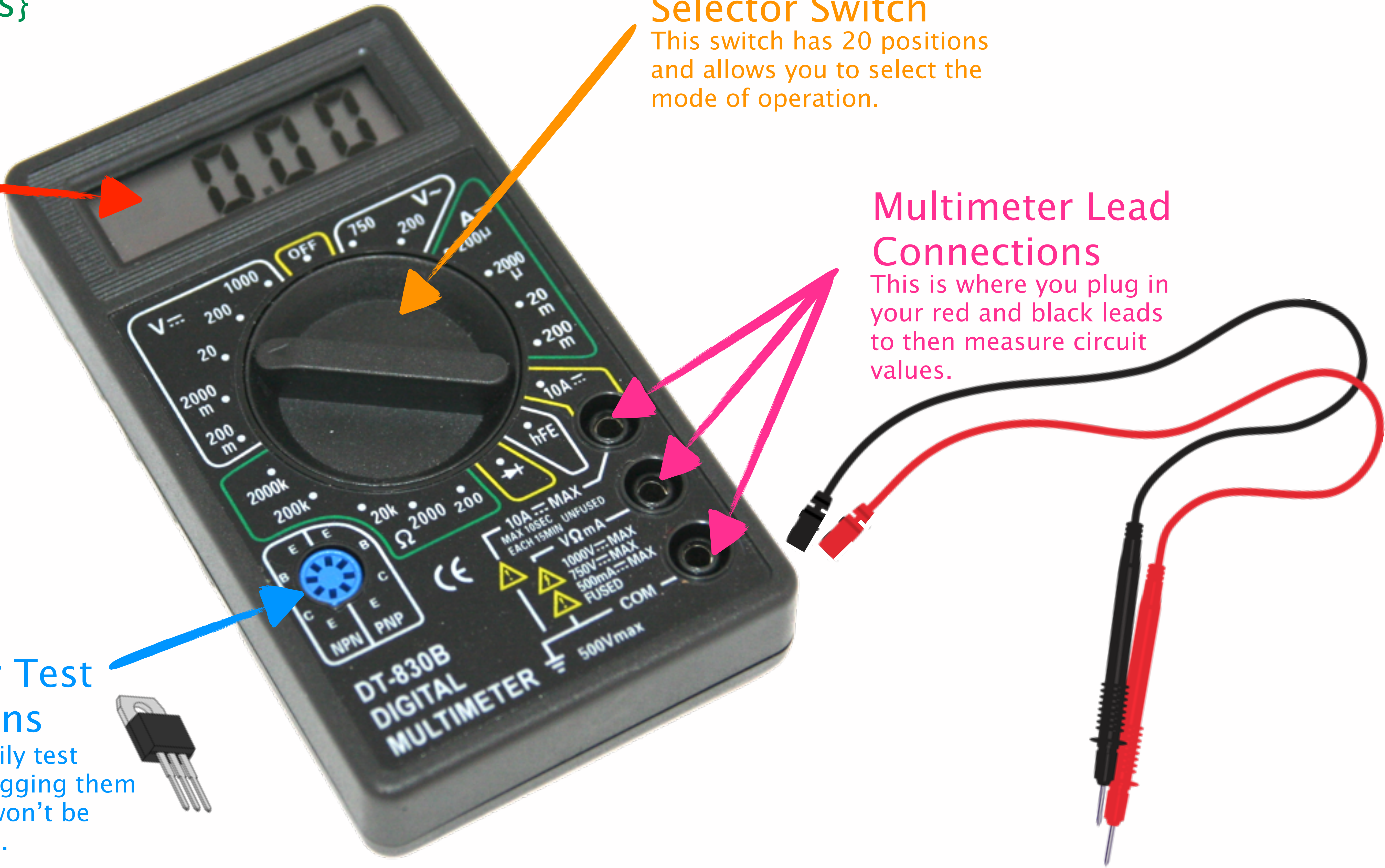
Multimeters come in a huge range of colours and sizes. Some have only the very basic functions such as the ability to measure voltage, current and resistance – while others extend their capabilities to measuring all sorts of other properties of an electronic circuit such as frequency, capacitance, inductance, temperature and more.

This chapter is an introduction to the multimeter and will serve to get you familiar with measuring the fundamental properties of electronic circuits which are voltage, current and resistance.

The theory will be based around the manual range multimeter which is provided as part of the experimenters kit. However the theory can easily be applied to practically any other multimeter.

{Multimeter Introduction}

{Hardware Features}



Rotary Function Selector Switch

This switch has 20 positions and allows you to select the mode of operation.

LCD Screen

This will give you a digital readout of Voltage, Current or Resistance. For Example:

120.1 Ohms

0.02 Amps

5.02 Volts

Multimeter Lead Connections

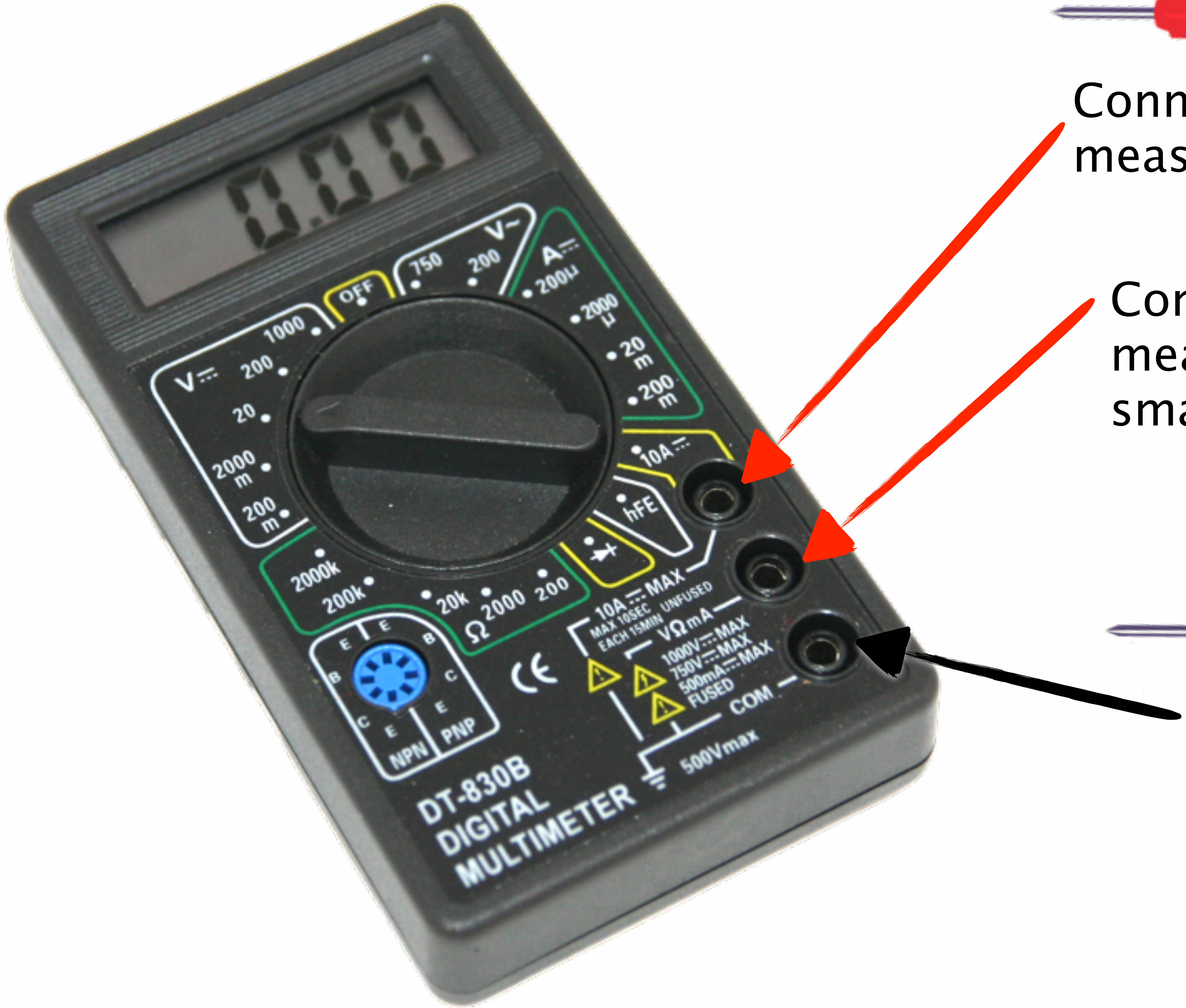
This is where you plug in your red and black leads to then measure circuit values.

Transistor Test Connections

Allows you to easily test transistors by plugging them in. (This feature won't be covered just now).

{Multimeter Introduction}

{Hardware Features}



Connect the red lead here to measure large values of current.

– or –

Connect the red lead here to measure Voltage, Resistance or small values of Current

The black lead will always connect to this COM (Common) connection

{Multimeter Introduction}

{Modes of Operation}

Power Off

Voltage Measurement Selections

Small Current Measurement Selections

Large Current Measurement Selection

Resistance Measurement Selections

{Multimeter Introduction}

{Voltage Selection}

This multimeter has 5 different selections to measure circuit voltage. The numbers printed on them indicate the maximum voltage you can measure for that selection.

For example: with the selector switch in the '20' position we will be able to measure up to a maximum of 20 Volts.

If we had the selector switch in the '1000' position, we would be able to measure up to a maximum of 1000 Volts.

The 2000m selection is a maximum of 2000 millivolts which is the same as saying 2 Volts. Much the same as how 2000 millimetres is the same as saying 2 Metres. Concepts such as 'milli' will be covered in detail in the calculator chapter.

{Multimeter Introduction}

{Current Selection}

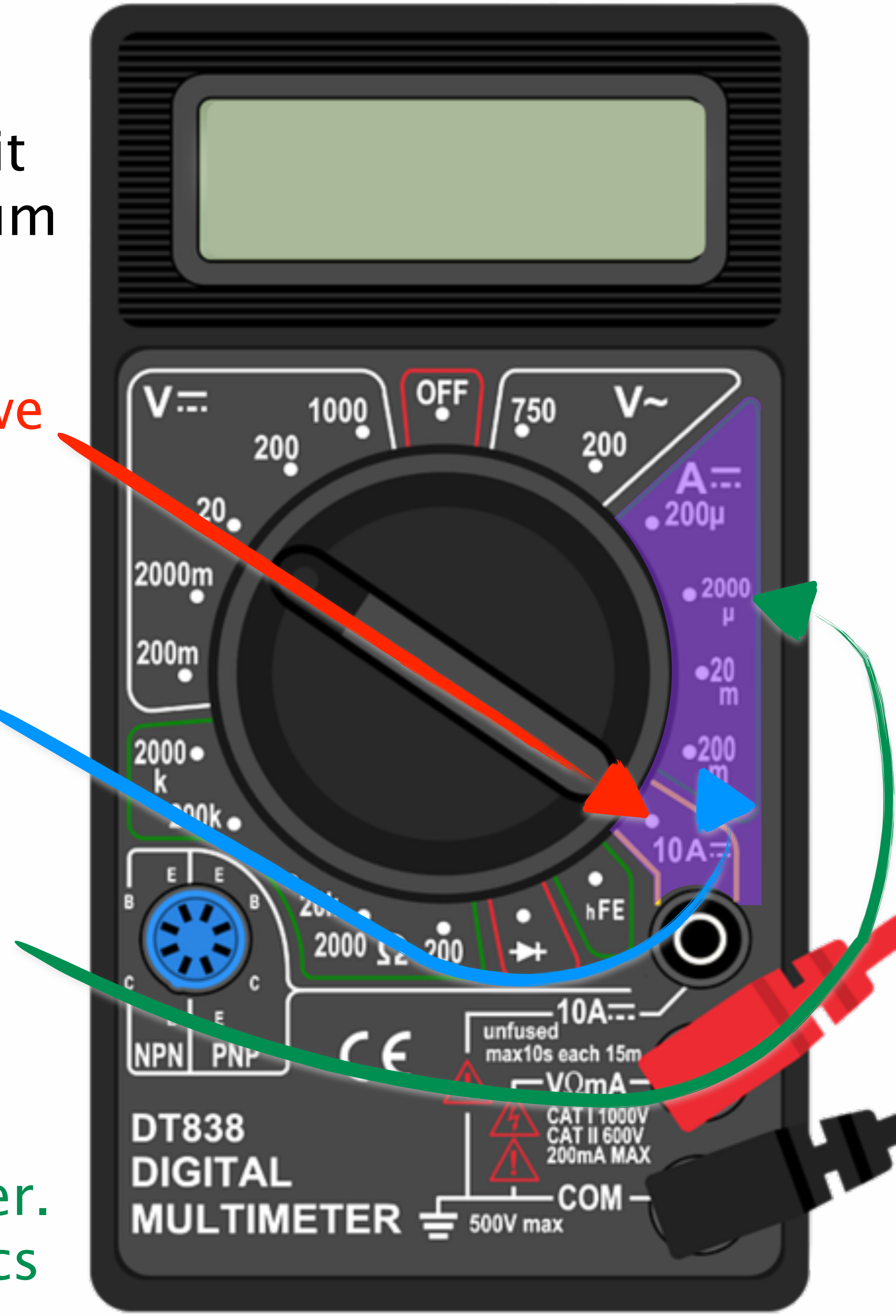
This multimeter has 5 different selections to measure circuit current. The numbers printed on them indicate the maximum current you can measure for that selection.

For example with the selector switch in the '10A' position we will be able to measure a maximum current of 10 Amps.

The 200m selection gives a maximum of 200 milliamps which is the same as saying 0.2 Amps. Much the same as how 200 millimetres is the same as saying 0.2 Metres.

The 2000µ selection is a maximum of 2000 microamps which
is the same as saying 2 milliamps. Much the same as how 2000 micrometres is the same as saying 2 millimetres.

Remember, this will all be covered in detail in a later chapter. All you need to worry about at the moment is the very basics of multimeters.



{Multimeter Introduction}

{Resistance Selection}

This multimeter has 5 different selections to measure resistance. The numbers printed on them indicate the maximum resistance you can measure for that selection.

For example with the selector switch in the '200' position we will be able to measure a maximum resistance of 200 Ohms.

If we had the selector switch in the '2000' position, we would be able to measure up to a maximum of 2000 Ohms.

The 200k selection means we can measure up to a maximum
of 200 kilo ohms. kilo means 'thousand' so therefore we can measure up to 200 000 ohms. This is very much the same as how 200 kilometres is the same as 200 000 metres.

{Multimeter Introduction}

{Pre Use Check}

This check is a very basic way to determine if your multimeter and its leads are working correctly.

You will simply be checking to see if there is a very high resistance when the red and black probes are not touching each other and then a very low resistance when they are touching each other.

1. Turn the function select switch to the 200Ω setting

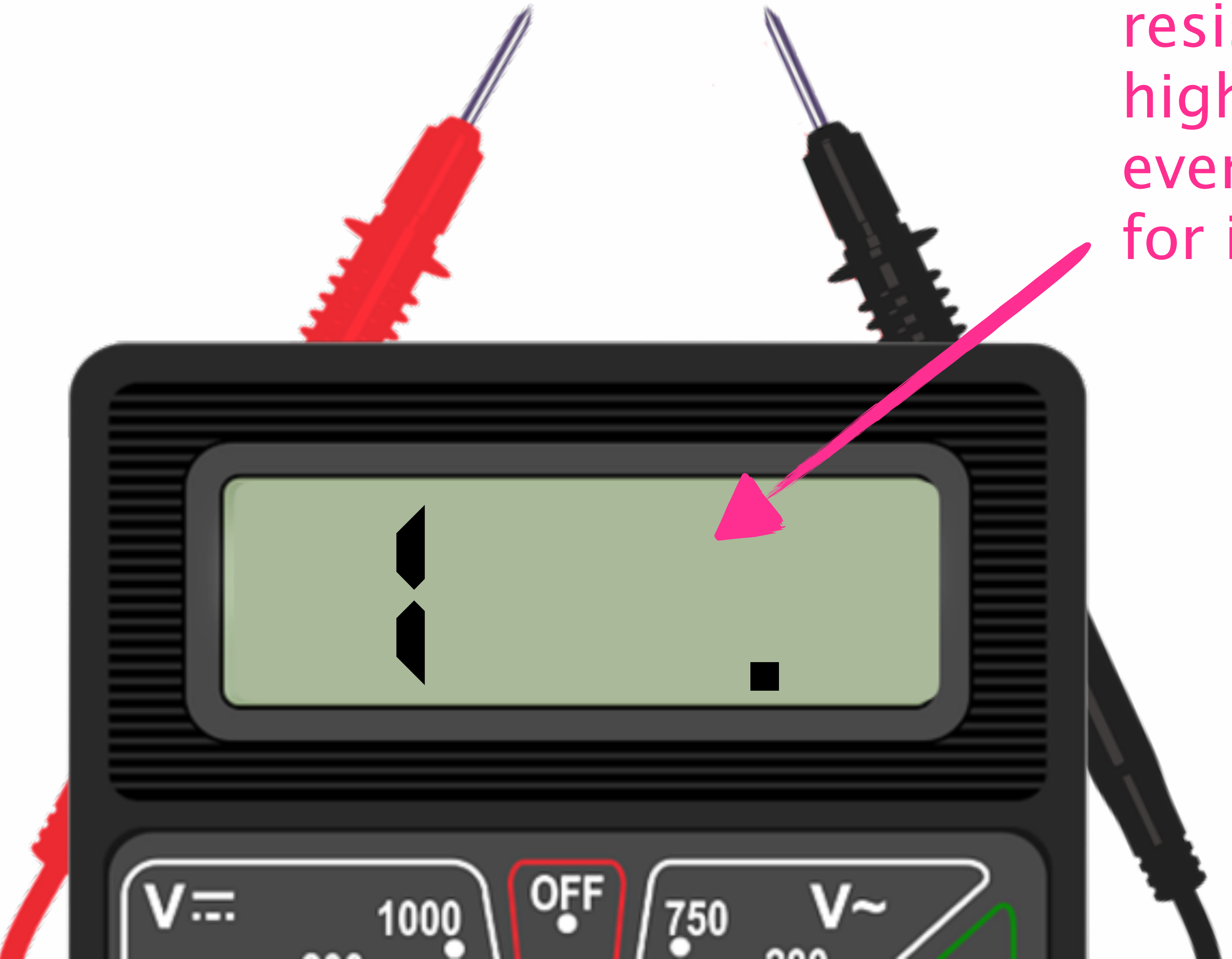
2. Plug the red lead into the middle (VΩmA) connection

3. Plug the black lead into the bottom (COM) connection

{Multimeter Introduction}

{Pre Use Check}

With the probes not touching each other, there is a very high resistance between them and the multimeter screen will show the following:



This means the resistance is so high, we can't even get a value for it!

With the probes touching each other, there should be a very low resistance between them. It should be less than 1 Ω.

This means very low resistance

{Multimeter Introduction}

{Pre Use Check}

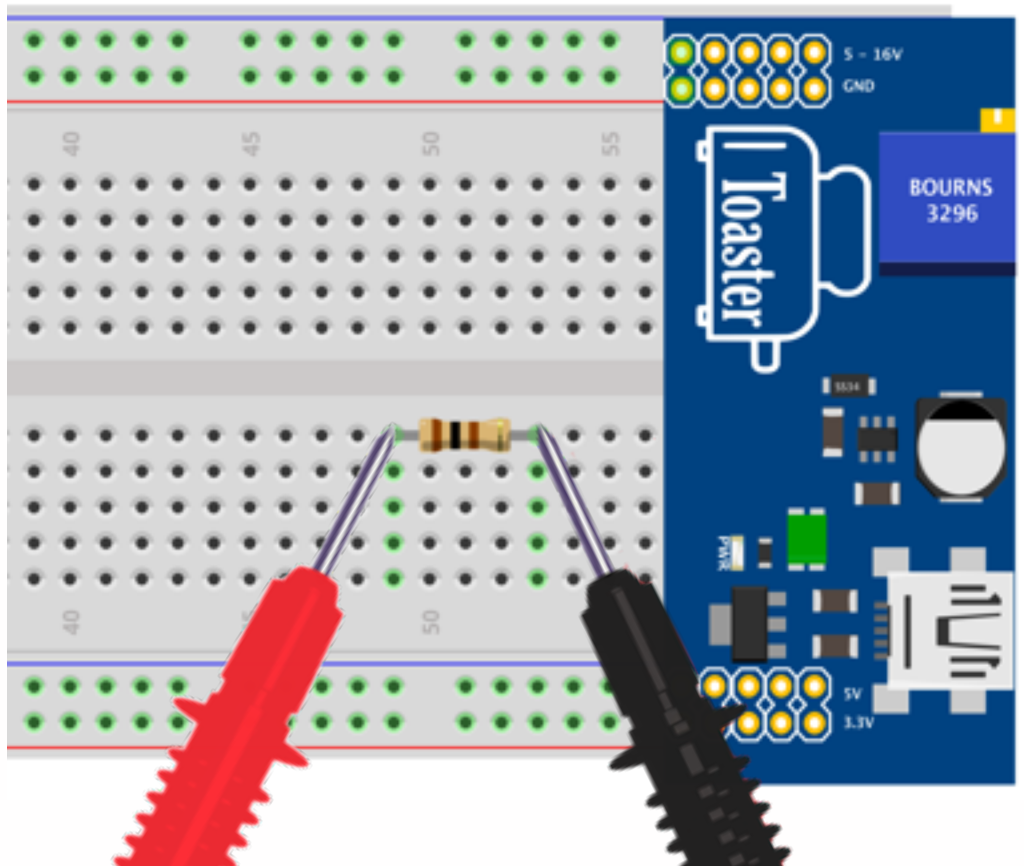
If your multimeter shows a high resistance when the probes are connected together (as shown below) then you most probably have a broken wire inside one of the probes. This can possibly happen since multimeter leads tend to get wrapped up and unwrapped a lot.

{Multimeter Introduction}

{Measuring Resistance}

There is a chapter dedicated to resistors coming up a little later however there's no problem with running through some basic resistance measurements with our multimeter now.

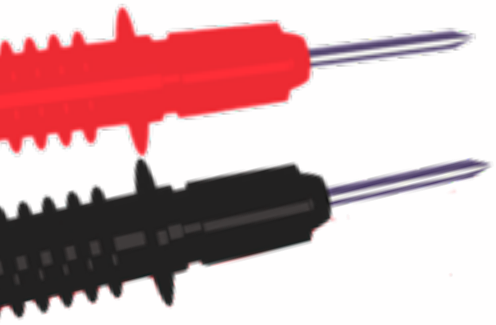
The resistor shown below has a value of 100 Ohms. The best setting for our multimeter is 200 Ohms (remember, this means we can measure a maximum of 200 Ohms).



{Multimeter Introduction}

{Measuring Resistance}

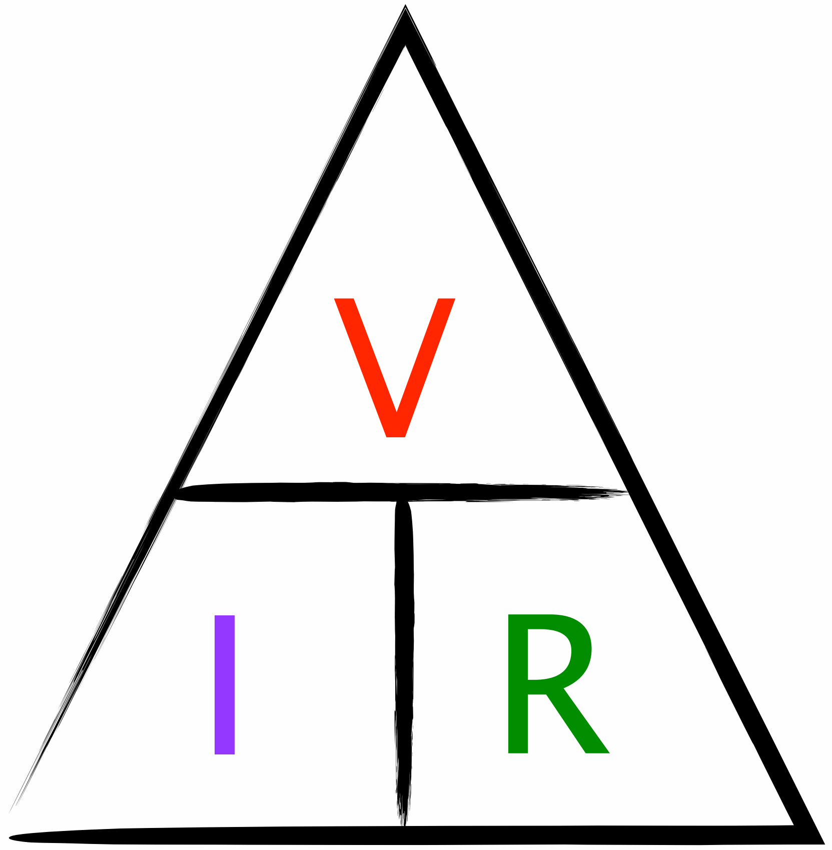
This section on multimeters
is incomplete...

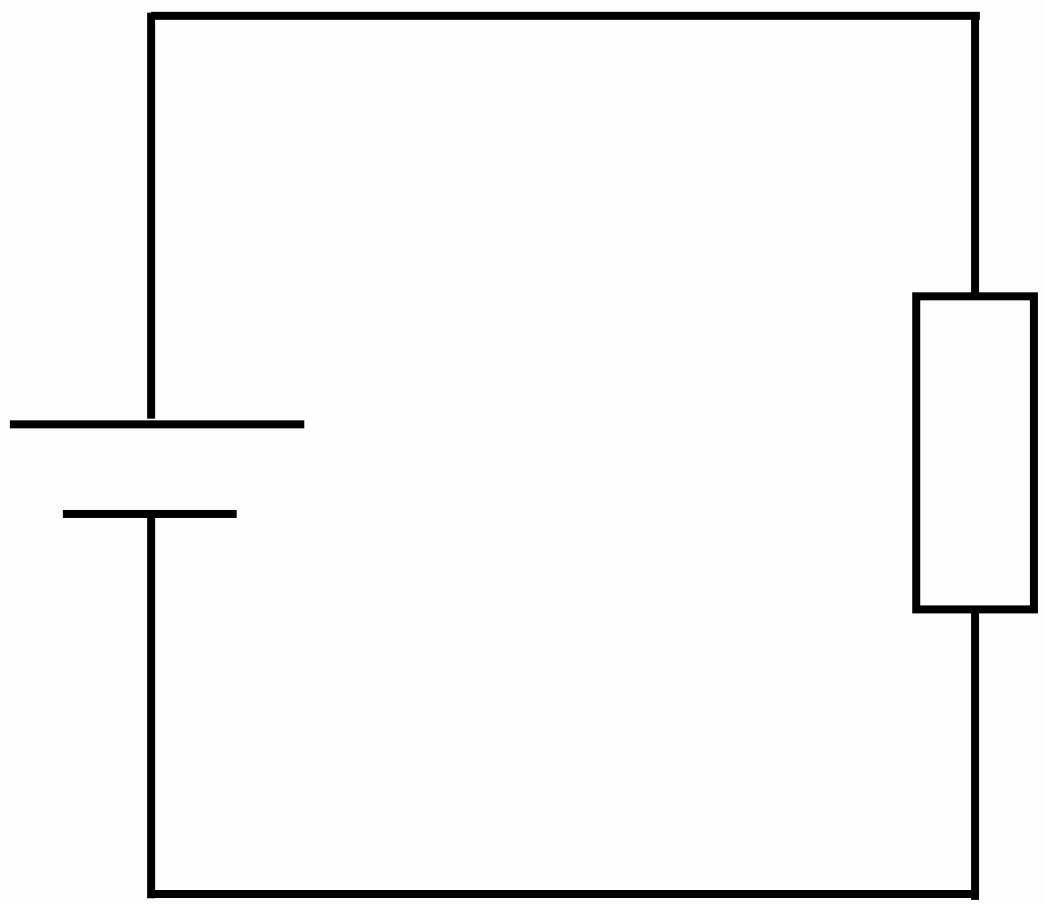


{Ohm's Law}

{Learning Outcomes}

4.1 State Ohm's Law
4.2 Calculate Voltage, Current and Resistance using the Ohm's law triangle
4.3 State the letters, units of measure and symbols for Voltage, Current and Resistance





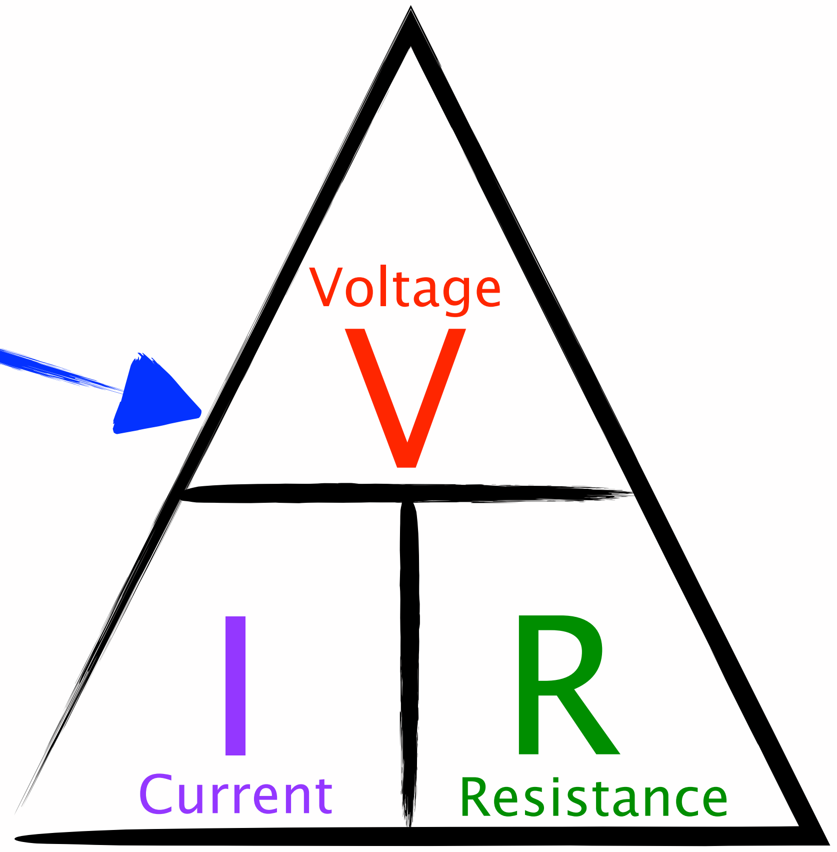
{Ohm's Law}

{What is Ohm's Law?}

Ohm's law was named after the German physicist Georg Ohm who found that the amount of current in a circuit would increase if the power supply voltage increased and would decrease if the amount of resistance in the circuit increased. Hopefully this is bringing back some memories of the previous chapter!

This can be stated in a more formal manner like this:
"Current is directly proportional to voltage and inversely proportional to resistance"

Ohm's law can be represented by the 'Ohm's Law Triangle'



While we will be covering quite a great deal of circuit calculations in later sections, the mathematical concepts of Ohm's Law are quite straight forward so we will learn about the principles now.

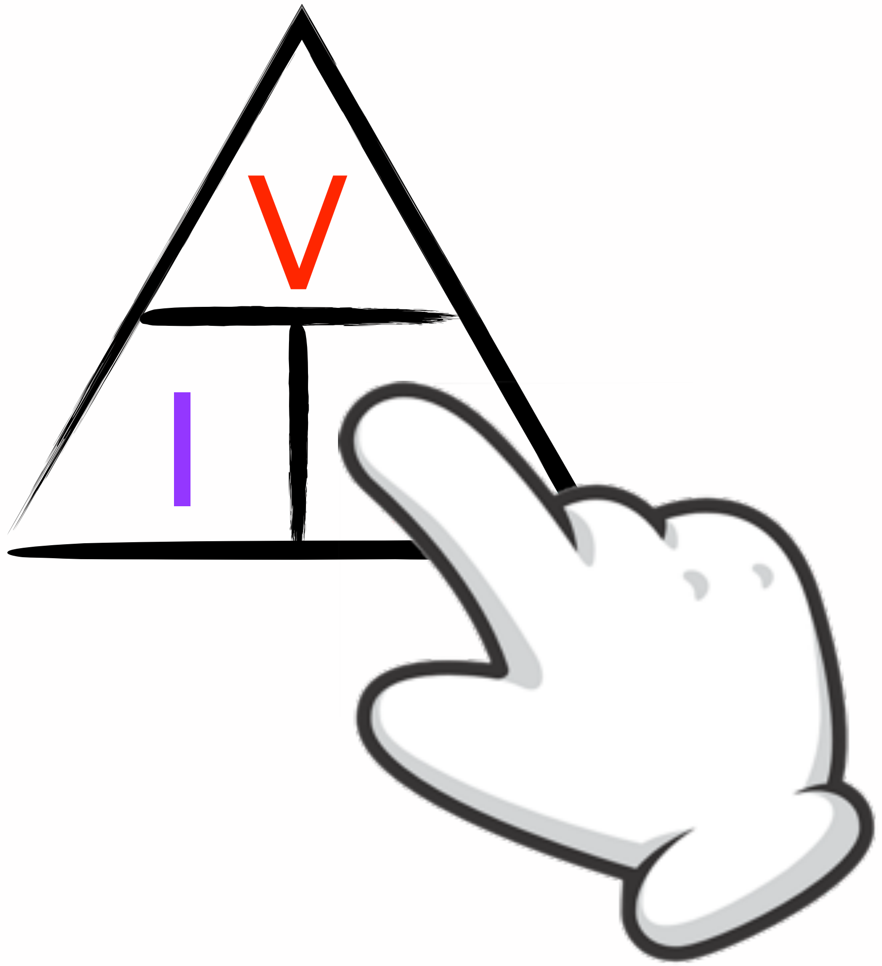
From the triangle, as long as we know two values, we can calculate the third unknown value.

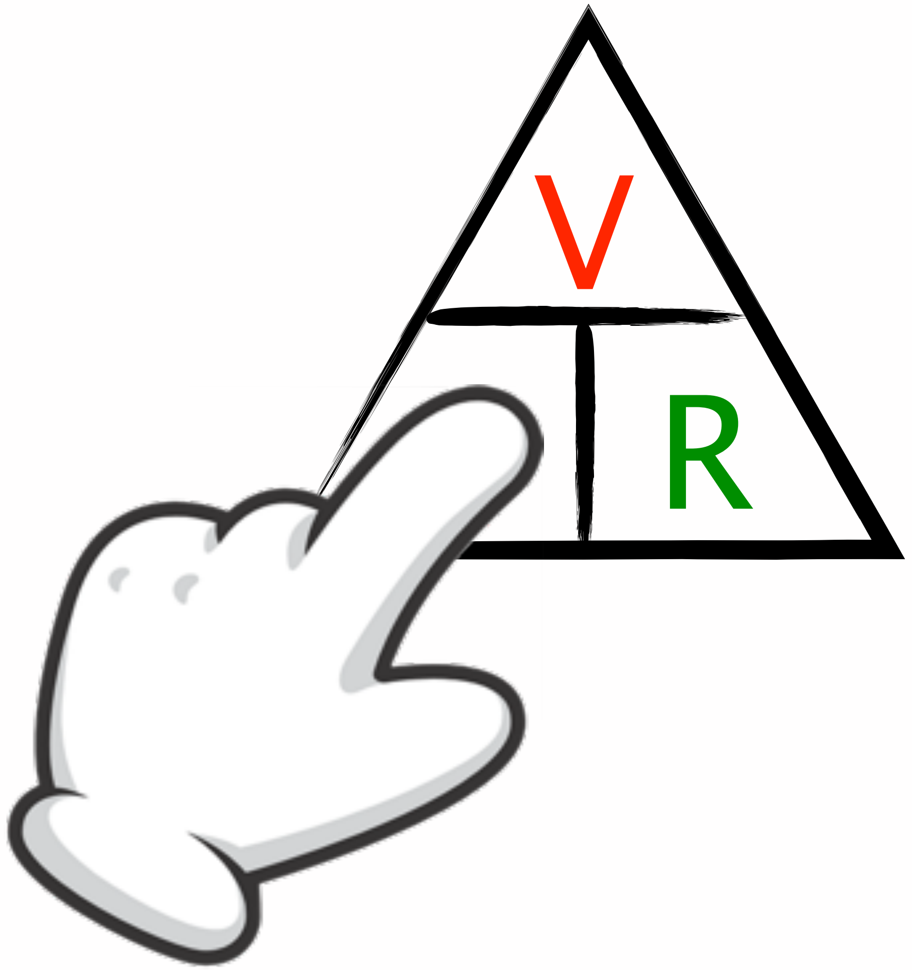
- If you know Voltage and Resistance, you can calculate Current
- If you know Voltage and Current, you can calculate Resistance
- If you know Current and Resistance, you can calculate Voltage

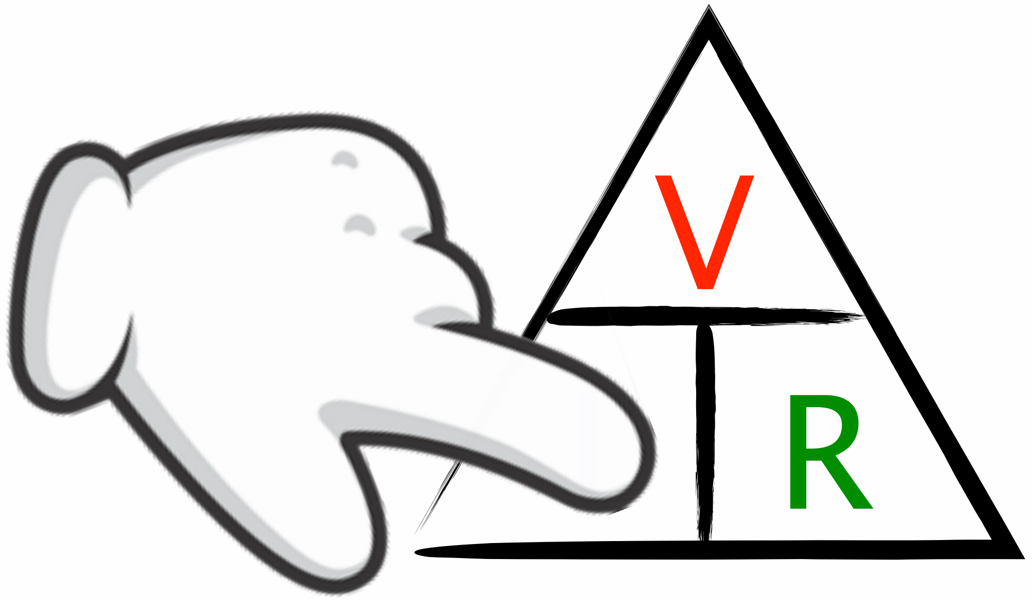
Recall from page 3.3 that:
- Voltage is given the letter V
- Current is given the letter I
- Resistance is given the letter R

Continue on to see how this all works.

{Ohm's Law}







To find Resistance, simply cover up the letter R. The calculation then becomes:

$$R = \frac{V}{I}$$

To find Current, simply cover up the letter I. The calculation then becomes:

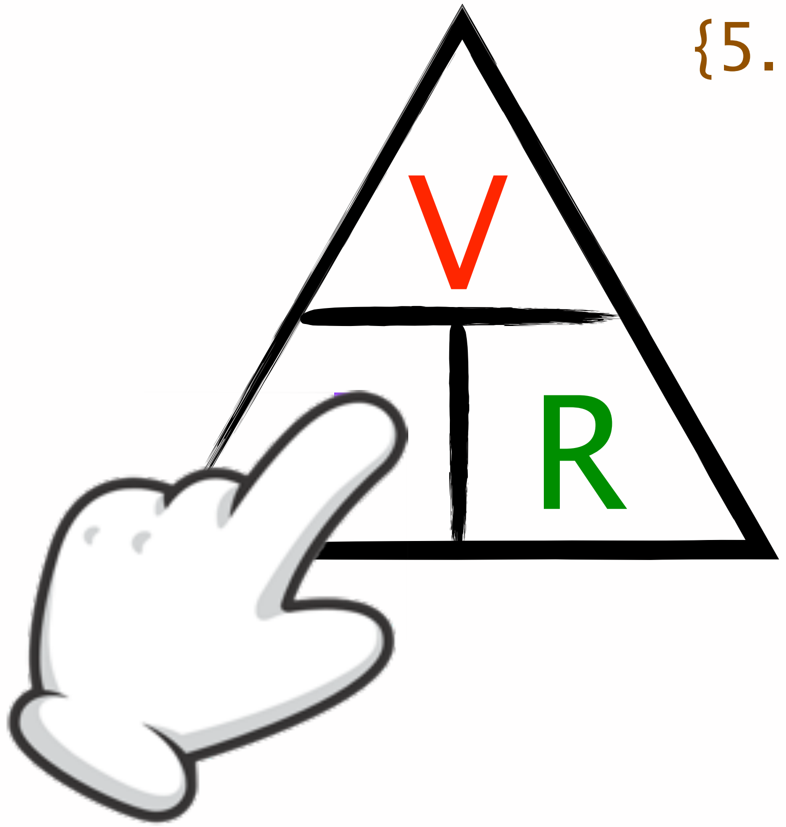
$$I = \frac{V}{R}$$

To find Voltage, simply cover up the letter V. The calculation then becomes:

$$V = I \times R$$

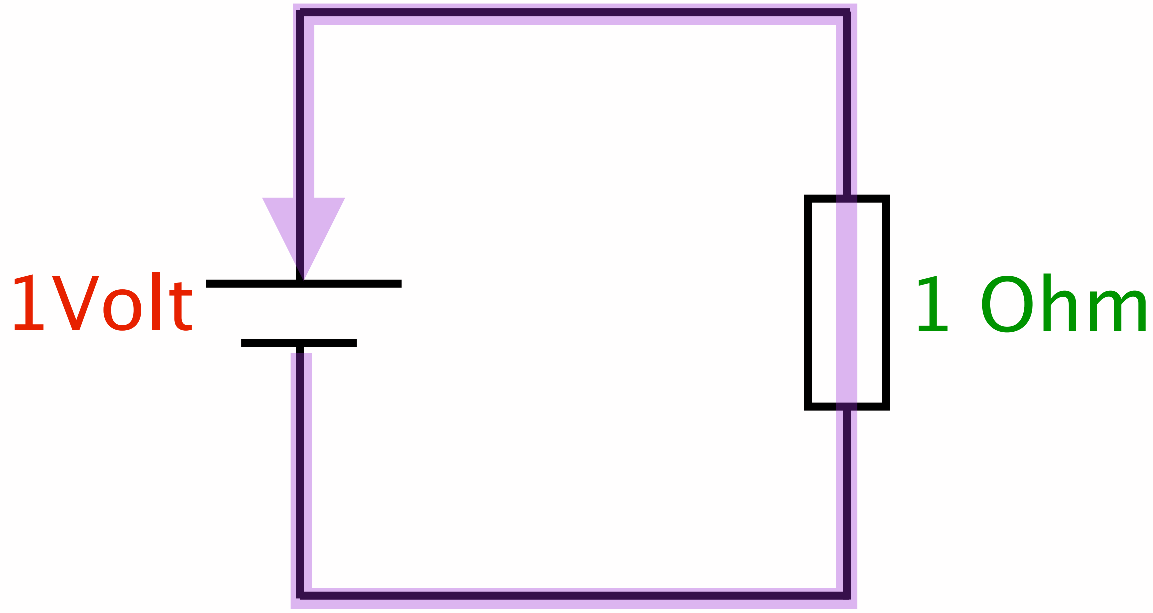
Here comes the fun part – let’s put this theory into action!

{Ohm's Law}



{Example #1 – Calculate current}

Let's have a look at what we do have and then use those values to figure out what we don't have. In this case we have the voltage and the resistance. Using the Ohm's law triangle, we can then figure out how much current we have in the circuit.

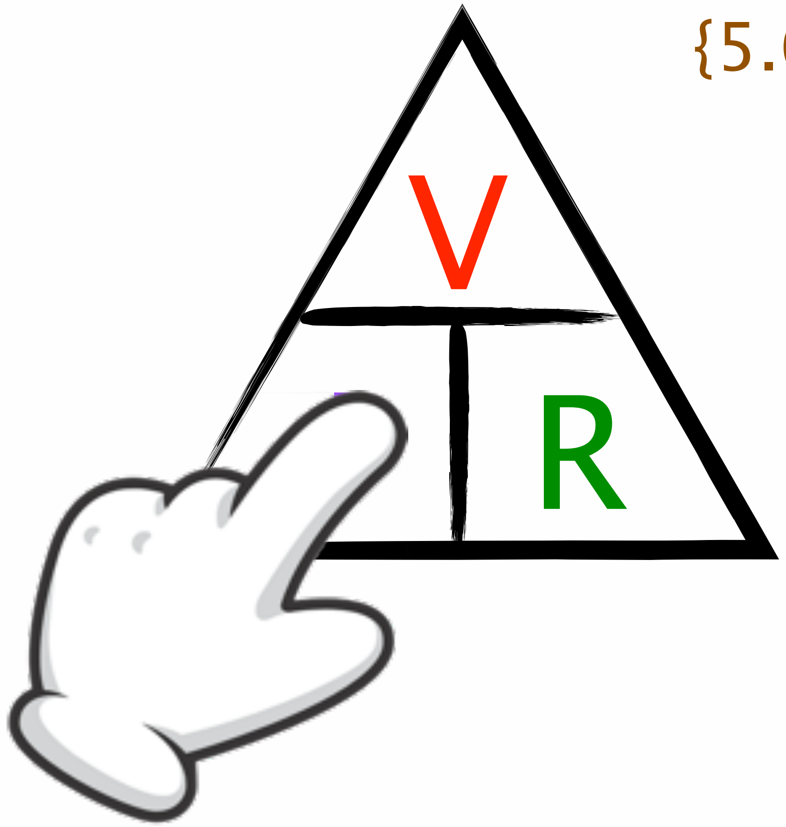


$$I = \frac{V}{R}$$

$$I = \frac{1\ \text{Volt}}{1\ \text{Ohm}}$$

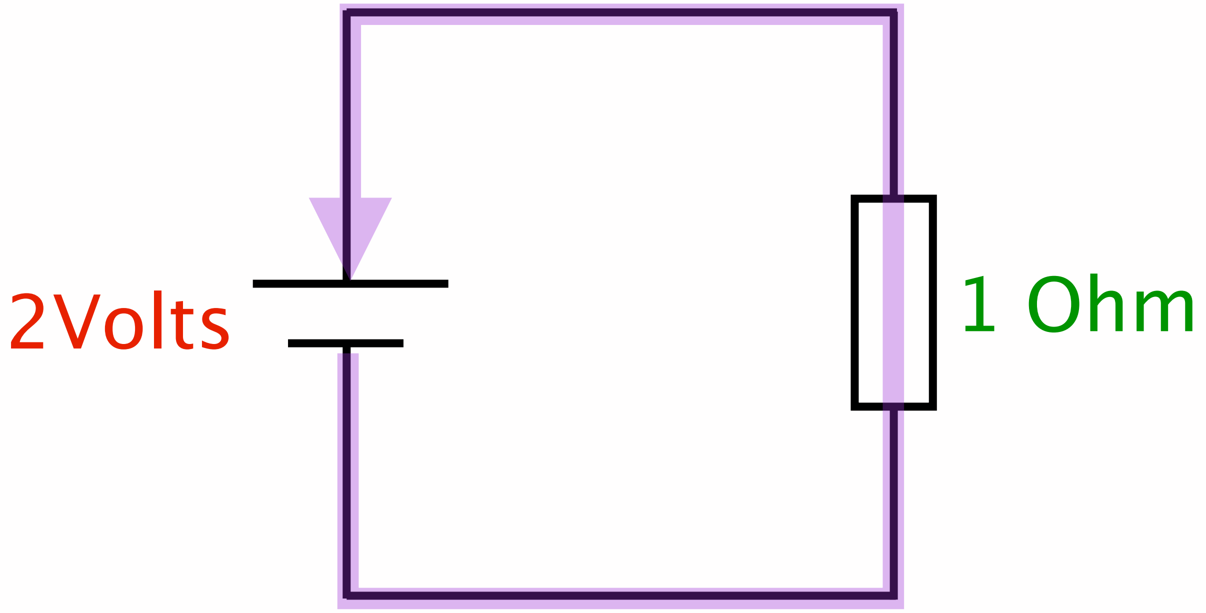
$$I = 1\ \text{Amp}$$

{Ohm's Law}



{Example #2 – Calculate current}

Just like the previous example, we know the voltage and we know the resistance. Therefore we can work out the current.



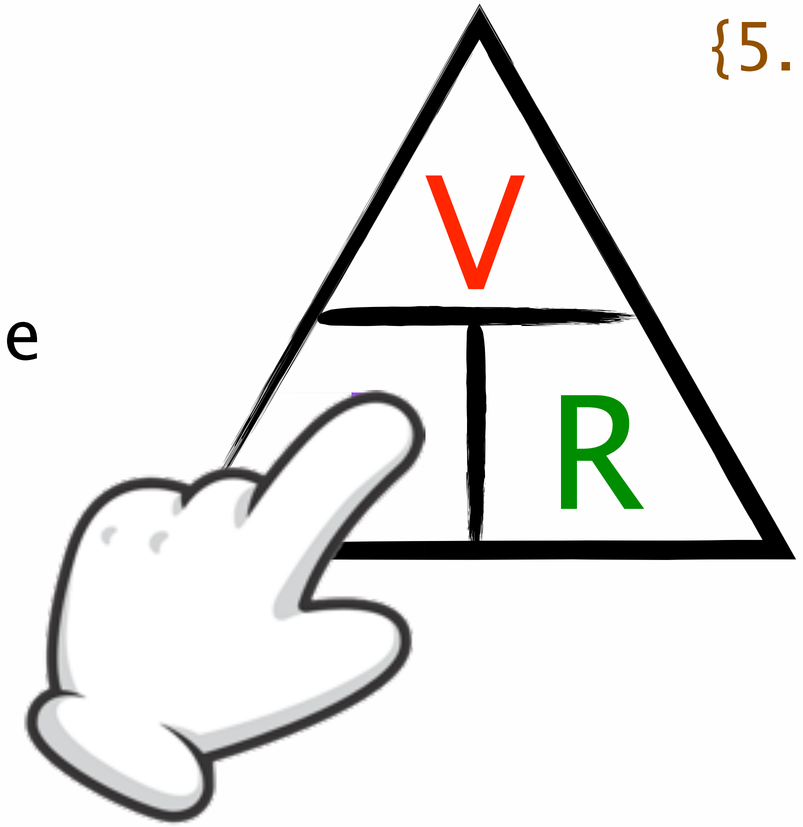
$$I = \frac{V}{R}$$

$$I = \frac{2\text{ Volts}}{1\text{ Ohm}}$$

$$I = 2\text{ Amps}$$

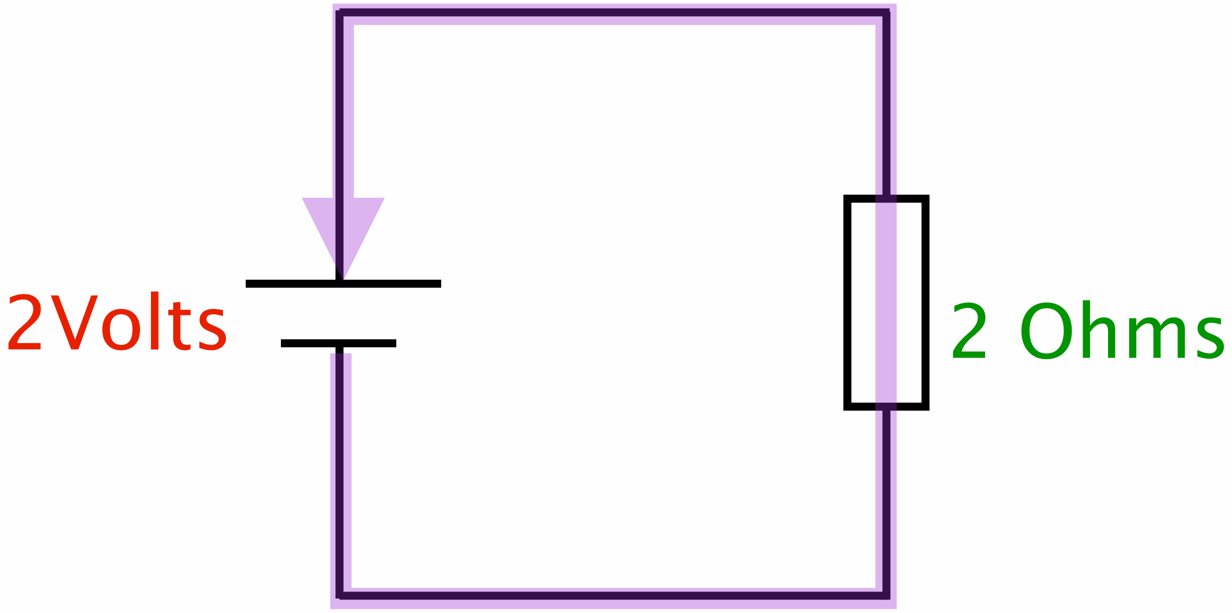
Notice how we have twice as much current as example #1 because we have twice as much voltage.

{Ohm’s Law}



{Example #3 – Calculate current}

This time we will keep the voltage at 2 Volts but also increase the resistance to 2 Ohms.



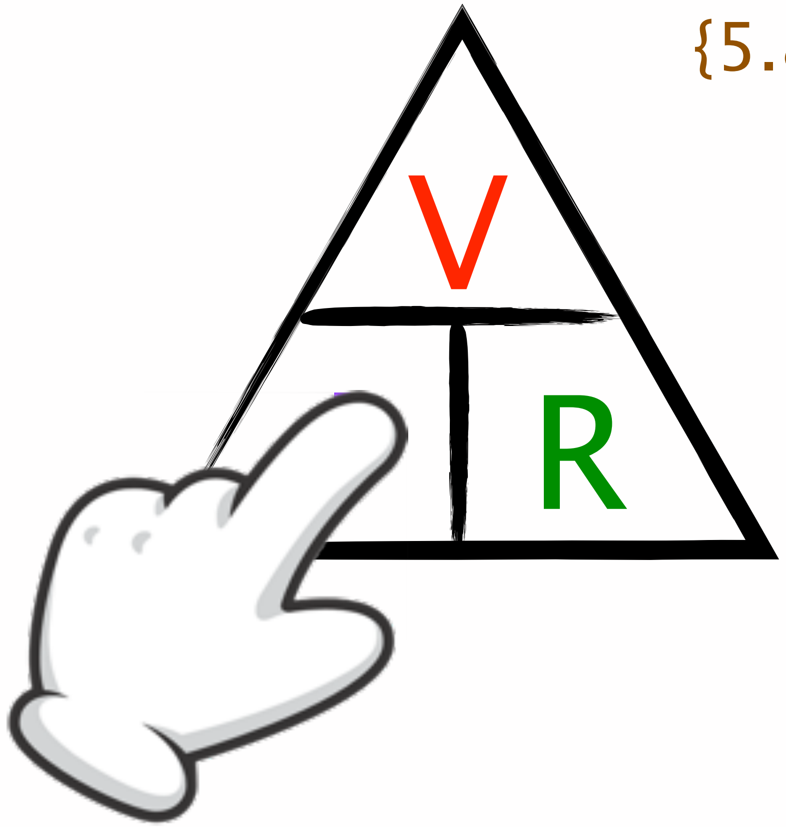
$$I = \frac{V}{R}$$

$$I = \frac{2 \text{ Volts}}{2 \text{ Ohms}}$$

$$I = 1 \text{ Amp}$$

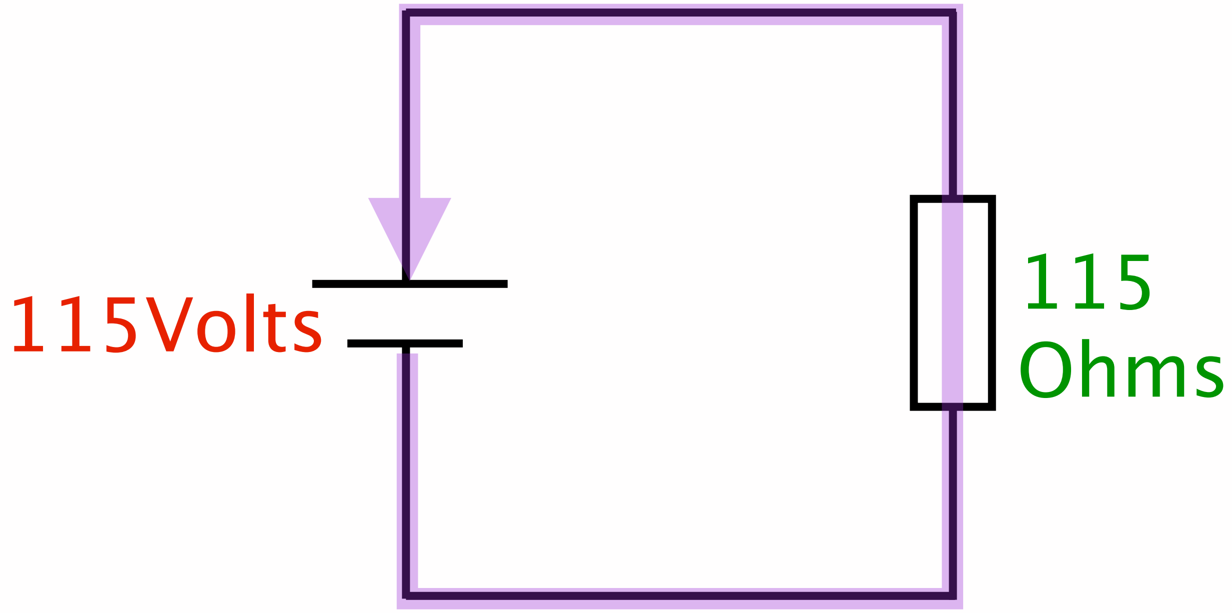
The current has decreased back to 1 Amp because there is now twice as much resistance as example #2

{Ohm's Law}



{Example #4 – Calculate current}

What if we increase the voltage way up to 115 Volts but also increase the resistance to 115 Ohms?



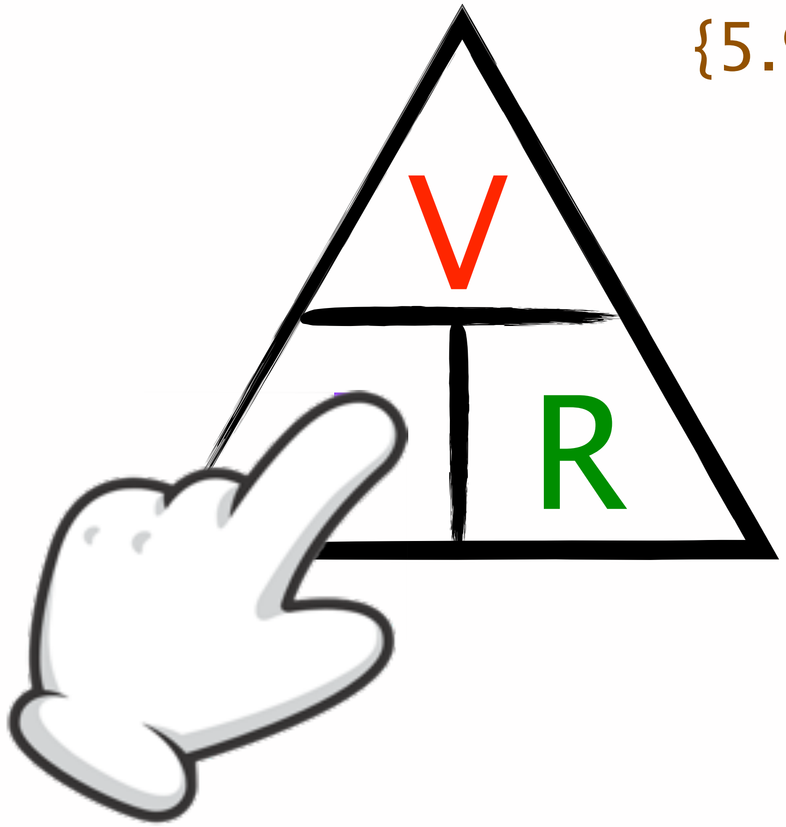
$$I = \frac{V}{R}$$

$$I = \frac{115 \text{ Volts}}{115 \text{ Ohms}}$$

$$I = 1 \text{ Amp}$$

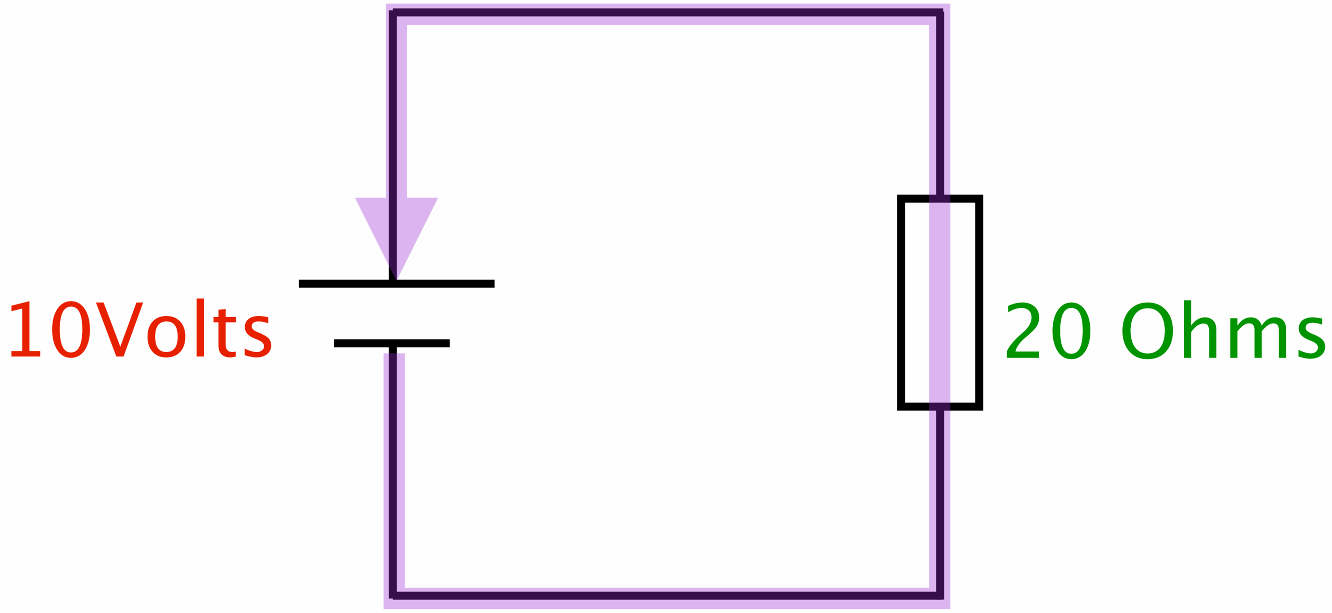
Well look at that! The current is once again 1 Amp!

{Ohm's Law}



{Example #5 – Calculate current}

Let's see about decreasing the current below 1 Amp...



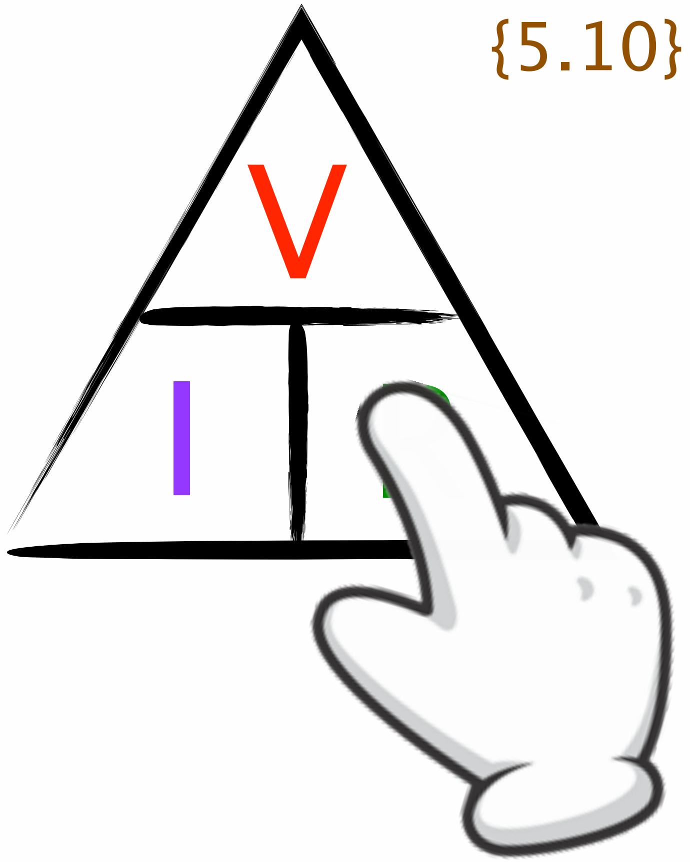
$$I = \frac{V}{R}$$

$$I = \frac{10 \text{ Volts}}{20 \text{ Ohms}}$$

With the resistance being twice the voltage, we end up with half an Amp.

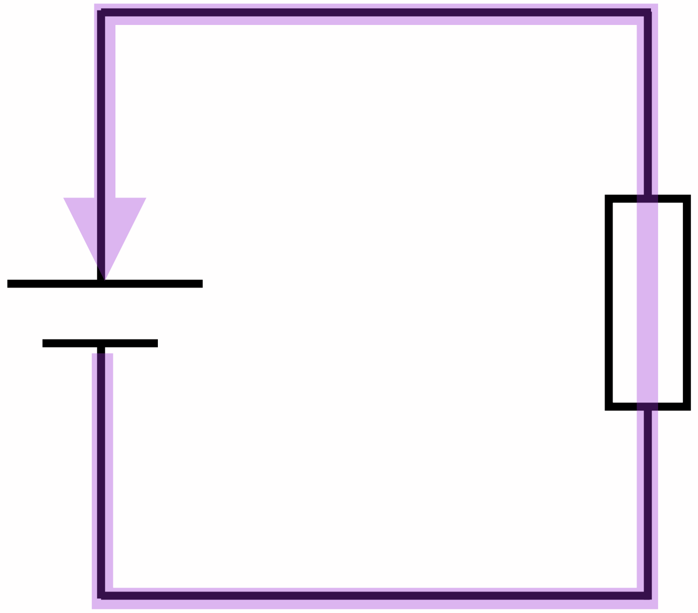
$$I = 0.5 \text{ Amps}$$

{Ohm's Law}



{Example #6 – Calculate resistance}

Let's mix things up by figuring out the resistance in the circuit.



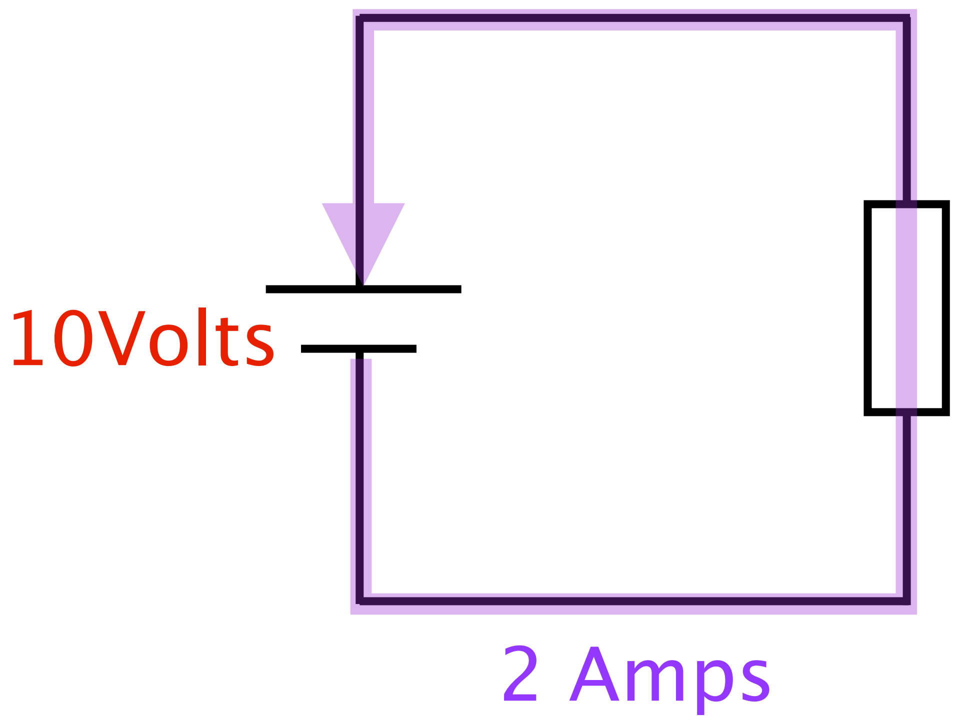
$$R = \frac{V}{I}$$

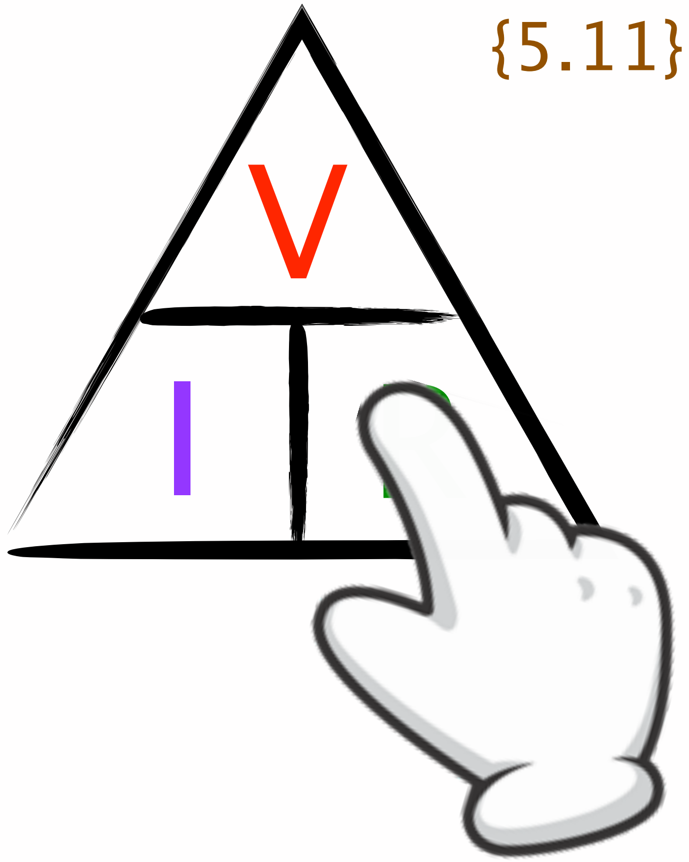
$$R = \frac{2 \text{ Volts}}{2 \text{ Amps}}$$

$$R = 1 \text{ Ohm}$$

{Ohm's Law}

{Example #7 – Calculate resistance}





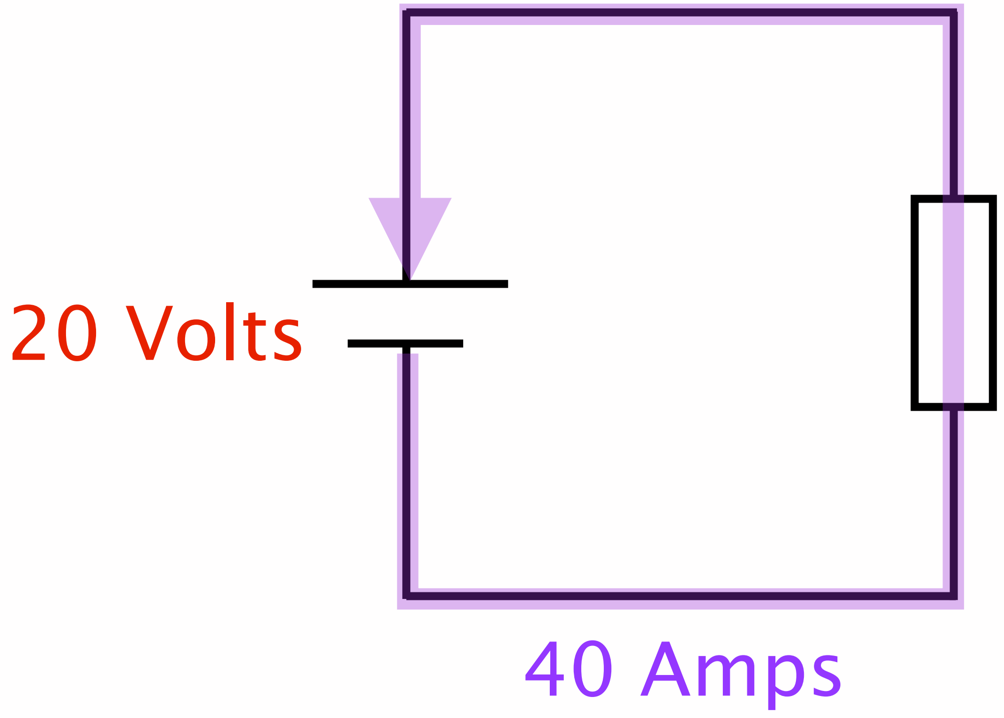
$$R = \frac{V}{I}$$

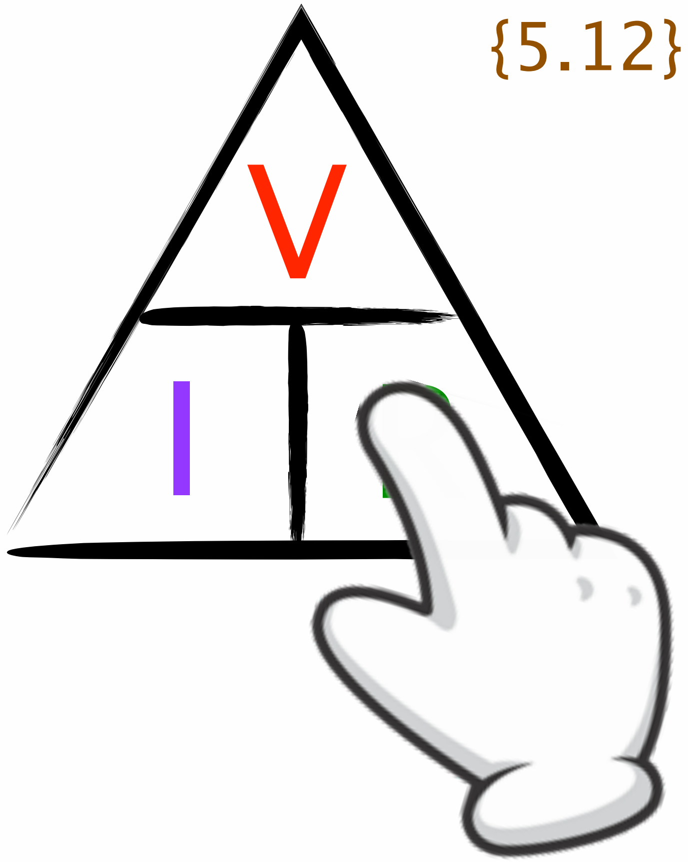
$$R = \frac{10 \text{ Volts}}{2 \text{ Amps}}$$

$$R = 5 \text{ Ohms}$$

{Ohm’s Law}

{Example #8 – Calculate resistance}





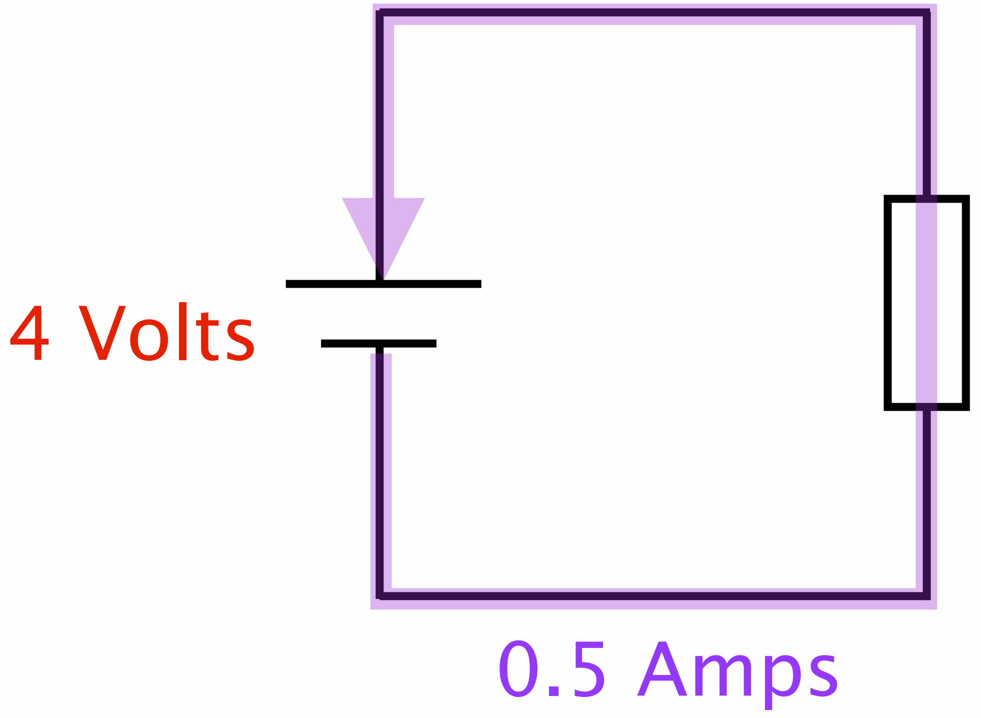
$$R = \frac{V}{I}$$

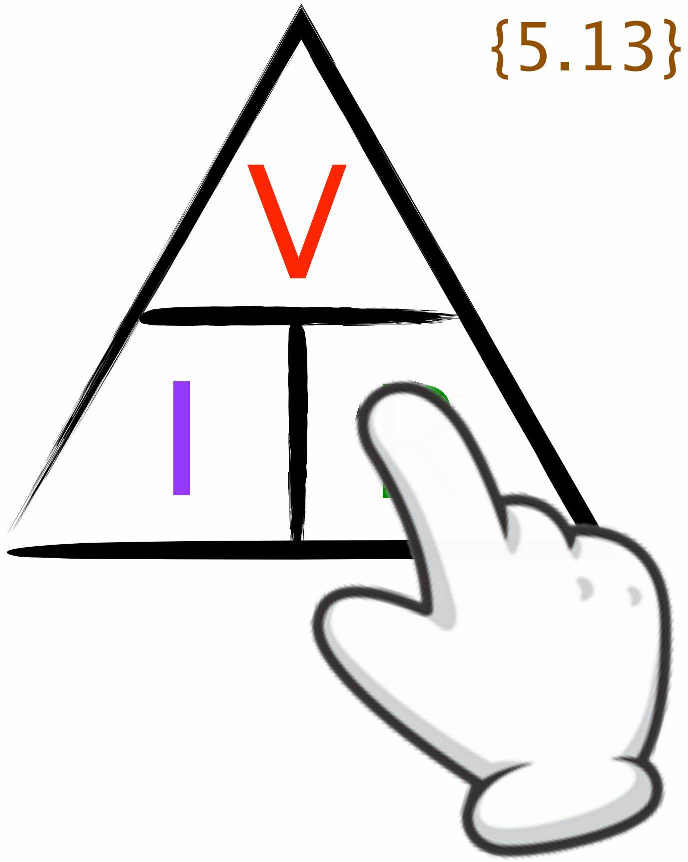
$$R = \frac{20 \text{ Volts}}{40 \text{ Amps}}$$

$$R = 0.5 \text{ Ohms}$$

{Ohm's Law}

{Example #9 – Calculate resistance}



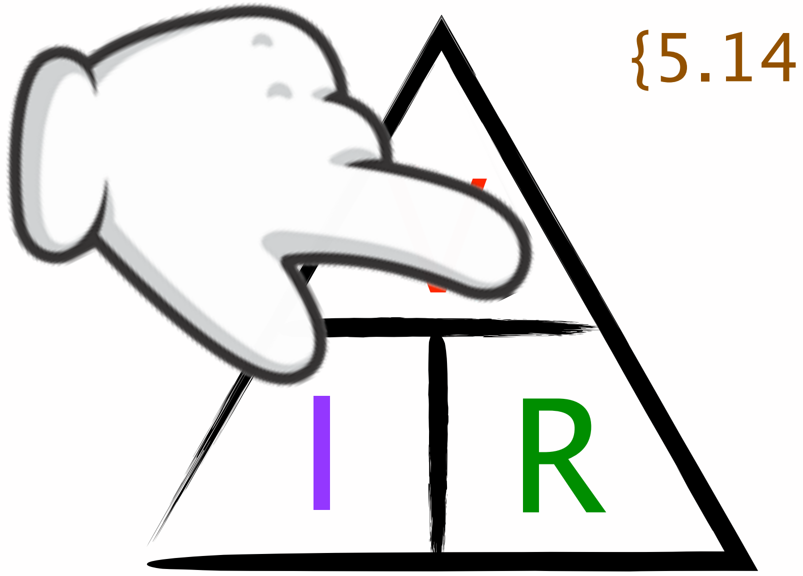


$$R = \frac{V}{I}$$

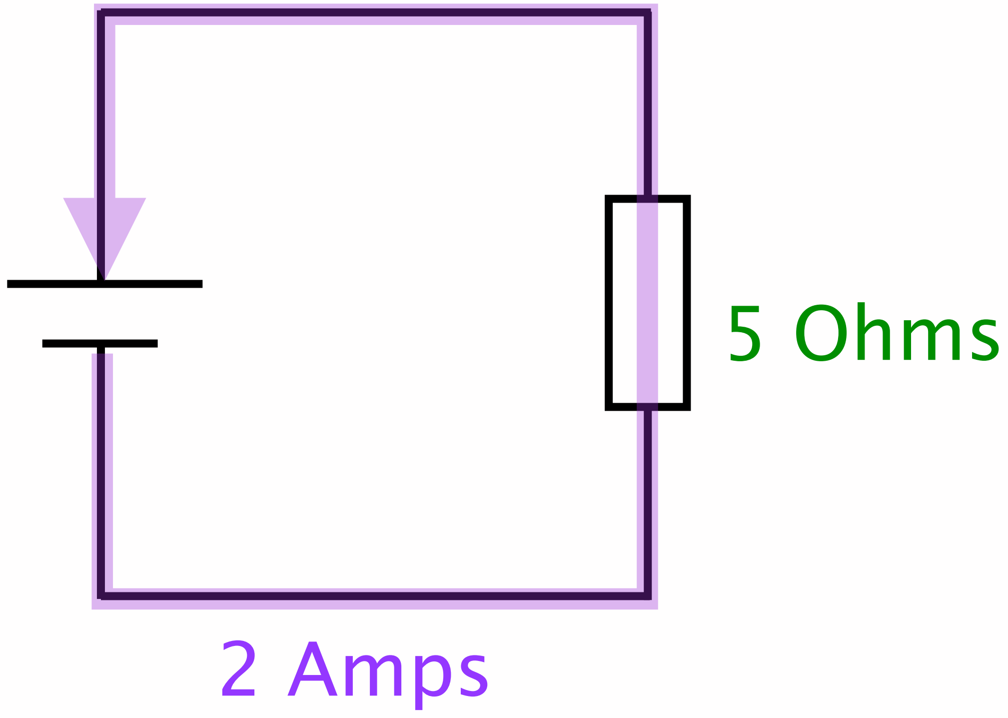
$$R = \frac{4\ \text{Volts}}{0.5\ \text{Amps}}$$

$$R = 8\ \text{Ohms}$$

{Ohm’s Law}



{Example #10 – Calculate voltage}



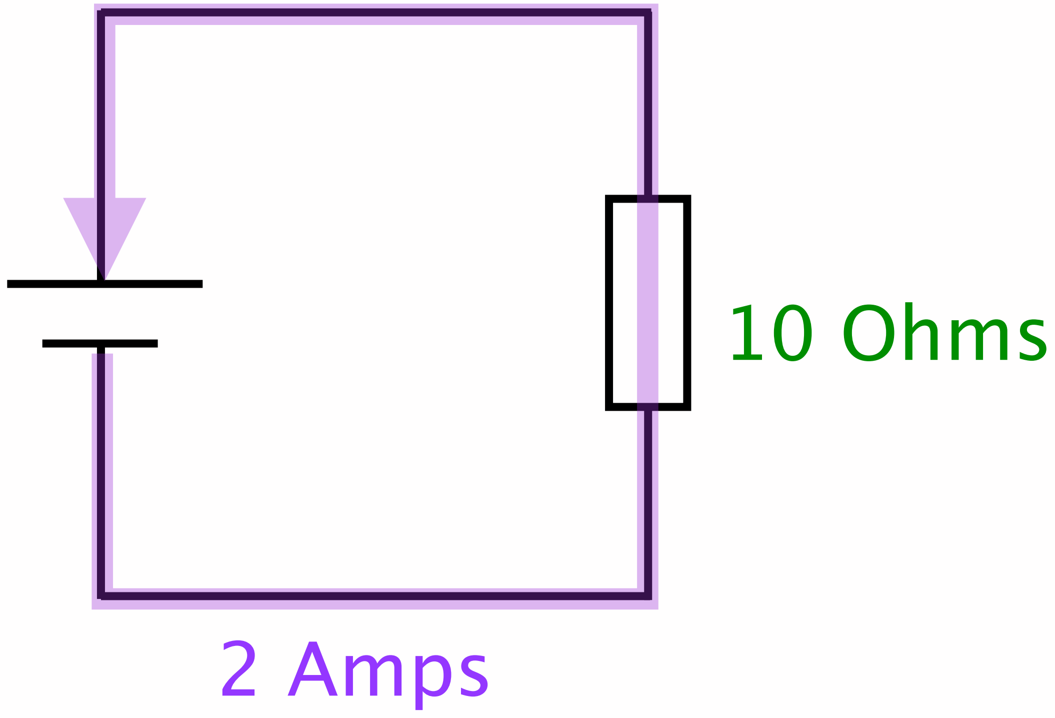
$$V = I \times R$$

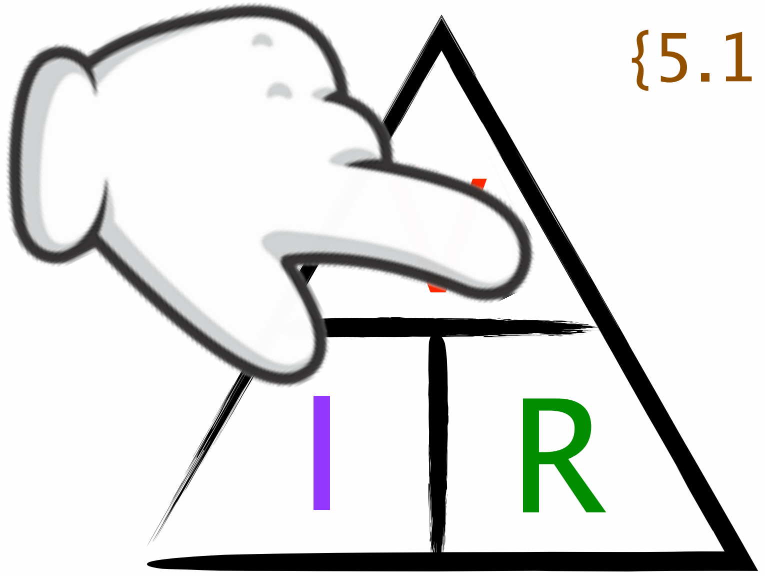
$$V = 2 \text{ Amps} \times 5 \text{ Ohms}$$

$$V = 10 \text{ Volts}$$

{Ohm's Law}

{Example #11 – Calculate voltage}





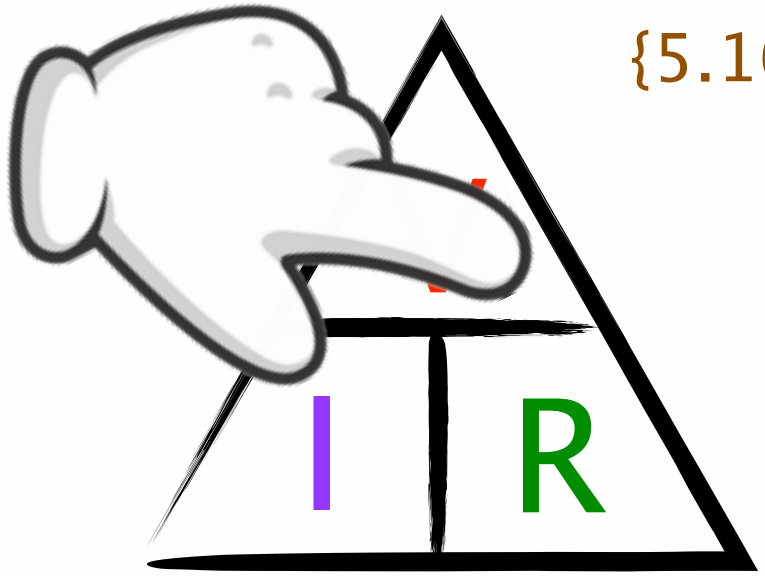
$$V = I \times R$$

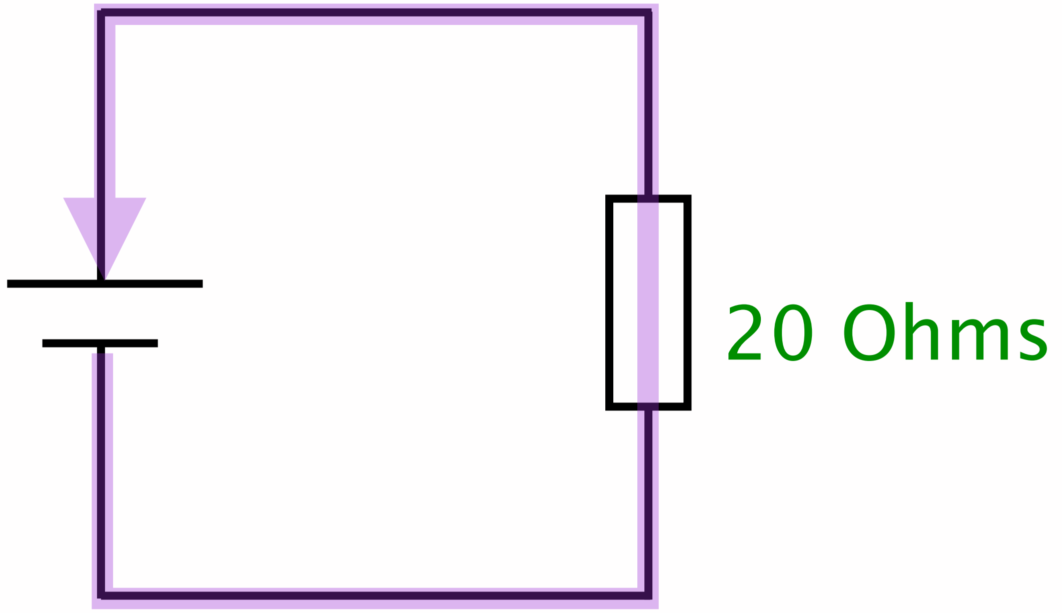
$$V = 2\text{ Amps} \times 10\text{ Ohms}$$

$$V = 20\text{ Volts}$$

{Ohm's Law}

{Example #11 – Calculate voltage}





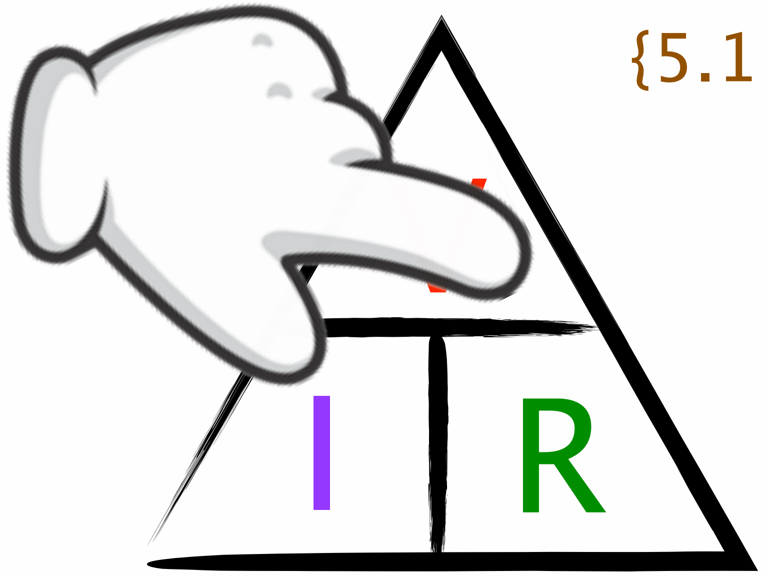
$$V = I \times R$$

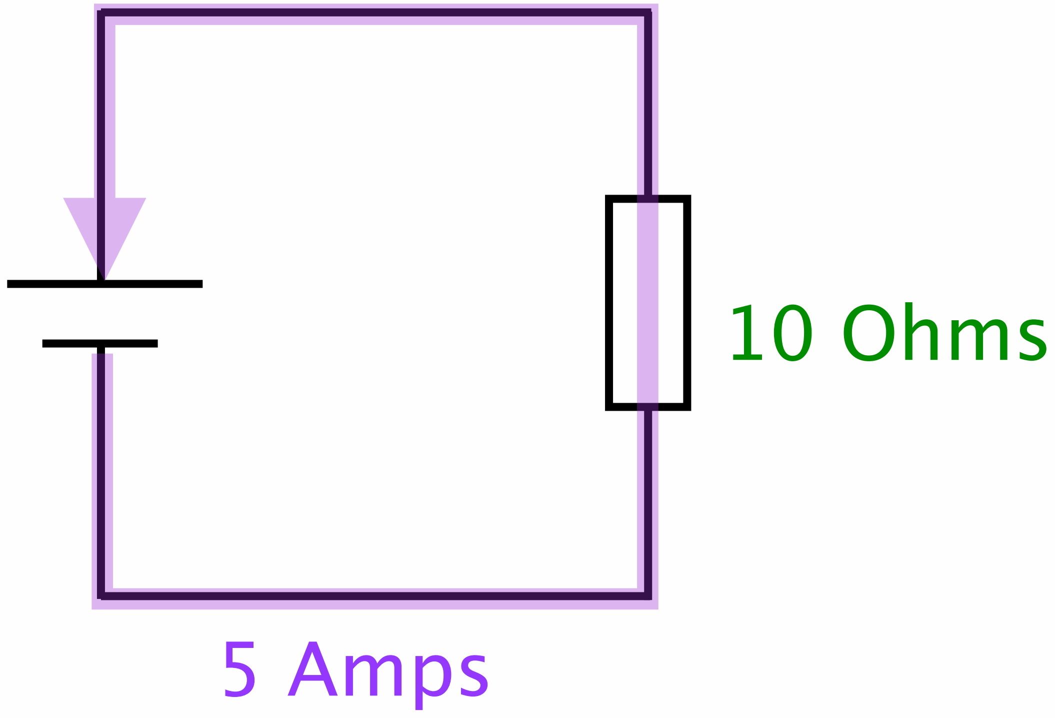
$$V = 3 \text{ Amps} \times 20 \text{ Ohms}$$

$$V = 60 \text{ Volts}$$

{Ohm’s Law}

{Example #12 – Calculate voltage}





$$V = I \times R$$

$$V = 5 \text{ Amps} \times 10 \text{ Ohms}$$

$$V = 50 \text{ Volts}$$

{Ohm's Law}

Hopefully all those examples have sunk in quite well by now. Lets now make things easier for ourselves when working through our calculations by writing letters in place of Volts, Amps and Ohms.

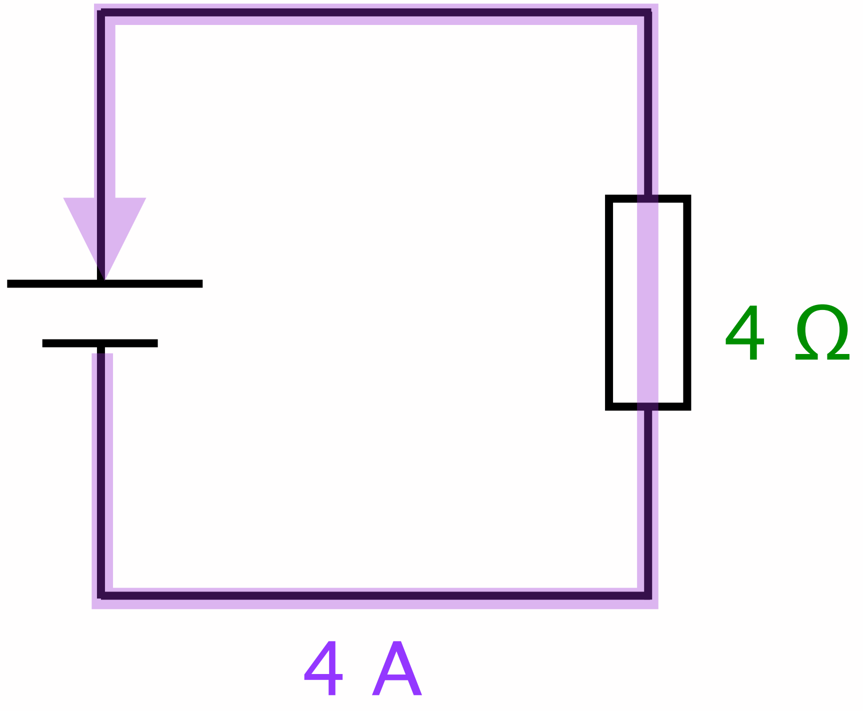
You may recall from the summary on page 3.17 that:

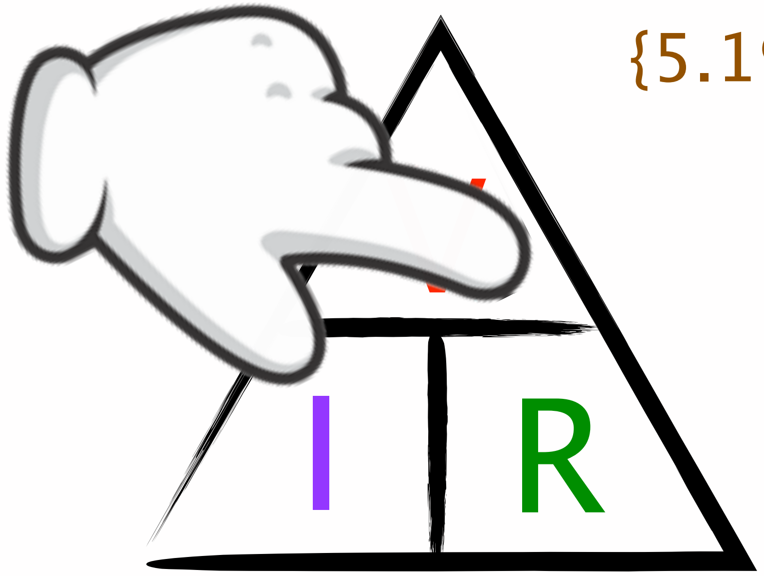
- Voltage is represented by the letter V and is measured in Volts which is given the letter V
- Resistance is represented by the letter R and is measured in Ohms which is given the greek letter Ω
- Current is represented by the letter I and is measured in Amps which is given the letter A

So with that in mind, let's now have a look at three additional circuit examples, one to find Voltage, one to find Resistance and one to find Current.

{Ohm’s Law}

{Example #13 – Calculate voltage}





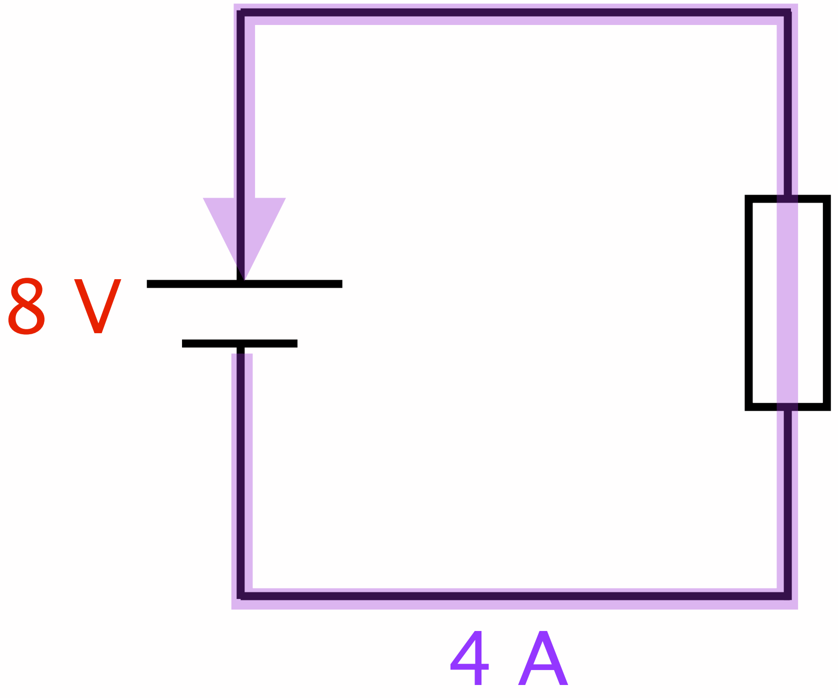
$$V = I \times R$$

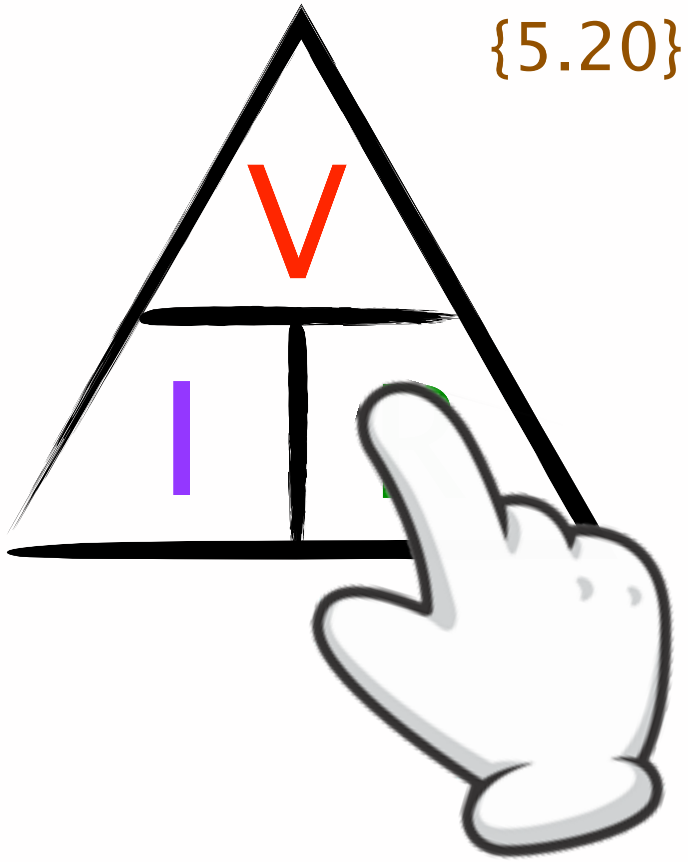
$$V = 4\ A \times 4\ \Omega$$

$$V = 16\ V$$

{Ohm's Law}

{Example #14 – Calculate resistance}





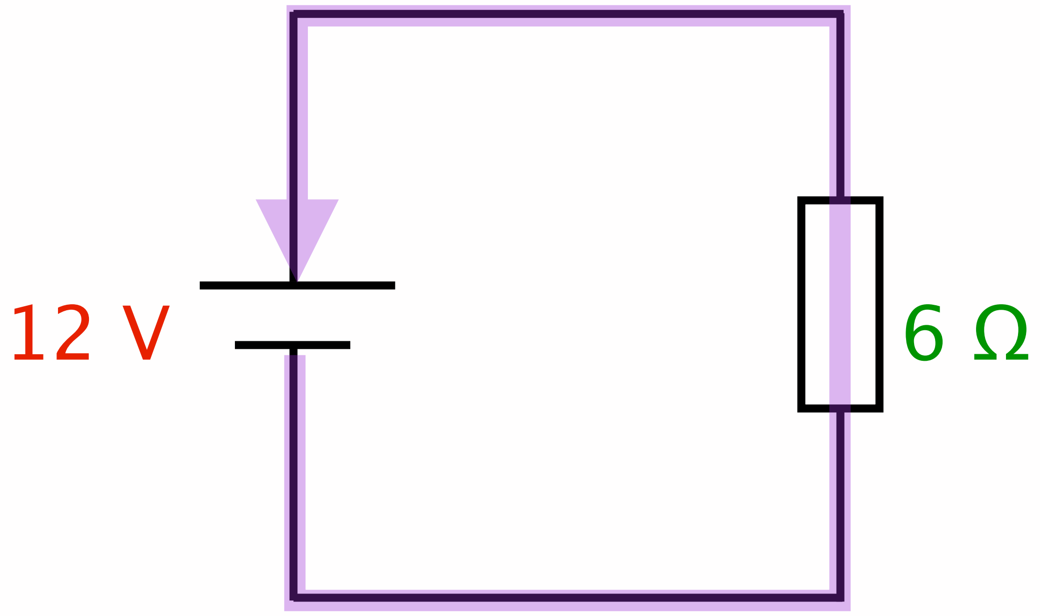
$$R = \frac{V}{I}$$

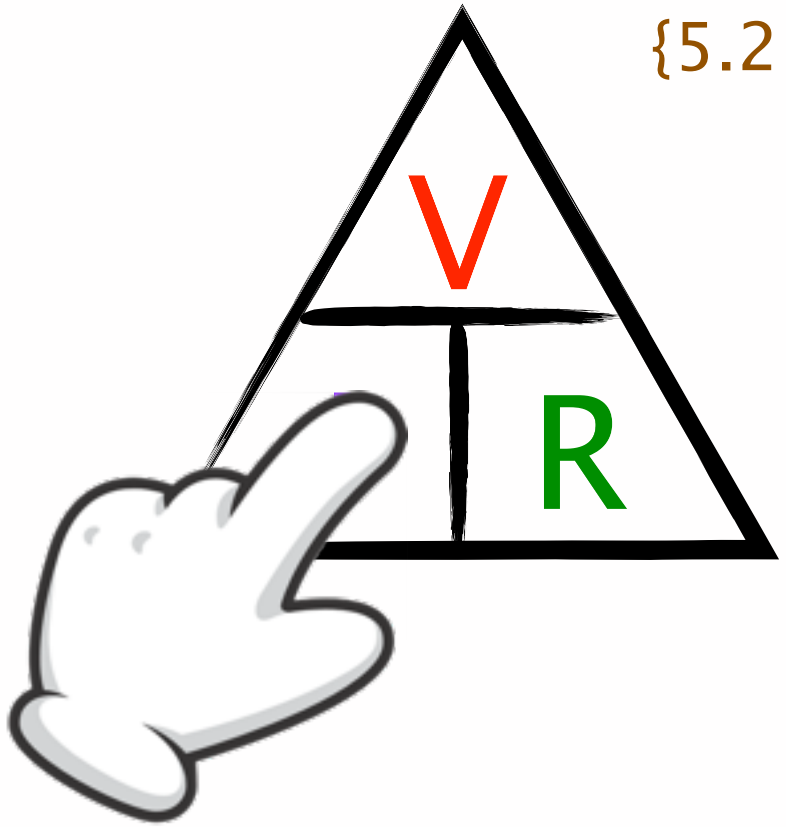
$$R = \frac{8\ \text{V}}{4\ \text{A}}$$

$$R = 2\ \Omega$$

{Ohm's Law}

{Example #15 – Calculate current}



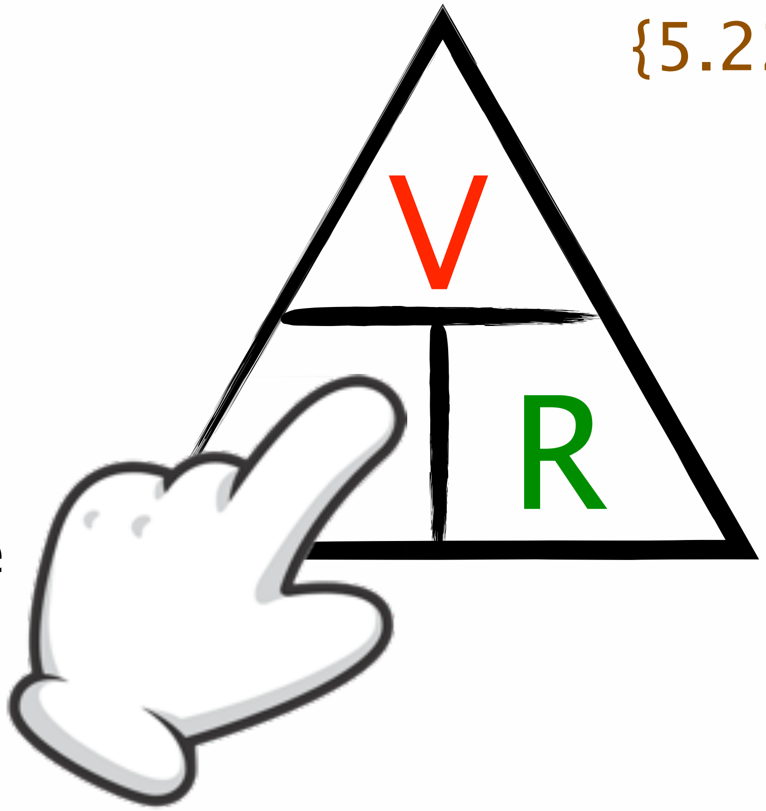


$$I = \frac{V}{R}$$

$$I = \frac{12\ V}{6\ \Omega}$$

$$I = 2\ A$$

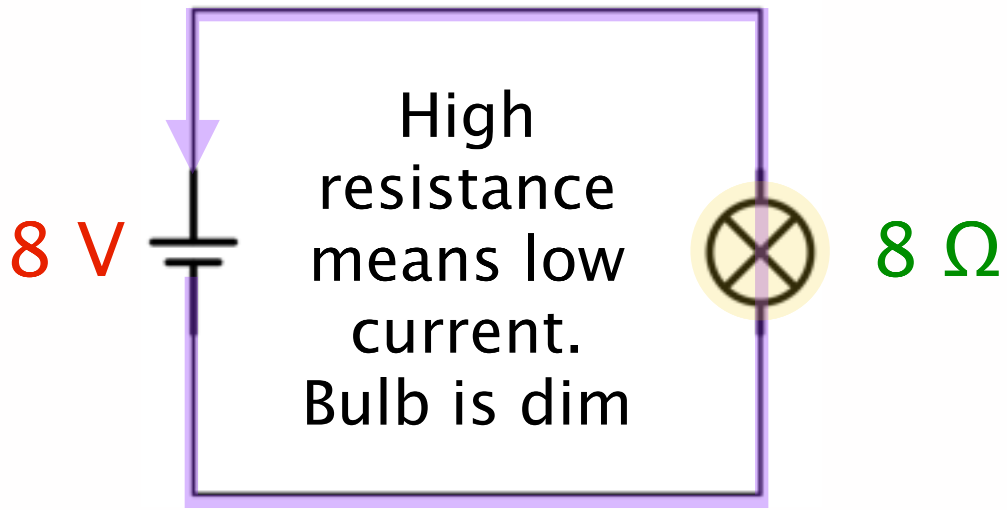
{Ohm's Law}



{A practical example}

So we have been covering a lot of theory on how to calculate Voltage, Current and Resistance however let's think about where this could play out with a simple practical example.

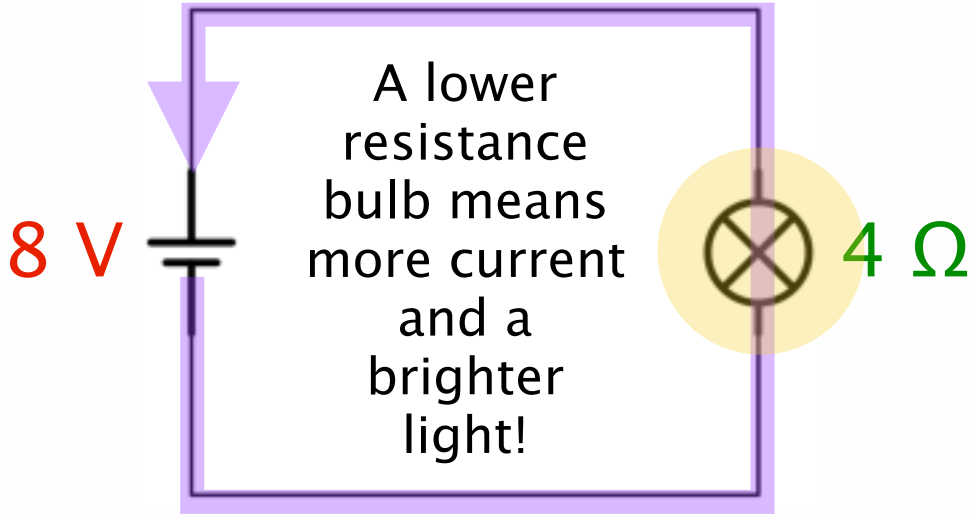
A light bulb can be considered to be a resistor since the coils of wire inside the bulb have resistance. You can get all sorts of light bulbs with all sorts of different resistances. Let's have a look at some light bulbs which each have a different amount of resistance. The brightest bulb will be the one with the most current flowing through it.



$$I = \frac{V}{R}$$

$$I = \frac{8\ V}{8\ \Omega}$$

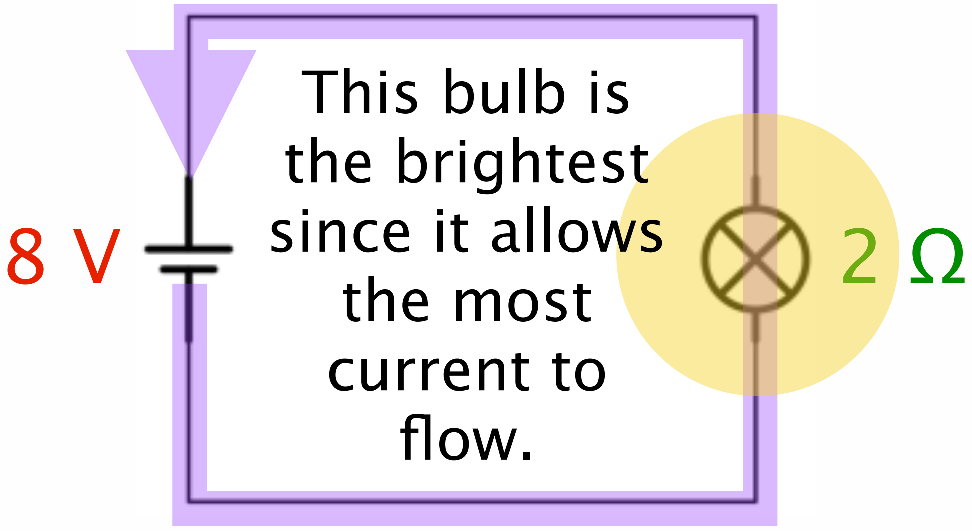
$$I = 1\ A$$



$$I = \frac{V}{R}$$

$$I = \frac{8\ V}{4\ \Omega}$$

$$I = 2\ A$$



$$I = \frac{V}{R}$$

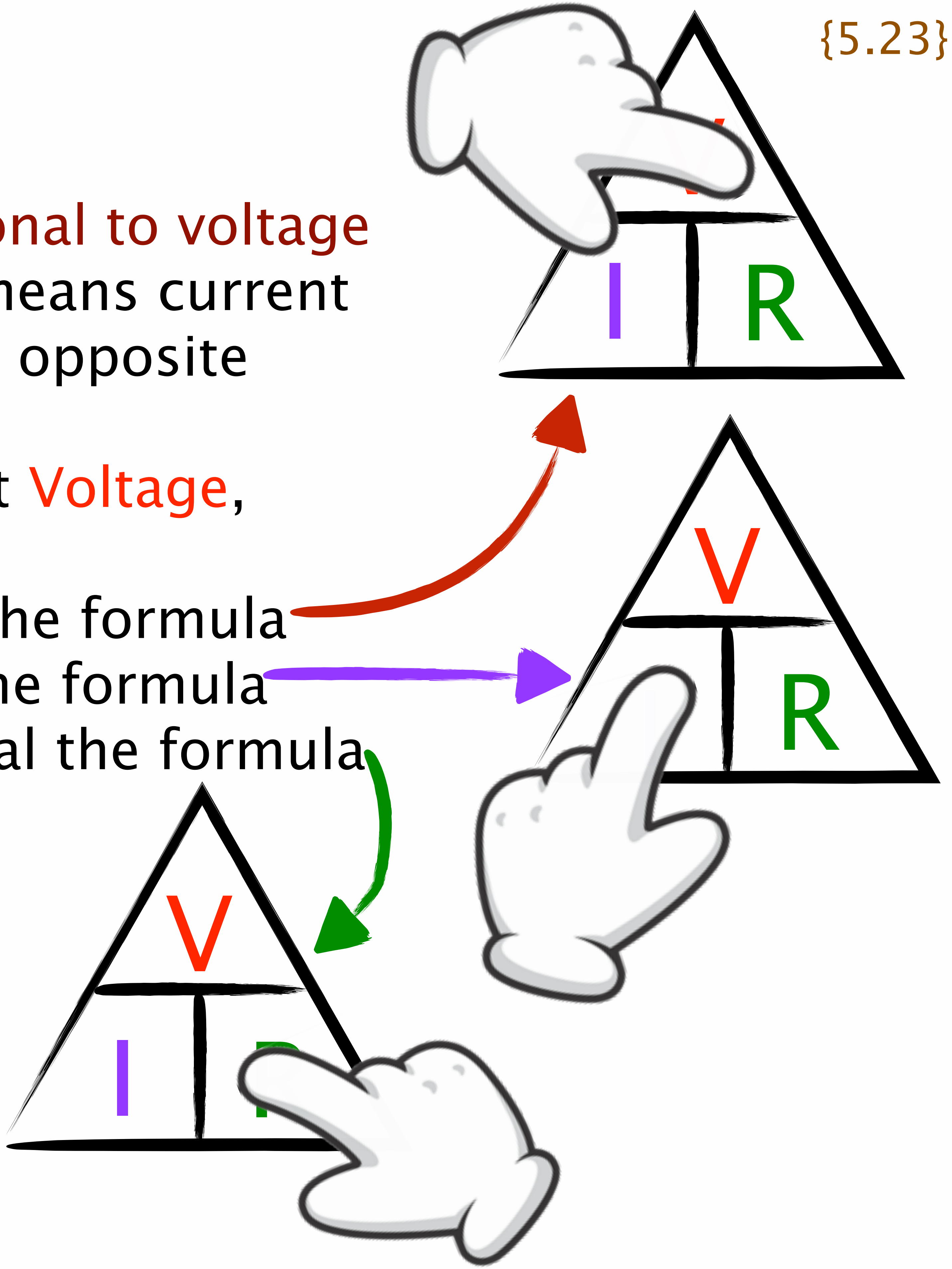
$$I = \frac{8\ V}{2\ \Omega}$$

$$I = 4\ A$$

{Ohm's Law}

{Summary}

- Ohm's Law states "Current is directly proportional to voltage and inversely proportional to resistance" This means current will go in the same direction as voltage and the opposite direction to resistance.
- We can use the Ohm's Law triangle to work out Voltage, Current and Resistance.
- To calculate Voltage, cover up the V to reveal the formula
- To calculate Current, cover up the I to reveal the formula
- To calculate Resistance, cover up the R to reveal the formula
- Voltage (V) is measured in Volts (V)
- Current (I) is measured in Amps (A)
- Resistance (R) is measured in Ohms (Ω)

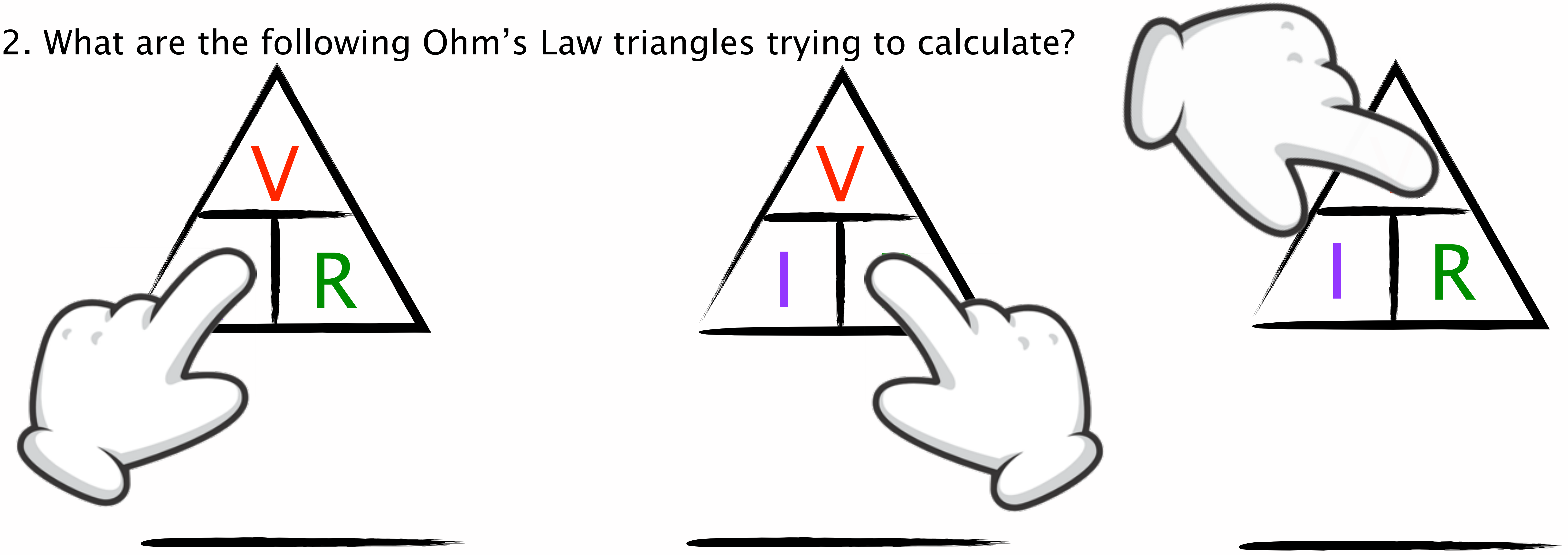


{Ohm's Law}

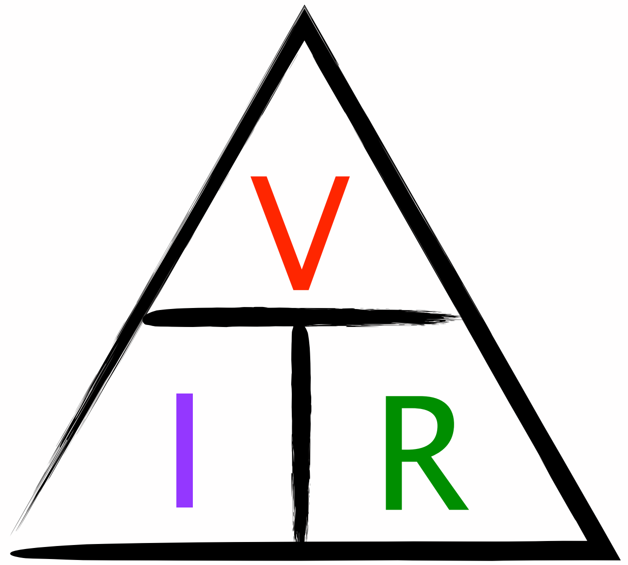
{Questions}

1. Ohm's Law tells us that Current is proportional to ______________ and inversely proportional to ______________

2. What are the following Ohm's Law triangles trying to calculate?



{Ohm's Law}



{Questions}

3. Using the Ohm's Law triangle, write the formula to calculate Current:

4. Using the Ohm's Law triangle, write the formula to calculate Voltage:

5. Using the Ohm's Law triangle, write the formula to calculate Resistance:

{Ohm’s Law}

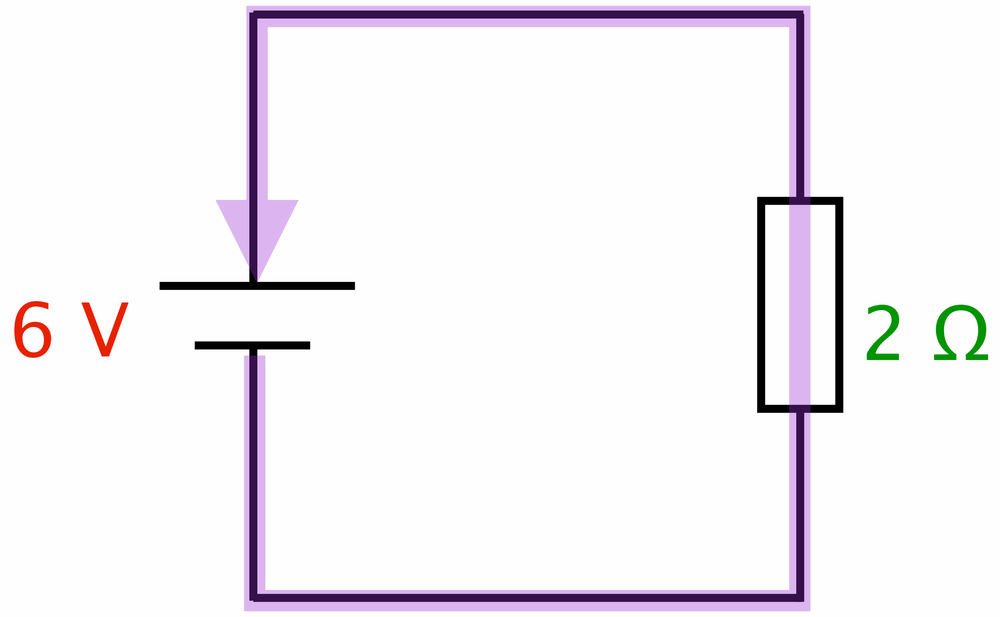
{Questions}

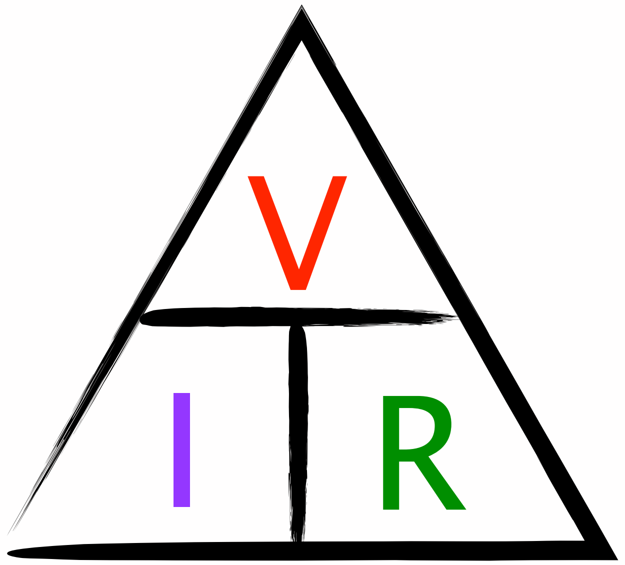
6. The letter used to represent Current is ____ and it is measured in Amps which is given the letter ____

7. The letter used to represent Voltage is ____ and it is measured in Volts which is given the letter ____

8. The letter used to represent Resistance is ____ and it is measured in Ohms which is given the Greek letter ____

9. Using the Ohm’s Law triangle, calculate the Current in this circuit:

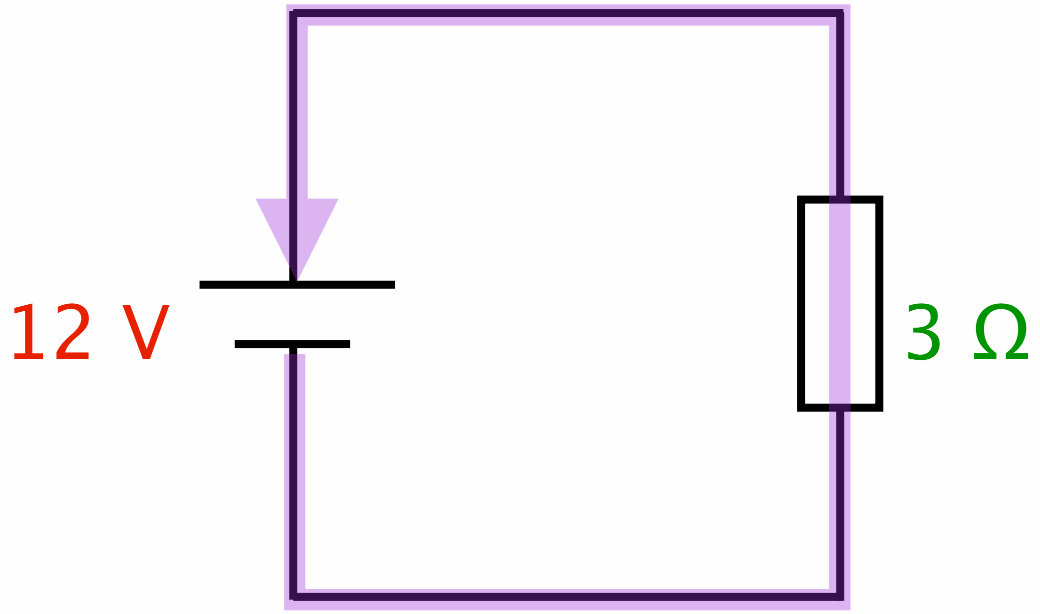




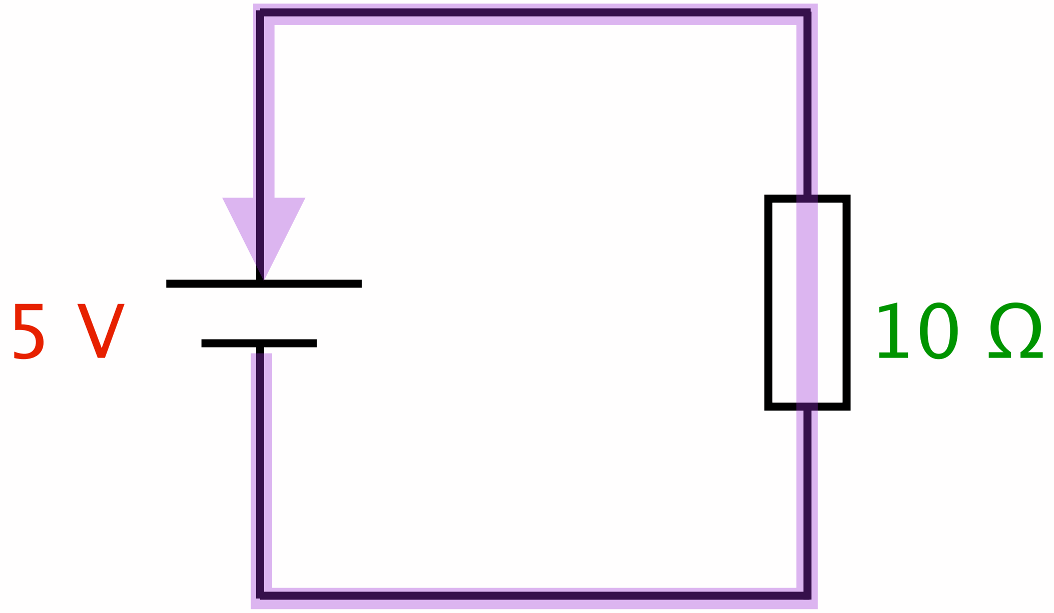
{Ohm’s Law}

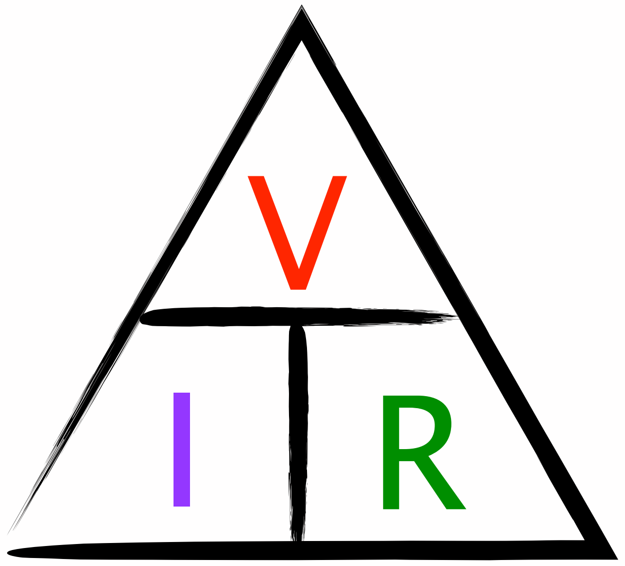
{Questions}

10. Using the Ohm’s Law triangle, calculate the Current in this circuit:



11. Using the Ohm’s Law triangle, calculate the Current in this circuit:

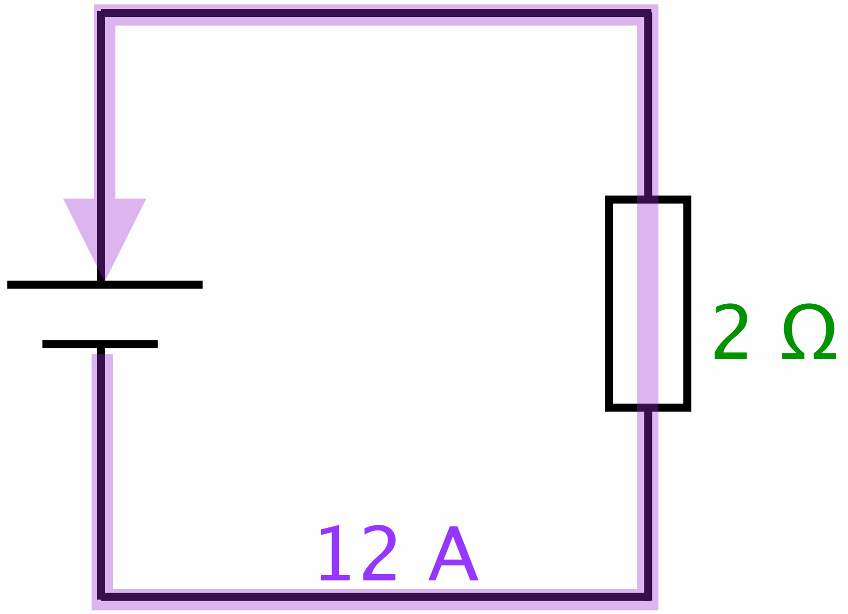




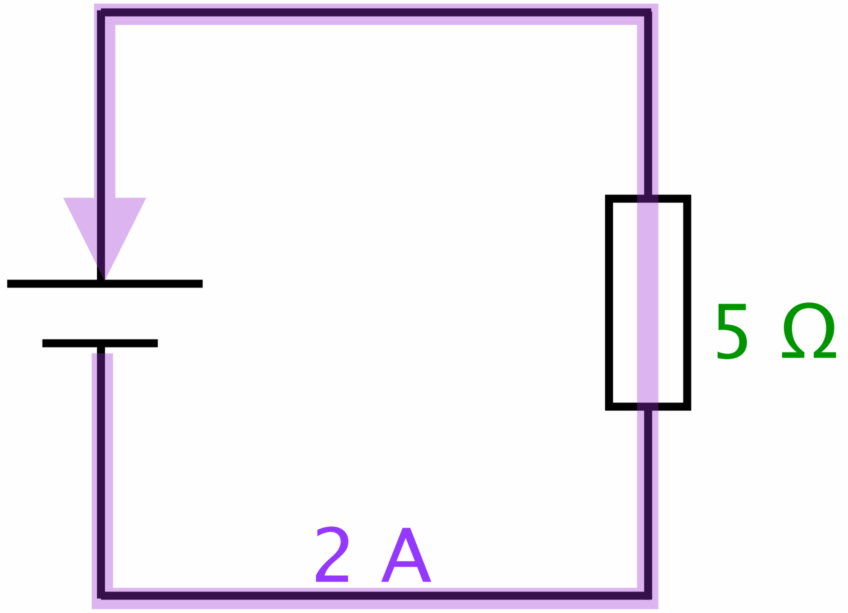
{Ohm's Law}

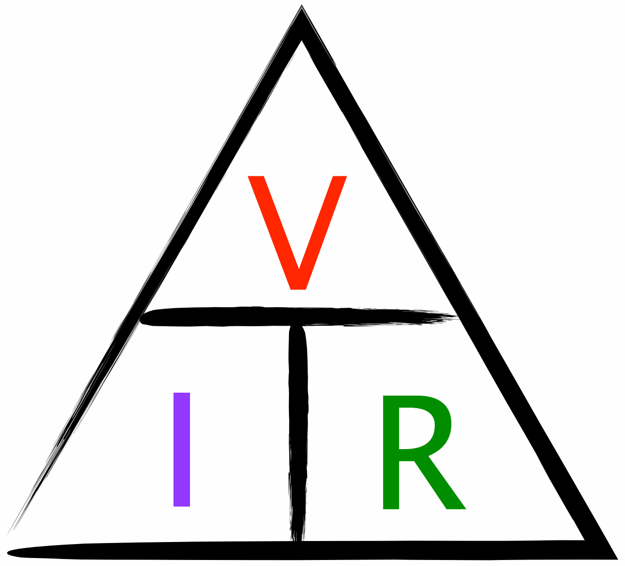
{Questions}

12. Using the Ohm's Law triangle, calculate the Voltage in this circuit:



13. Using the Ohm's Law triangle, calculate the Voltage in this circuit:

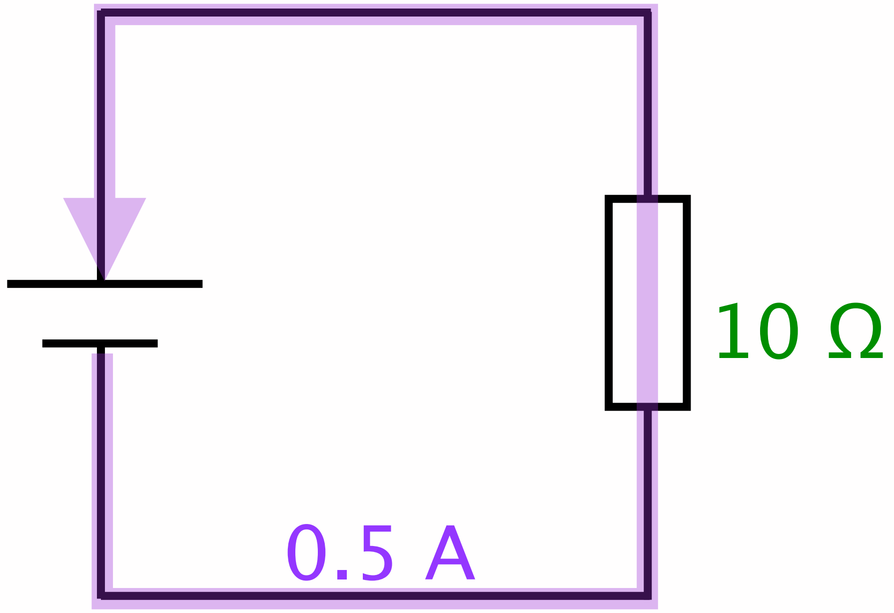




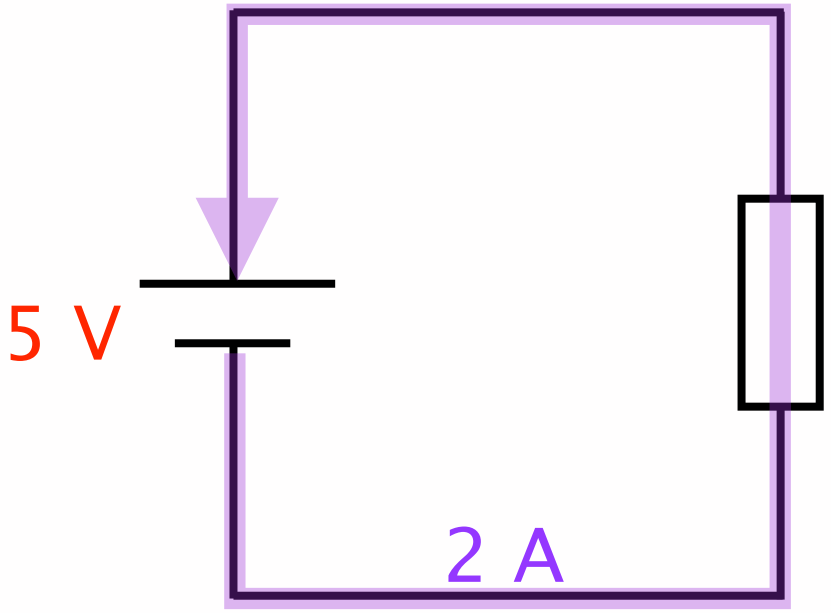
{Ohm's Law}

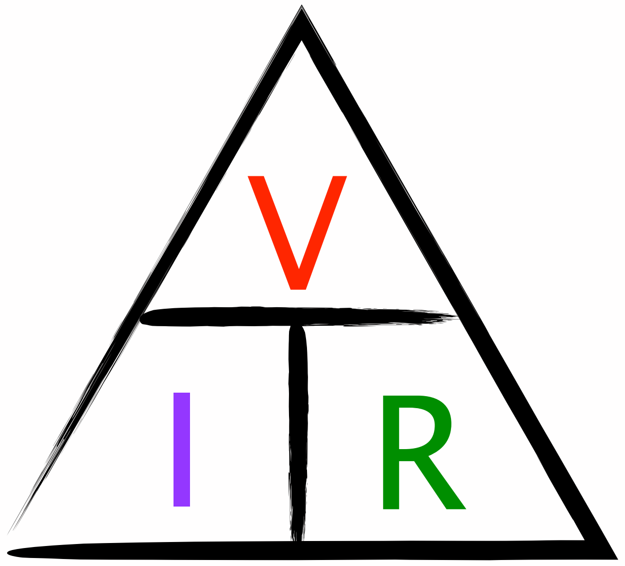
{Questions}

14. Using the Ohm's Law triangle, calculate the Voltage in this circuit:



15. Using the Ohm's Law triangle, calculate the Resistance in this circuit:

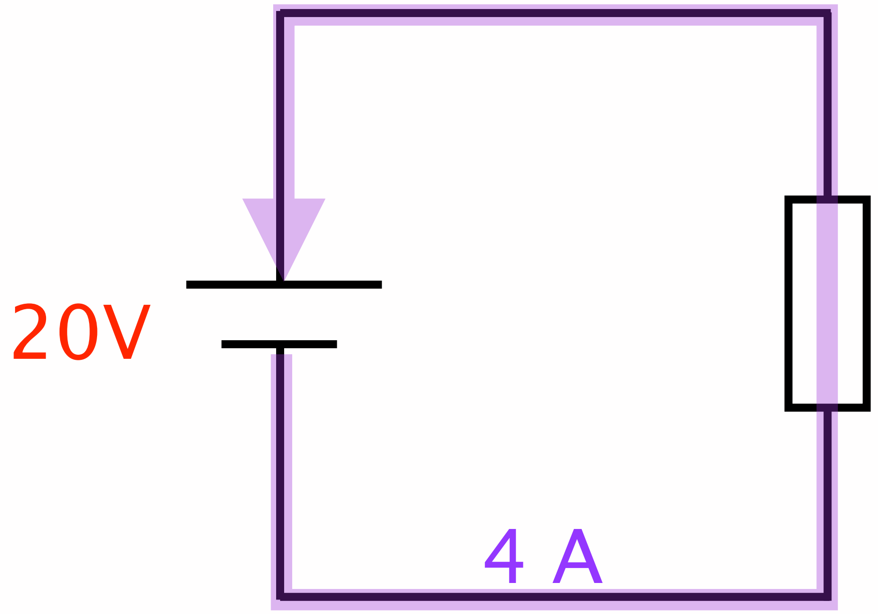




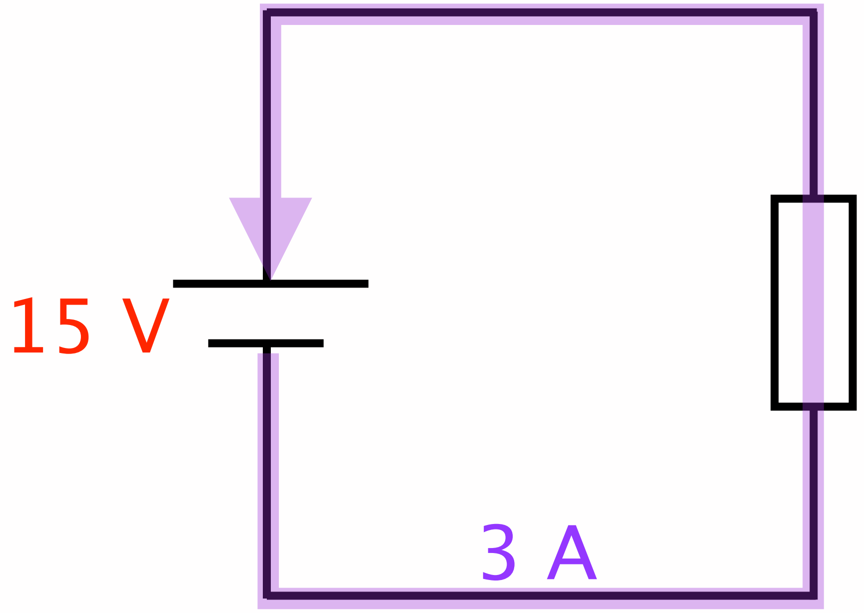
{Ohm's Law}

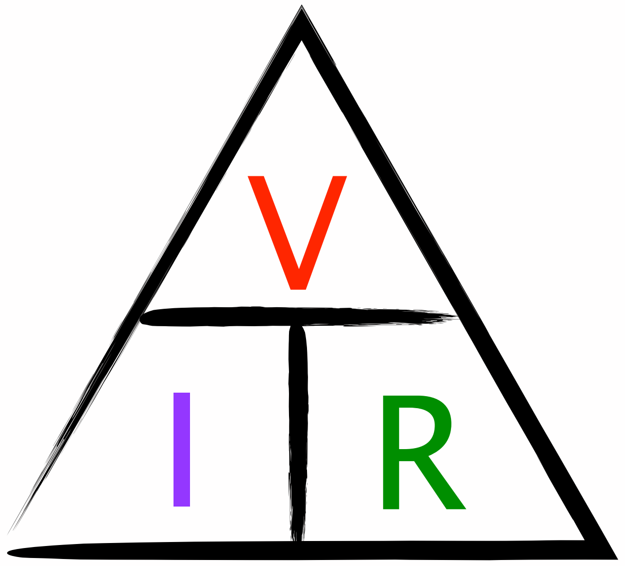
{Questions}

16. Using the Ohm's Law triangle, calculate the Resistance in this circuit:



17. Using the Ohm's Law triangle, calculate the Resistance in this circuit:





{How to use Your Calculator}

{Learning Outcomes}

5.1 Get a scientific calculator
5.2 Describe Prefixes
5.3 Describe engineering notation
5.4 Calculate values of Voltage, Current and Resistance to two decimal places using engineering notation
5.5 Convert numbers on a calculator to engineering notation
5.6 State the symbols and exponent for the following:

- Giga
- Mega
- Kilo
- Base Unit
- milli
- micro
- nano
- pico

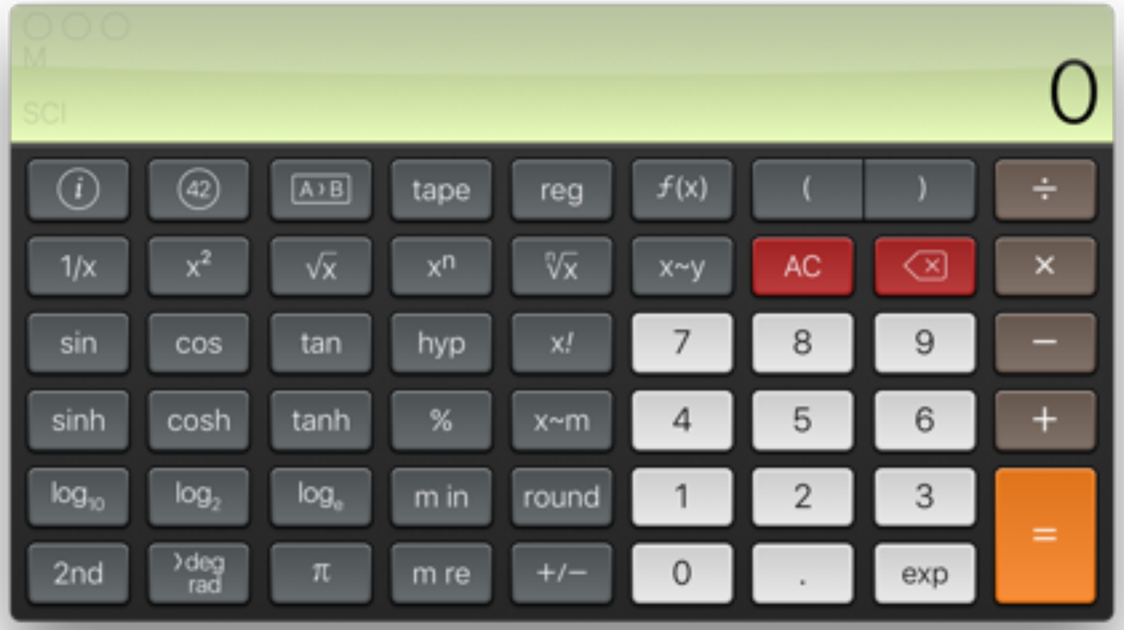
{How to use Your Calculator}

{Get a calculator}

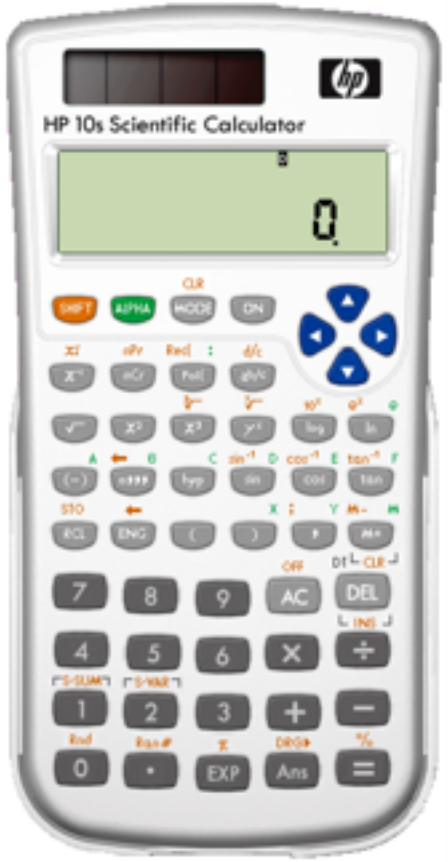
Up until this point we have dealt with very basic calculations that are easy to work out in your head. However as you progress through this course, the calculations are going to become quite involved. This is where we will want to bring in a calculator.

Just about any scientific calculator will do. This could be a physical calculator such as this one, or a virtual calculator on a phone or computer.

RealCalc For Android



PCalc for macOS



HP 10s

{How to use Your Calculator}

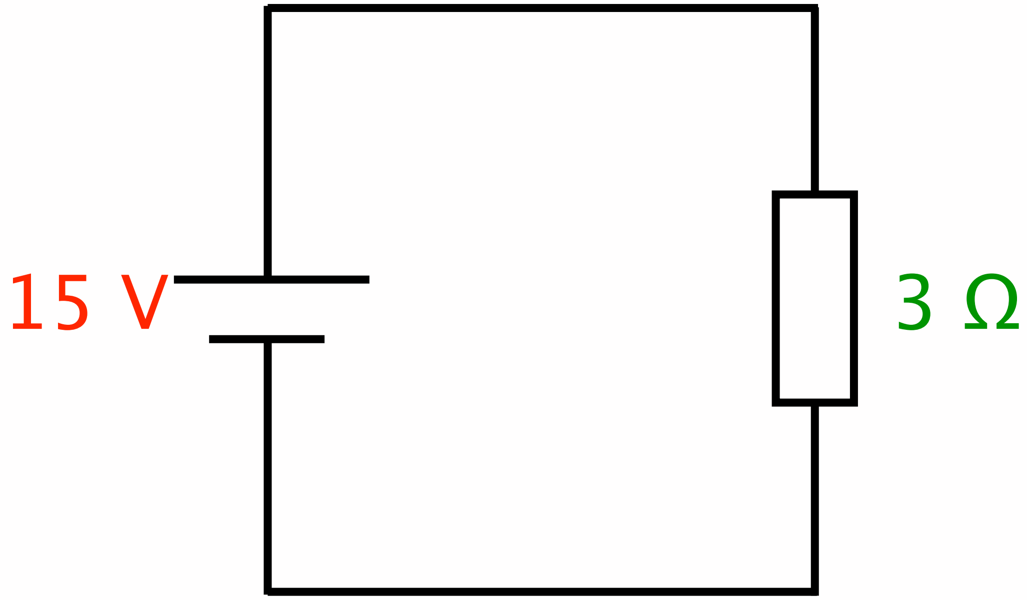
{Just before we start…}

We will be starting off with some simple calculator exercises and then we will look into how to input calculations in a form that is known as engineering notation. Don't worry too much about the fancy name, it is quite a simple concept and after doing a number of practice exercises, you should find it quite easy to use.

{How to use Your Calculator}

{Some simple calculations}

Let’s get used to using our calculator by going through a few circuit calculations. (You will need to remember the Ohms Law triangle from chapter 4)

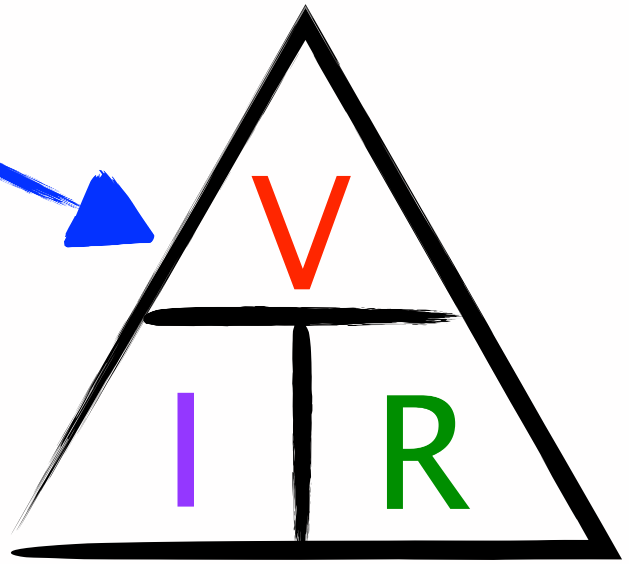


The formula to find current is:

$$I = \frac{V}{R}$$

$$I = \frac{15\ V}{3\ \Omega}$$

$$I = 5\ A$$

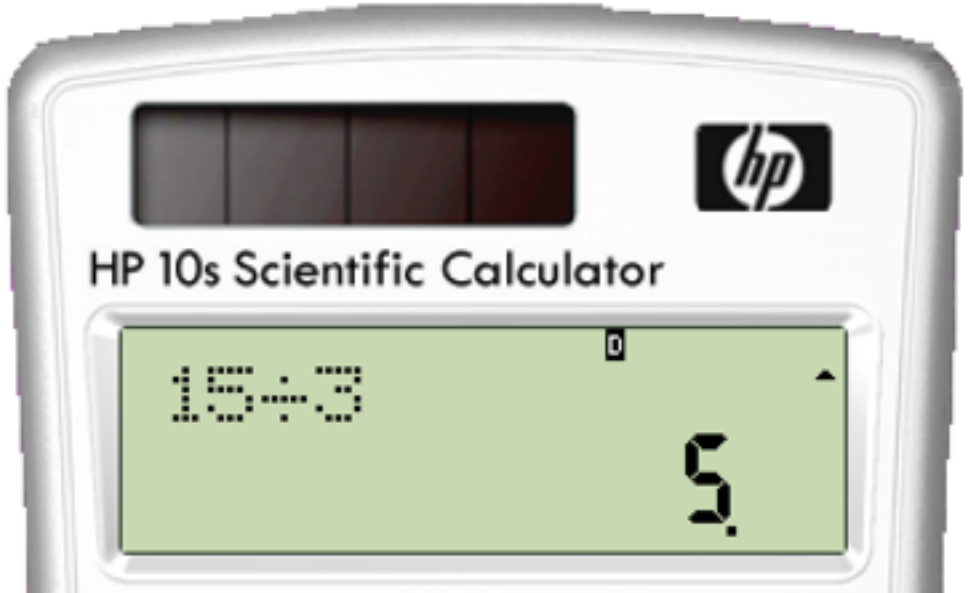


To perform the calculation you would press the buttons in this sequence:

Voltage | Resistance

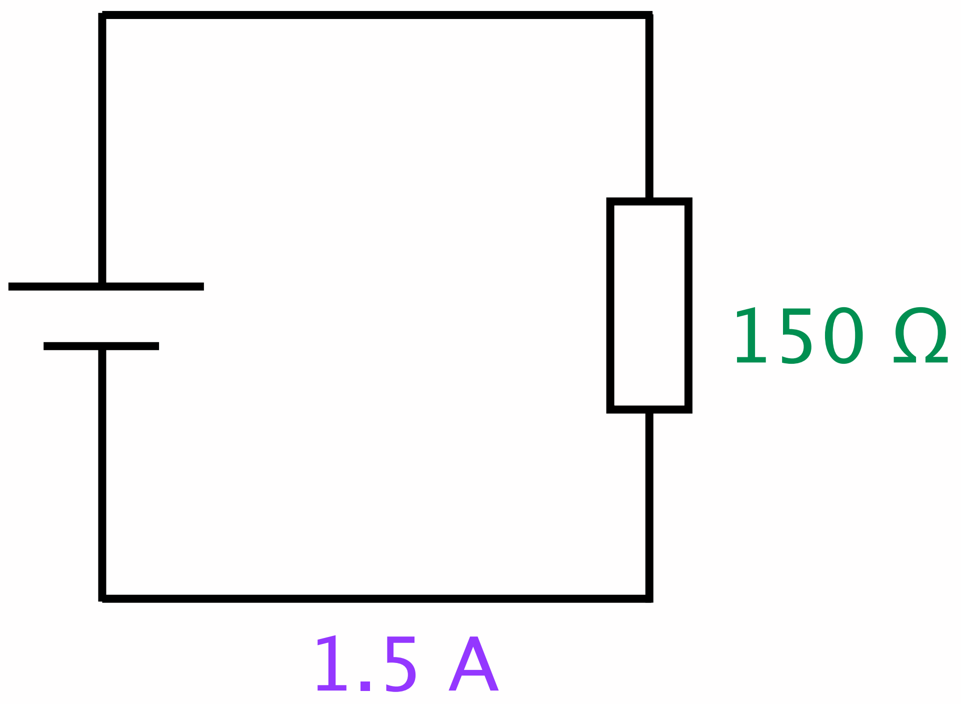
1 5 ÷ 3 =

Current



{How to use Your Calculator}

{Some simple calculations}

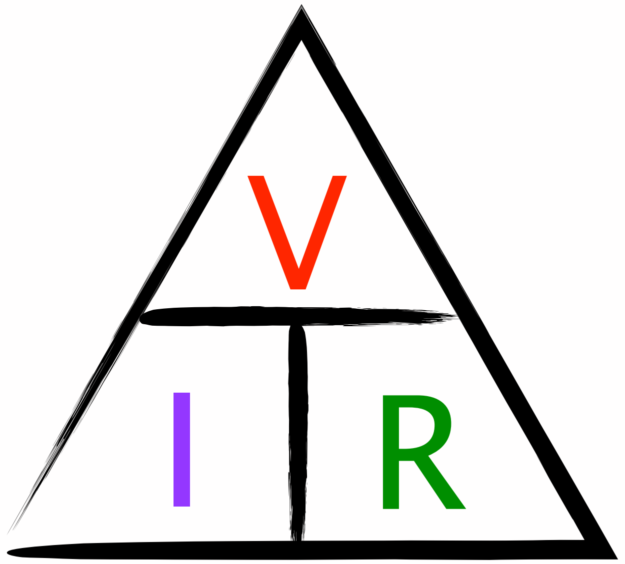


The formula to find voltage is:

$V = I \times R$

$V = 1.5\ A \times 150\ \Omega$

$V = 225\ V$



To perform the calculation you would press the buttons in this sequence:

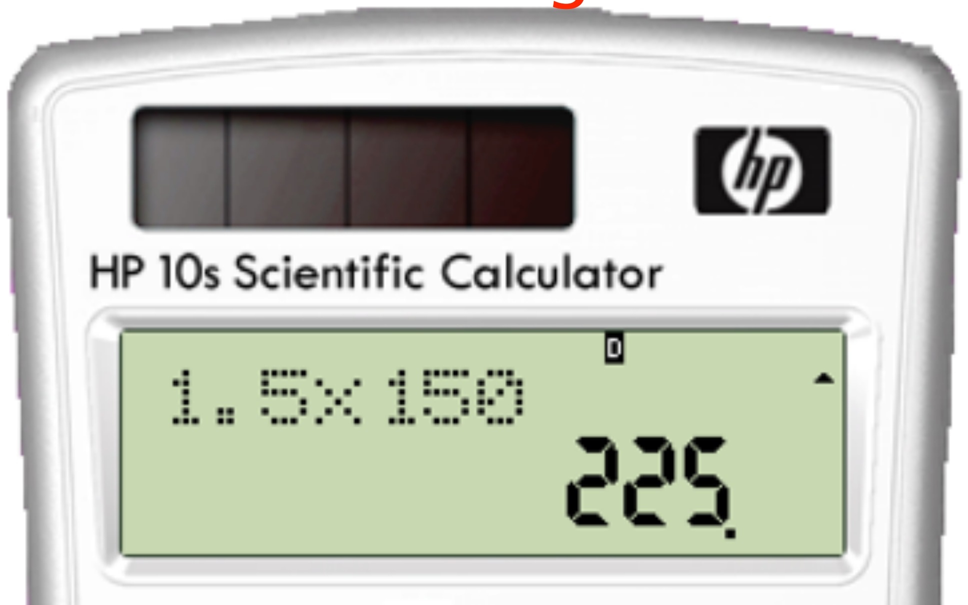
Current: 1 . 5

x

Resistance: 1 5 0

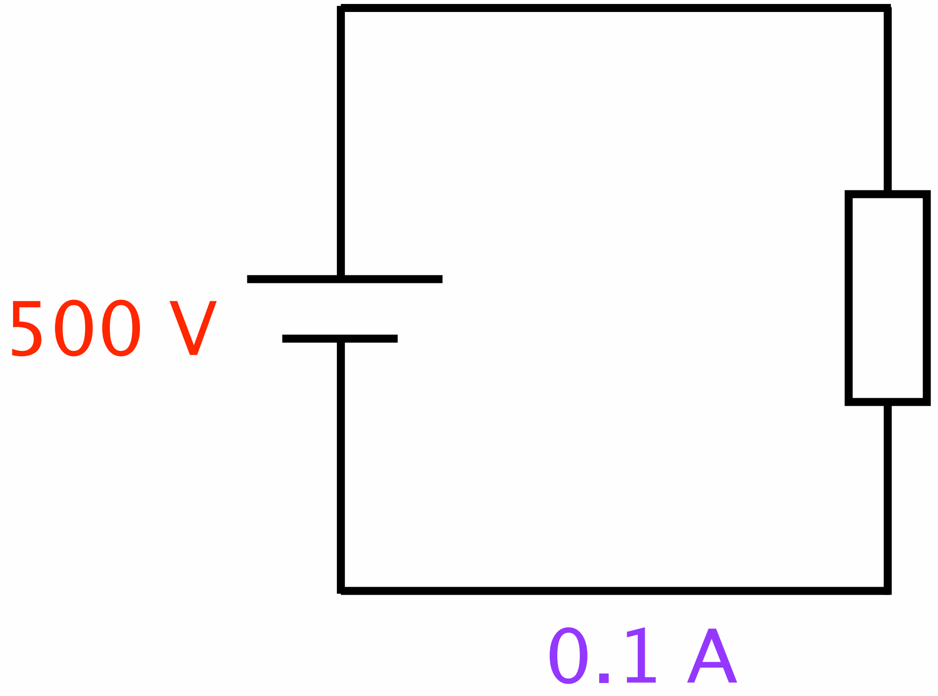
=

Voltage



{How to use Your Calculator}

{Some simple calculations}

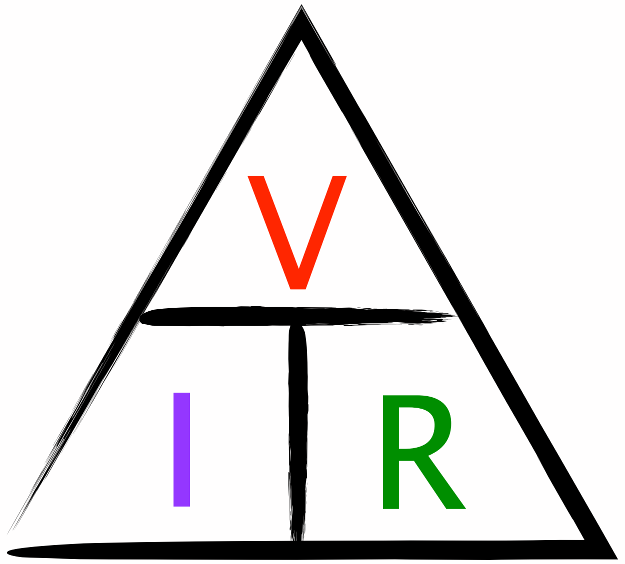


The formula to find resistance is:

$$R = \frac{V}{I}$$

$$R = \frac{500\ \text{V}}{0.1\ \text{A}}$$

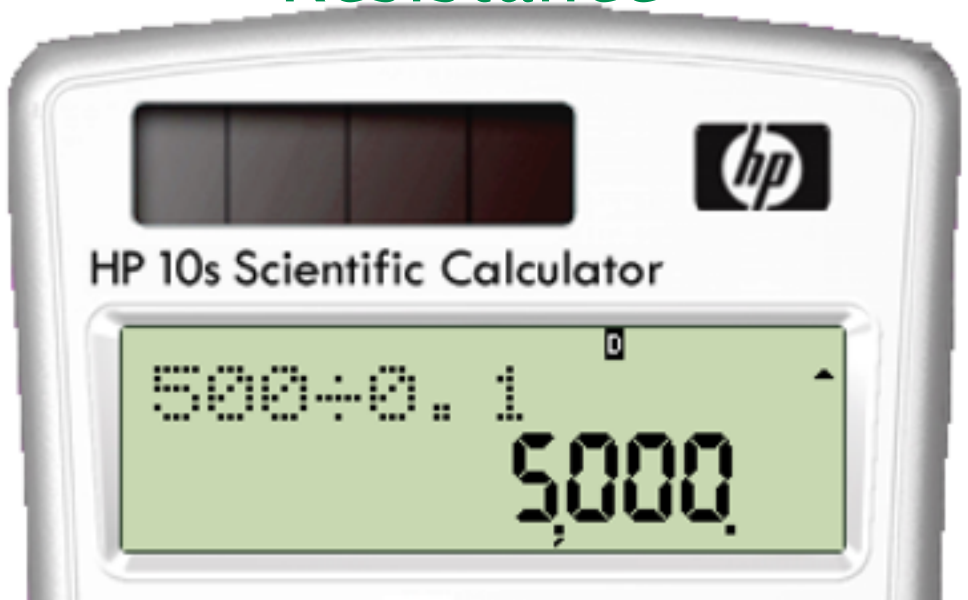
$$R = 5\ 000\ \Omega$$



To perform the calculation you would press the buttons in this sequence:

Voltage: 5 0 0 ÷ Current: 0 . 1 =

Resistance



{How to use Your Calculator}

{What about really large and really small numbers?}

Quite often you will be dealing with circuit values that are either really large such as:

$$45\ 000\ 000\ \Omega$$

You will also be dealing with circuit values that are really small such as:

$$0.000\ 007\ \text{A}$$

While it is perfectly fine to write the numbers out with straight decimal numbers as seen above, it is much easier to use prefixes and engineering notation. While you may not notice these names, you will no doubt have used these methods just about everyday! Let's use a distance as an example:

$$15\ 000 \text{ metres} = 15 \text{ kilometres} = 15 \text{ km} = 15 \times 10^{3} \text{ m}$$

{How to use Your Calculator}

{Prefixes and Engineering Notation}

All we have done in the previous example is remove three zero's and replace it with the prefix 'kilo' or 'k'. Let's see it again:

15 000 metres = 15 kilo metres = 15 km

Here we have added the prefix 'kilo' to the measurement 'metre'. We have also written it the short way by adding the prefix 'k' to the measurement 'm'.

If we were dealing with resistance, we would apply the same principle:

15 000 ohms = 15 kilo ohms = 15 kΩ

Engineering notation follows the same principles however it is written in a slightly different fashion. I.E. we multiply by ten which is raised to a certain power:

$$15\ 000 \text{ ohms} = 15 \times 10^{3}\ \Omega$$

{How to use Your Calculator}

{Handy Reference Table}

Here's a handy reference table that will help you when using prefixes and engineering notation with your circuit values. The best way to let this table sink in is by going through lots of examples!

Decimal Number	Value	Prefix Name	Prefix Symbol	Engineering Notation
1 000 000 000	Billion	giga	G	$x10^{9}$
1 000 000	Million	mega	M	$x10^{6}$
1 000	Thousand	kilo	k	$x10^{3}$
1	one			$x10^{0}$
0.001	thousandth	milli	m	$x10^{-3}$
0.000 001	millionth	micro	µ	$x10^{-6}$
0.000 000 001	billionth	nano	n	$x10^{-9}$
0.000 000 000 001	trillionth	pico	p	$x10^{-12}$

{How to use Your Calculator}

{Examples Using Voltage}

7 000 Volts = Seven Thousand Volts = 7 kilovolts = 7 kV = 7×10^{3} V

25 000 000 Volts = Twenty Five Million Volts = 25 megavolts = 25 MV = 25×10^{6} V

0.008 Volts = Eight thousandths of a volt = 8 millivolts = 8 mV = 8×10^{-3} V

Decimal Number	Value	Prefix Name	Prefix Symbol	Engineering Notation
1 000 000 000	Billion	giga	G	$\times 10^{9}$
1 000 000	Million	mega	M	$\times 10^{6}$
1 000	Thousand	kilo	k	$\times 10^{3}$
1	one			$\times 10^{0}$
0.001	thousandth	milli	m	$\times 10^{-3}$
0.000 001	millionth	micro	µ	$\times 10^{-6}$
0.000 000 001	billionth	nano	n	$\times 10^{-9}$
0.000 000 000 001	trillionth	pico	p	$\times 10^{-12}$

{How to use Your Calculator}

{Examples Using Current}

0.085 Amps = Eighty Five thousands of an Amp = 85 milliAmps = 85 mA = 85×10^{-3} A

5 200 Amps = Five Thousand Two Hundred Amps = 5.2 kiloAmps = 5.2 kA = 5.2×10^{3} A

0.000 300 Amps = Three Hundred millionths of an Amp = 300 microAmps = 300 μA = 300×10^{-6} A

Decimal Number	Value	Prefix Name	Prefix Symbol	Engineering Notation
1 000 000 000	Billion	giga	G	$\times 10^{9}$
1 000 000	Million	mega	M	$\times 10^{6}$
1 000	Thousand	kilo	k	$\times 10^{3}$
1	one			$\times 10^{0}$
0.001	thousandth	milli	m	$\times 10^{-3}$
0.000 001	millionth	micro	μ	$\times 10^{-6}$
0.000 000 001	billionth	nano	n	$\times 10^{-9}$
0.000 000 000 001	trillionth	pico	p	$\times 10^{-12}$

{How to use Your Calculator}

{Examples Using Resistance}

1 700 Ohms = One Thousand Seven Hundred Ohms = 1.7 kiloOhms = 1.7 kΩ = $1.7 \times 10^{3}\ \Omega$

49 000 Ohms = Forty Nine Thousand Ohms = 49 kiloOhms = 49 kΩ = $49 \times 10^{3}\ \Omega$

22 000 000 Ohms = Twenty Two Million Ohms = 22 MegaOhms = 22 MΩ = $22 \times 10^{6}\ \Omega$

Decimal Number	Value	Prefix Name	Prefix Symbol	Engineering Notation
1 000 000 000	Billion	giga	G	$x10^{9}$
1 000 000	Million	mega	M	$x10^{6}$
1 000	Thousand	kilo	k	$x10^{3}$
1	one			$x10^{0}$
0.001	thousandth	milli	m	$x10^{-3}$
0.000 001	millionth	micro	µ	$x10^{-6}$
0.000 000 001	billionth	nano	n	$x10^{-9}$
0.000 000 000 001	trillionth	pico	p	$x10^{-12}$

{How to use Your Calculator}

Still confused?

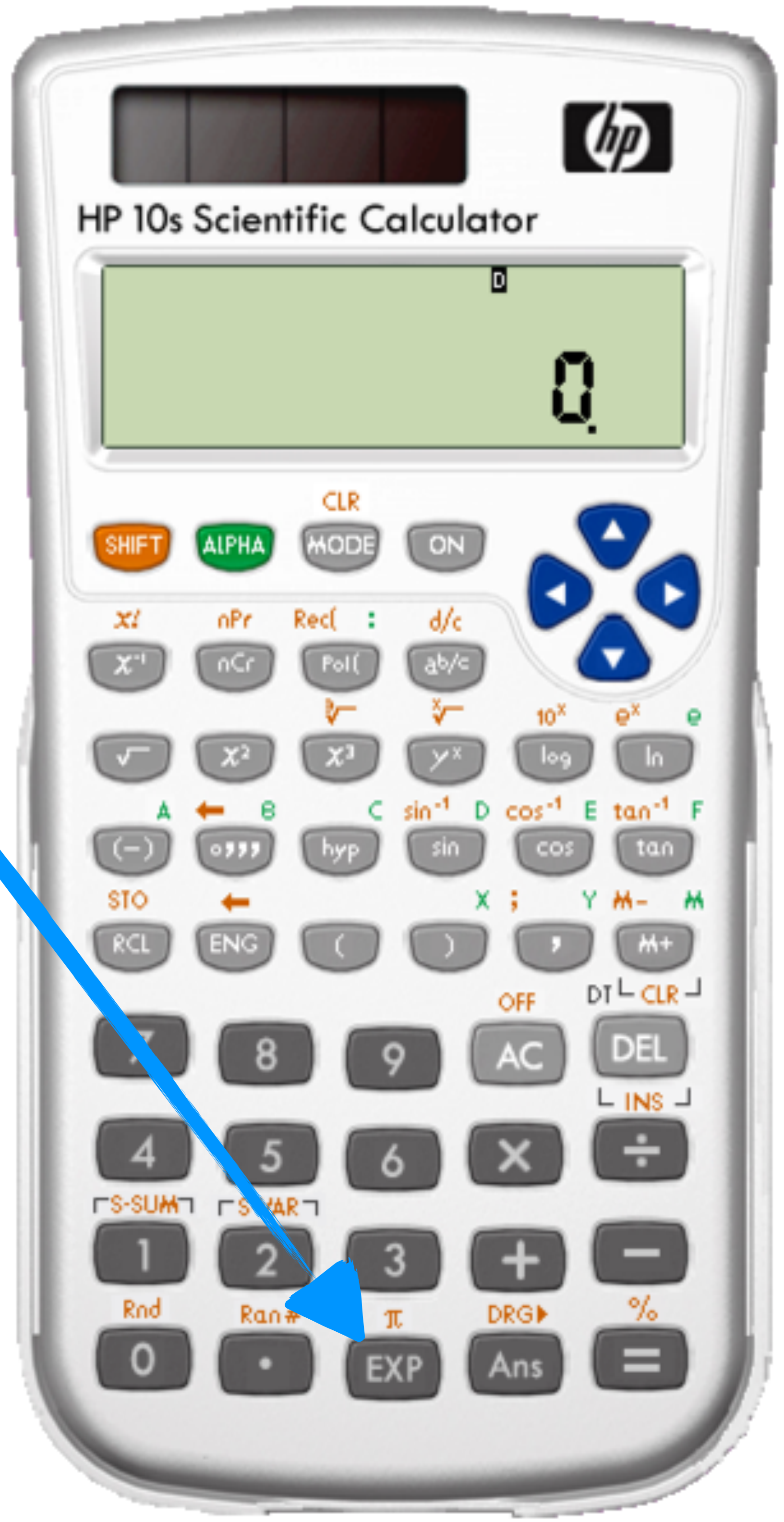
Well don't fear because I am confident it will sink in by the end of this chapter. We will run through some calculator exercises then have a summary and then finally you will complete some example questions. Practice makes perfect!

{How to use Your Calculator}

{Engineering Notation on the Calculator}

We will use engineering notation from here on when using our calculator. Remember, the table on page 5.9 will be handy while getting used to entering numbers using engineering notation.

To do this, we need to use what is known as the exponential button. Most calculators will simply have a button labelled ‘EXP’ however some other calculators will have a button labelled like this. Either way, they both achieve the same purpose.



{How to use Your Calculator}

{Entering Data into the Calculator}

Let's look at entering numbers in as standard decimal and then in engineering notation form. Note, all of these examples are numbers which are greater than one.

Enter in the number 1000:

Standard Decimal

1 0 0 0 =

Engineering Notation

1 exp 3 =

This means multiply by 1000

Enter in the number 386000:

3 8 6 0 0 0 =

3 8 6 exp 3 =

Enter in the number 2000000:

This means multiply by 1 000 000

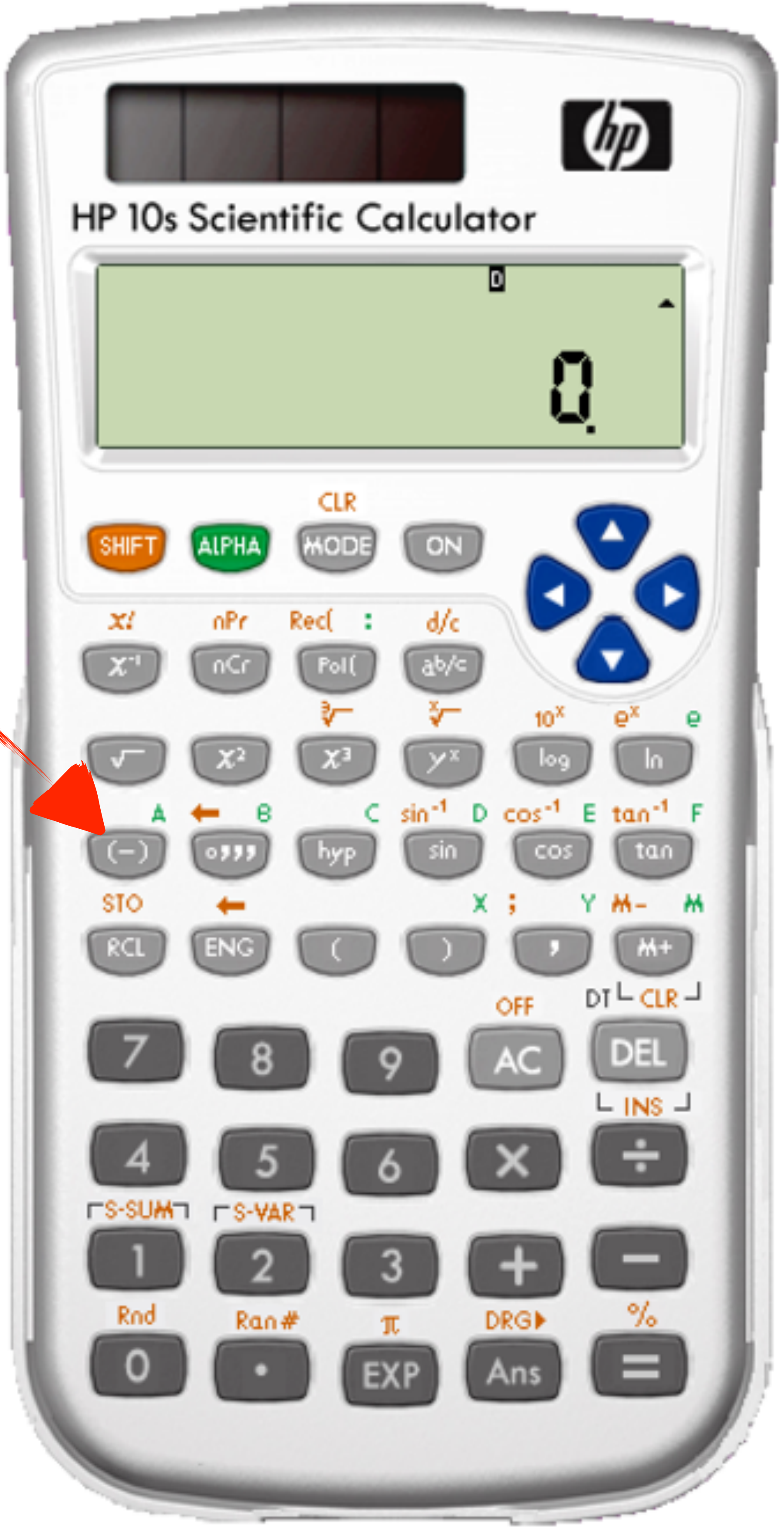
2 0 0 0 0 0 0 =

2 exp 6 =

{How to use Your Calculator}

{Entering Data into the Calculator}

For numbers less than 1, we need to use the calculators ‘change sign’ button. This button presents itself in one of two forms normally. These being this or this.



{How to use Your Calculator}

{Entering Data into the Calculator}

Here are some examples of entering numbers in that are less than one in both standard decimal and engineering notation:

Enter in the number 0.005:

Standard Decimal

[0] [.] [0] [0] [5] [=]

Engineering Notation

[5] [exp] [(-)] [3] [=]

This means multiply by 0.001

Enter in the number 0.184:

[0] [.] [1] [8] [4] [=]

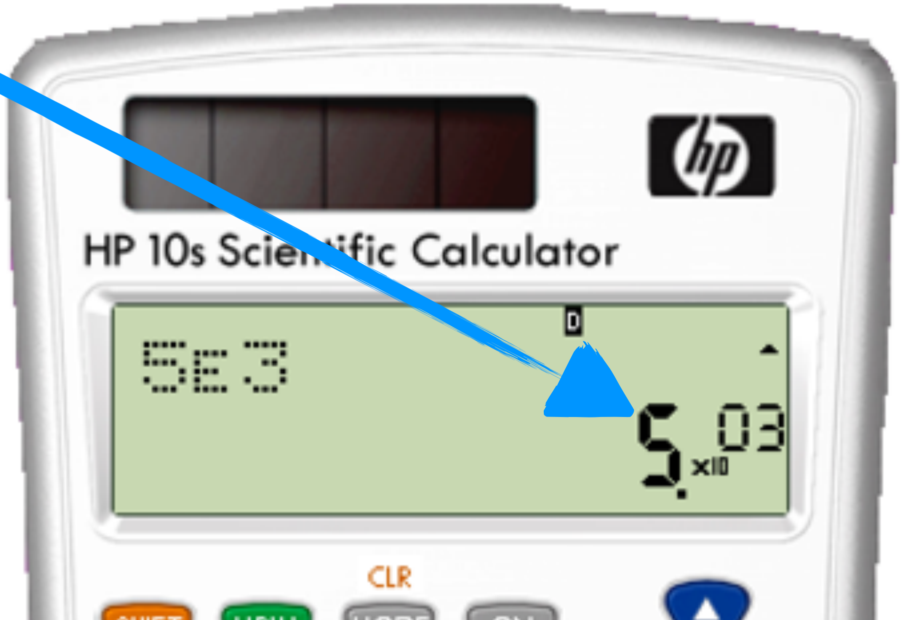
[1] [8] [4] [exp] [(-)] [3] [=]

{How to use Your Calculator}

{Viewing Data in Engineering Notation on a Calculator}

Most calculators I have used will default to showing your answers in standard decimal form. That means even if you type a number in engineering notation form, it will display the result as standard decimal. For example:

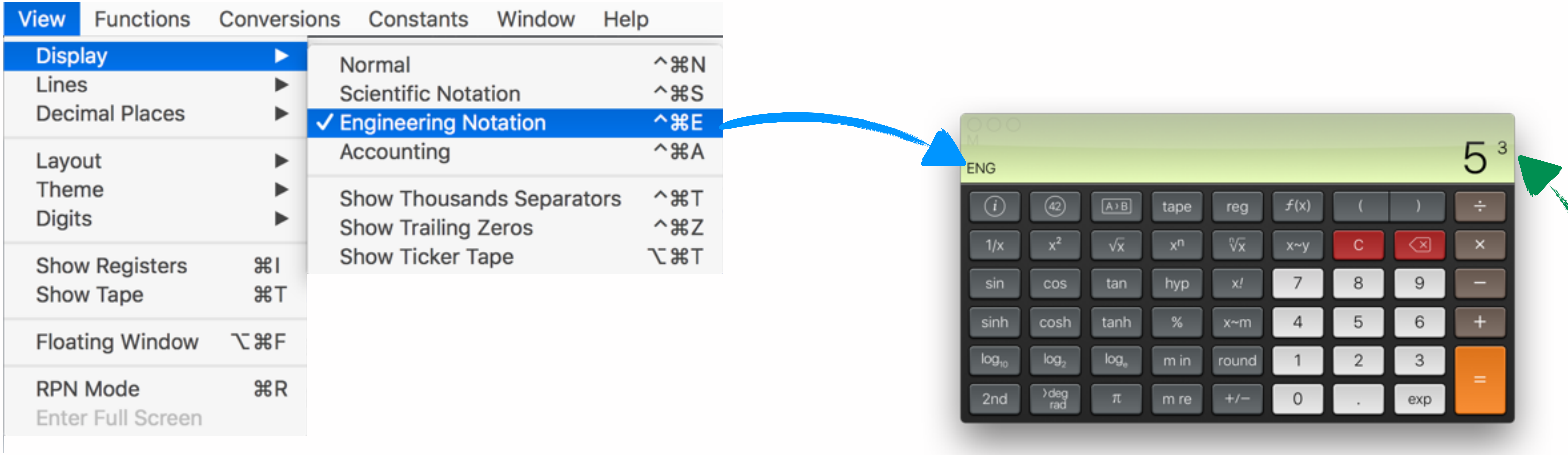
In order to then display your answer in engineering notation, you need to press the ENG button. This will change the display from standard decimal, into engineering notation like this:



{How to use Your Calculator}

{Viewing Data in Engineering Notation on a Calculator}

Some calculators might have a setting whereby you can always have the screen display values in engineering notation. Virtual calculators on a smart phone or computer will most probably have this sort of feature.

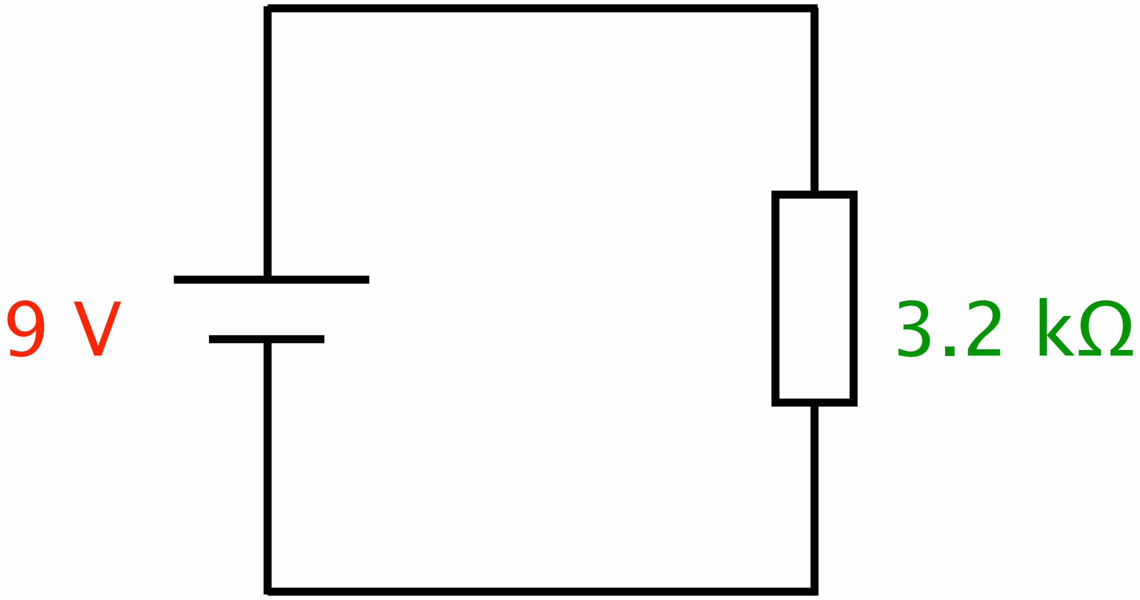


By selecting Engineering Notation from the Display menu, numbers will always be presented in engineering notation form.

{How to use Your Calculator}

{More Circuit Calculations – Current}

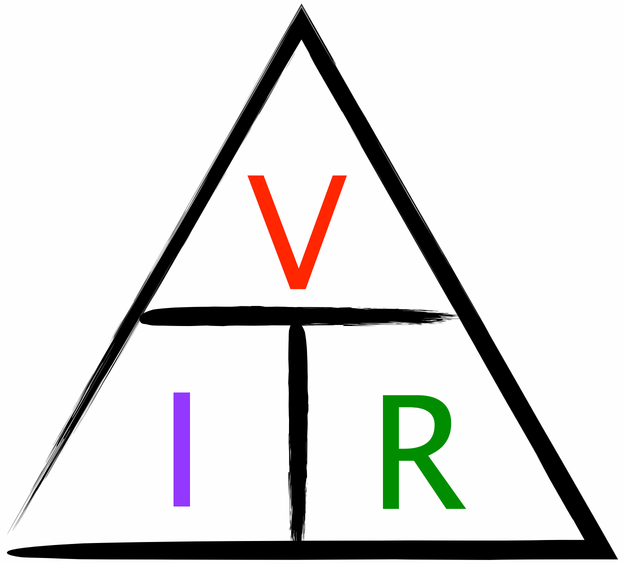
Now this is where all the theory should really sink in. Once again, the table on page 5.9 will help with these calculations. Remember also to press the **ENG** button at the completion of each calculation, to have the answer displayed in engineering notation form.



$$I = \frac{V}{R}$$

$$I = \frac{9\ V}{3.2\ k\Omega}$$

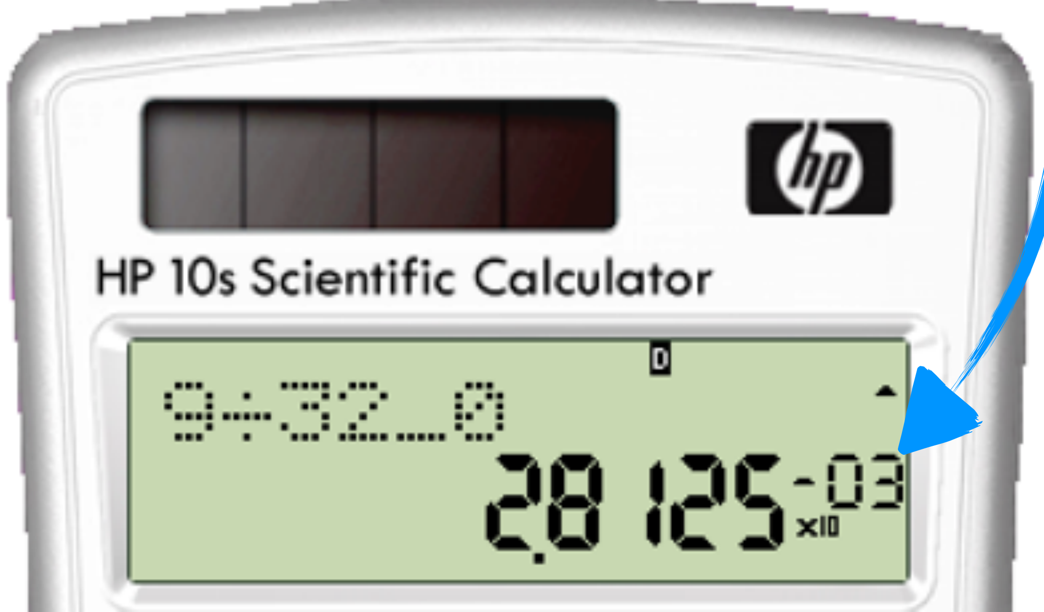
$$I = 2.81\ mA$$



Looking at the table on page 5.9, we can see that $\times 10^{-3}$ is ‘milli’ or ‘m’. We then write our answer as milliAmps.

Round every answer to two decimal places (this means there should only be two numbers to the right of the decimal point) We will round up only if the third number to the right is five or greater.

Current



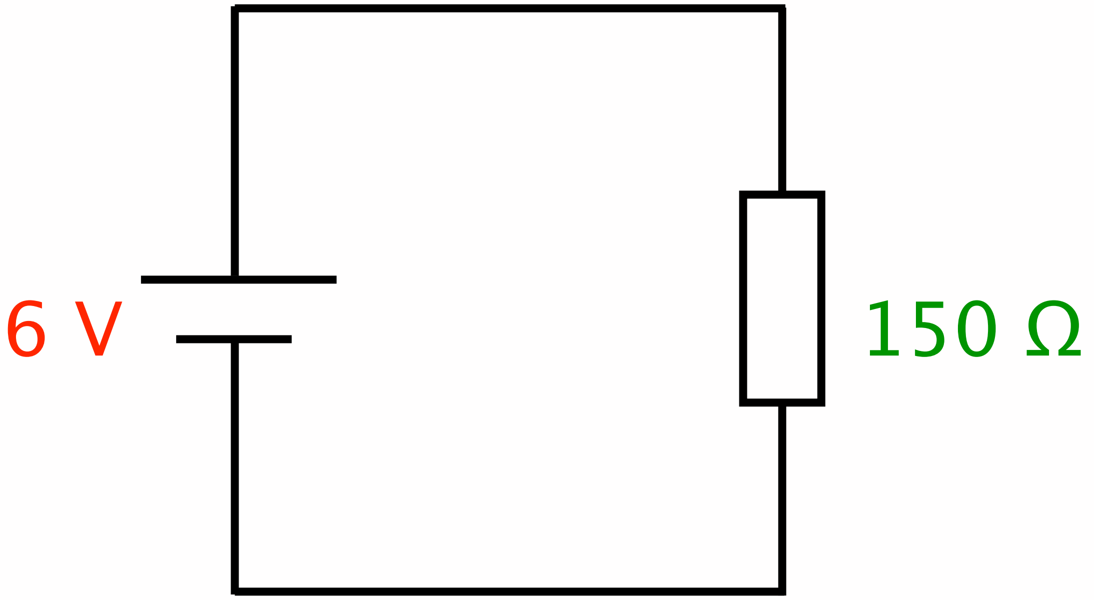
Voltage — Resistance

9 **÷** **3** **.** **2** **exp** **3** **=**

{How to use Your Calculator}

{More Circuit Calculations – Current}

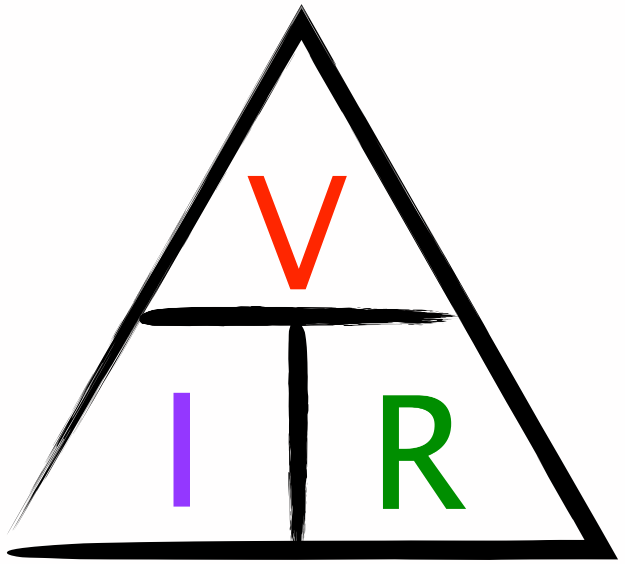
Let’s do some more! (remember we will be rounding our answers to two decimal places).

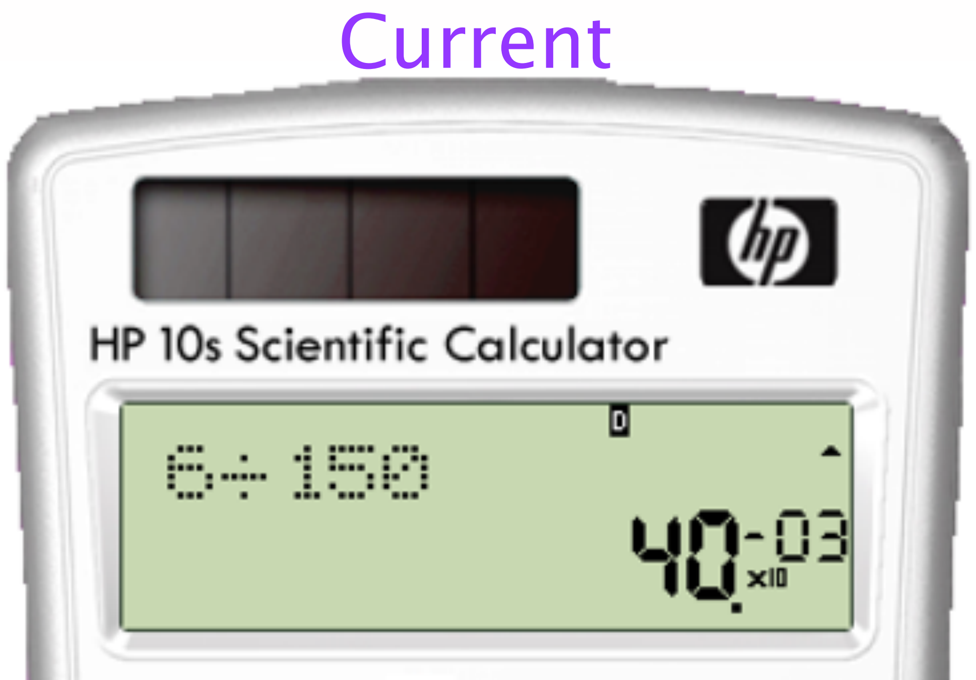


$$I = \frac{V}{R}$$

$$I = \frac{6\ V}{150\ \Omega}$$

$$I = 40\ mA$$

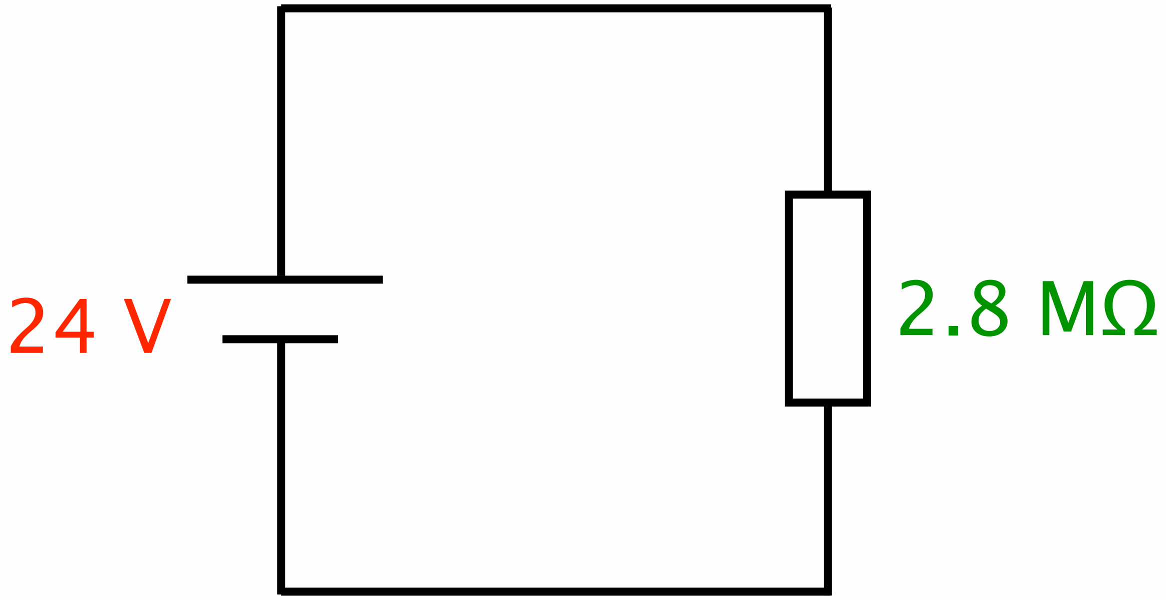




{How to use Your Calculator}

{More Circuit Calculations – Current}

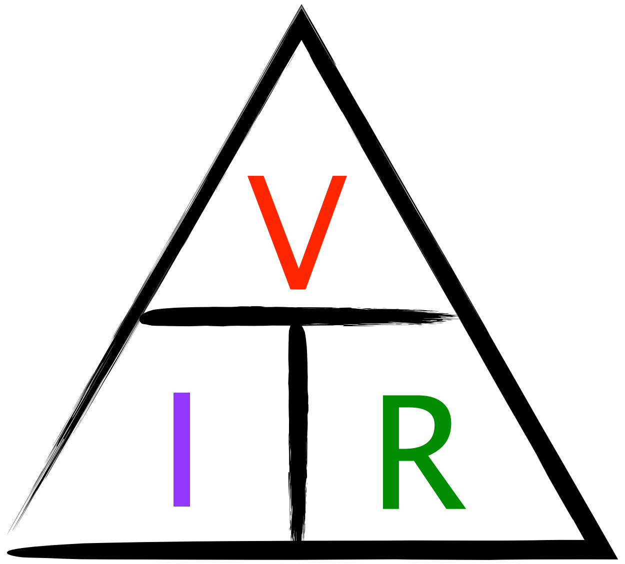
Let's do some more! (remember we will be rounding our answers to two decimal places).



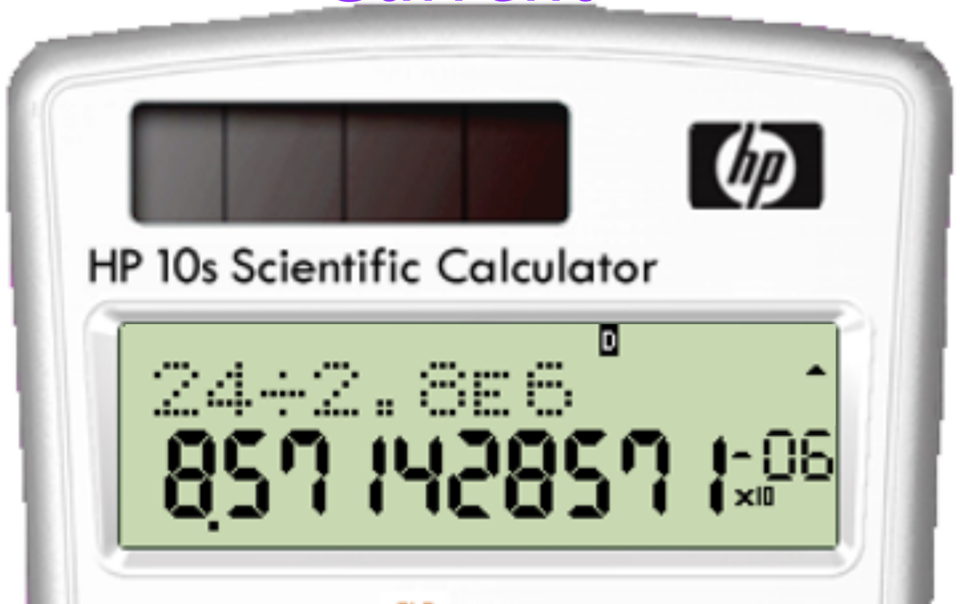
$$I = \frac{V}{R}$$

$$I = \frac{24\ V}{2.8\ M\Omega}$$

$$I = 8.57\ \mu A$$



Current



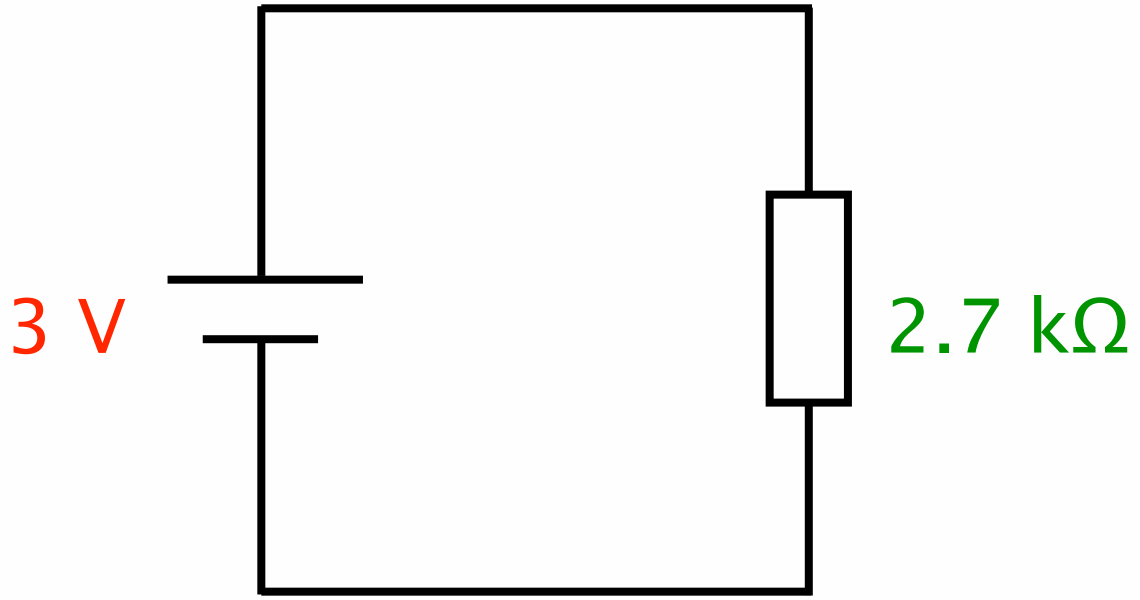
Voltage | Resistance

2 4 ÷ 2 . 8 exp 6 =

{How to use Your Calculator}

{More Circuit Calculations – Current}

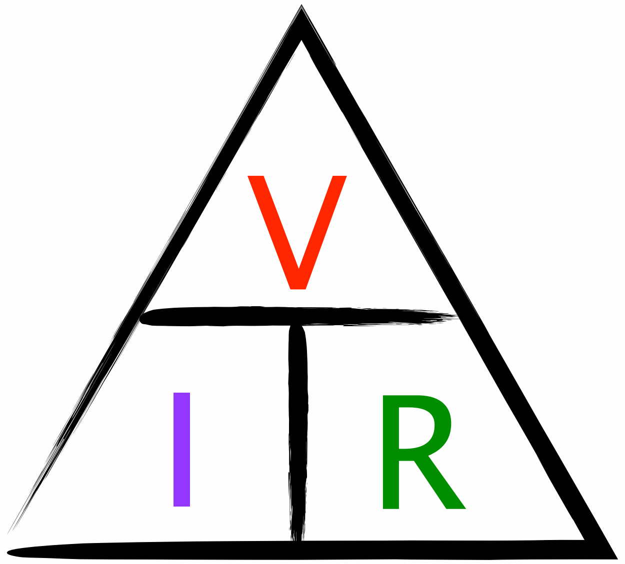
Let's do some more! (remember we will be rounding our answers to two decimal places).



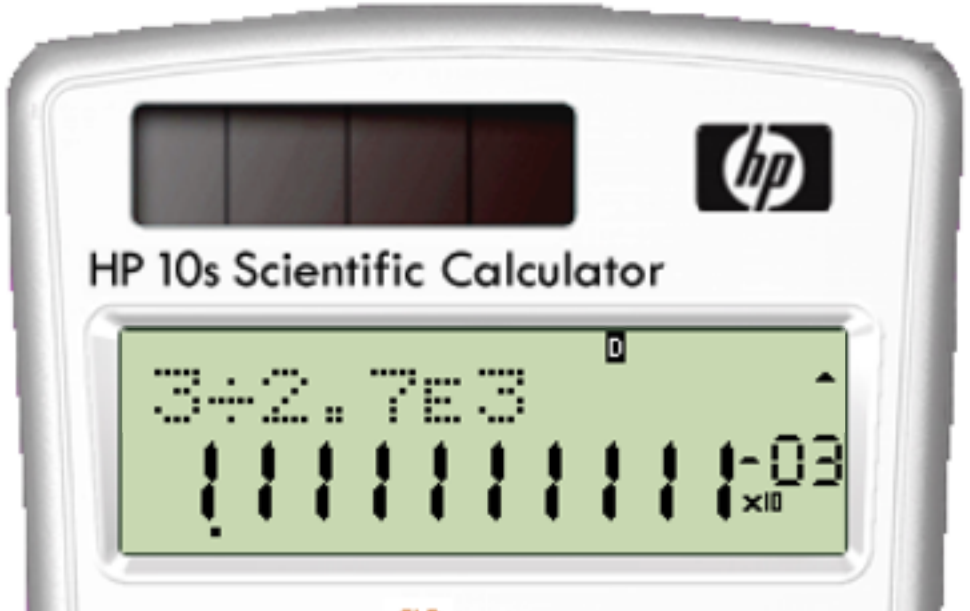
$$I = \frac{V}{R}$$

$$I = \frac{3\ V}{2.7\ k\Omega}$$

$$I = 1.11\ mA$$



Current

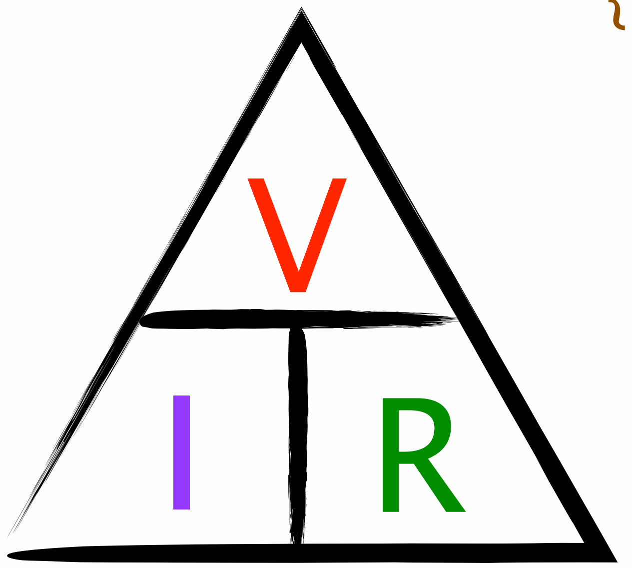


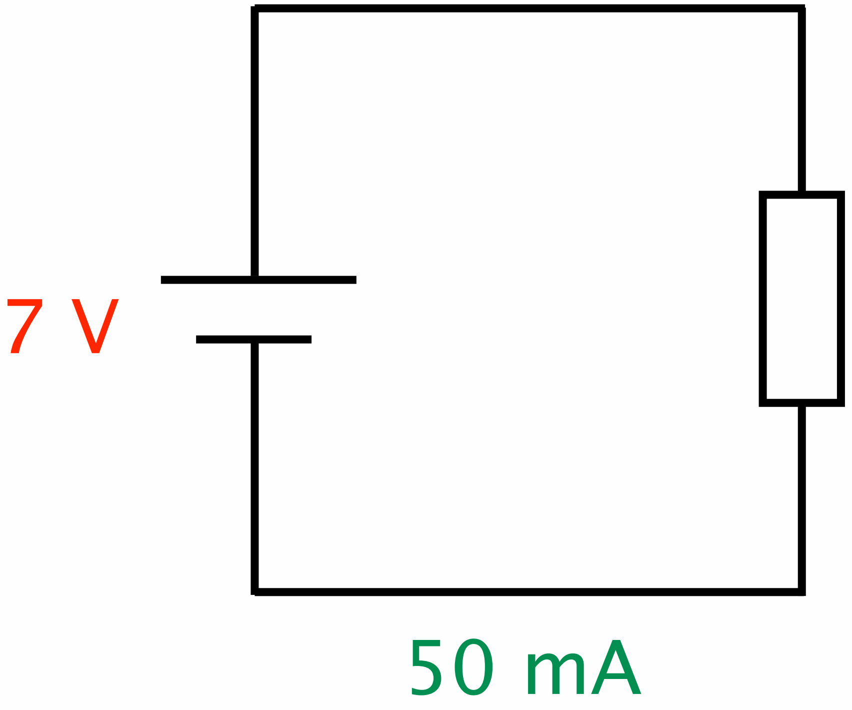
Voltage — Resistance

3 ÷ 2 . 7 exp 3 =

{How to use Your Calculator}

{More Circuit Calculations – Resistance}





$$R = \frac{V}{I}$$

$$R = \frac{7\ \text{V}}{50\ \text{mA}}$$

$$R = 140\ \Omega$$

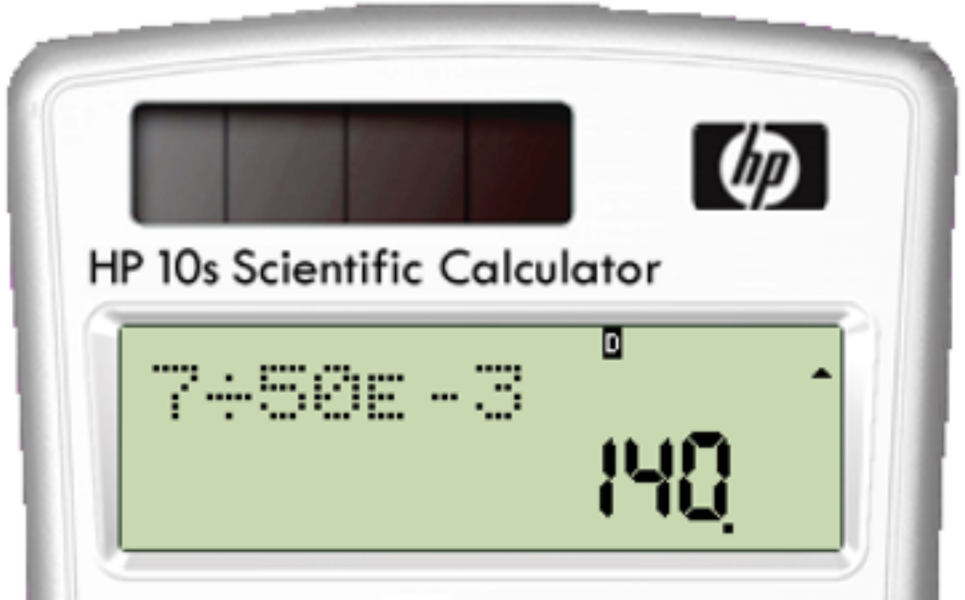
Sometimes the answer might not need to be in engineering notation because it is less than 1 000. Pressing the ENG button will simply show 140 $\times 10^{0}$

Remember this button will change the sign to a negative so we can represent milliAmps.

Voltage | Current

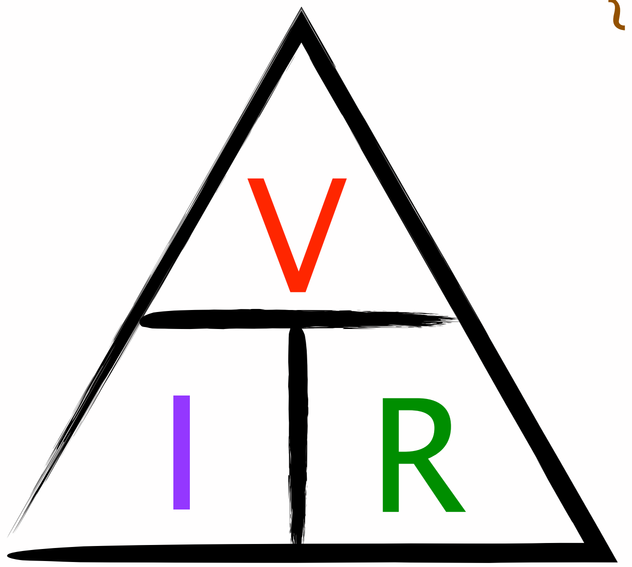
7 ÷ 5 0 exp (–) 3 =

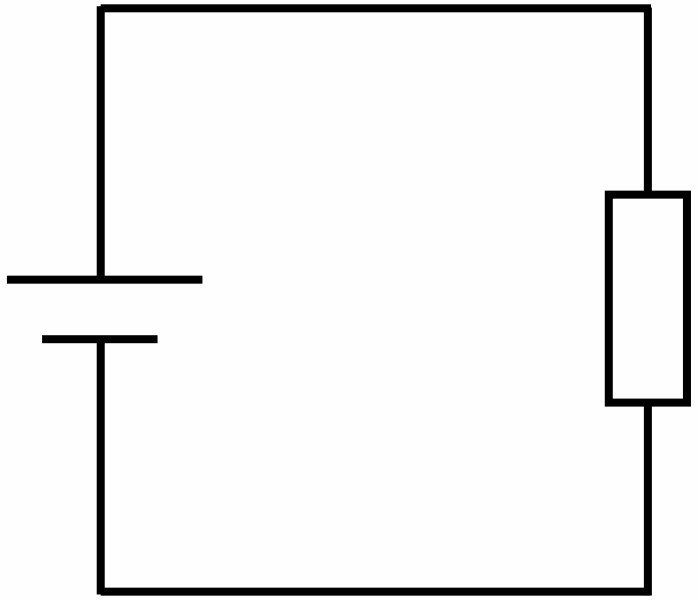
Resistance



{How to use Your Calculator}

{More Circuit Calculations – Resistance}



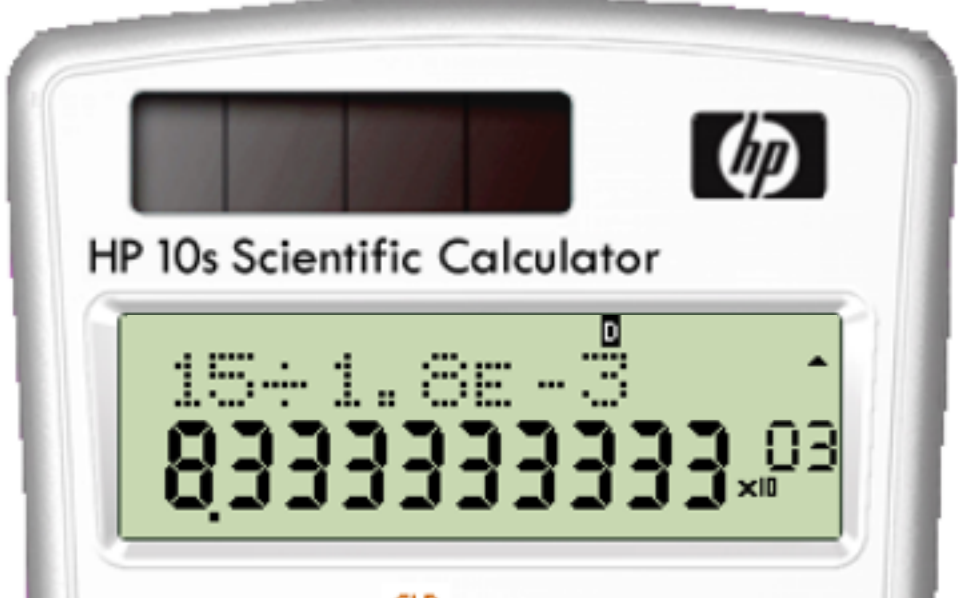


$$R = \frac{V}{I}$$

$$R = \frac{15\ \text{V}}{1.8\ \text{mA}}$$

$$R = 8.33\ \text{k}\Omega$$

Resistance

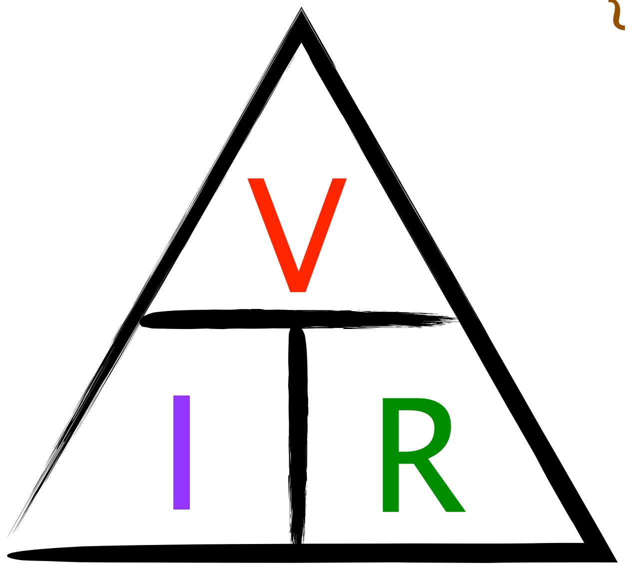


Voltage | Current

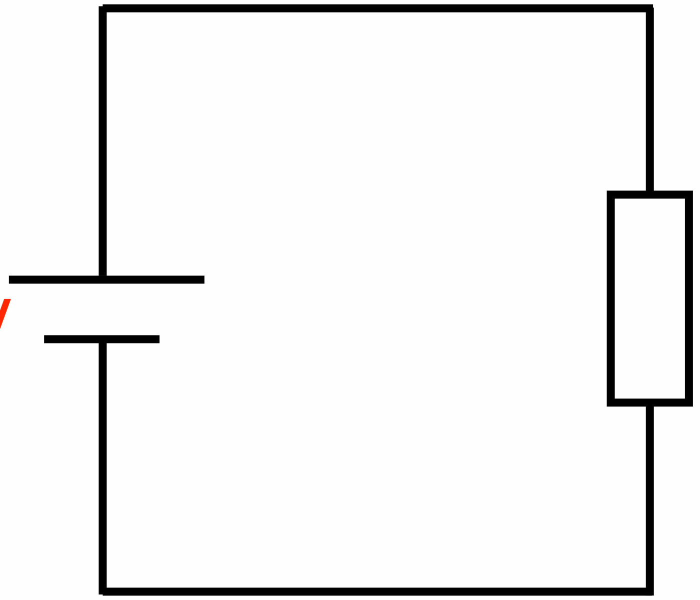
1 | 5 | ÷ | 1 | . | 8 | exp | (−) | 3 | =

{How to use Your Calculator}

{More Circuit Calculations – Resistance}



1.5 V



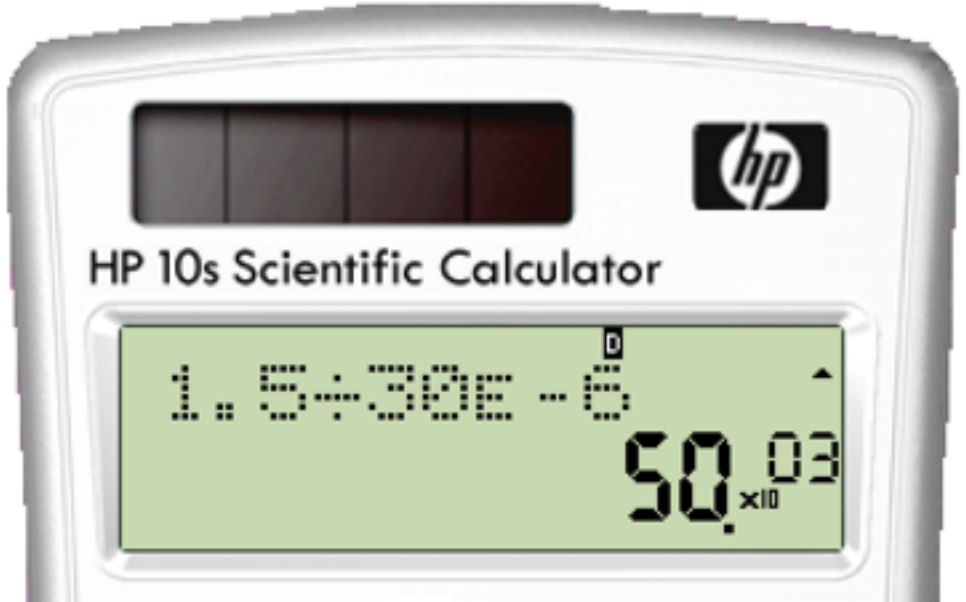
30 μA

$$R = \frac{V}{I}$$

$$R = \frac{1.5\ \text{V}}{30\ \mu\text{A}}$$

$$R = 50\ \text{k}\Omega$$

Resistance



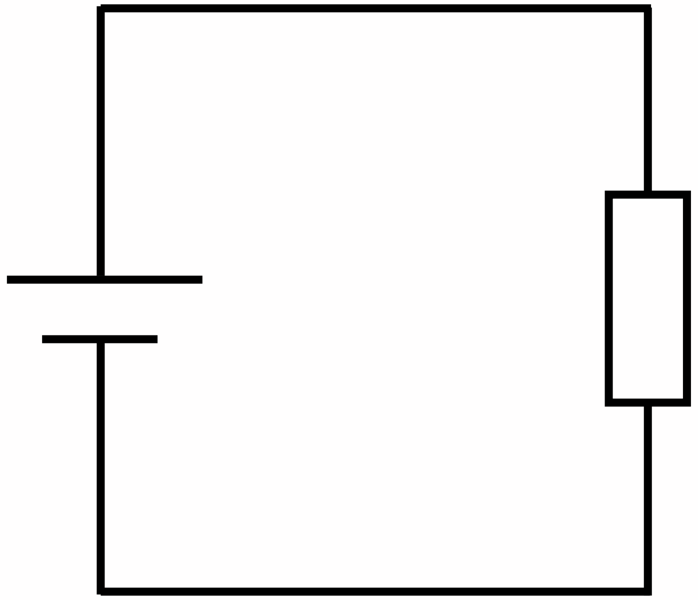
Voltage | Current

1 . 5 ÷ 3 0 exp (–) 6 =

{How to use Your Calculator}

{More Circuit Calculations – Resistance}

10 V

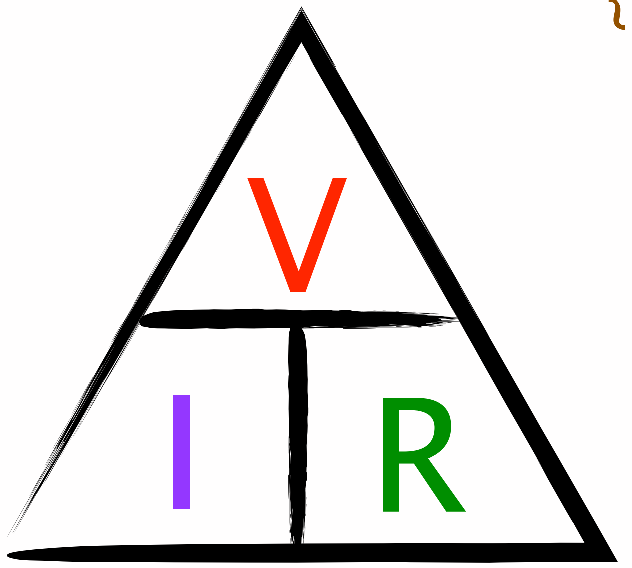


9.7 μA

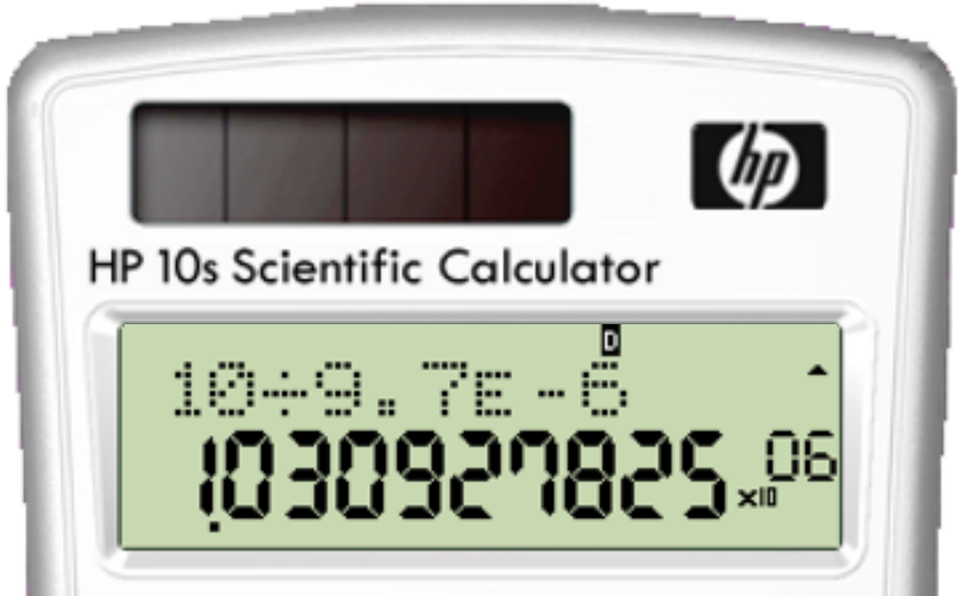
$$R = \frac{V}{I}$$

$$R = \frac{10\ \text{V}}{9.7\ \mu\text{A}}$$

$$R = 1.03\ \text{M}\Omega$$



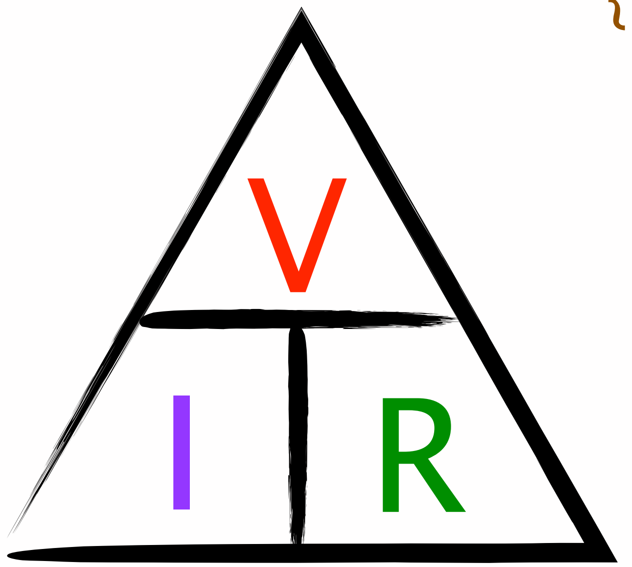
Resistance



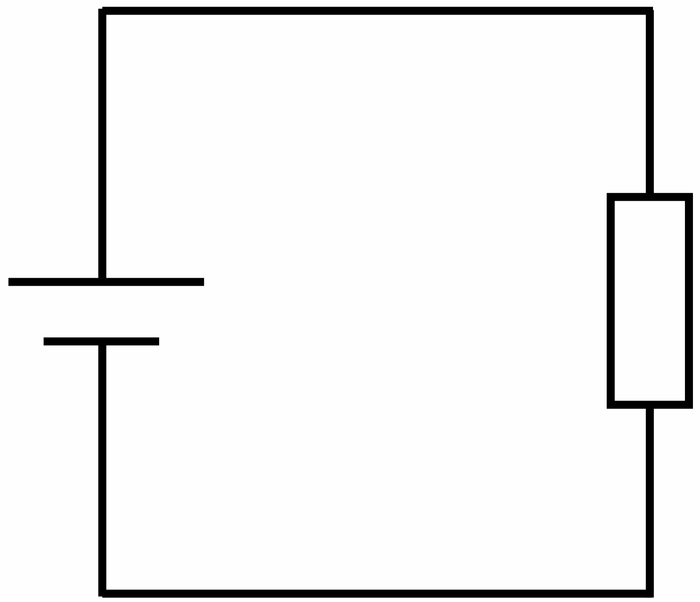
Voltage | Current

1 | 0 | ÷ | 9 | . | 7 | exp | (–) | 6 | =

{How to use Your Calculator}



{More Circuit Calculations – Voltage}



800 Ω

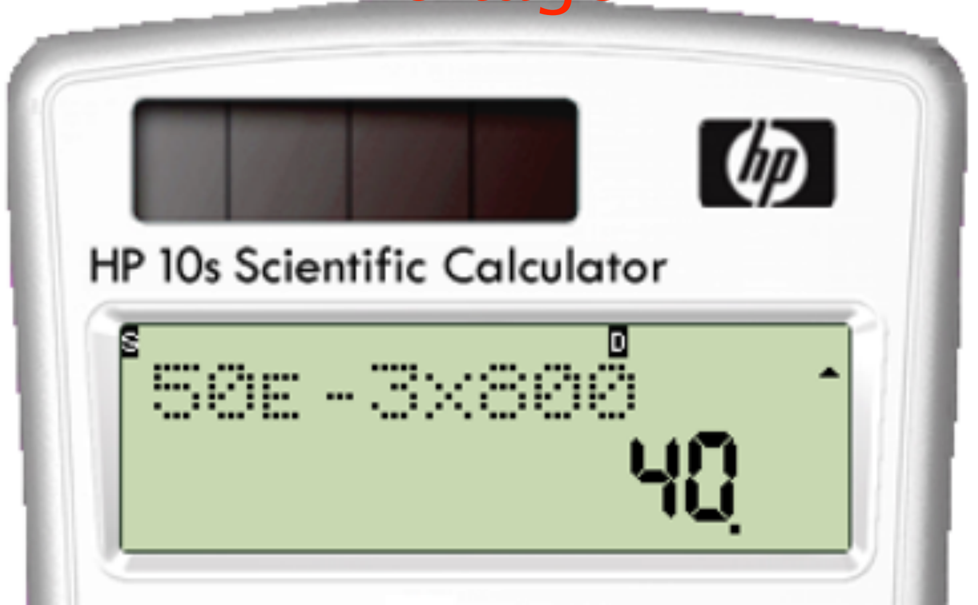
50 mA

V = I x R

V = 50mA x 800 Ω

V = 40 V

Voltage

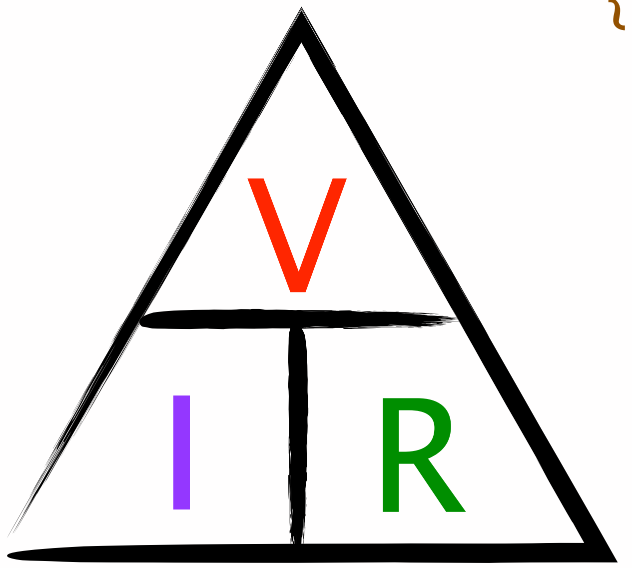


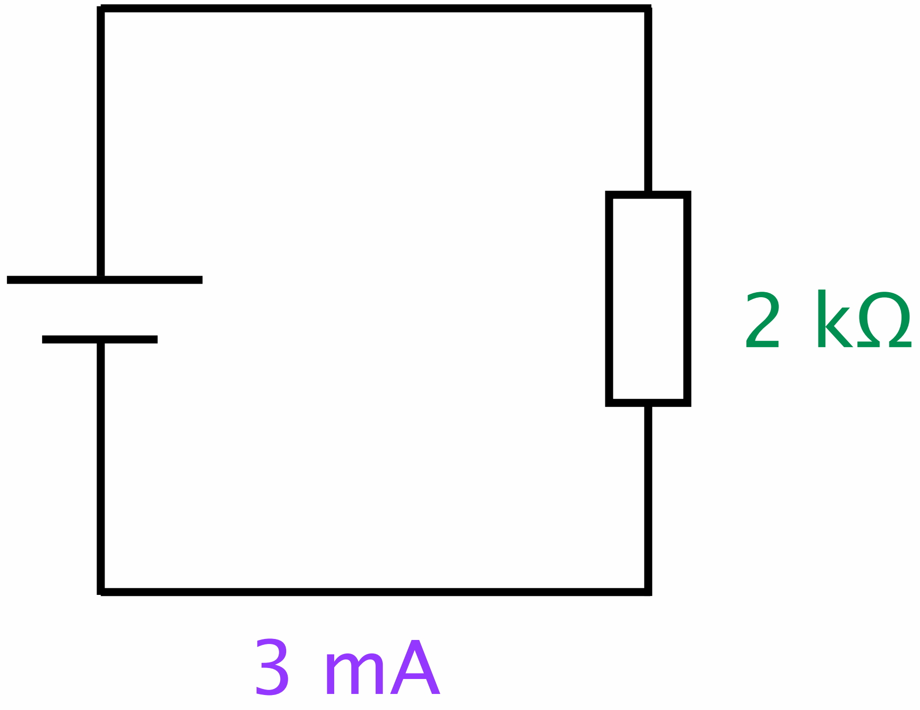
Current | Resistance

5 0 exp (-) 3 x 8 0 0 =

{How to use Your Calculator}

{More Circuit Calculations – Voltage}



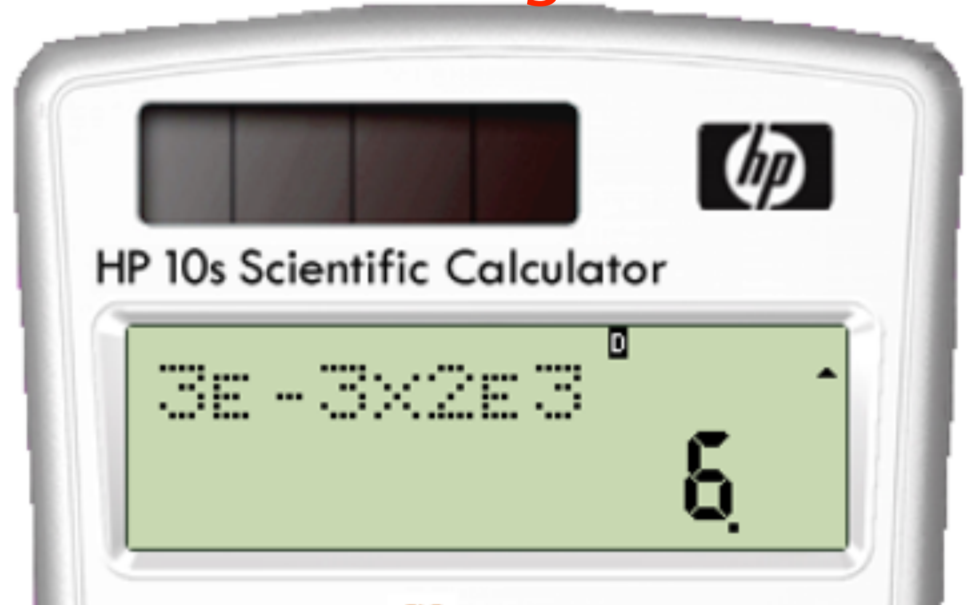


V = I x R

V = 3 mA x 2 kΩ

V = 6 V

Voltage

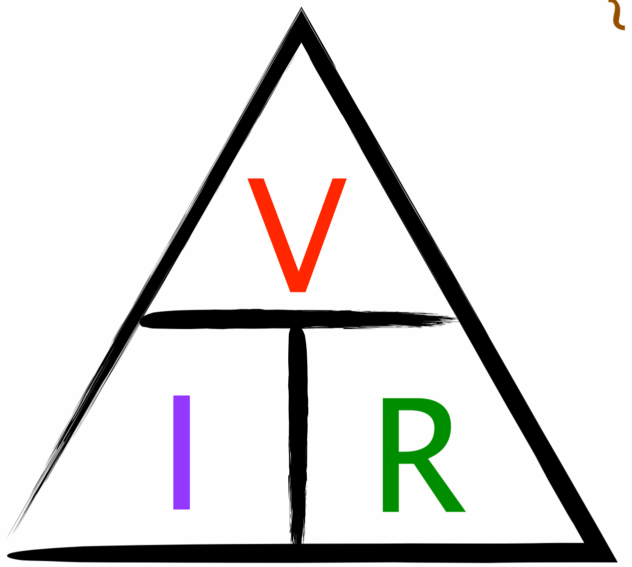


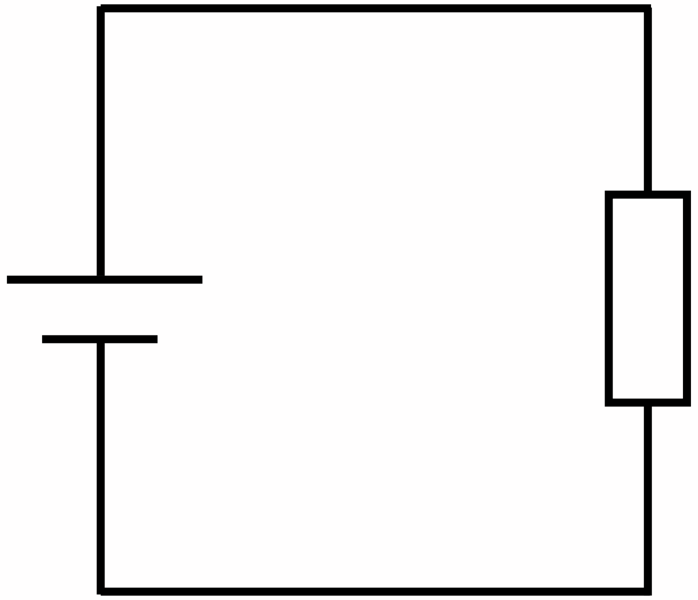
Current | Resistance

3 | exp | (–) | 3 | x | 2 | exp | 3 | =

{How to use Your Calculator}

{More Circuit Calculations – Voltage}





43 MΩ

43 μA

$V = I \times R$

$V = 43\ \mu A \times 43\ M\Omega$

$V = 1.85\ kV$

Current

4 | 3 | exp | (-) | 6

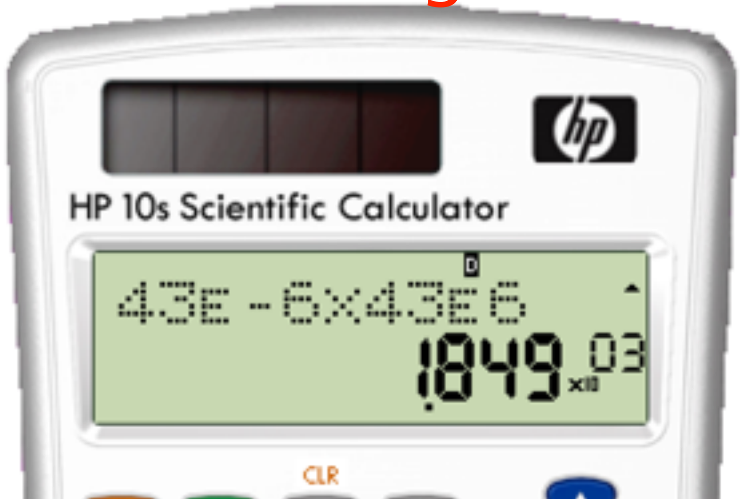
x

Resistance

4 | 3 | exp | 6

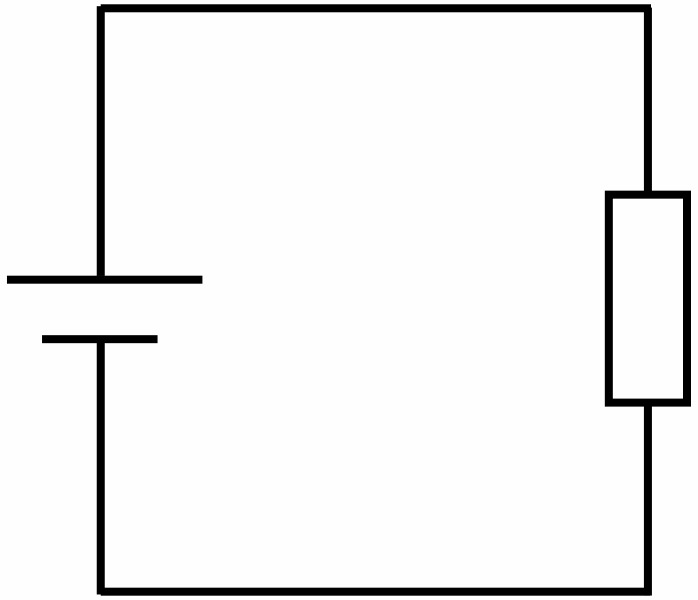
=

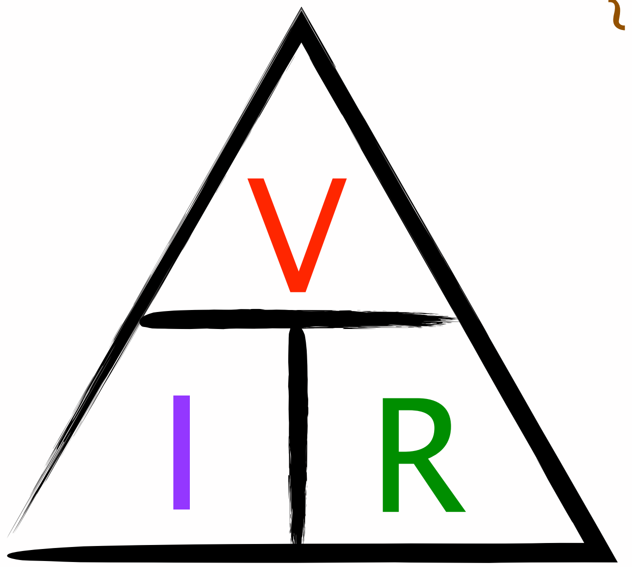
Voltage



{How to use Your Calculator}

{More Circuit Calculations – Voltage}





1.42 kΩ

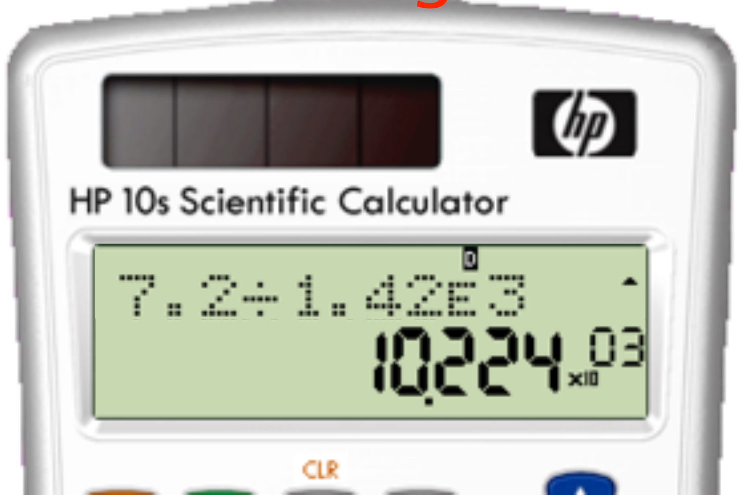
7.2 A

V = I x R

V = 7.2 A x 1.42 kΩ

V = 10.22 kV

Voltage



Current | Resistance

7 . 2 x 1 . 4 2 exp 3 =

{How to use Your Calculator}

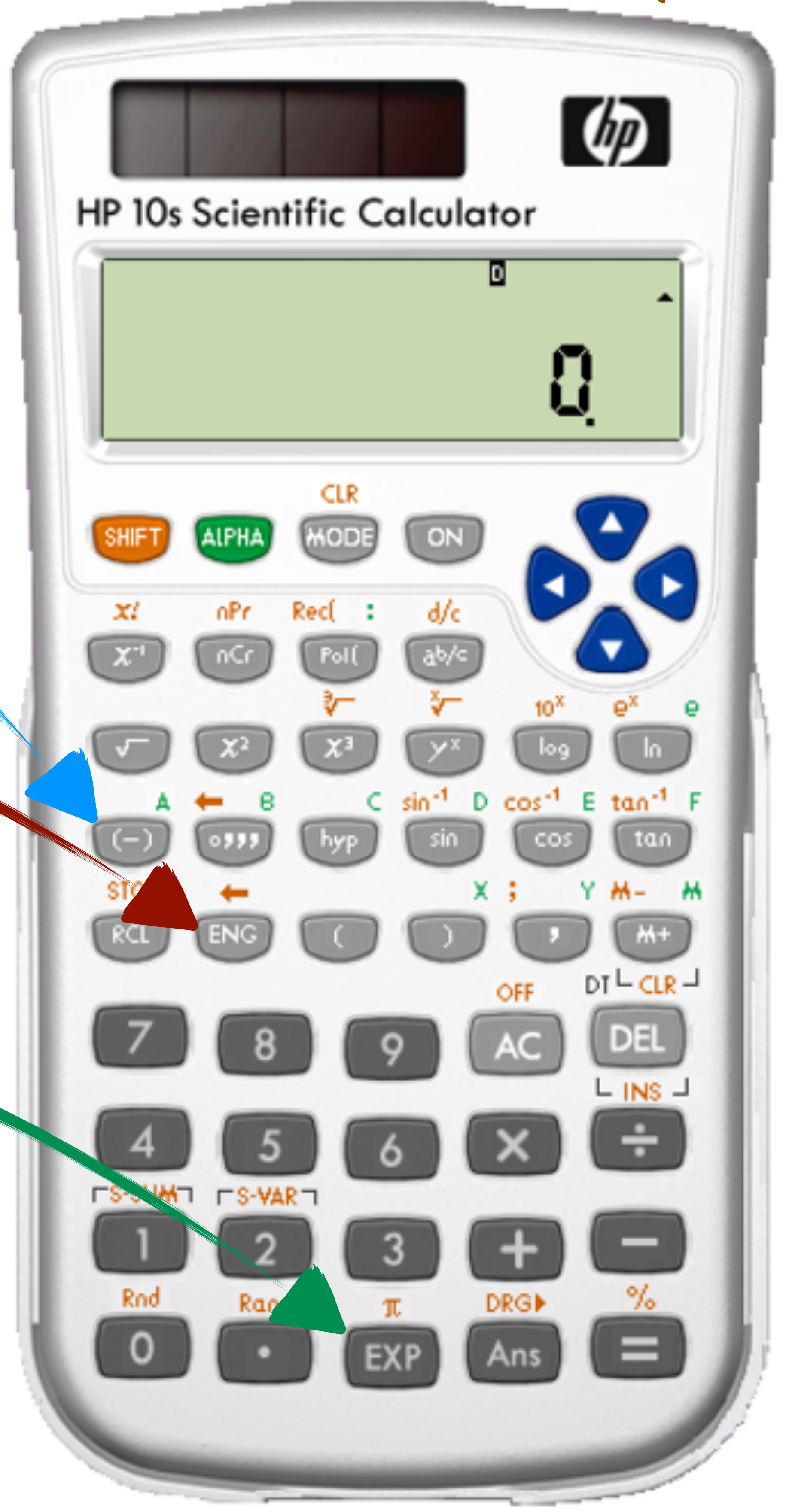
{Questions}

1. What does this button do?

2. What does this button do?

3. What does this button do?

4. Draw the button which some calculators use instead of **EXP**



{How to use Your Calculator}

{Questions}

5. Draw the button which some calculators use instead of **(−)**

6. What will this calculator screen change to AFTER the ENG button is pressed?

7. What will this calculator screen change to AFTER the ENG button is pressed?

8. What will this calculator screen change to AFTER the ENG button is pressed?

{How to use Your Calculator}

{Questions}

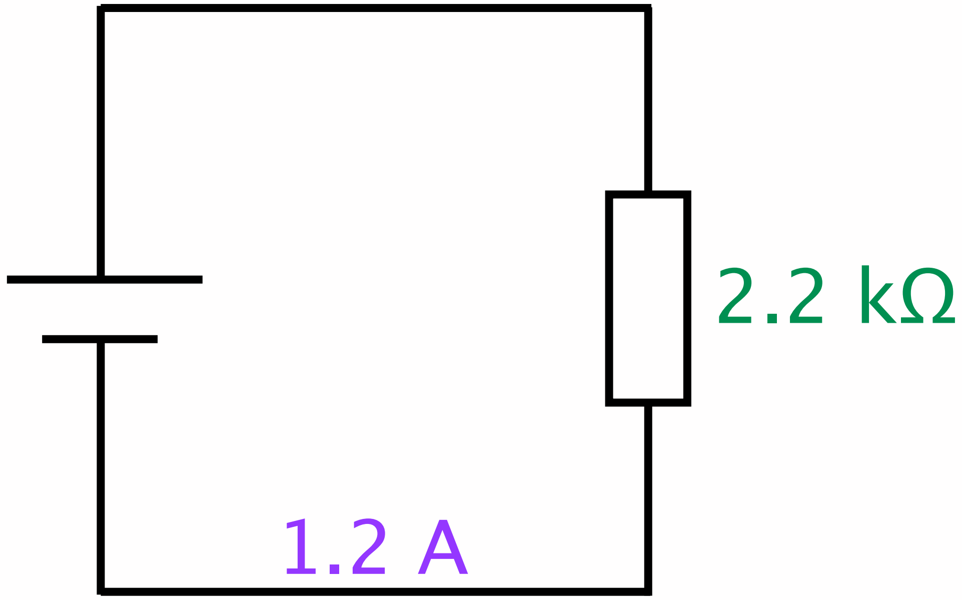
9. Fill in the Prefix Name and Prefix Symbol in the following table:

Decimal Number	Value	Prefix Name	Prefix Symbol	Engineering Notation
1 000 000 000	Billion			$x10^{9}$
1 000 000	Million			$x10^{6}$
1 000	Thousand			$x10^{3}$
1	one			$x10^{0}$
0.001	thousandth			$x10^{-3}$
0.000 001	millionth			$x10^{-6}$
0.000 000 001	billionth			$x10^{-9}$
0.000 000 000 001	trillionth			$x10^{-12}$

{How to use Your Calculator}

{Questions}

10. Fill in the squares to enter engineering notation into the calculator, then write the answer using the correct prefix.

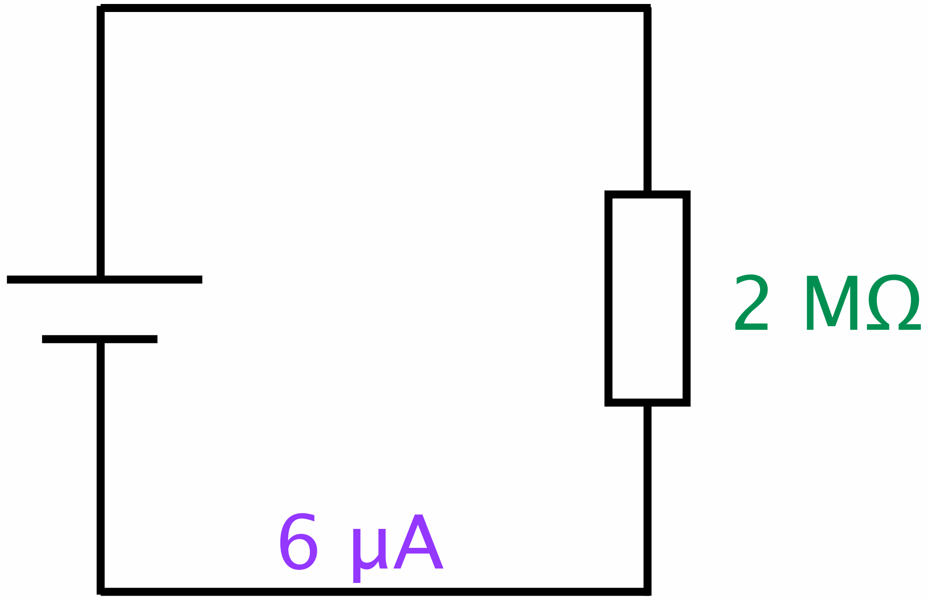


V = I x R

V = 1.2 A x 2.2 kΩ

V = [ ] [ ] [ ] x [ ] [ ] [ ] [ ] [ ] =

11. Fill in the squares to enter engineering notation into the calculator, then write the answer using the correct prefix.



V = I x R

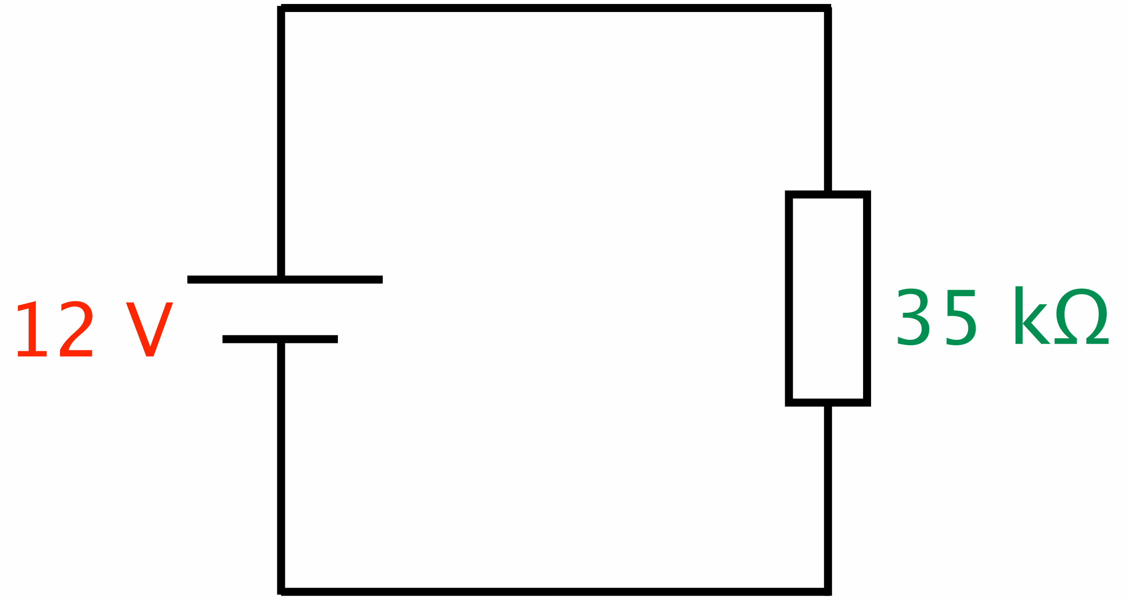
V = 6 μA x 2 MΩ

V = [ ] [ ] [ ] [ ] x [ ] [ ] [ ] =

{How to use Your Calculator}

{Questions}

12. Fill in the squares to enter engineering notation into the calculator, then write the answer using the correct prefix.

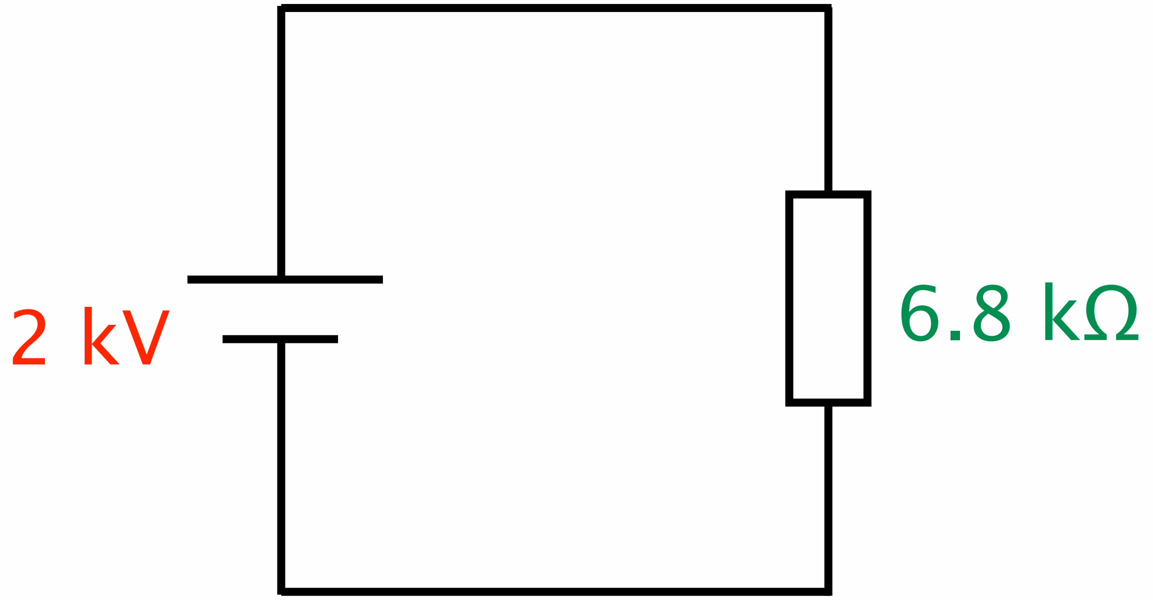


$$I = \frac{V}{R}$$

$$I = \frac{12\ \text{V}}{35\ \text{k}\Omega}$$

I = ☐ ☐ ÷ ☐ ☐ ☐ ☐ =

13. Fill in the squares to enter engineering notation into the calculator, then write the answer using the correct prefix.



$$I = \frac{V}{R}$$

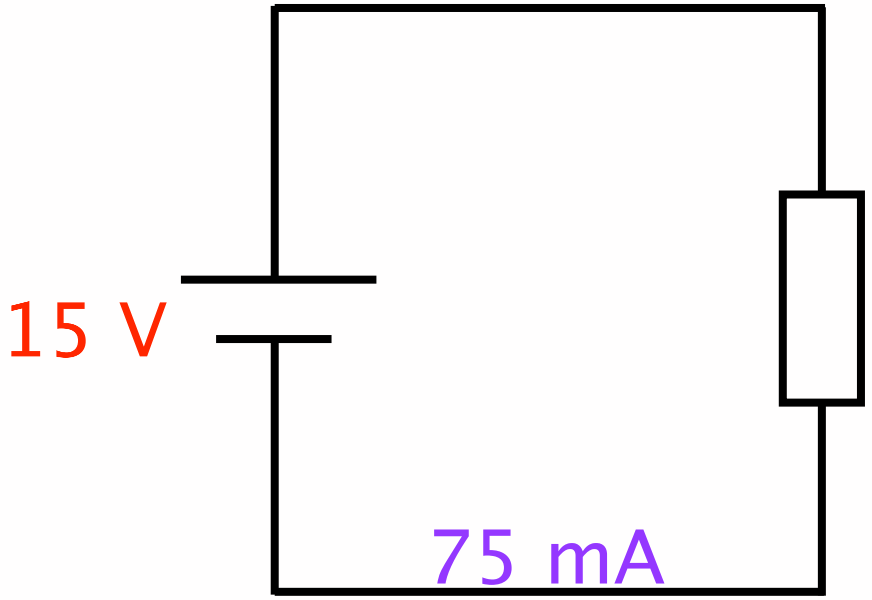
$$I = \frac{2\ \text{kV}}{6.8\ \text{k}\Omega}$$

I = ☐ ☐ ☐ ÷ ☐ ☐ ☐ ☐ ☐ =

{How to use Your Calculator}

{Questions}

14. Fill in the squares to enter engineering notation into the calculator, then write the answer using the correct prefix.

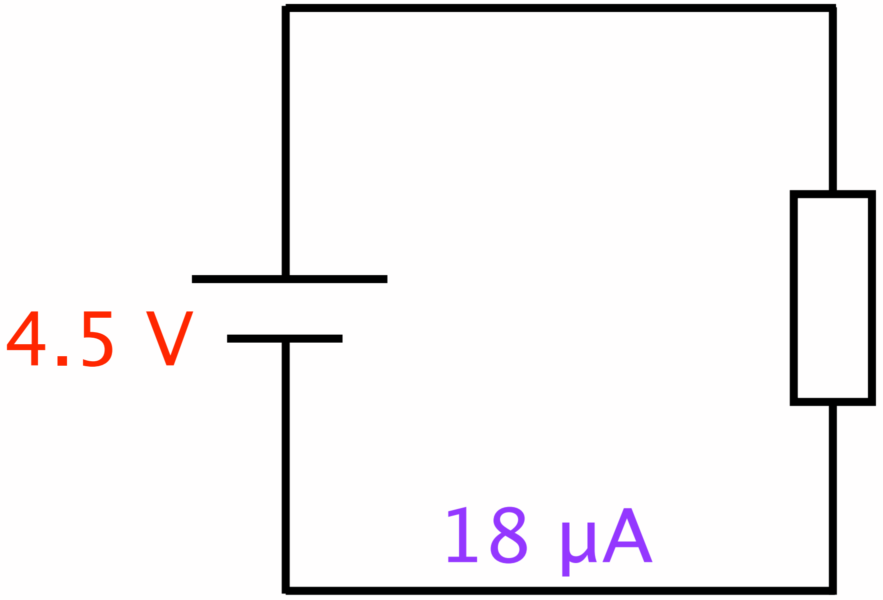


$$R = \frac{V}{I}$$

$$R = \frac{15\ \text{V}}{75\ \text{mA}}$$

R = ☐ ☐ ÷ ☐ ☐ ☐ ☐ ☐ =

15. Fill in the squares to enter engineering notation into the calculator, then write the answer using the correct prefix.



$$R = \frac{V}{I}$$

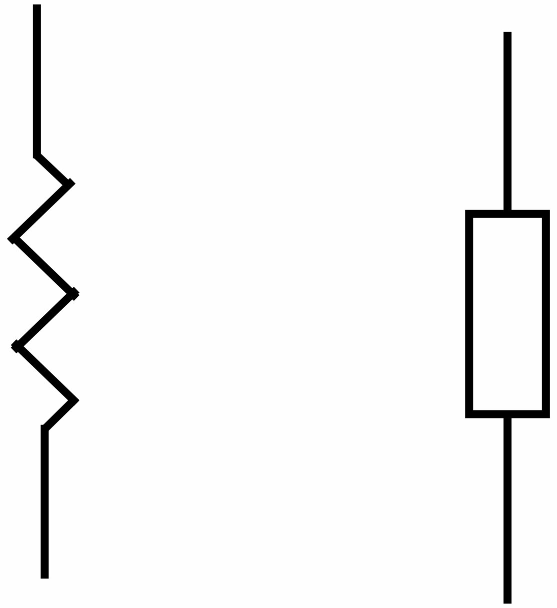
$$R = \frac{4.5\ \text{V}}{18\ \mu\text{A}}$$

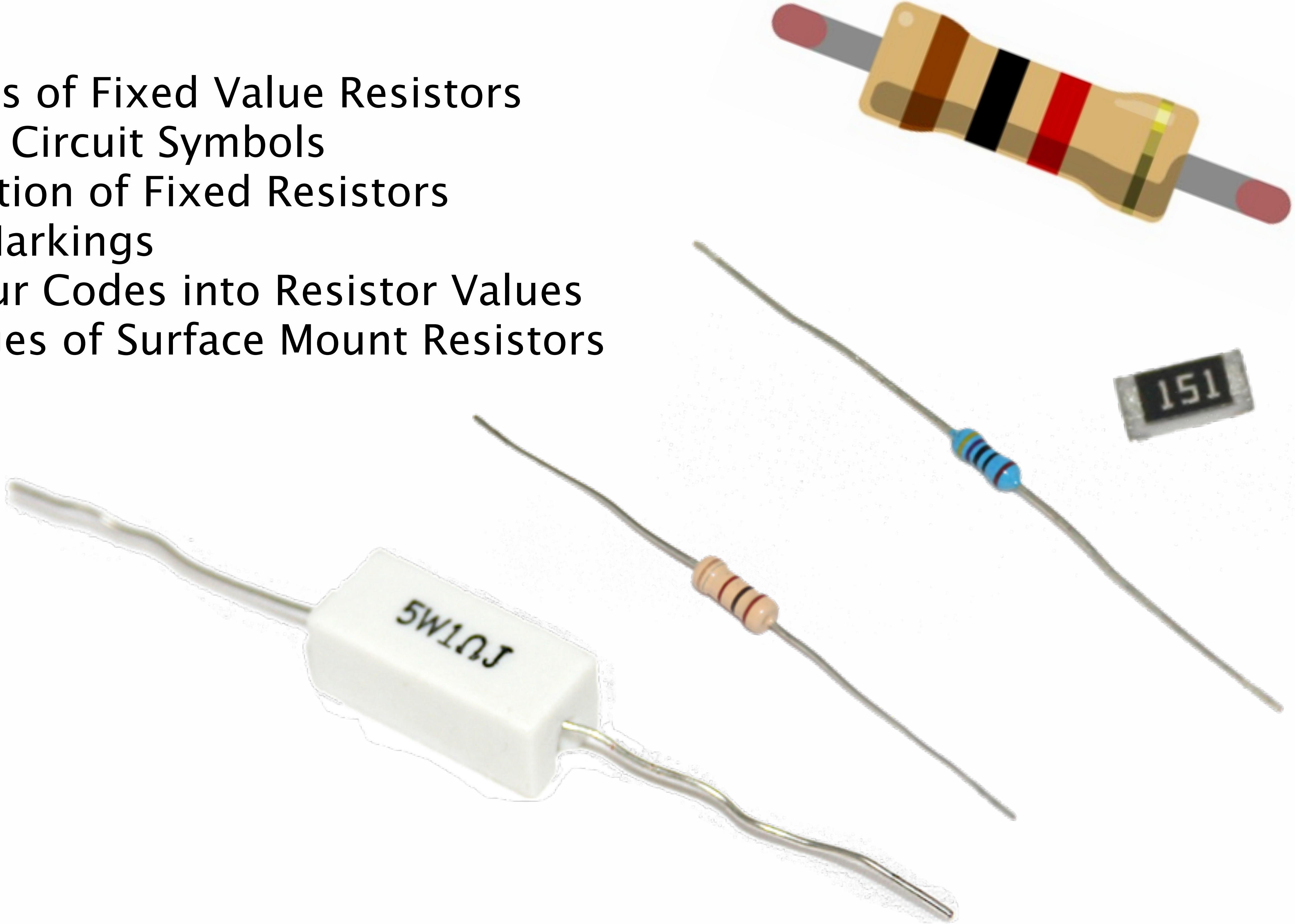
R = ☐ ☐ ☐ ÷ ☐ ☐ ☐ ☐ ☐ =

{Fixed Value Resistors}

{Learning Outcomes}

6.1 Identify Different Types of Fixed Value Resistors
6.2 Identify Fixed Resistor Circuit Symbols
6.2 Describe the Construction of Fixed Resistors
6.3 Understand Resistor Markings
6.4 Convert Resistor Colour Codes into Resistor Values
6.5 Describe the Advantages of Surface Mount Resistors

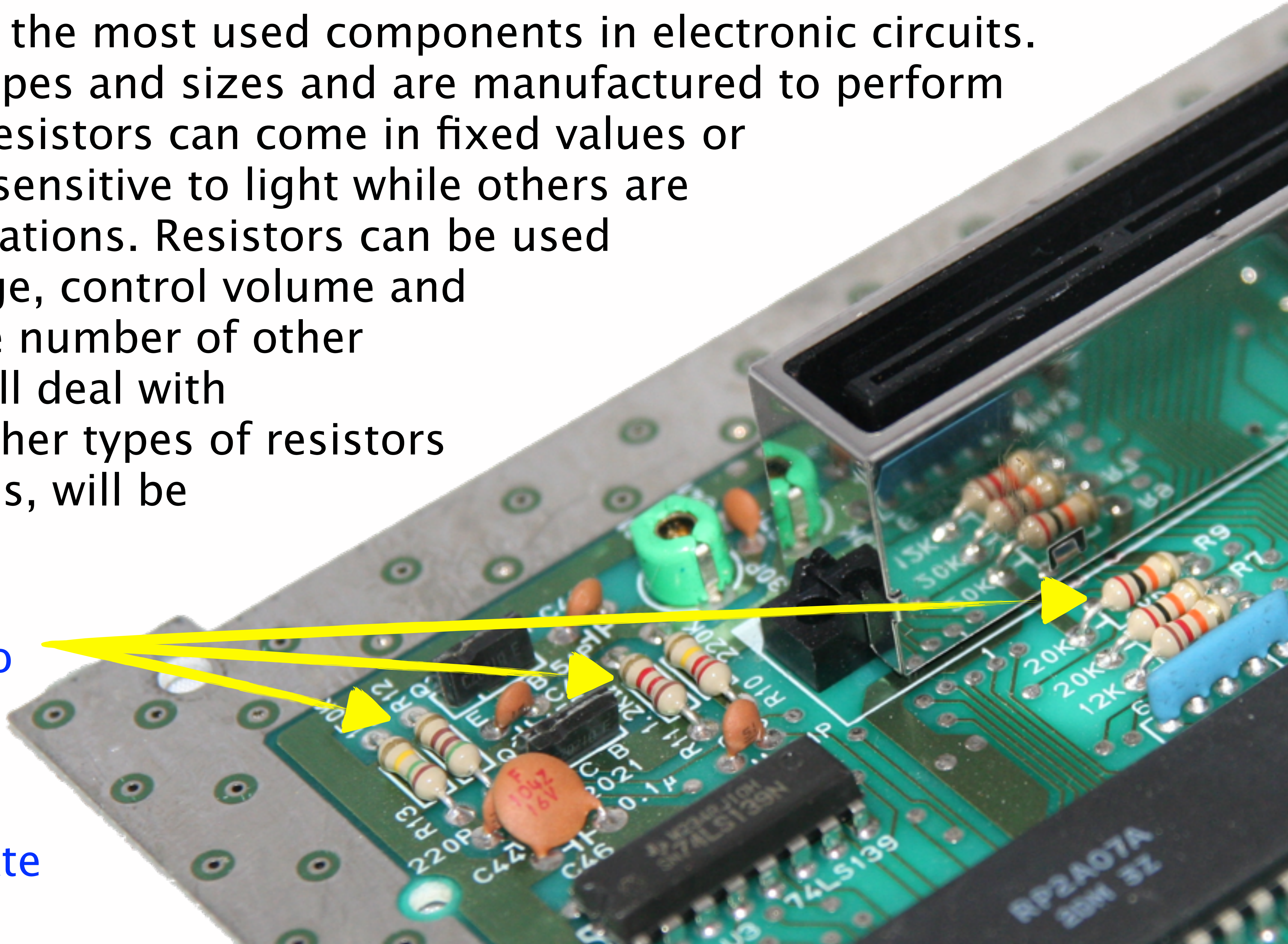




{Fixed Value Resistors}

{Introduction}

Resistors are perhaps one of the most used components in electronic circuits. They come in all sorts of shapes and sizes and are manufactured to perform all sorts of different tasks. Resistors can come in fixed values or variable. Some resistors are sensitive to light while others are sensitive to temperature variations. Resistors can be used to limit current, divide voltage, control volume and brightness, as well as a huge number of other applications. This chapter will deal with fixed value resistors while other types of resistors and practical circuit examples, will be covered in later chapters.



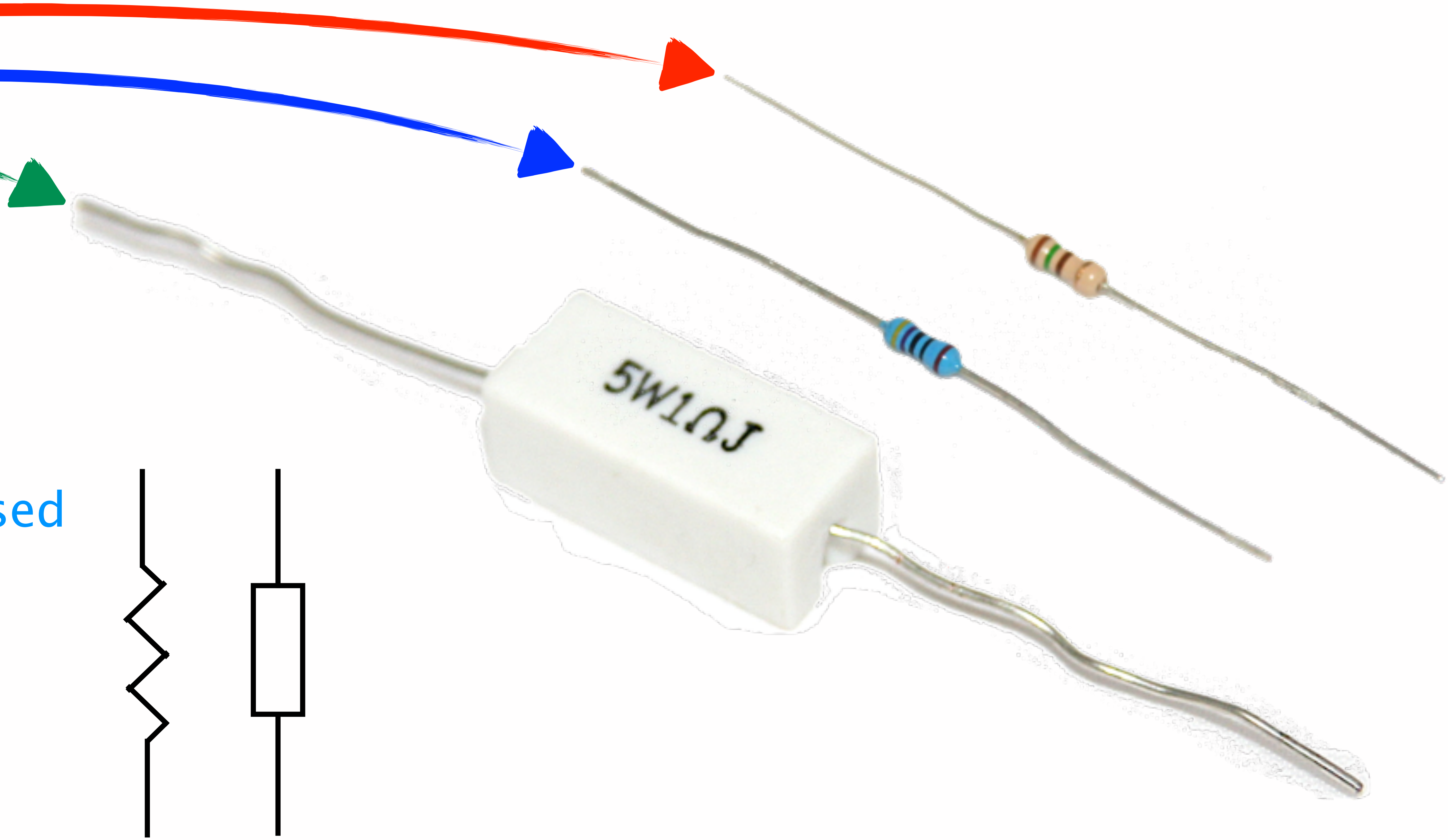
This image shows a Nintendo Entertainment System Motherboard which contains a bunch of resistors to help make the entire circuit operate correctly.

{Fixed Value Resistors}

{Common Types of Fixed Resistors}

A fixed resistor is one who's value cannot be changed since they are manufactured to give a specific amount of resistance. The three main types of fixed resistors are:

- Carbon Film
- Metal Film
- Wire Wound

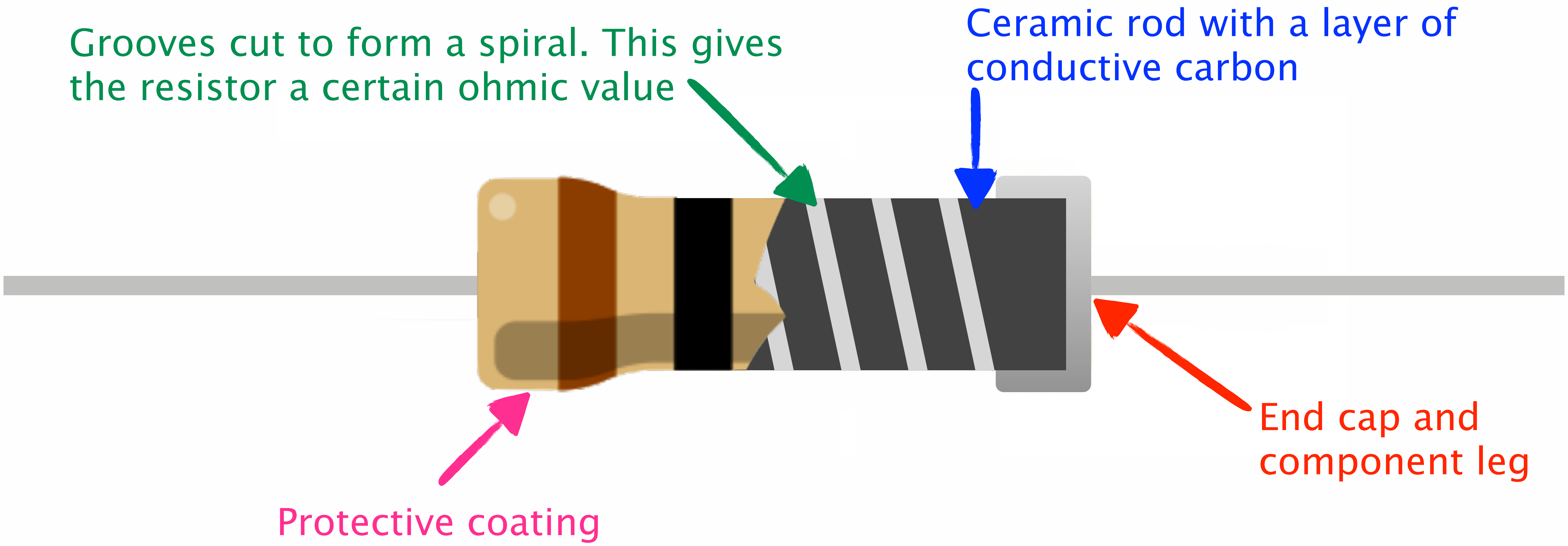


Here are the two commonly used circuit symbols for fixed value resistors

{Fixed Value Resistors}

{Carbon Film}

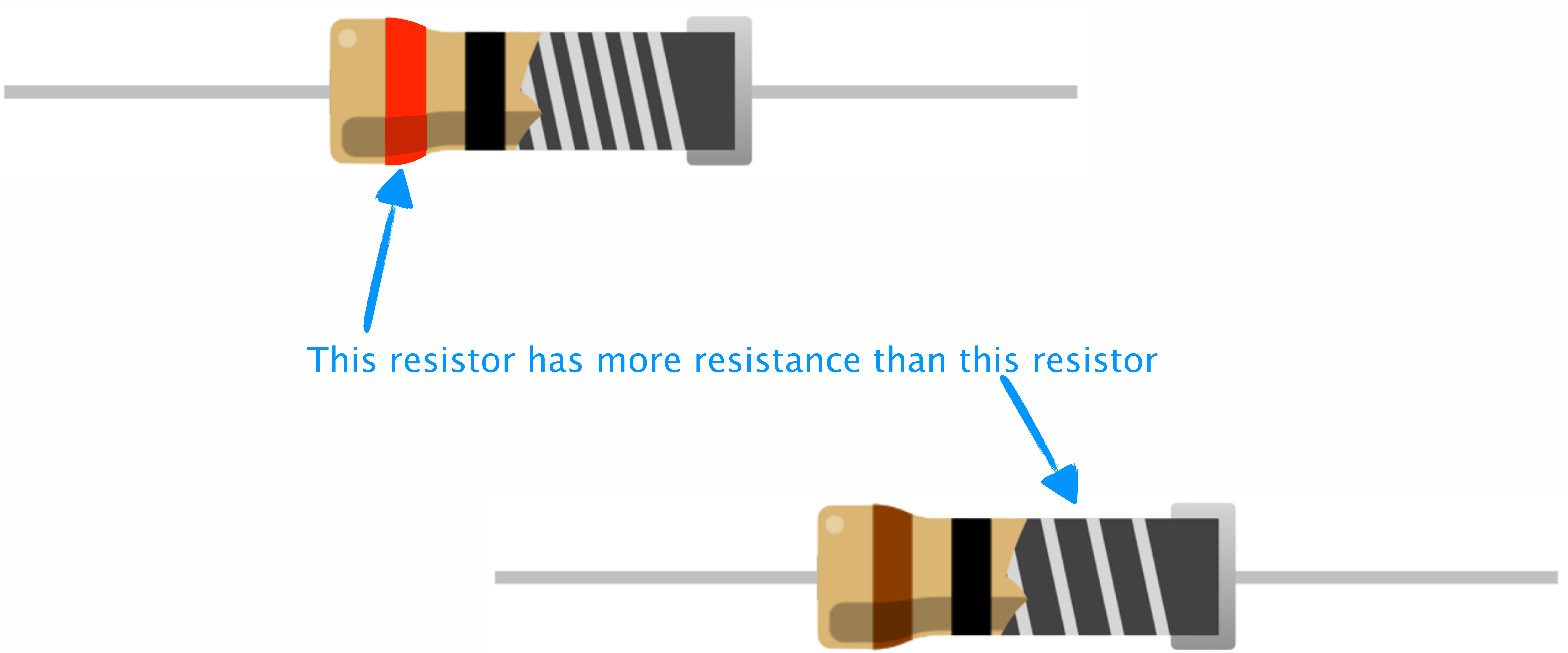
Carbon film resistors come in a wide range of sizes and values. They are constructed out of a ceramic rod which is coated with a thin film of conducting carbon. A thin groove is then cut into the rod in a spiral fashion which gives the resistor a specific ohmic value. The component legs are attached to each end of the resistor and then finally, a protective insulating coating is sprayed over the top which is normally tan in colour.



{Fixed Value Resistors}

{Carbon Film}

The longer the groove spirals around the ceramic body, the larger the resistor value.



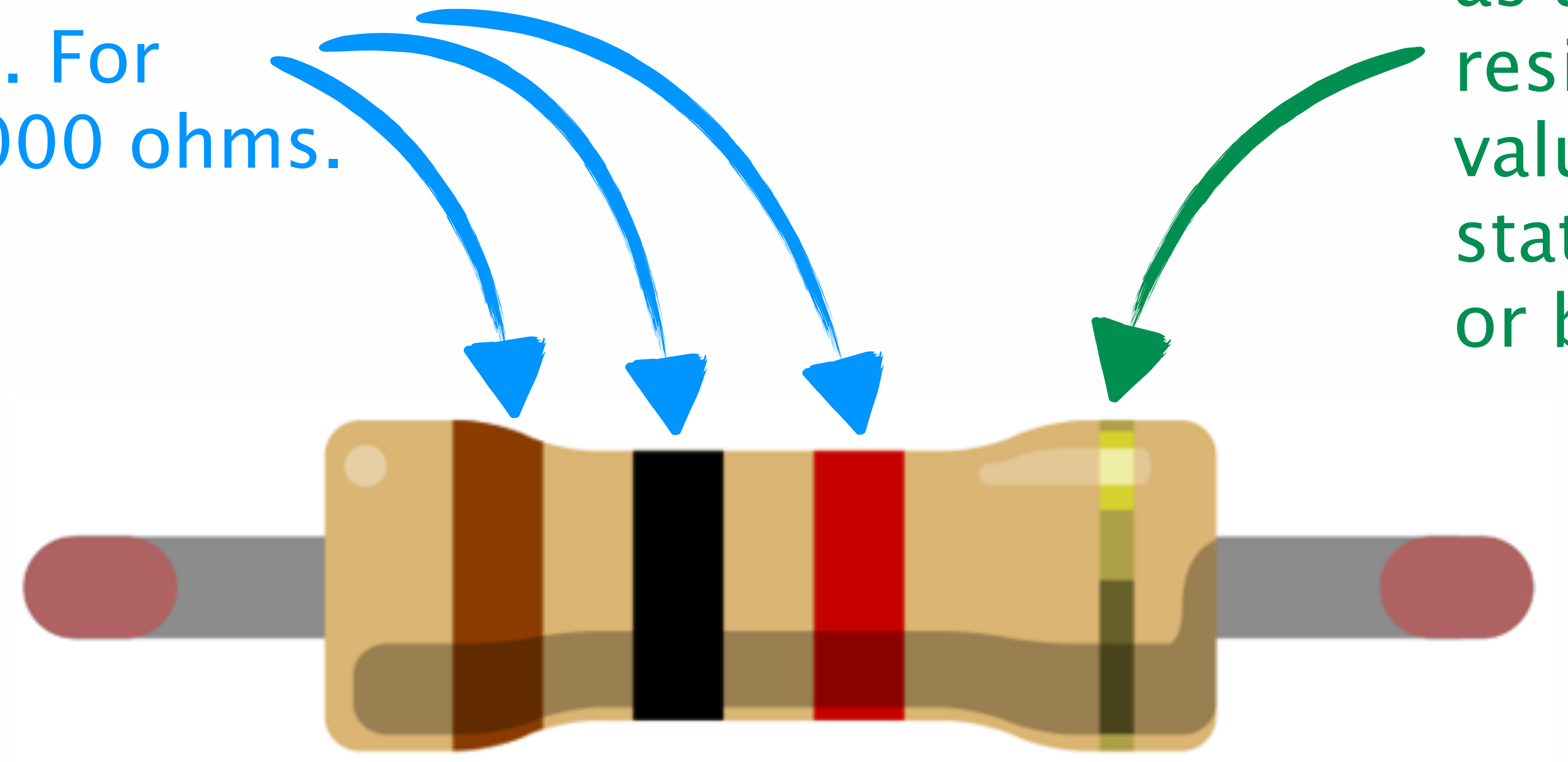
{Fixed Value Resistors}

{Carbon Film}

Most carbon film resistors will have their value printed on them with a unique combination of four coloured bands. We will cover the theory to convert colour codes into actual values shortly.

The first three colour bands are normally grouped quite close together and they tell us the ohmic value of the resistor. For example 1000 ohms.

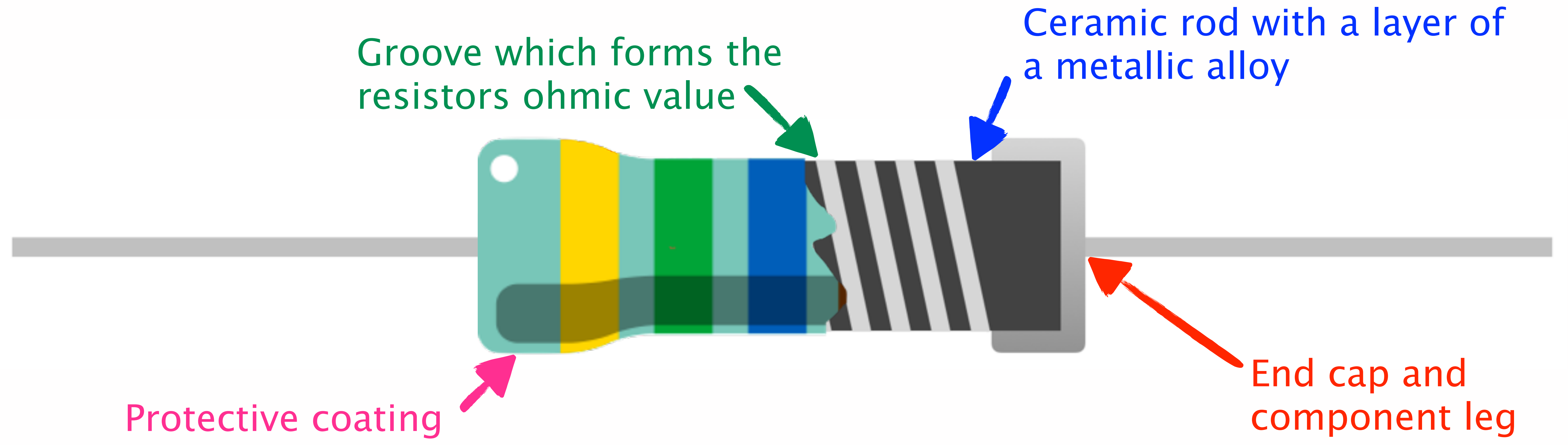
The fourth colour band is normally a little further away from the rest and it tells us the tolerance of the resistor as a percentage. The tolerance of the resistor is the maximum amount its value could be above or below the stated value. For example 5% above or below 1000 ohms.



{Fixed Value Resistors}

{Metal Film}

Metal film resistors are manufactured in much the same way as carbon film however a metallic alloy is sprayed on instead of conducting carbon. A groove is then cut into the rod to give it a certain ohmic value. Once again, the longer the groove spirals around the ceramic rod, the higher the ohmic value. The component legs are mounted on each end of the rod and a protective insulating film is sprayed over the top which is normally blue in colour. Metal film resistors have a better tolerance than carbon film and are commonly rated at +/- 1%. This means that if you buy a 100 ohm resistor, it is going to be a maximum of 1 ohm above or below the stated 100 ohms.



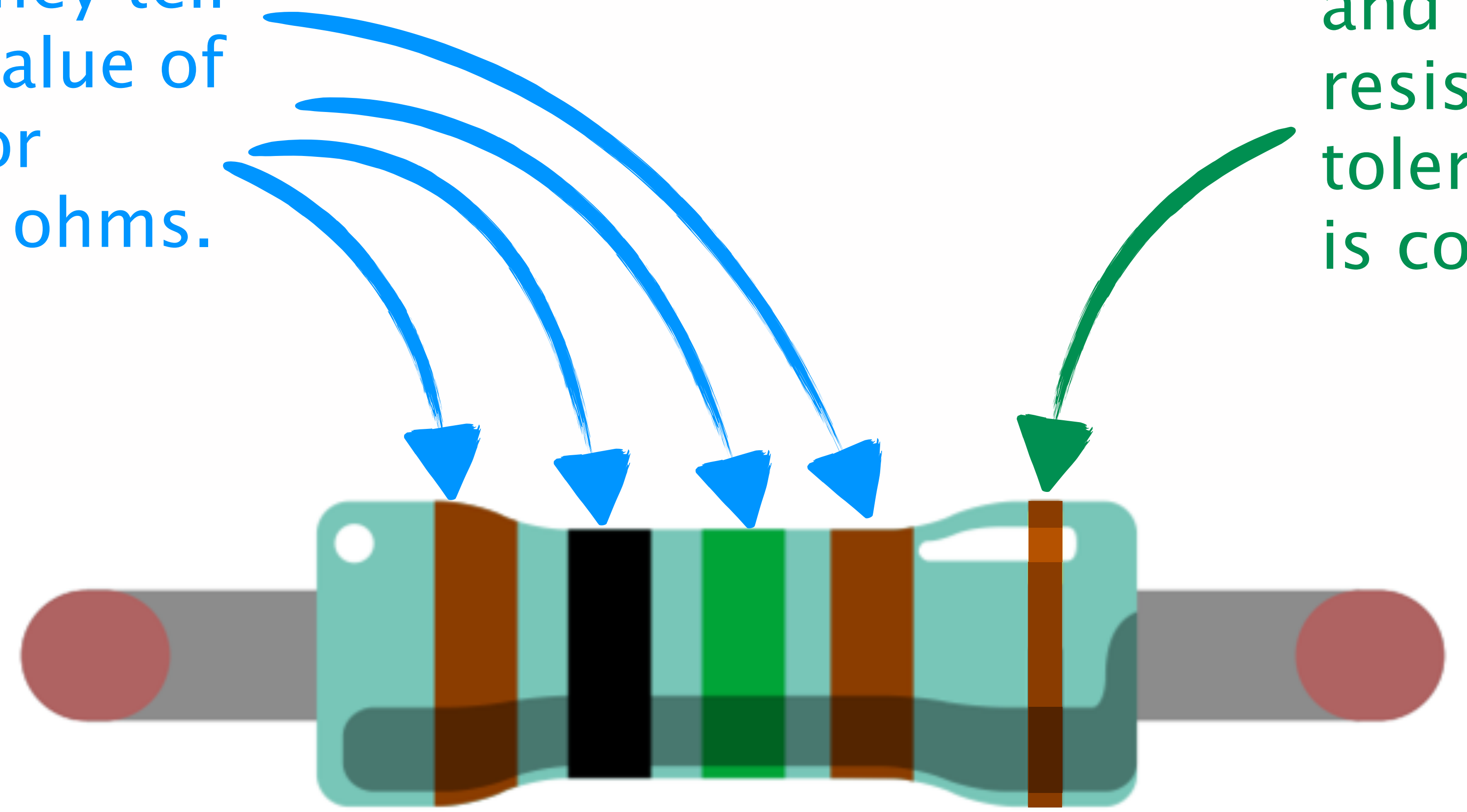
{Fixed Value Resistors}

{Metal Film}

Most metal film resistors will have their value printed on them with a unique combination of five coloured bands. The extra band (compared to carbon film) is to allow for a wider range of ohmic values.

The first four colour bands are normally grouped quite close together and they tell us the ohmic value of the resistor. For example 1050 ohms.

The fifth colour band is normally a little further away from the rest and it tells us the tolerance of the resistor. As stated previously, the tolerance for metal film resistors is commonly +/- 1%



{Fixed Value Resistors}

{Universal Resistor Colour Code Chart}

This resistor colour code chart will help you to convert a resistors coloured bands into its ohmic value and can be used for resistors with four or five coloured bands. The Mnemonic can be a helpful memory prompt for if you don’t have access to a chart such as this one.

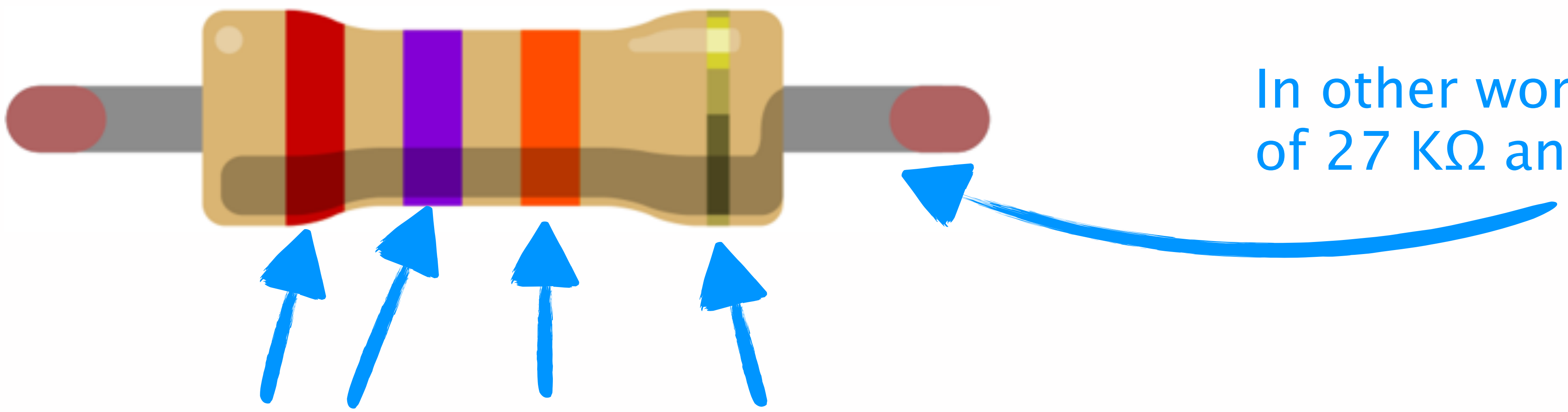
Colour	Number		Multiplier	Number of Zero’s to Add	Tolerance	Tolerance Letter	Mnemonic
Black	0		1	0			Better
Brown	1		10	1	+/− 1%	F	Be
Red	2		100	2	+/− 2%	G	Right
Orange	3		1000	3			On
Yellow	4		10000	4			Your
Green	5		100000	5			Game
Blue	6		1000000	6			Because
Violet	7		10000000	7			Violent
Grey	8		100000000	8			Gangs
White	9		1000000000	9			Will
Gold			0		+/− 5%	J	Grab
Silver			0		+/− 10%	K	Some
None					+/− 20%	M	Nunchucks

{Fixed Value Resistors}

{Carbon Film – Converting Colour Codes}

To convert the colour code into an ohmic value, just use the resistor colour code chart on page 6.9 and follow these steps:

- Look at the resistor so the group of three coloured bands are to the left
- The first two colour bands are converted to their respective numbers (Red = 2 and Violet = 7)
- The third colour band is the multiplier or in most cases you can simply think of it as telling you how many zero's to add after the first two digits. In this case we have Orange which equals 3. This means we need to write down three zero's.
- Finally we have the fourth band which tells us the tolerance of the resistor. In this case it is Gold which tells us the resistor has a tolerance of +/- 5%



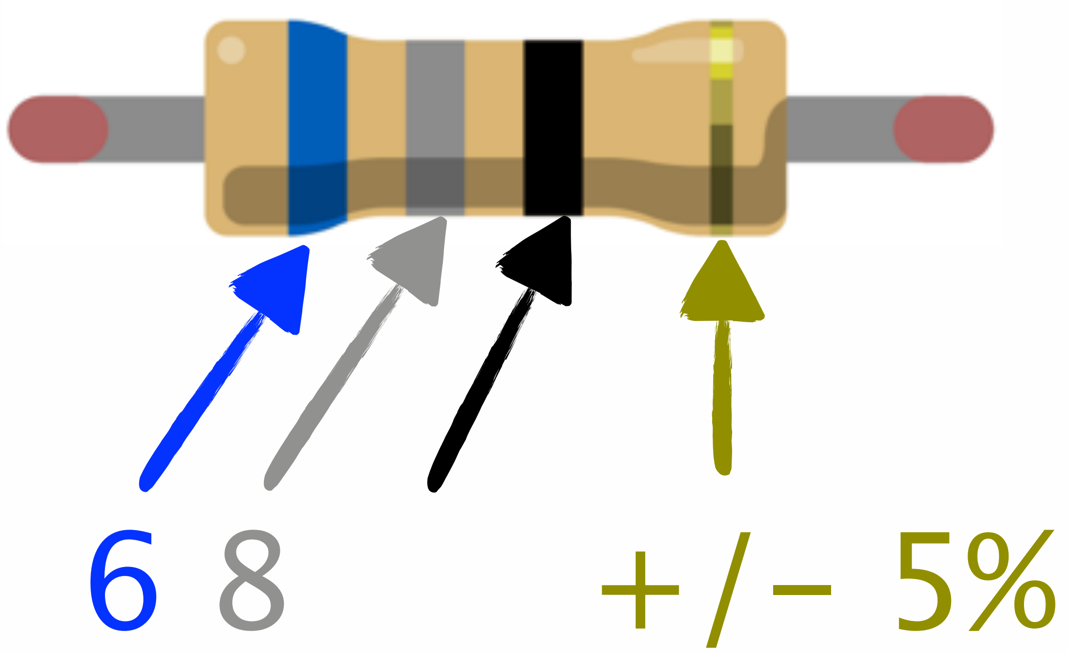
In other words, this resistor has a resistance of 27 KΩ and a tolerance of +/- 5%

2 7 000 +/- 5%

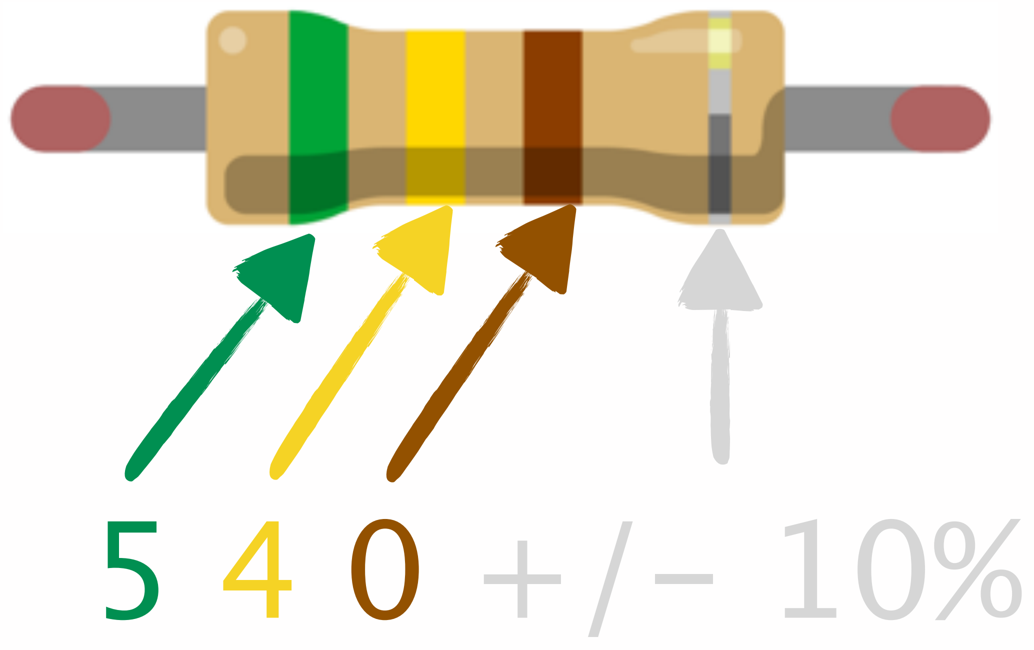
(Three Zero's)

{Fixed Value Resistors}

{Carbon Film – Colour Code Examples}



Therefore this resistor is 68 Ω +/- 5%

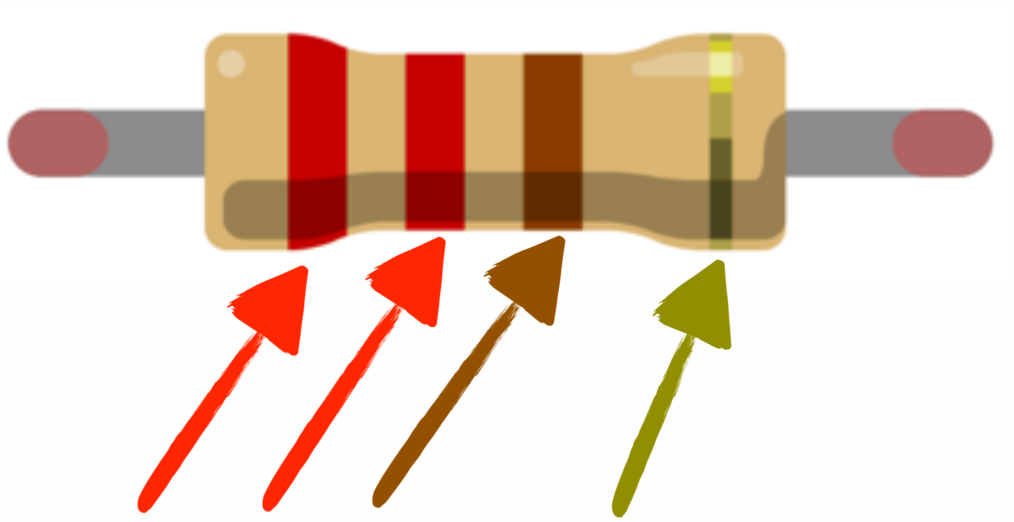


Therefore this resistor is 540 Ω +/- 10%

Notice how we do not write down anything when the third colour band is black. This is telling us to write down zero zero's. If we compare that to the second resistor it has brown as its third colour band. This is telling us to write down one zero. If the third band was red, it would be telling us to write down two zeros and so on.

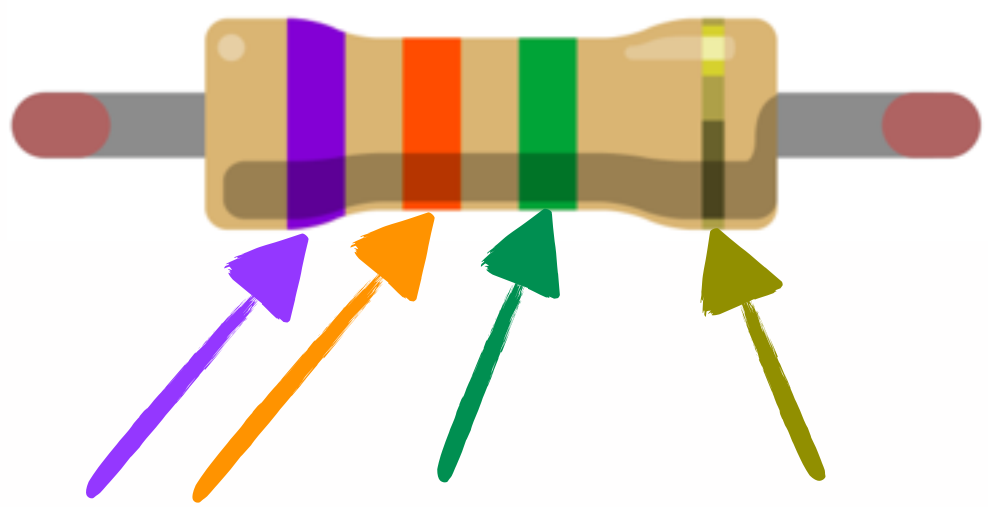
{Fixed Value Resistors}

{Carbon Film – Colour Code Examples}



2 2 0 +/- 5%

Therefore this resistor is 220 Ω +/- 5%



7 3 00000 +/- 5%

Therefore this resistor is 7.3 MΩ +/- 5%

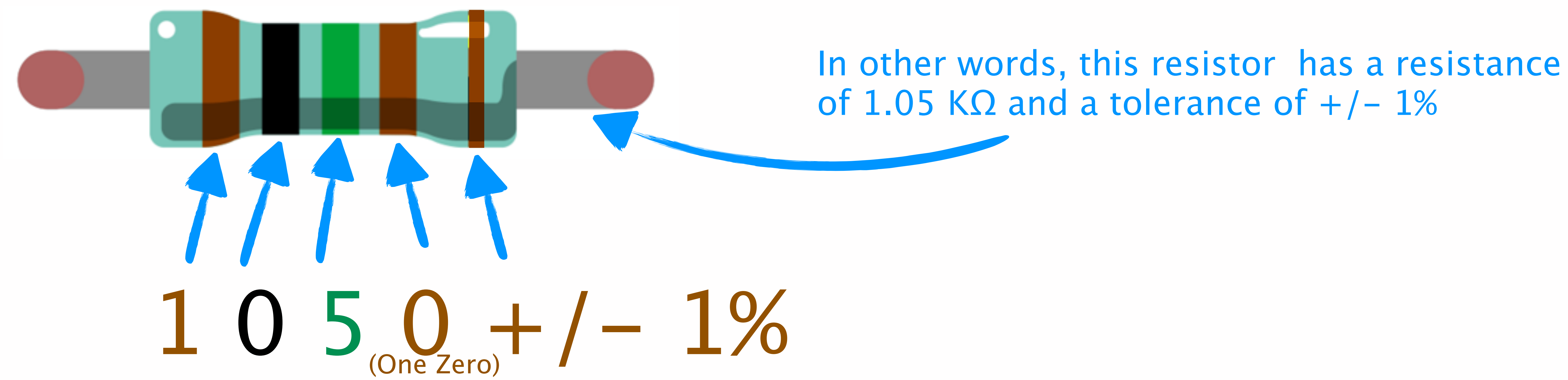
Sometimes you will end up with a large multiplier which can place the resistance value into millions of ohms.

{Fixed Value Resistors}

{Metal Film – Converting Colour Codes}

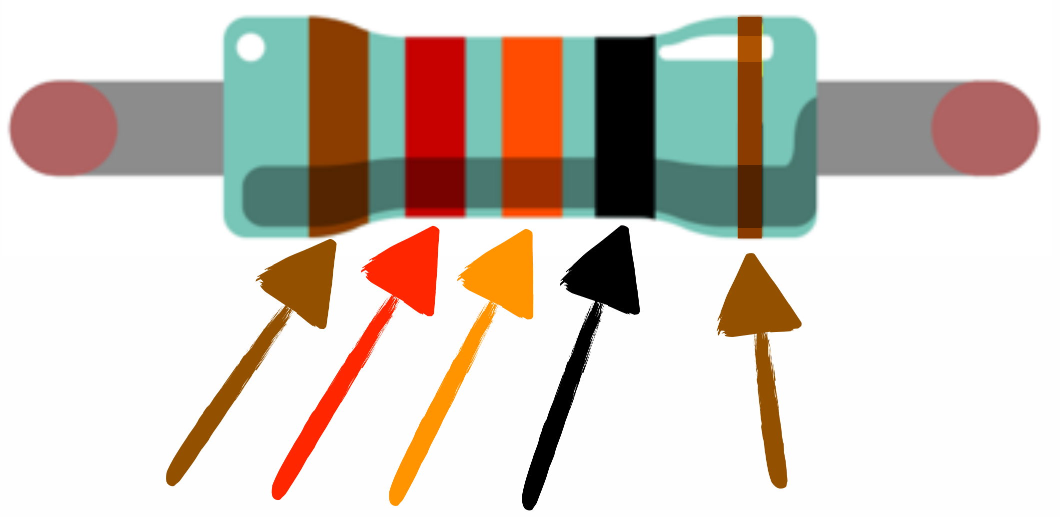
Using the colour code chart on page 6.9, follow these steps:

- Look at the resistor so the group of four coloured bands are to the left
- The first three colour bands are converted to their respective numbers (Brown = 1, Black = 0 and Green = 5)
- The fourth colour band is the multiplier or in most cases you can simply think of it as telling you how many zero’s to add after the first three digits. In this case we have Brown which equals 1. This means we need to write down one zero.
- Finally we have the fifth band which tells us the tolerance of the resistor. In this case it is Brown which tells us the resistor has a tolerance of +/– 1%



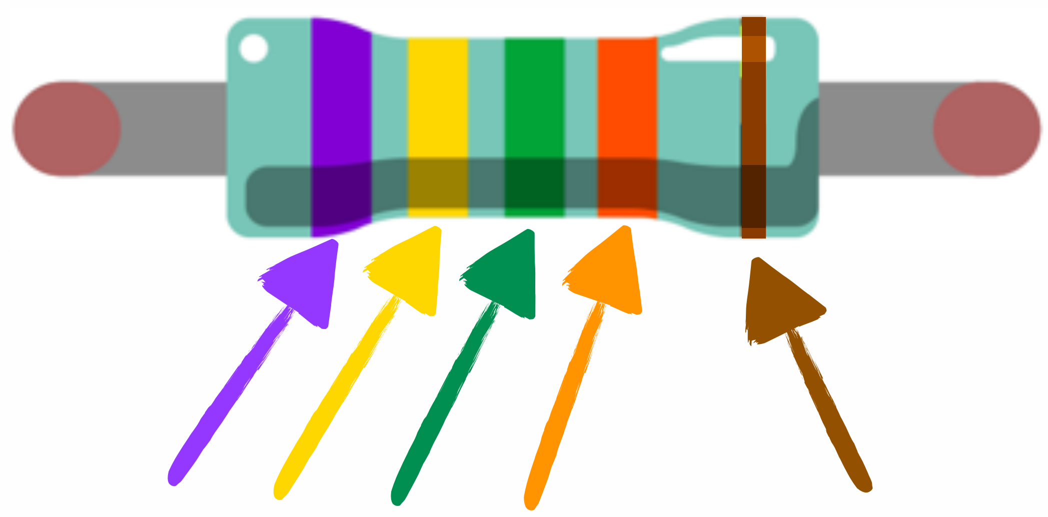
{Fixed Value Resistors}

{Colour Code Examples}



1 2 3 +/- 1%

Therefore this resistor is 123 Ω +/- 1%



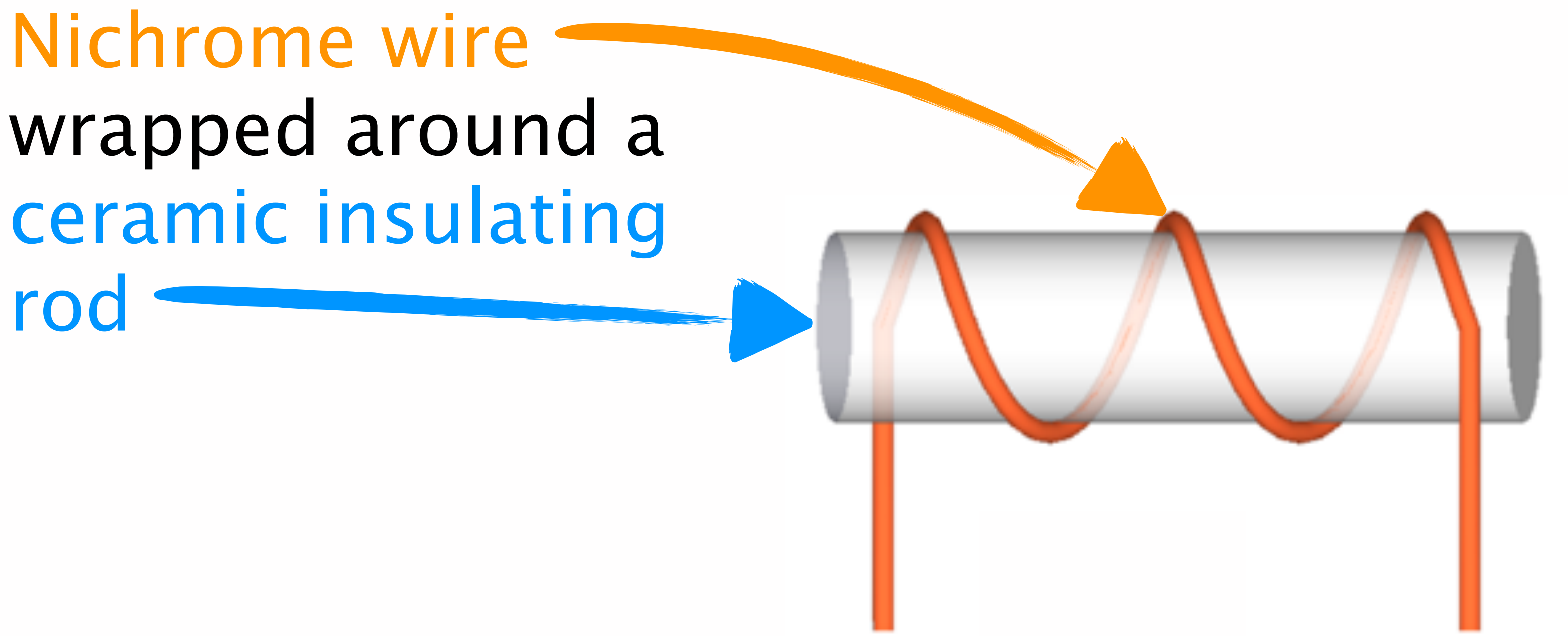
7 4 5 000 +/- 1%

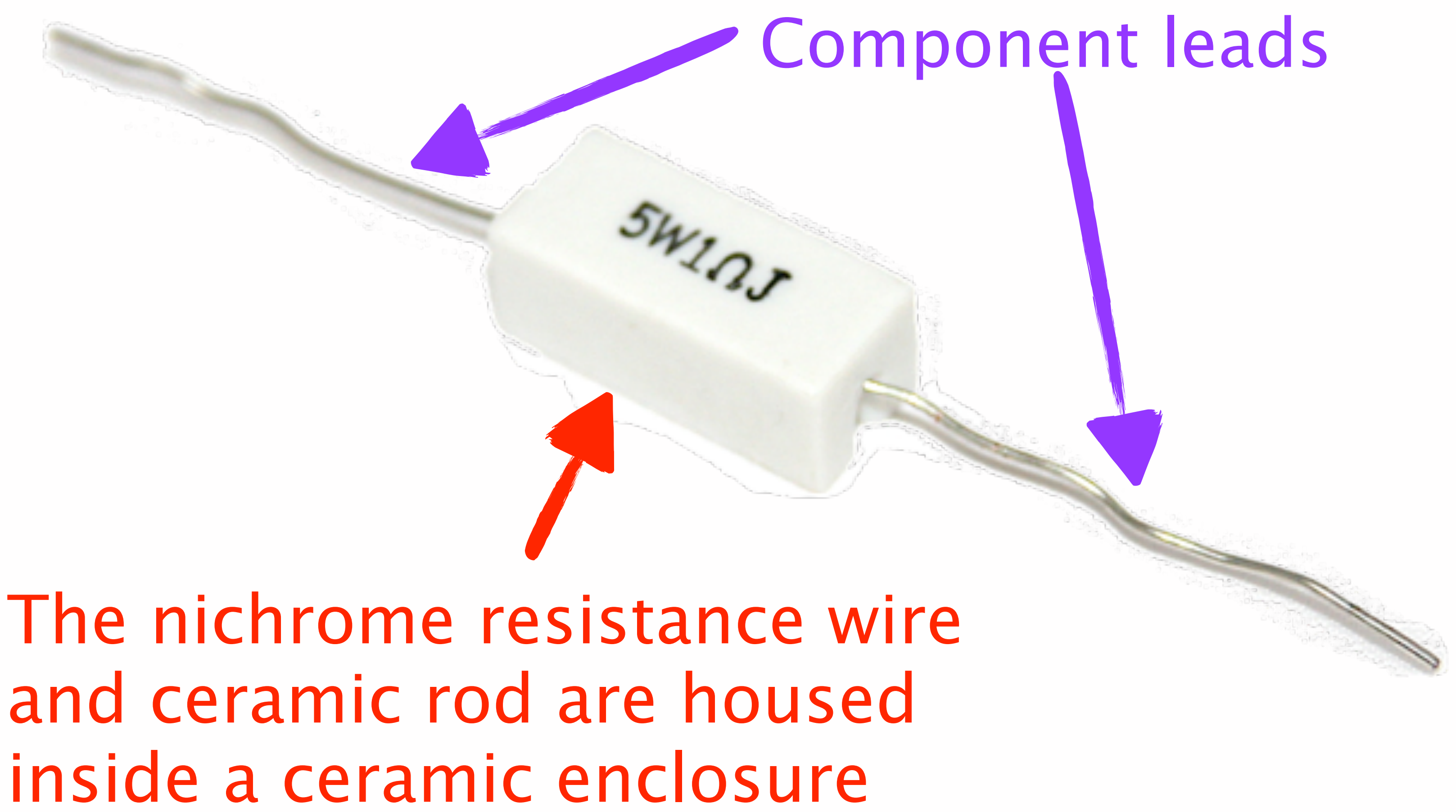
Therefore this resistor is 745 KΩ +/- 1%

{Fixed Value Resistors}

{Wire Wound Resistors}

Wire wound resistors are designed for high power applications which carbon film and metal film resistors can't handle. They are manufactured from a length of resistance wire (such as nichrome) which is wrapped around a ceramic insulating rod. The resistance wire is attached to the component leads at each end and the entire assembly is housed inside a ceramic container. The longer the resistance wire is, the more spirals there will be when wrapped around the rod. This results in a greater amount of resistance.

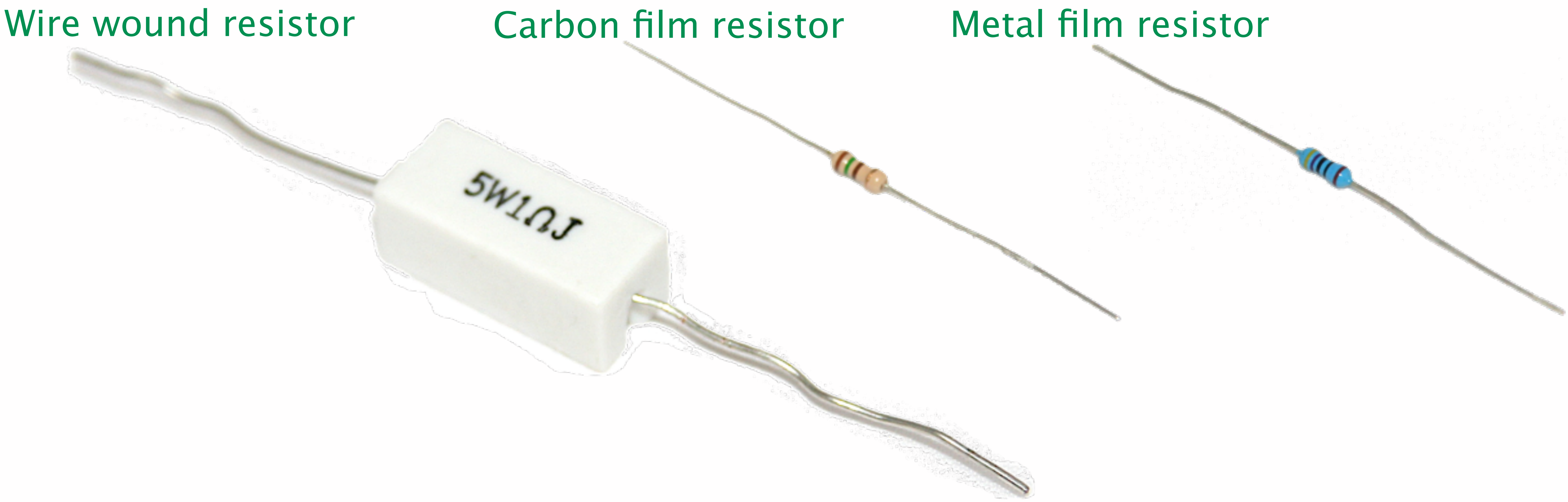




{Fixed Value Resistors}

{Wire Wound Resistors}

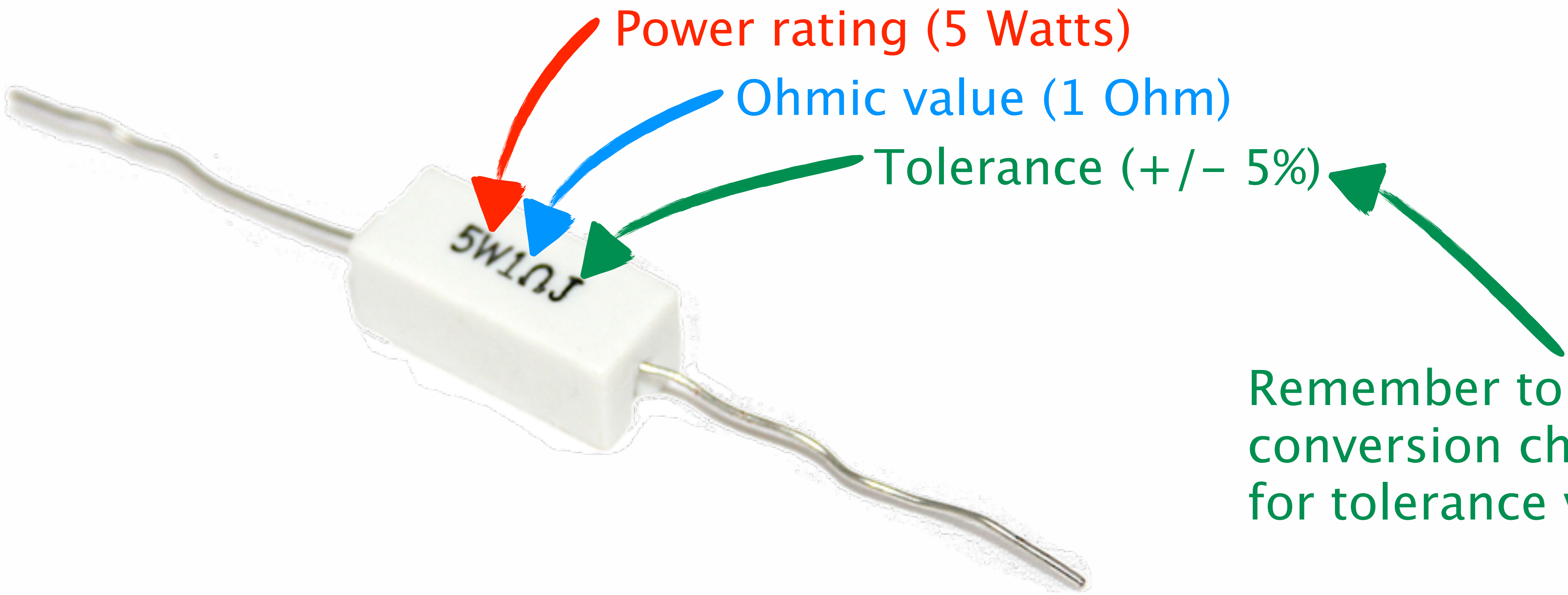
Wire wound resistors are physically larger than both carbon film and metal film resistors. As you progress through this course, you will understand the theory behind the role that the physical size of a resistor plays. But for now, here's a size comparison:



{Fixed Value Resistors}

{Wire Wound Resistors}

Rather than using a colour code system, wire wound resistors are large enough to simply print the ohmic value on its body. Wire wound resistors give an extra piece of information not given to us on carbon film or metal film and that is the power rating of the resistor. We will be covering power in detail in the coming chapters but for now, here’s the breakdown of a common wire wound resistor:

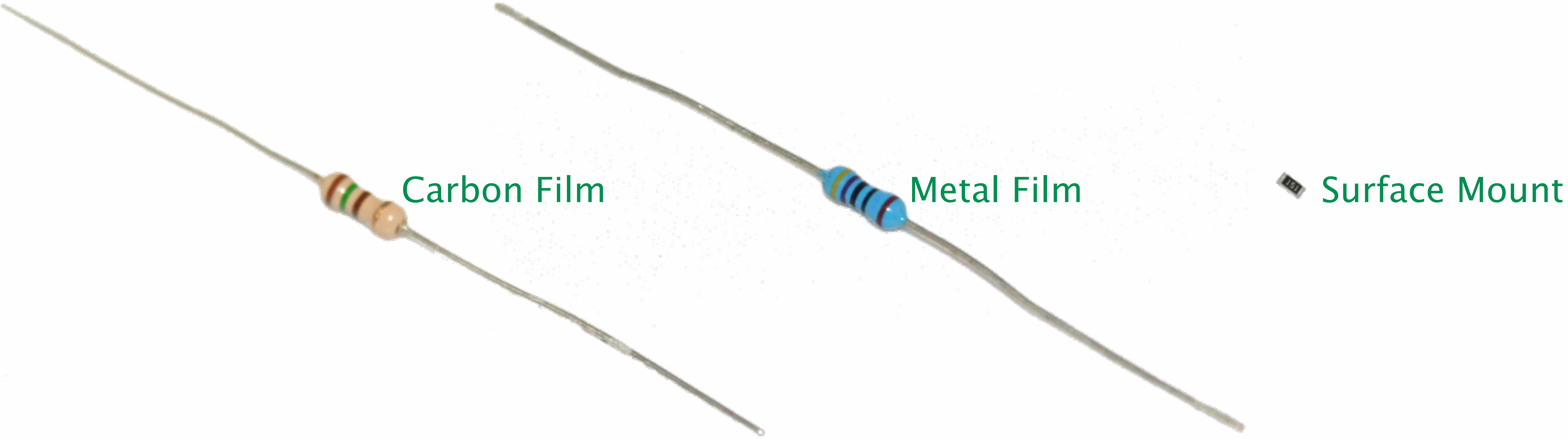


Remember to check the conversion chart on page 6.9 for tolerance values!

{Fixed Value Resistors}

{Surface Mount Resistors}

While we won't be delving into the internal workings of surface mount resistors we will have a look at what they look like and how to determine their ohmic value. Surface mount resistors are the smallest of all resistors and have no component legs. They are fantastic for mounting on circuit boards since they take up such a small amount of space compared to carbon film or metal film resistors. Here's a size comparison:

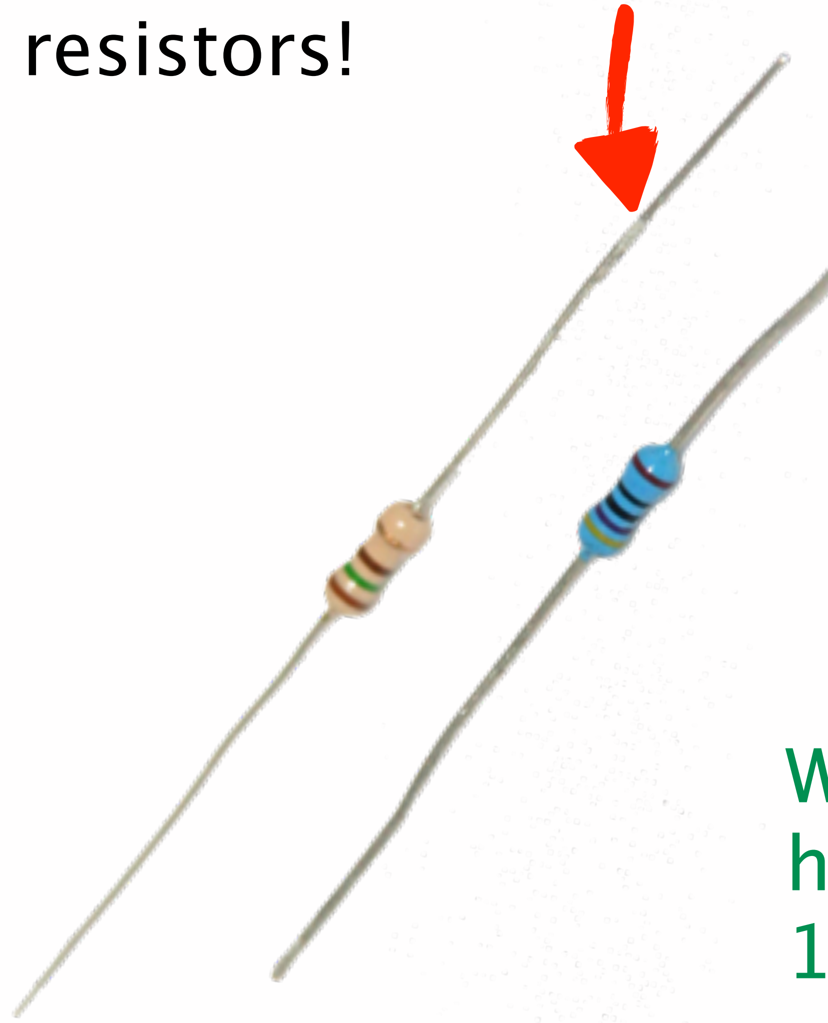


{Fixed Value Resistors}

{Why Use Surface Mount?}

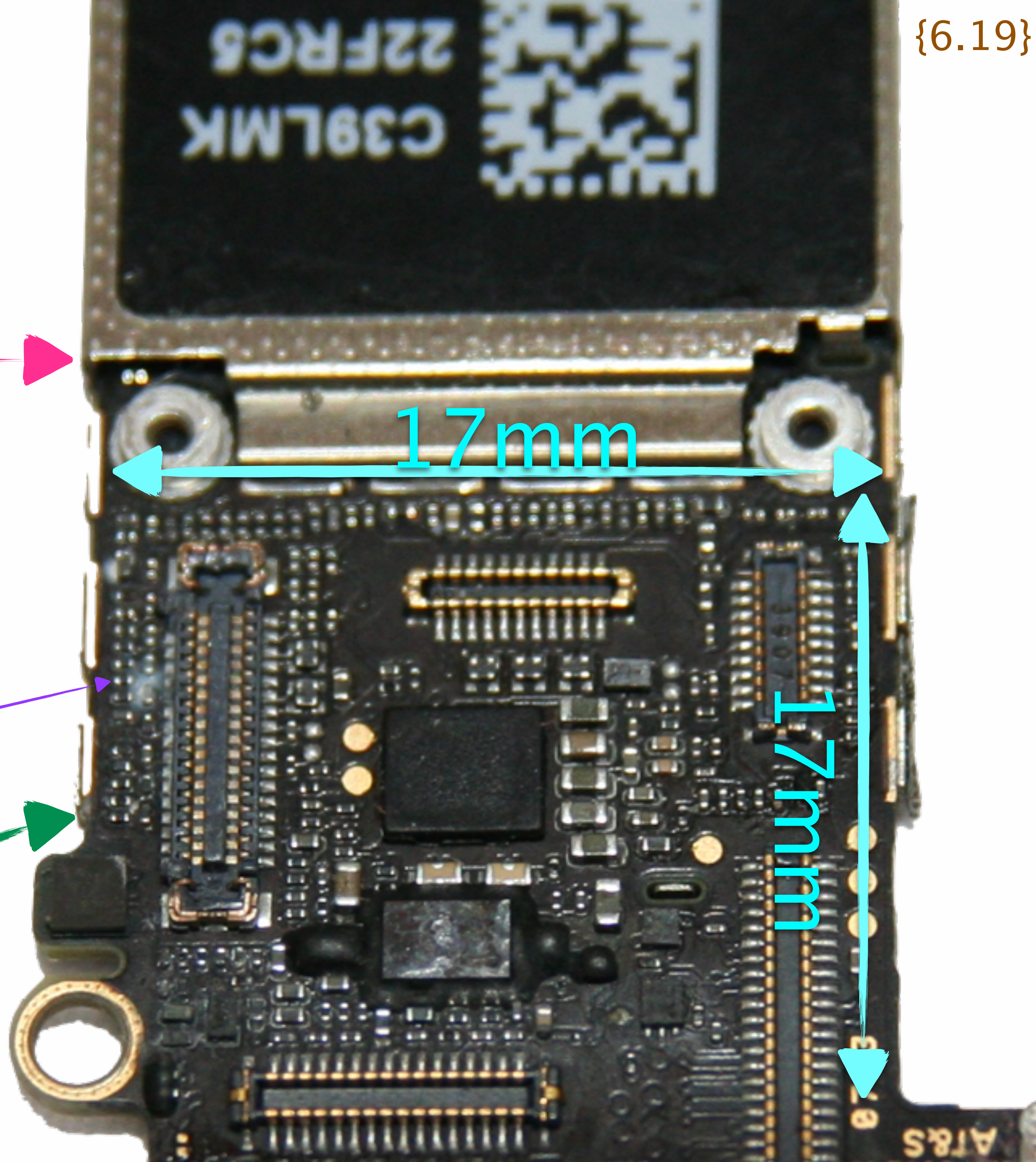
We can see the importance of using surface mount resistors when it comes to a mobile phone circuit board such as this one from an iPhone 5.

Mobile phones would be a lot bigger if we had to use standard carbon film or metal film resistors!



Look at how tiny some of these resistors are!

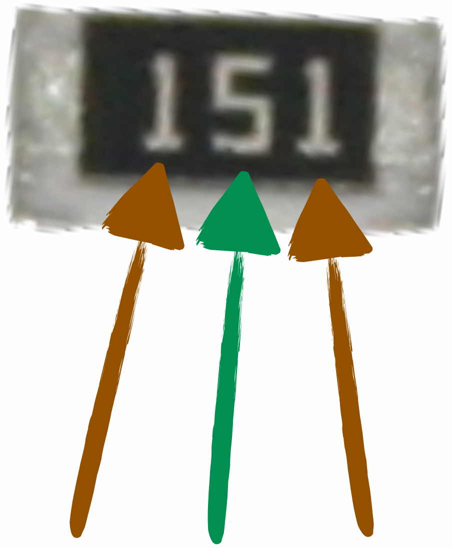
We can fit over a hundred resistors in this 17mm x 17mm space!



{Fixed Value Resistors}

{Reading Surface Mount Values}

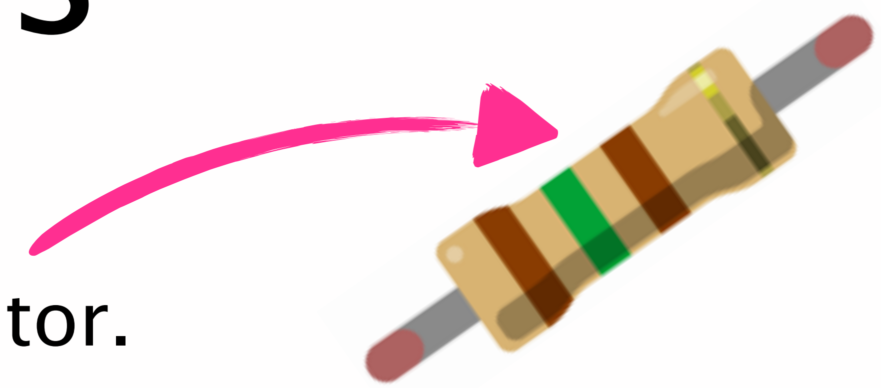
Surface mount resistors will often have their values printed on them in the same fashion as the resistor codes however instead of colours, numbers are used. Let’s zoom in on one such surface mount resistor to convert its numerical code into an ohmic value



1 5 0 ohms

(One Zero)

This is the equivalent of a brown, green, brown colour coded resistor.

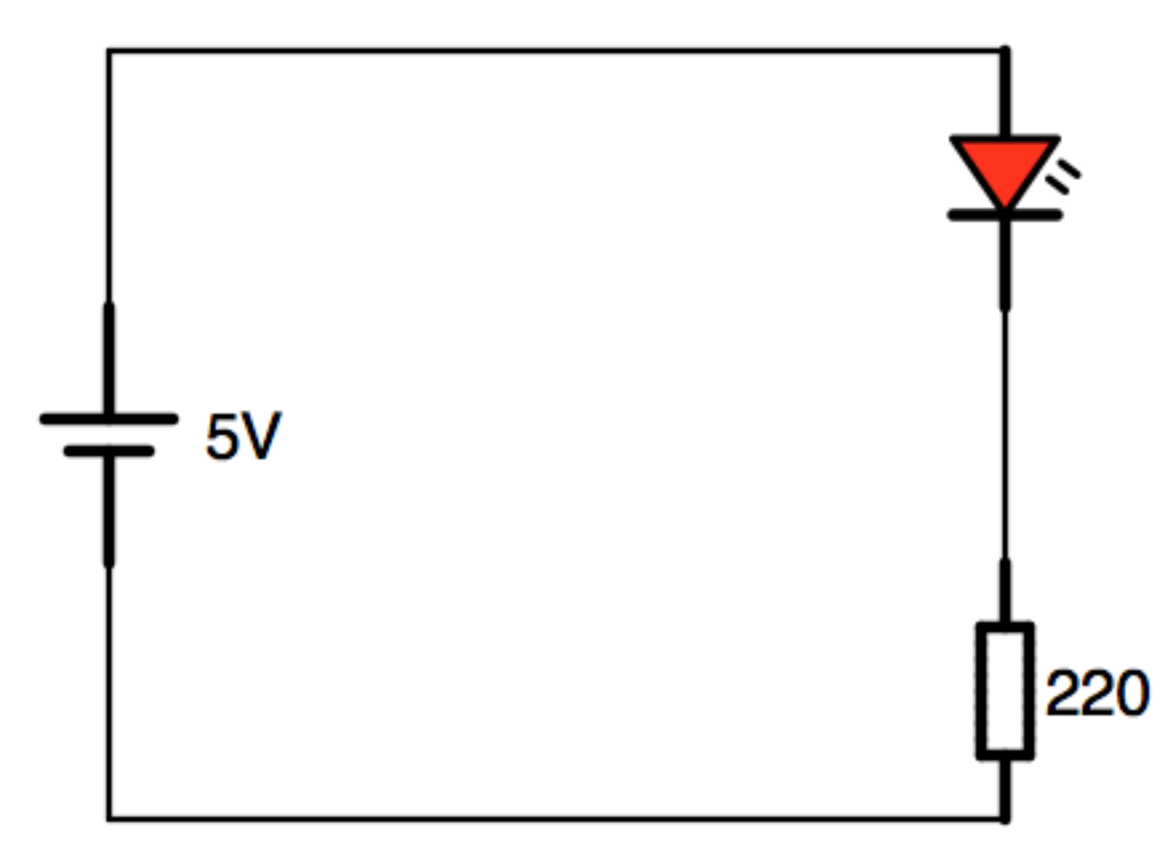


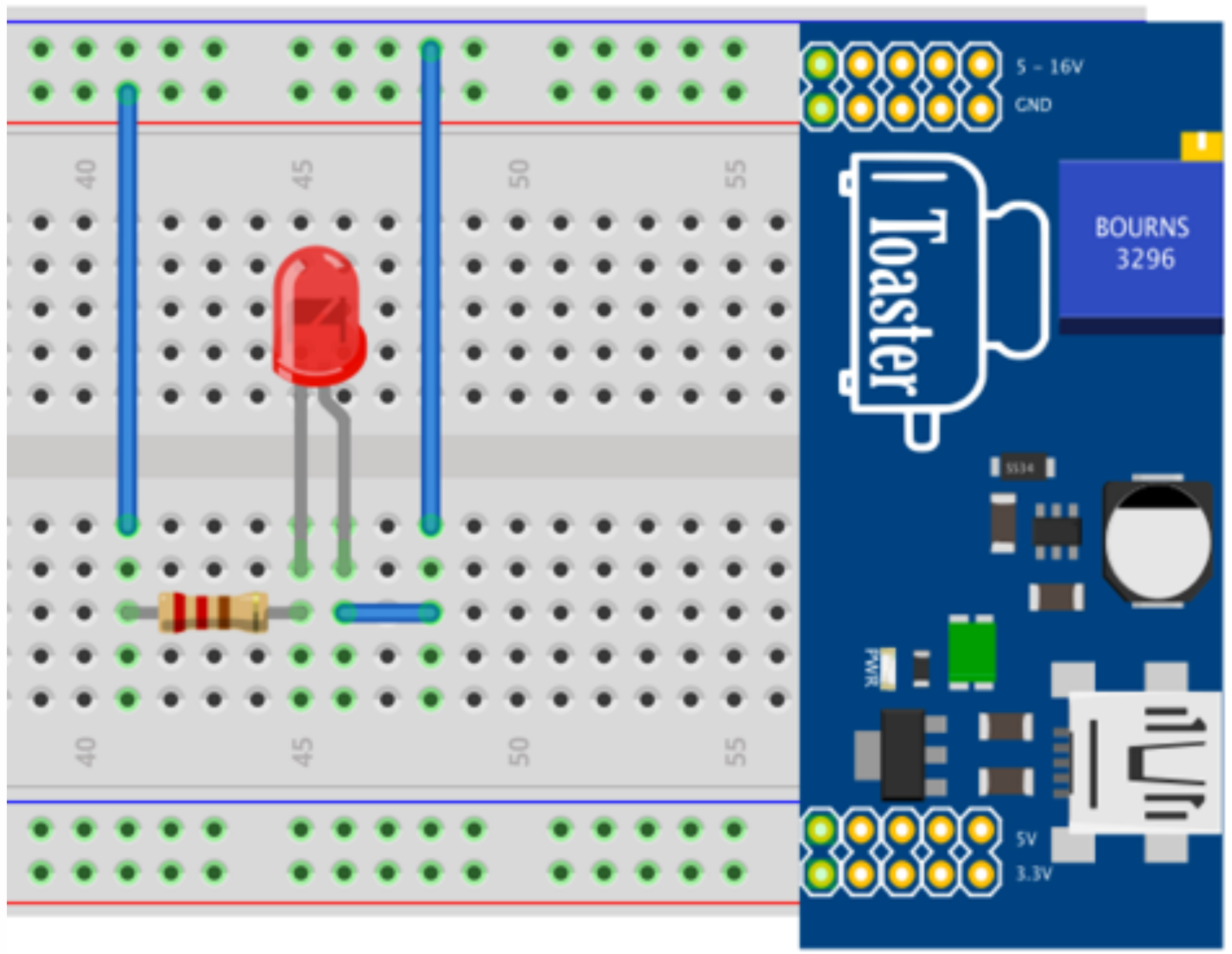
{Fixed Value Resistors}

{Conclusion}

This chapter was designed to give you an understanding of what resistors look like, how they are made and how to work out their value from colour codes and resistor markings. We will be covering all sorts of different resistor circuits in later chapters along with practical examples of how exactly you might want to use resistors in an electronic circuit.

So if feel as though you don't yet have a complete understanding of resistors, don't worry! There is still plenty more theory to come.





{Fixed Value Resistors}

{Summary}

- The three main types of fixed resistors are carbon film, metal film and wire wound
- Resistors are designed to limit current and divide voltage in an electronic circuit (theory on these concepts will be covered in later chapters)
- Carbon film and metal film resistors will normally have their resistance value and tolerance printed on them in the form of a colour code (see table page 6.9)
- Wire wound resistors are designed for high power application and are generally quite a bit larger than carbon film and metal film resistors
- Wire wound resistors have their value printed on them in ohms which removes the need for any sort of colour code conversion
- The longer the spiral inside a carbon film, metal film or wire wound resistor – the greater its resistance value will be
- Surface mount resistors are the smallest of all resistors and are designed for where space is limited such as small circuit boards
- Surface mount resistors will often have their resistance value printed on them in the form of a numeric code which is similar to a colour code

{Fixed Value Resistors}

{Questions}

1. What type of resistor has nichrome wire wrapped around a ceramic insulating rod?

2. What type of resistor has conductive carbon sprayed onto a ceramic insulating rod?

3. What type of resistor has metallic alloy sprayed onto a ceramic insulating rod?

4. Label these resistors from 1 to 3 in order of least resistance to most resistance:

{Fixed Value Resistors}

{Questions}

5. What is the resistance value and tolerance of this resistor?

6. What is the resistance value and tolerance of this resistor?

7. What is the resistance value and tolerance of this resistor?

8. What is the resistance value and tolerance of this resistor?

9. What is the resistance value and tolerance of this resistor?

{Fixed Value Resistors}

{Questions}

10. What is the resistance value and tolerance of this resistor?

11. What is the resistance value and tolerance of this resistor?

12. What is the resistance value and tolerance of this resistor?

13. What is the resistance value and tolerance of this resistor?

14. What is the resistance value and tolerance of this resistor?

{Fixed Value Resistors}

{Questions}

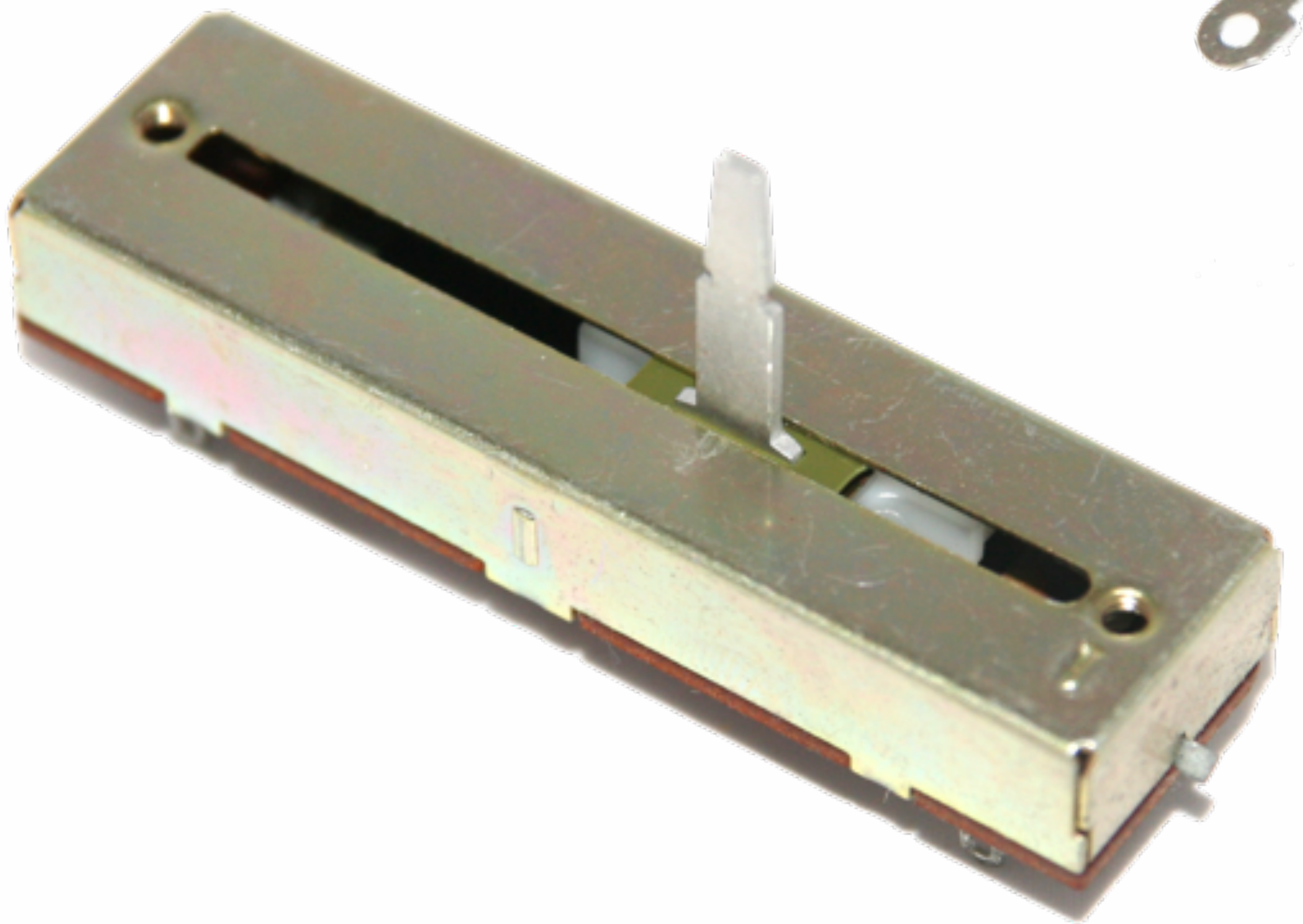
15. Draw the two circuit symbols used to represent fixed resistors:

16. What are the advantages of using surface mount resistors?

{Variable Resistors}

{Learning Outcomes}

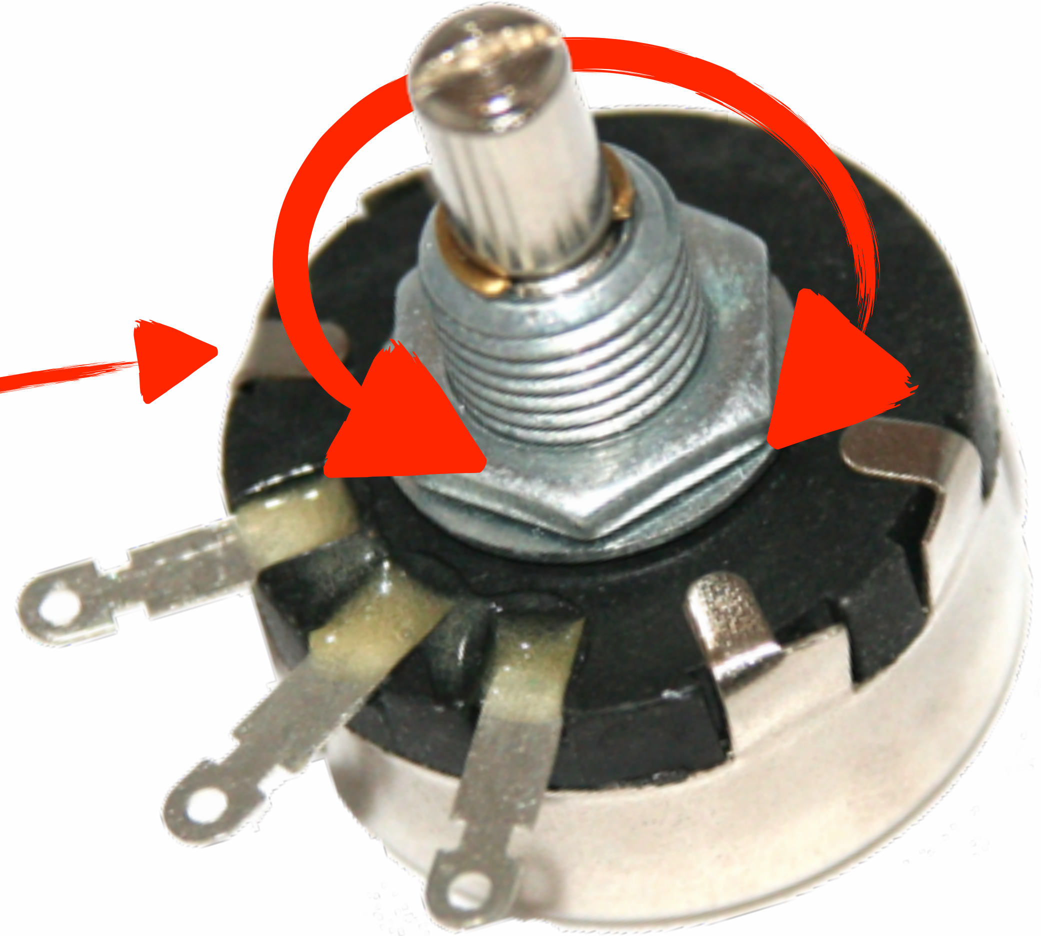
7.1 Describe the Different Types of Variable Resistors
7.2 Interpret Variable Resistor Markings
7.3 Describe the Internal Construction of Variable Resistors



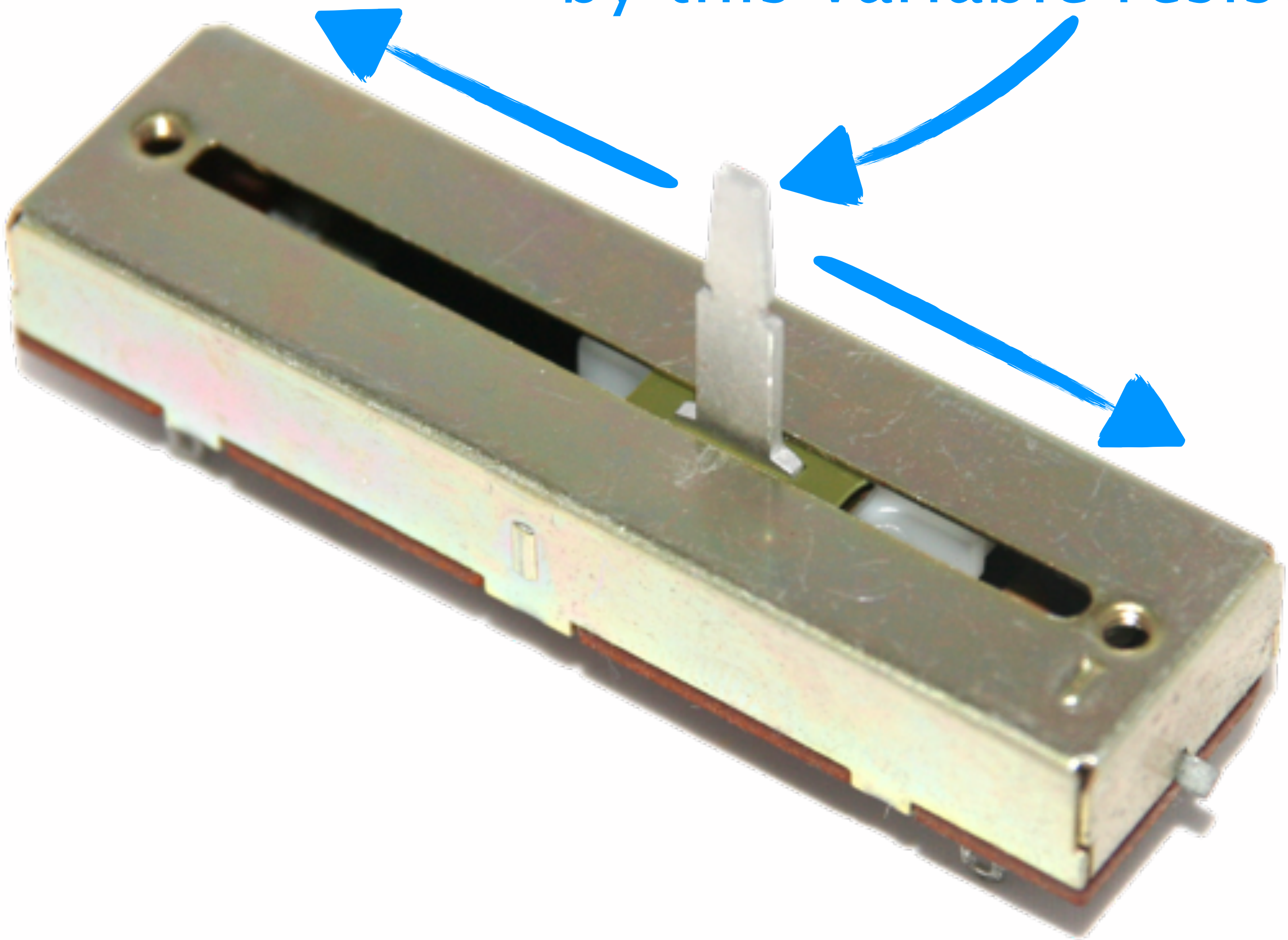
{Variable Resistors}

{Introduction}

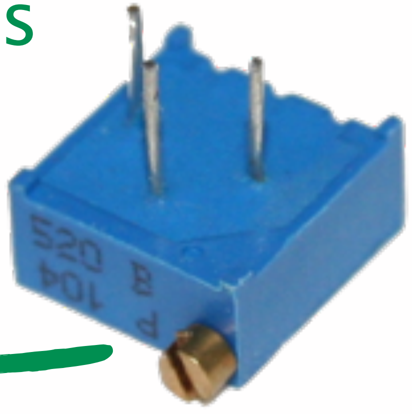
Variable resistors look completely different to fixed resistors and with good reason. They allow you to change their ohmic value by either rotating a shaft as demonstrated by this variable resistor,



Or by sliding a shaft as demonstrated by this variable resistor.



Some variable resistors require that you use a little screw driver to make adjustments to their resistance.



{Variable Resistors}

{Applications}

Variable resistors are used in a wide range of applications from volume control in audio equipment to brightness control for lighting.

Mixing desk with different styles of variable resistors

{Variable Resistors}

{Applications}

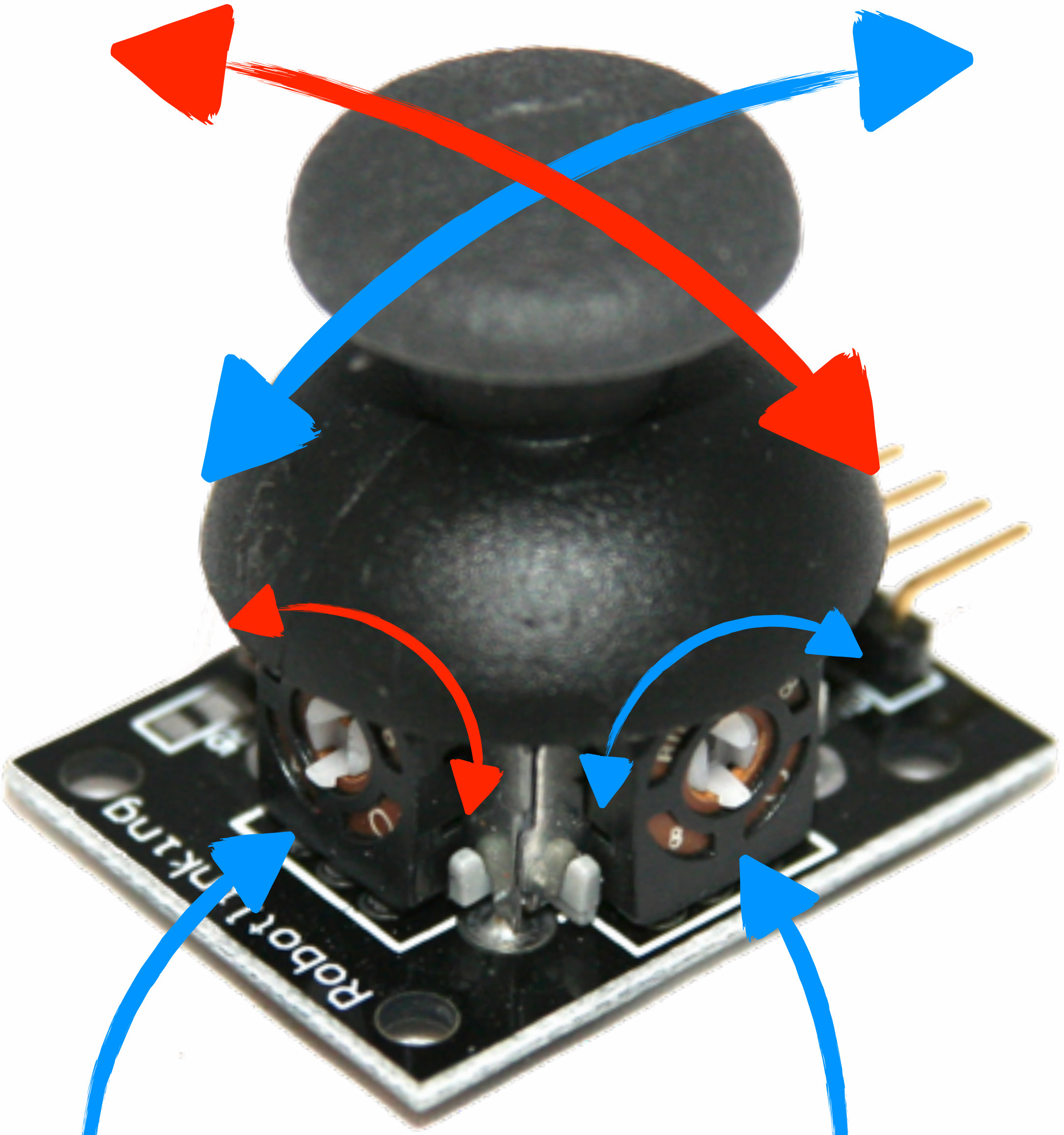
This variable resistor allows you to increase or decrease the display contrast on this GAME BOY pocket

{Variable Resistors}

{Applications}

Video game control pads often have ‘analog controls’.

Analog controls on a playstation control pad



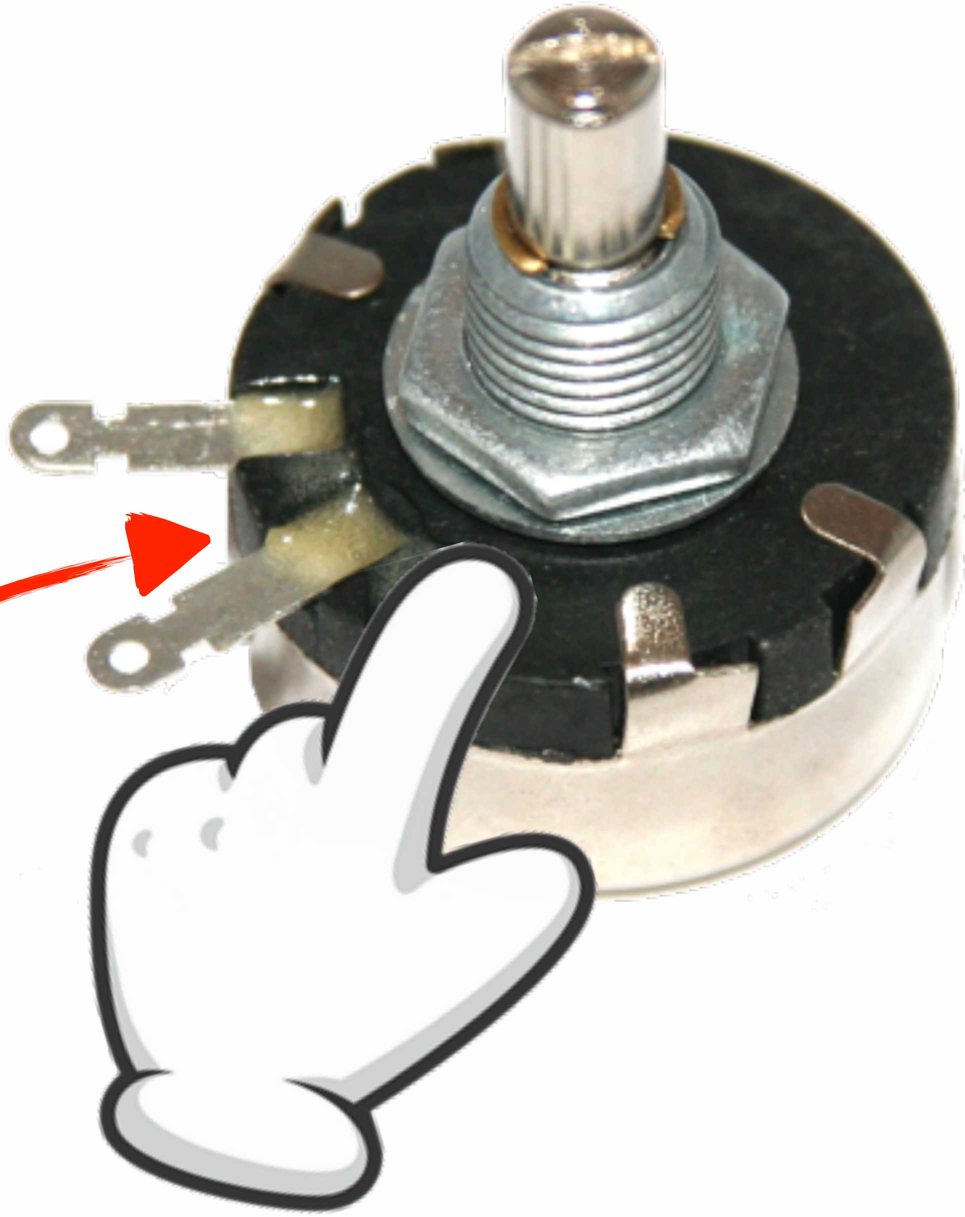
The analog controls have two variable resistors which are mounted at 90 degrees to each other. The resistance of each variable resistor will change depending on where the player has positioned the control. These resistances are then used by the video game system to make the game work.

{Variable Resistors}

{Types of Variable Resistors}

There are two types of variable resistors, these being the rheostat and the potentiometer. A rheostat has two connections while a potentiometer has three connections. A potentiometer can be used as a rheostat simply by leaving out one of the three connections.

A variable resistor with three connections is called a potentiometer or 'pot' for short.

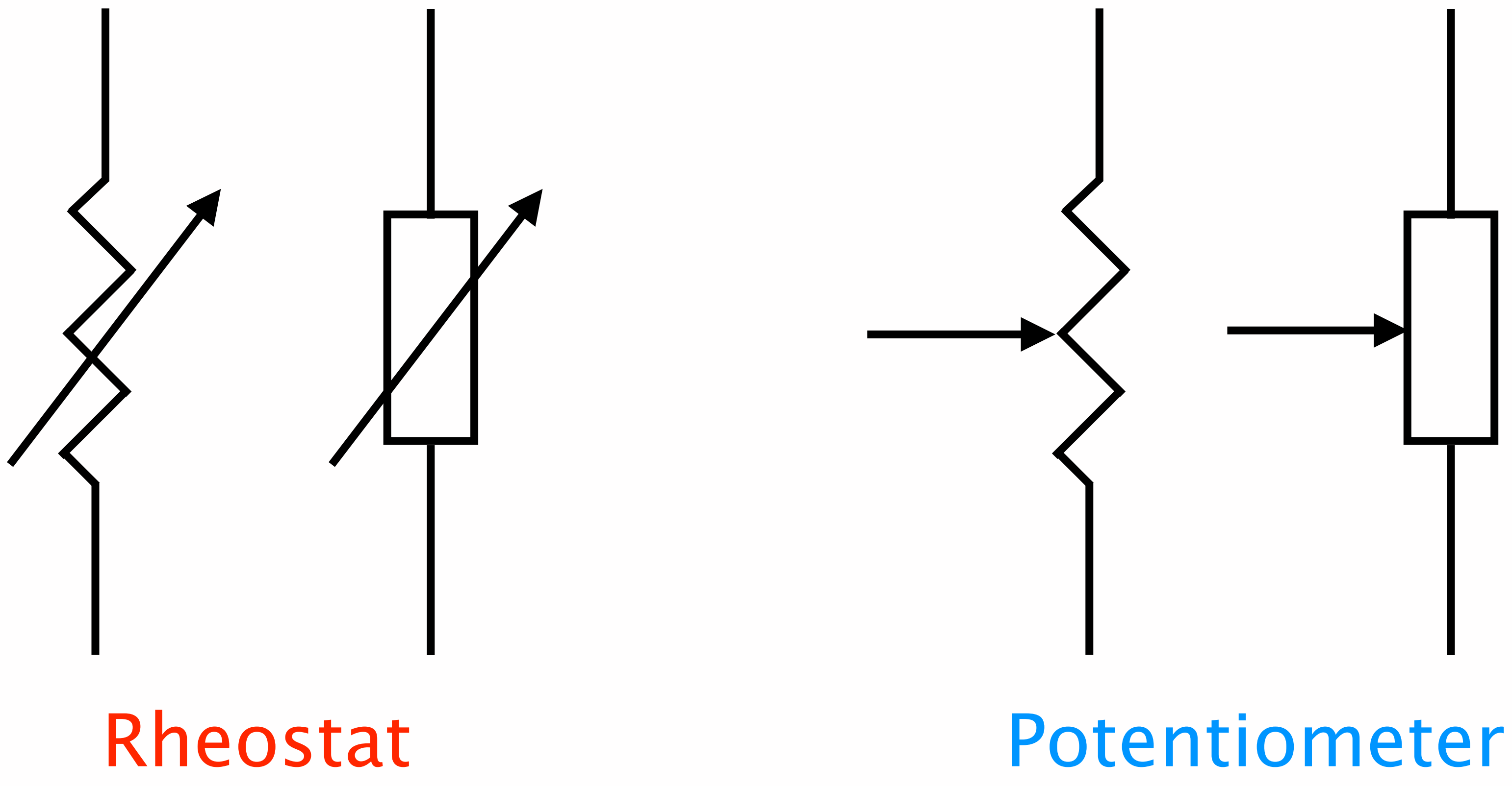


Cover up one of the end connections to turn a potentiometer into a rheostat.

{Variable Resistors}

{Variable Resistor Circuit Symbols}

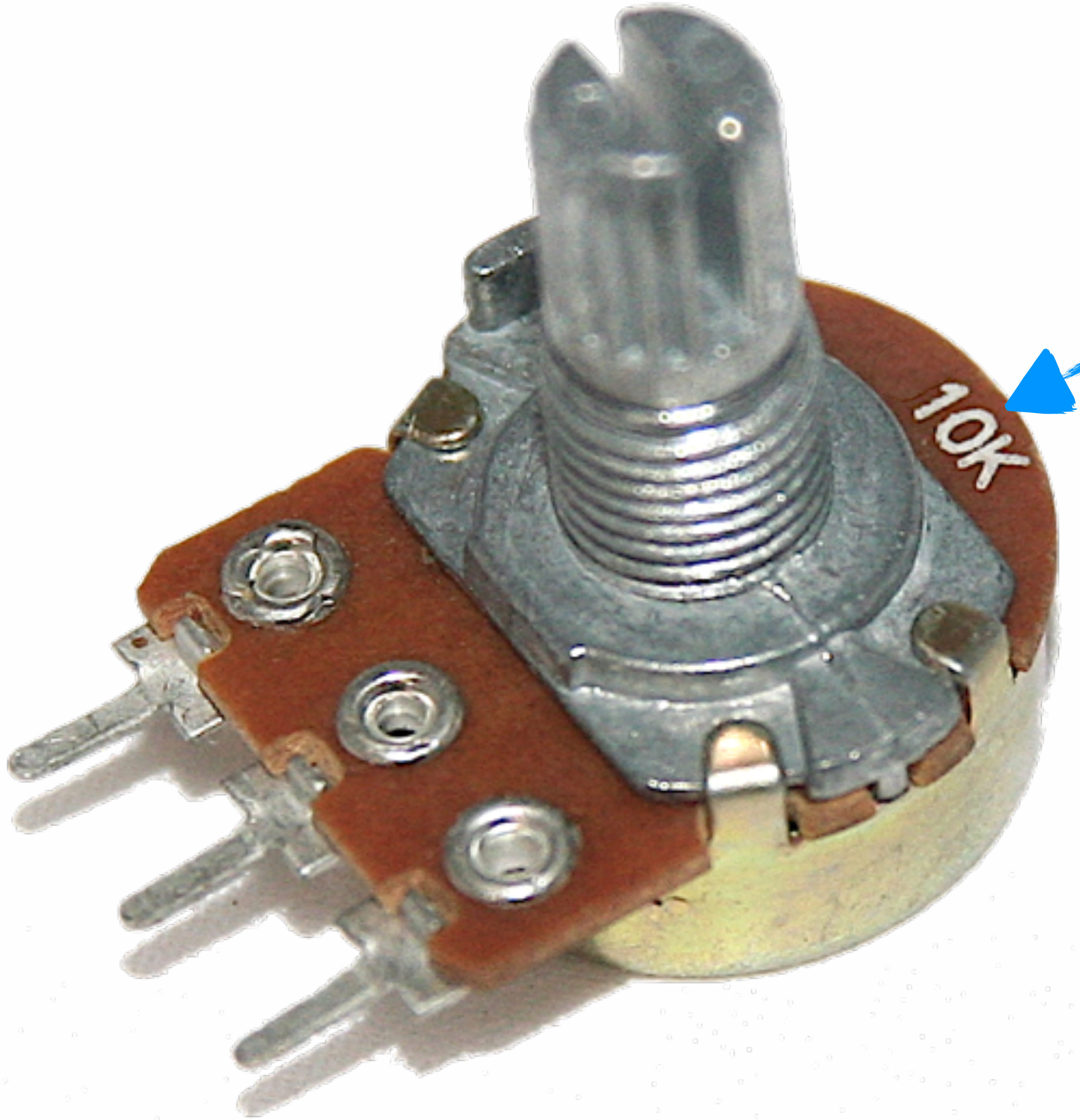
The circuit symbols for a rheostat and potentiometer are very similar to fixed value resistors. The inclusion of an arrow indicates they are variable.



{Variable Resistors}

{Variable Resistor Values}

Variable resistors will have the maximum resistance value printed on them. This means the resistance can be adjusted from 0Ω up to the value printed on the device.

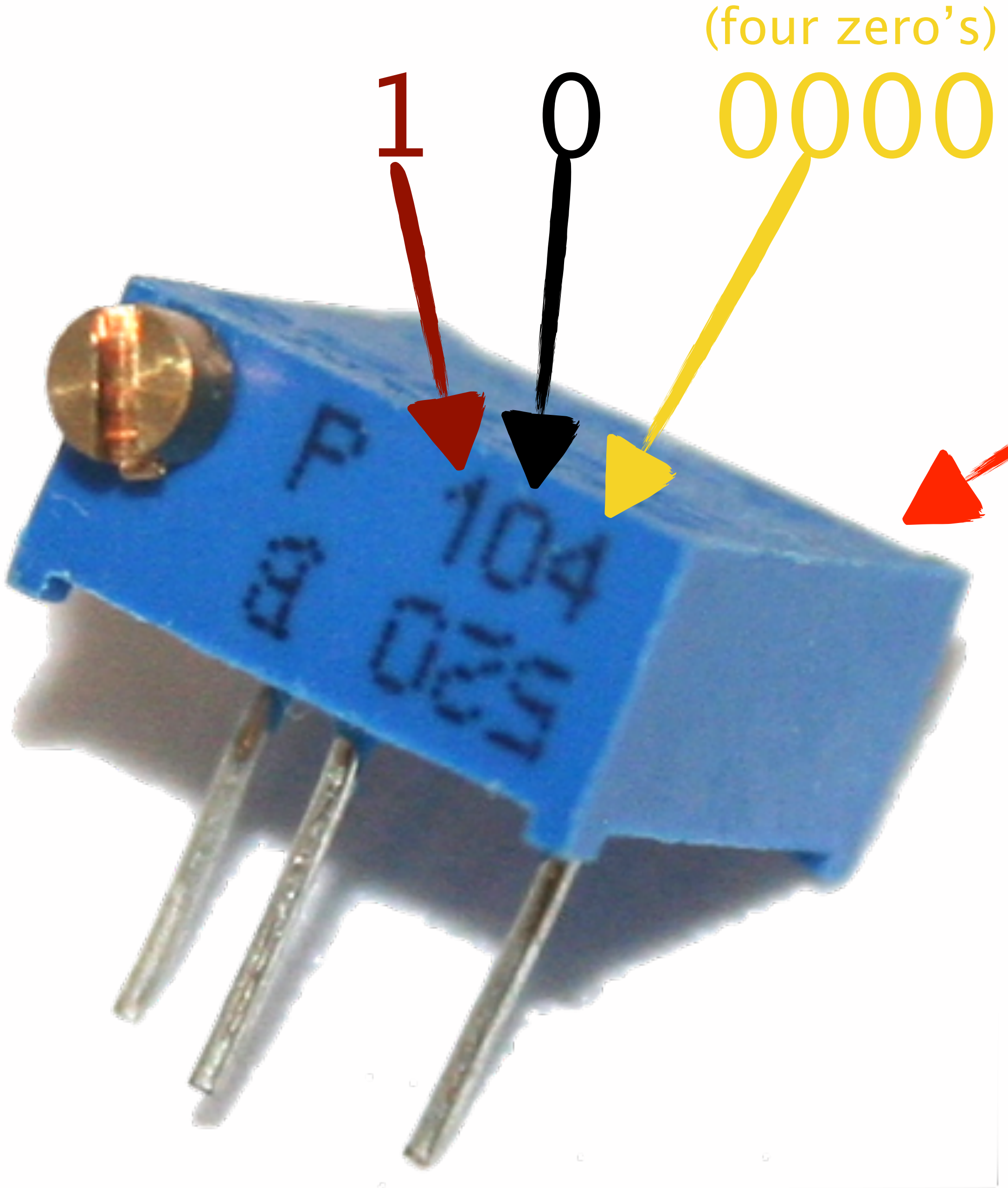


This variable resistor can be adjusted from 0Ω up to 10kΩ

{Variable Resistors}

{Variable Resistor Values}

Some variable resistors will have the ohmic value printed in a numeric code. This is worked out in the same fashion as a colour code – except you don't have to look up colours.



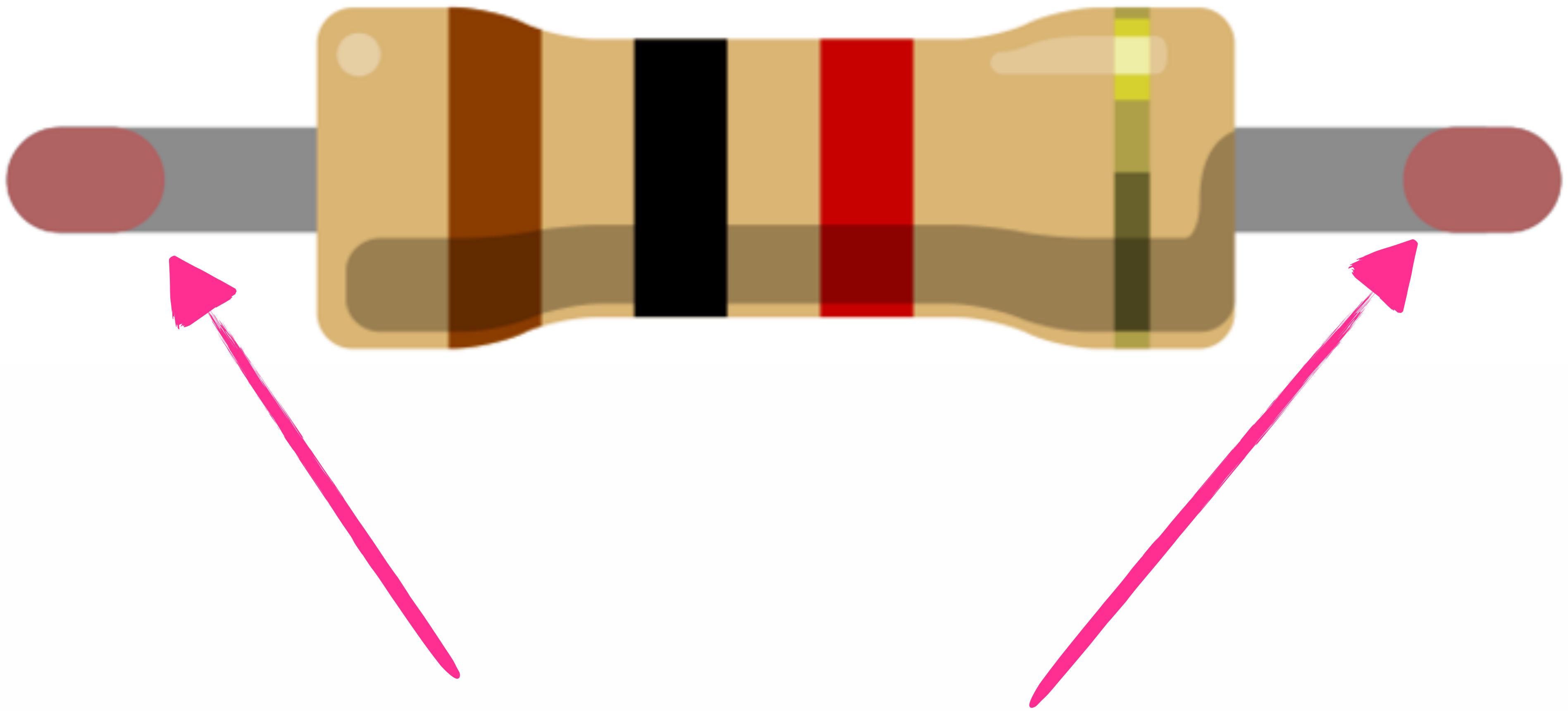
Therefore this variable resistor can be adjusted from 0Ω up to 100kΩ

The '104' Marking is the equivalent of a brown black yellow colour code

{Variable Resistors}

{Rheostat – Theory of Operation}

The theory of operation for a rheostat and potentiometer are very similar however we will look at the rheostat first. We can get a good idea of how a rheostat works by pulling apart a fixed value resistor.

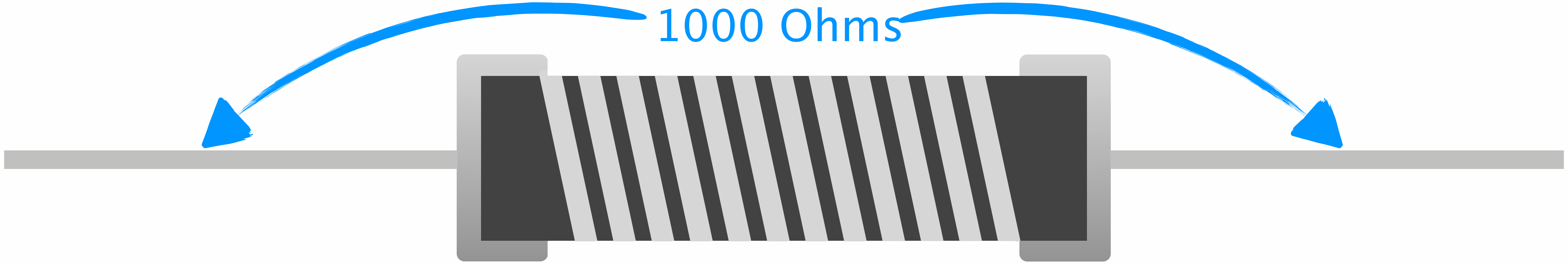


Between the two ends, we have 1000 Ohms of resistance. Let’s now look at the internals of this resistor:

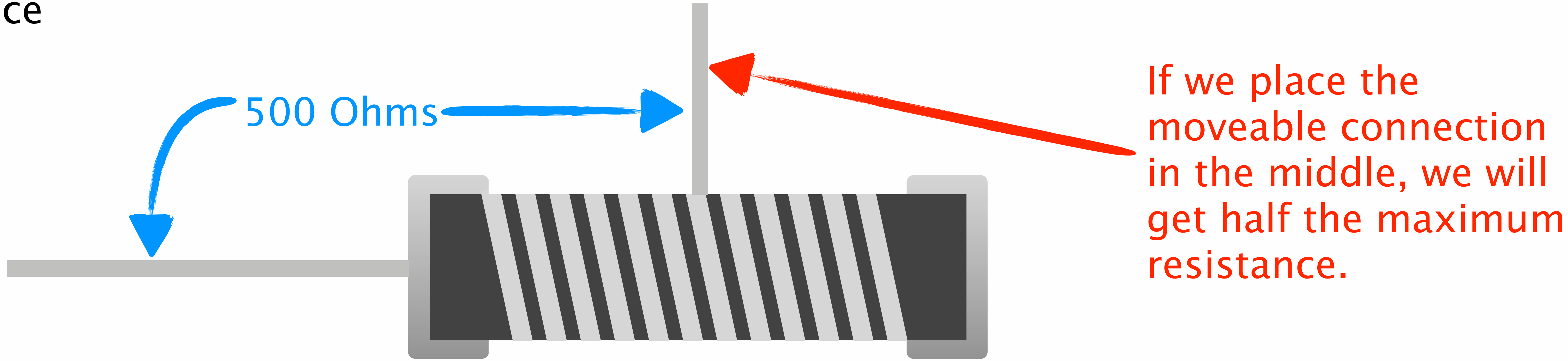
{Variable Resistors}

{Rheostat – Theory of Operation}

The 1000 Ohms of resistance is due to the number of spirals going around the resistor body.



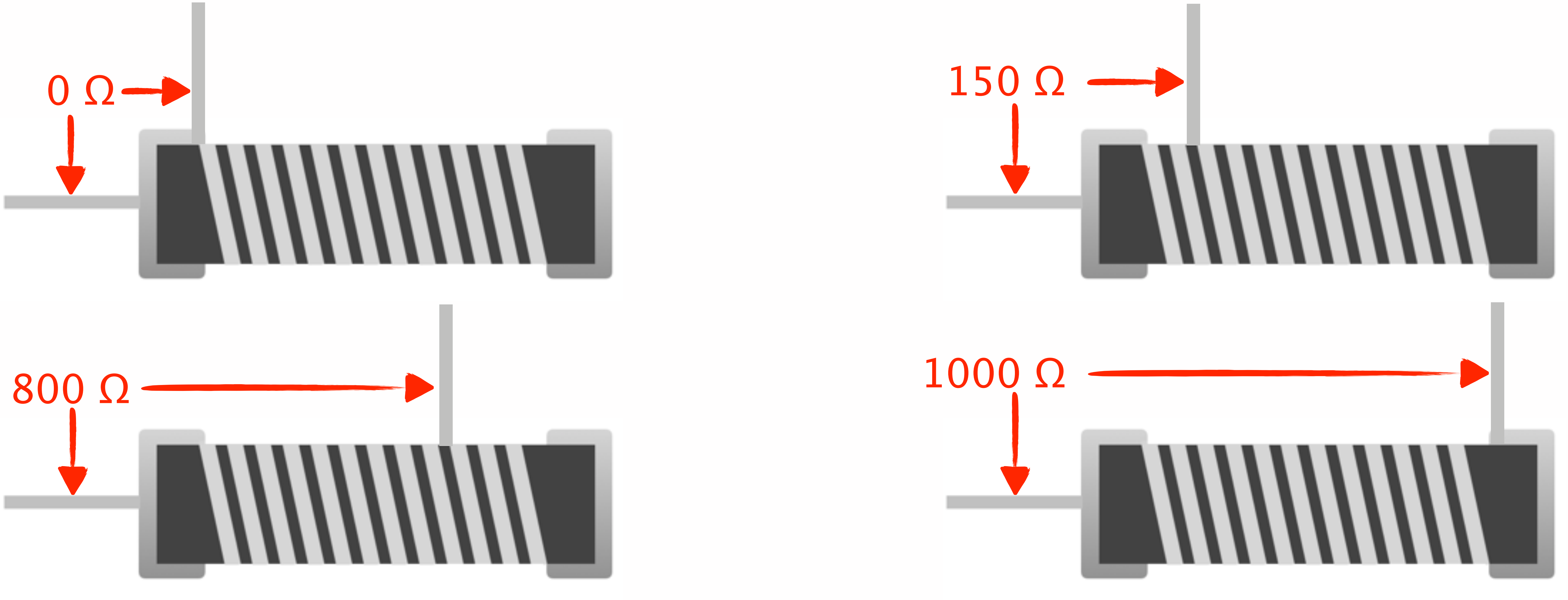
A rheostat works by removing one of the end connections and placing it somewhere on top of the resistor windings. This allows us to get any value between 0Ω and 1000 Ω depending on where we place it. The more coils between the two connections means we have more resistance



{Variable Resistors}

{Rheostat – Theory of Operation}

Here are four more examples of resistance values based on where we connect the top component lead. Notice how we could get any value between 0 Ω and the rated value of the resistor which is 1000 Ω.

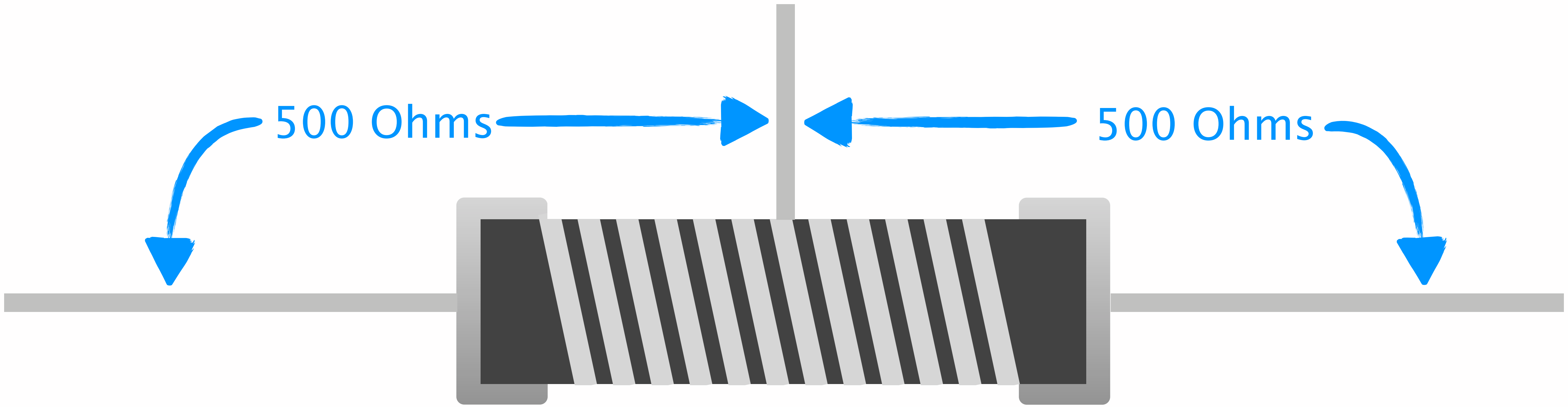


Let's now have a look at the operation of a potentiometer (pot)…

{Variable Resistors}

{Potentiometer – Theory of Operation}

A potentiometer has three connections rather than two like the rheostat. You can think of it as a standard fixed resistor with a third connection which can be moved toward the left side or toward the right side.

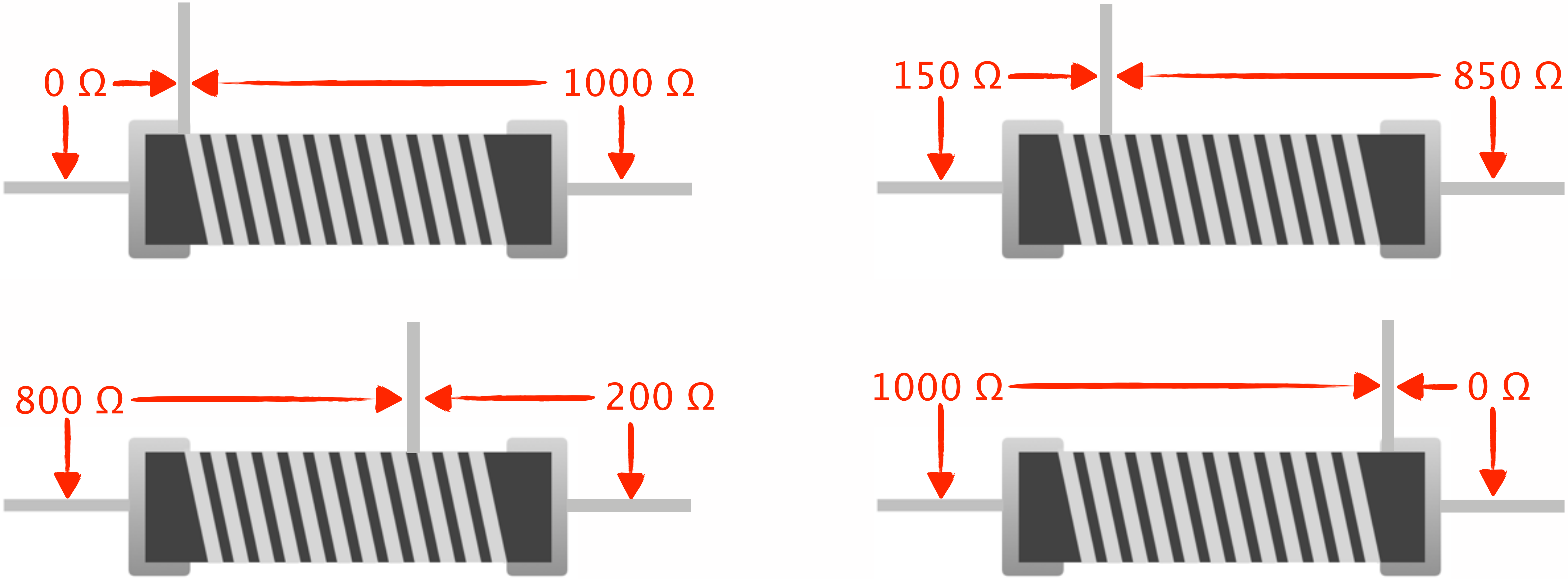


This gives us two resistance values which when added together, will always equal the maximum resistance value.

{Variable Resistors}

{Potentiometer – Theory of Operation}

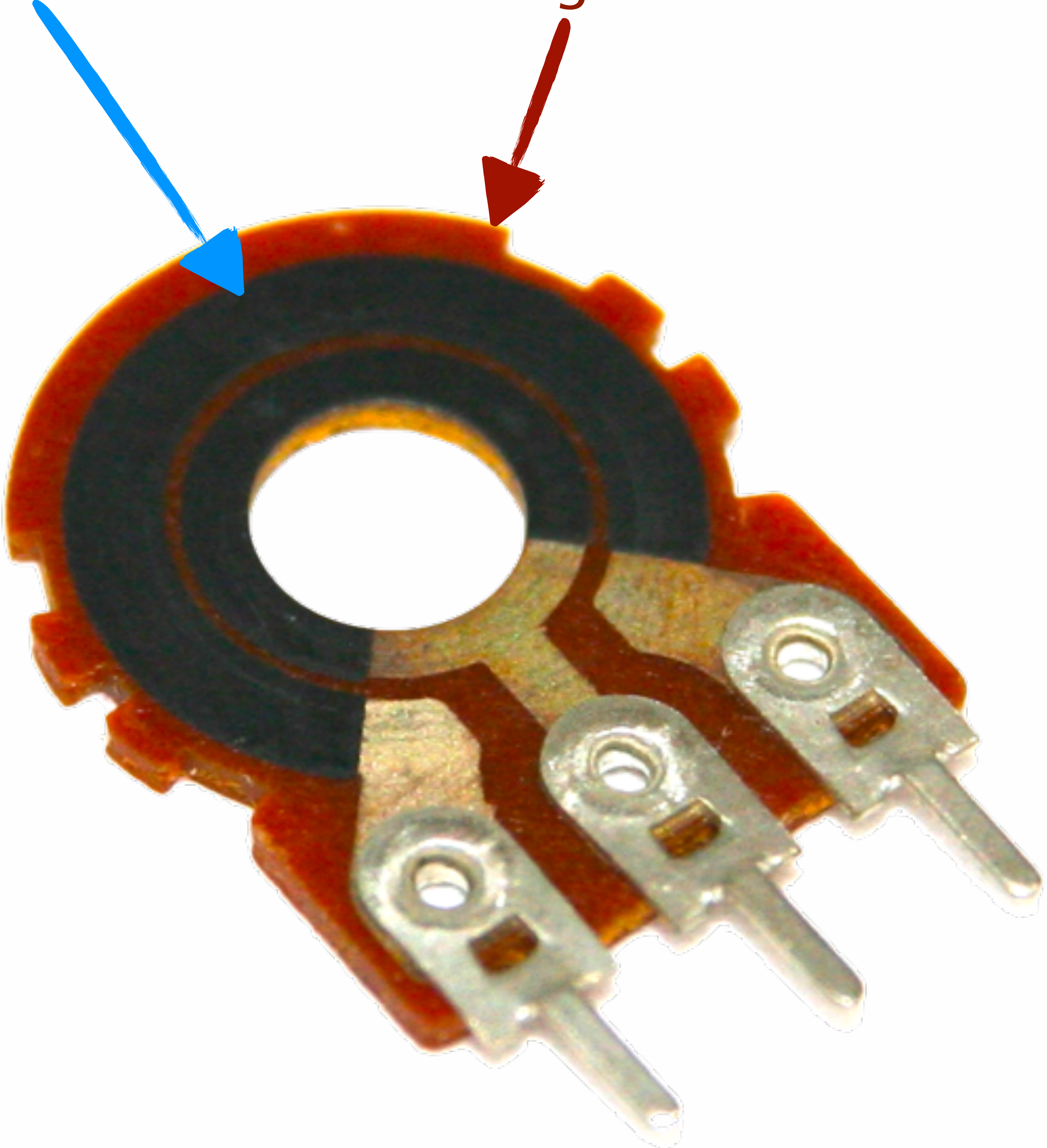
Here are four more examples of resistance values based on where we connect the top connection. It is very similar to the operation of the rheostat but we now have two resistance values between each side of the resistor and the top connection.



{Variable Resistors}

{Variable Resistors – Internal Workings}

While variable resistors can be made from a range of materials, they are commonly made of a coil of resistance wire or a thin film of conducting carbon on an insulating base.

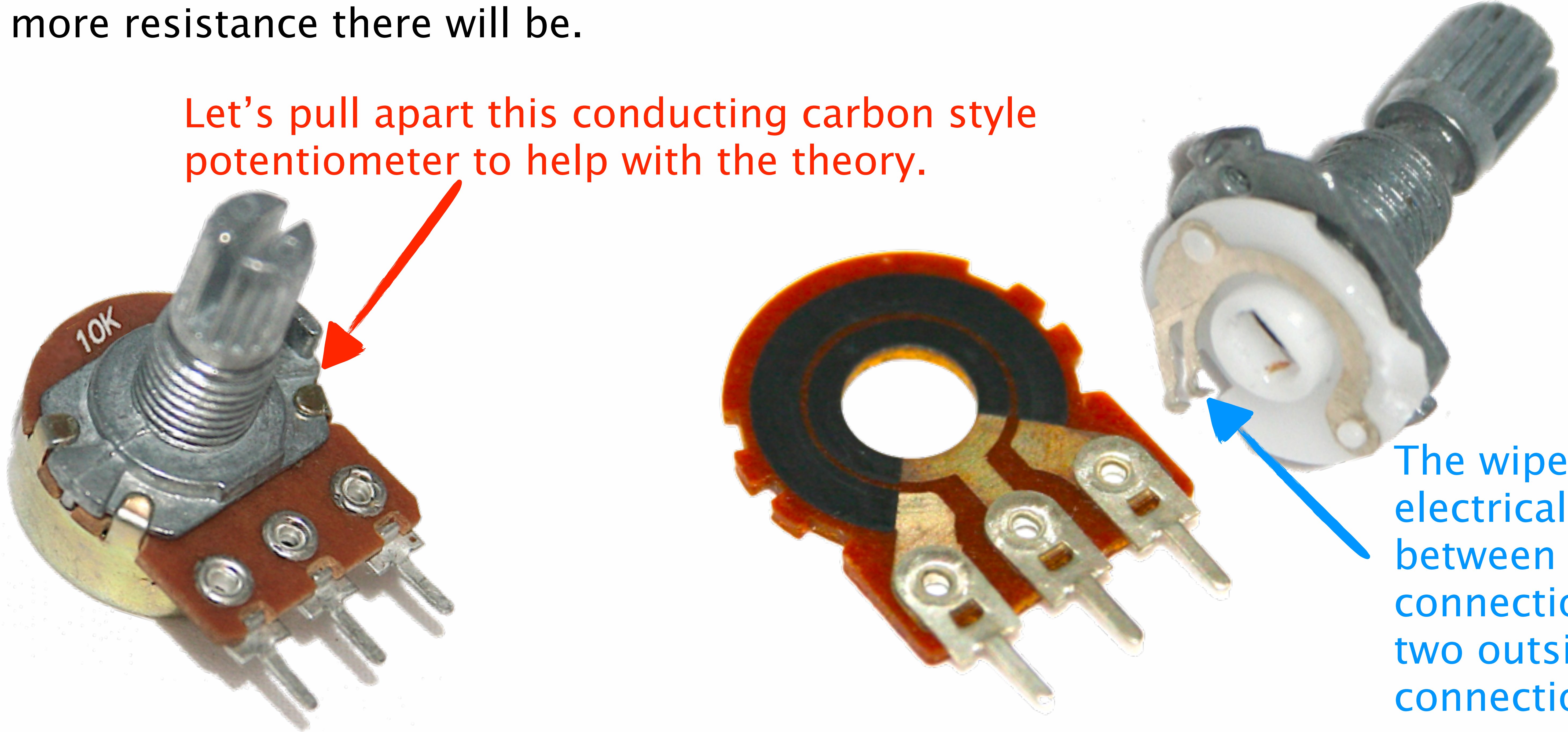


{Variable Resistors}

{Variable Resistors – Internal Workings}

In order to vary the resistance, a special connector called a ‘wiper arm’ is attached to a shaft which the operator can rotate. The wiper arm is the link between the centre connection and the outside connections. The further this link moves away from an outside connection, the more resistance there will be.

Let’s pull apart this conducting carbon style potentiometer to help with the theory.

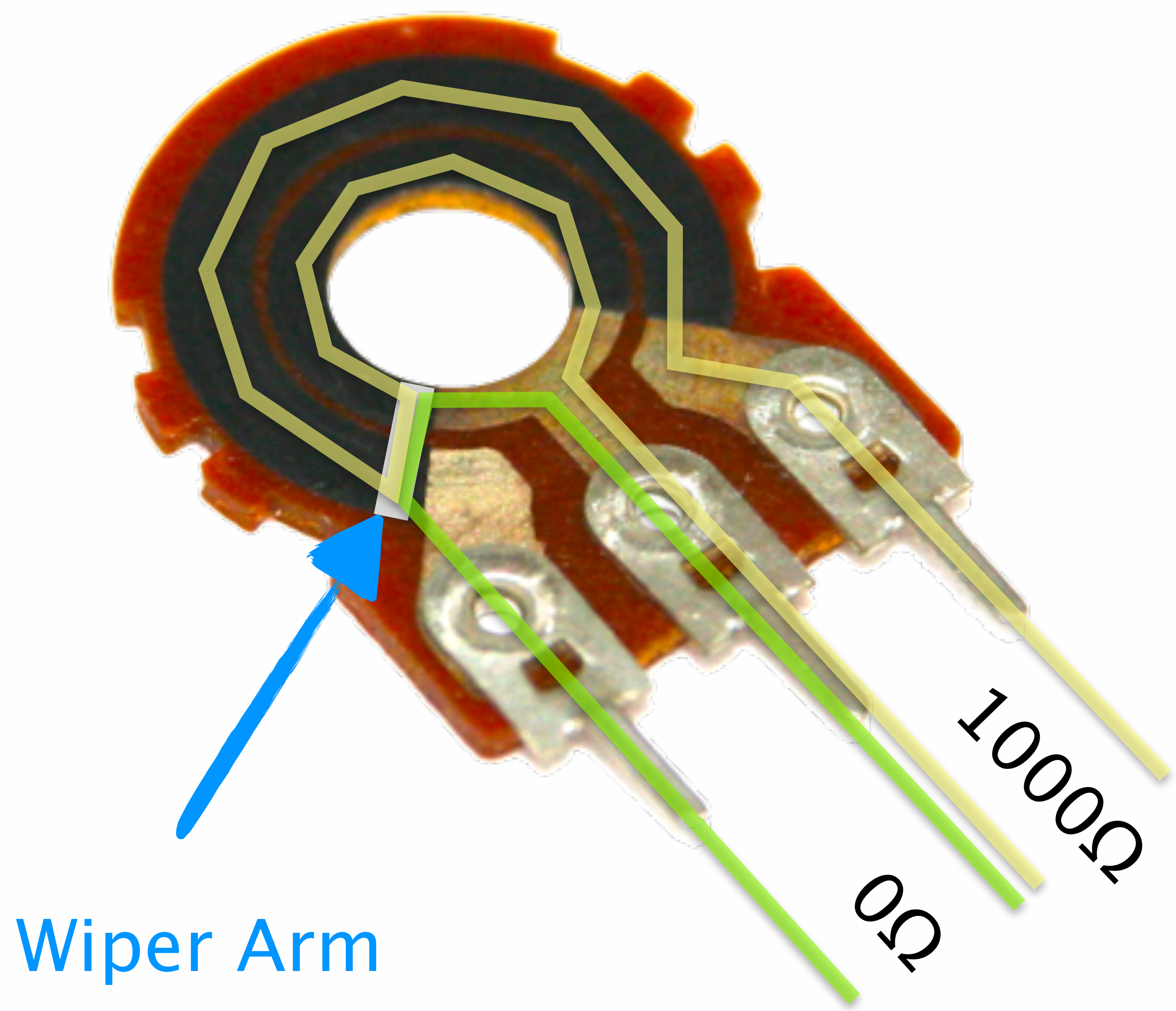


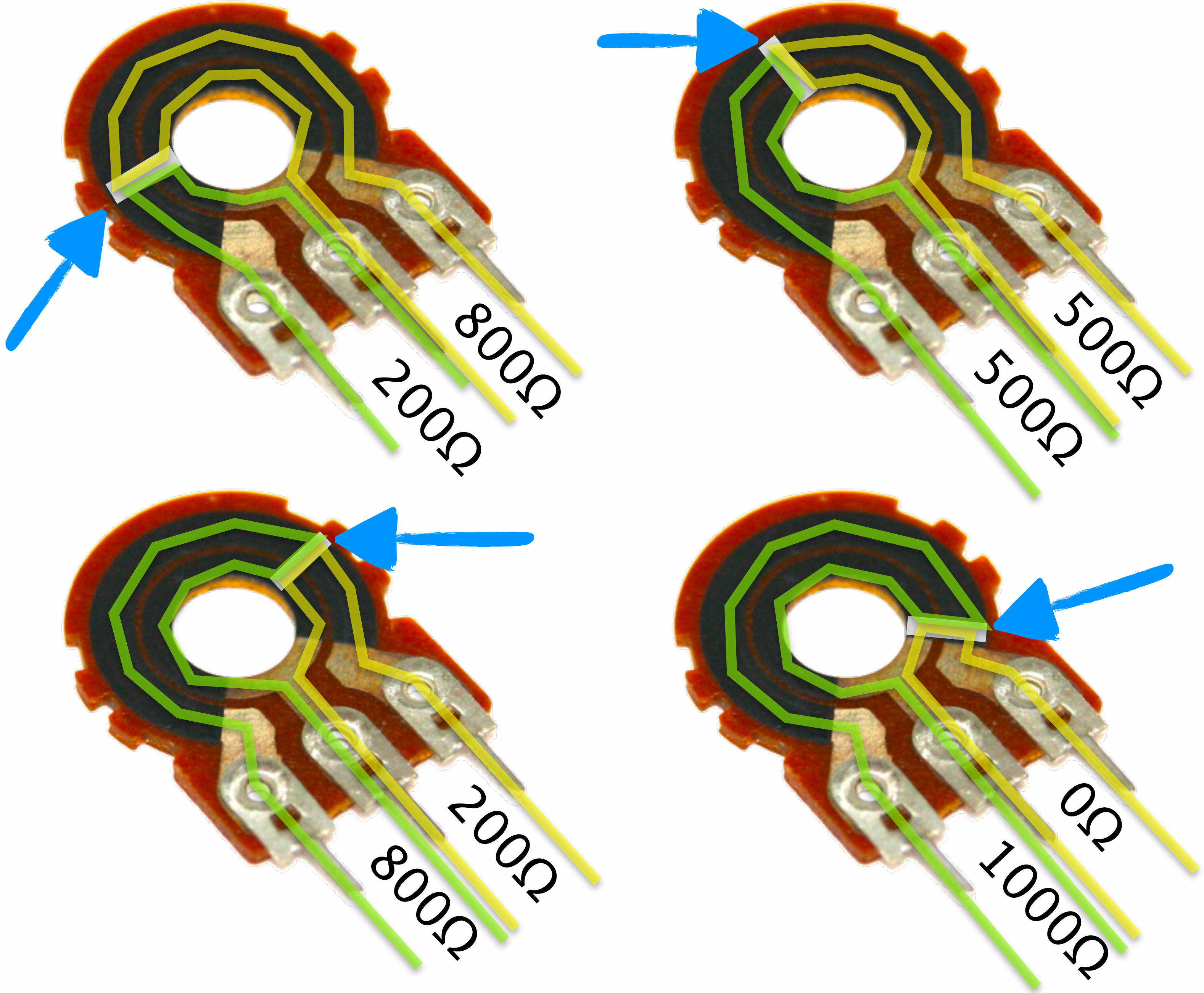
The wiper arm is the electrical contact between the middle connection and the two outside connections.

{Variable Resistors}

{Variable Resistors – Internal Workings}

With the wiper arm all the way counter clockwise we get a resistance of 0Ω between the left and middle connections and a resistance of 1000Ω between the right and middle connections. Notice how these two resistances change as we rotate all the way through to maximum clockwise.

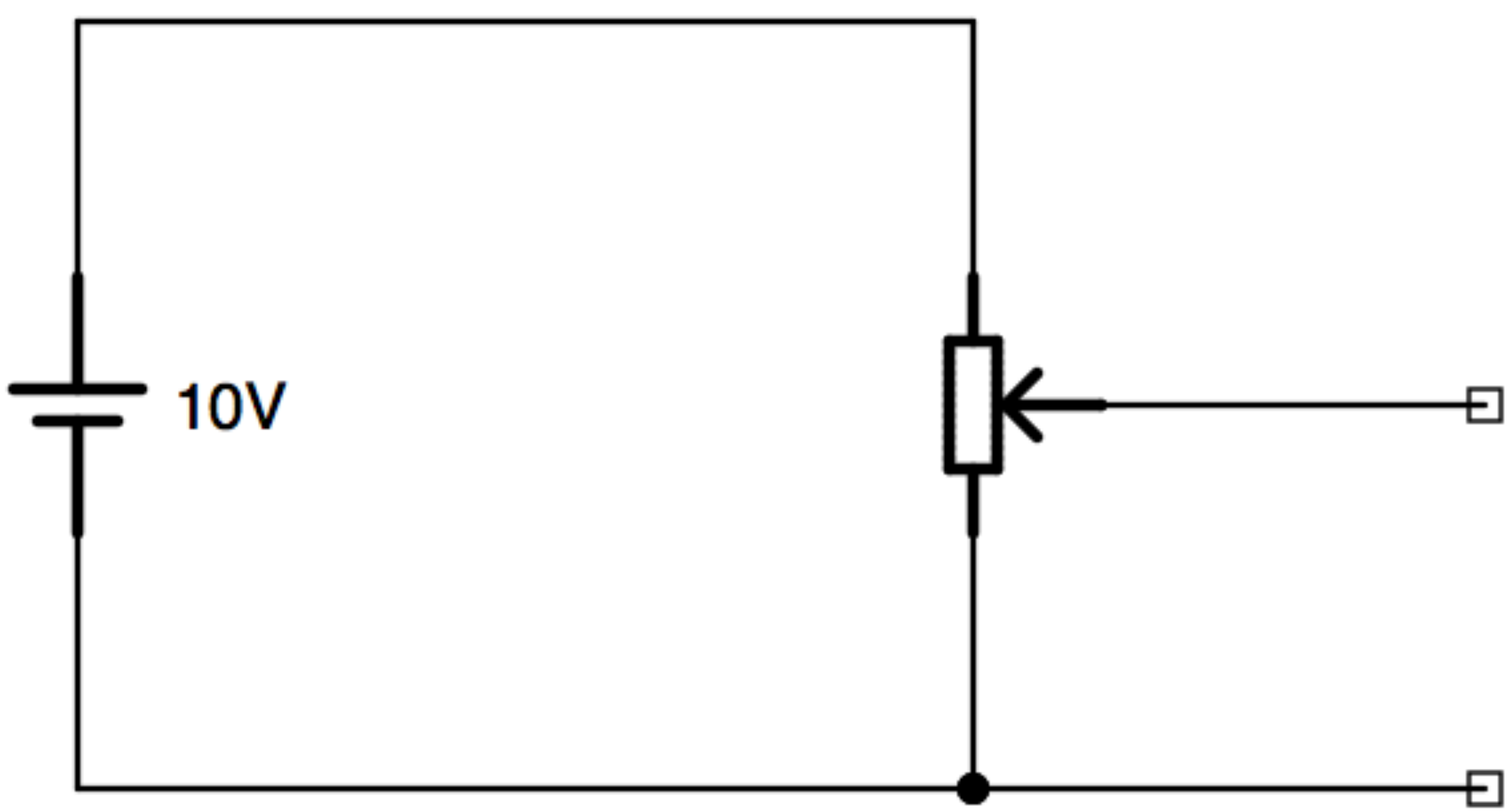


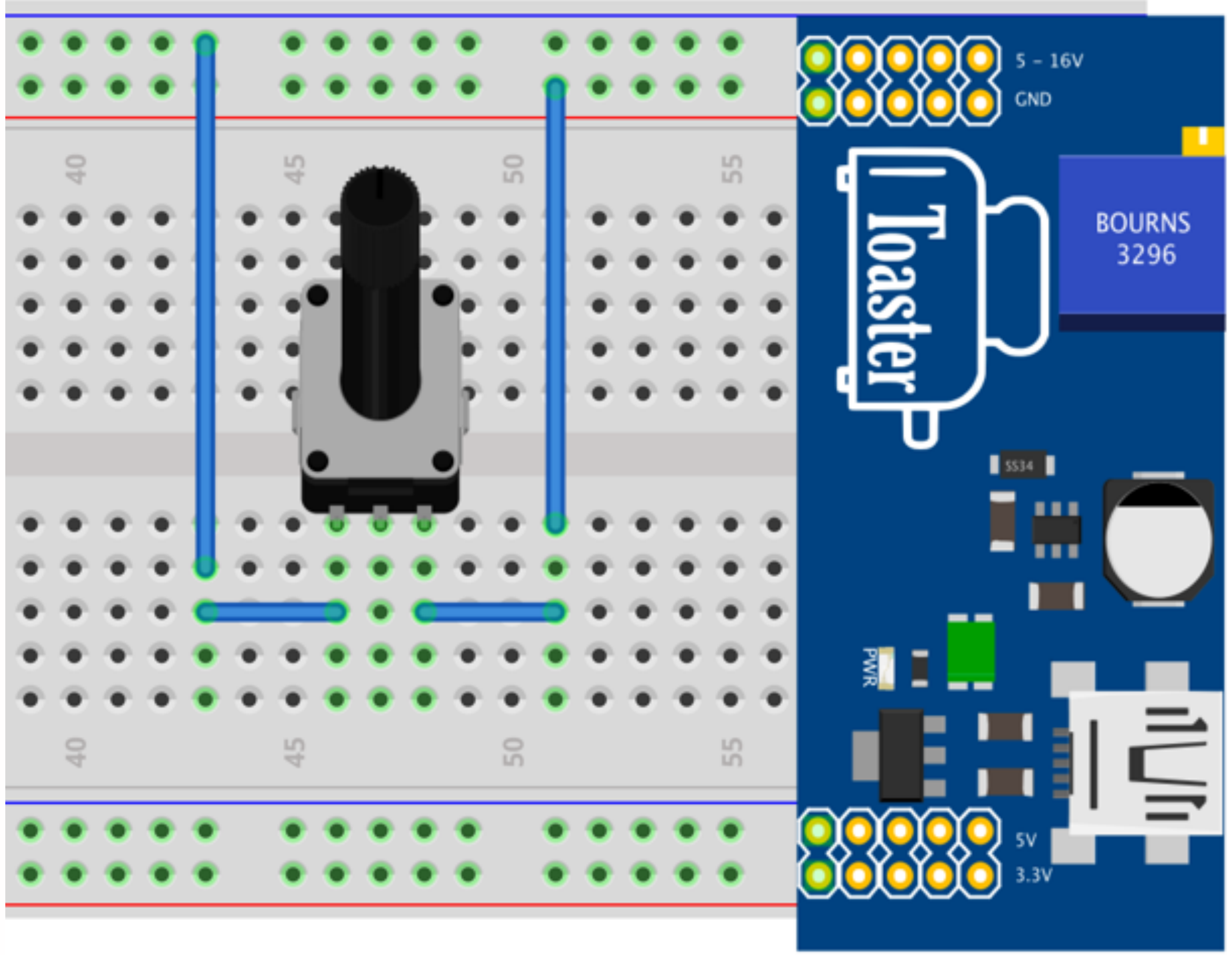


{Variable Resistors}

{Before we get to the Summary…}

We will be running through actual circuit examples including practical exercises using variable resistors in later chapters, so stay tuned!





{Variable Resistors}

{Summary}

- Variable resistors come in two forms: Rheostats and Potentiometers
- A rheostat uses only two connections and the resistance between the two connections increases or decreases as you rotate the shaft.
- A potentiometer uses three connections and as the resistance between the middle connections and one of the outside connections increases, the other outside connection will decrease.
- Variable resistors will have their maximum value printed on them. This means they can be adjusted from 0Ω up to their maximum value.
- The wiper arm forms the link between the centre connection and the outside connection / connections on the rheostat / potentiometer
- The further the wiper arm moves away from an outside connection, the more resistance there will be

{Variable Resistors}

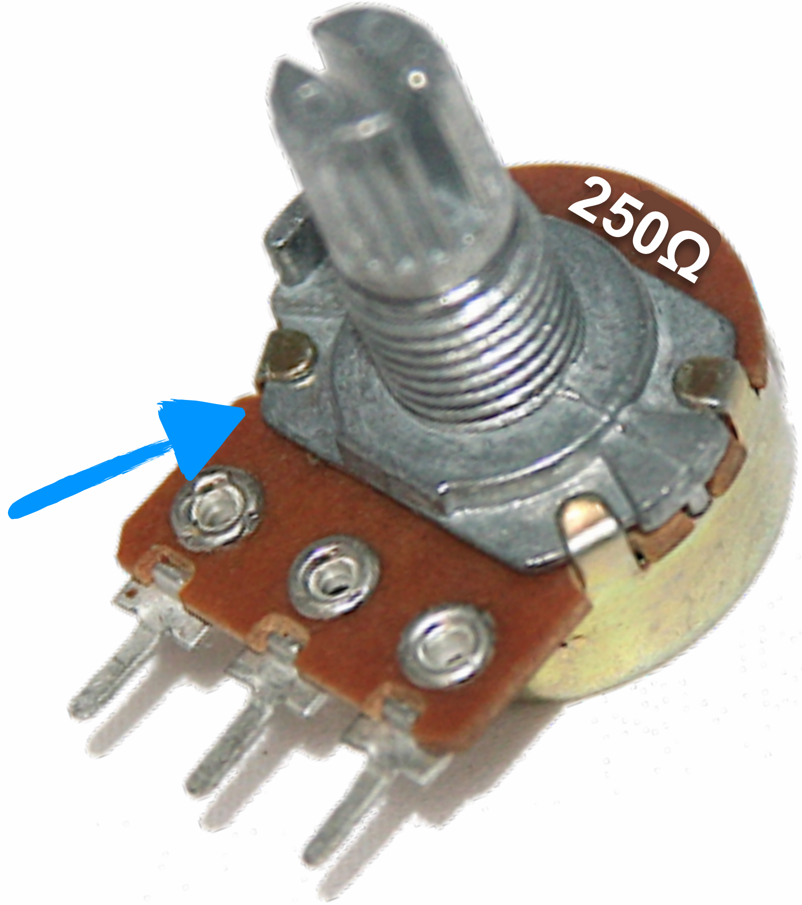
{Questions}

1. How many connections does a potentiometer have?

2. How many connections does a rheostat have?

3. How would you use a potentiometer as a rheostat?

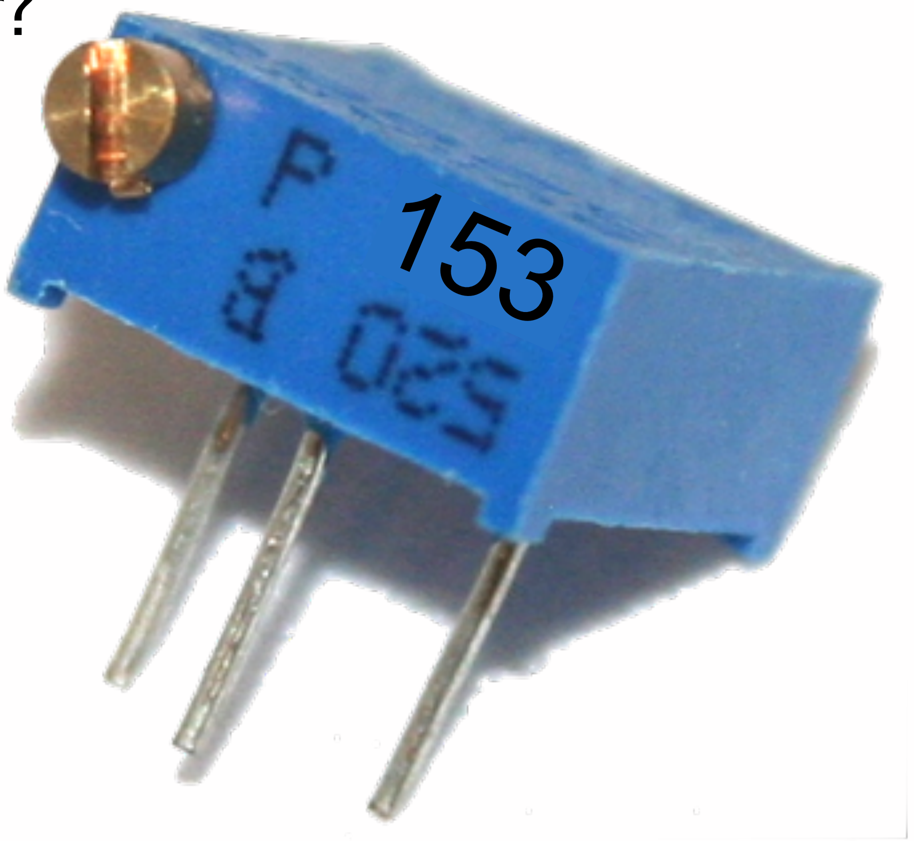
4. What is the minimum and maximum value of this variable resistor?



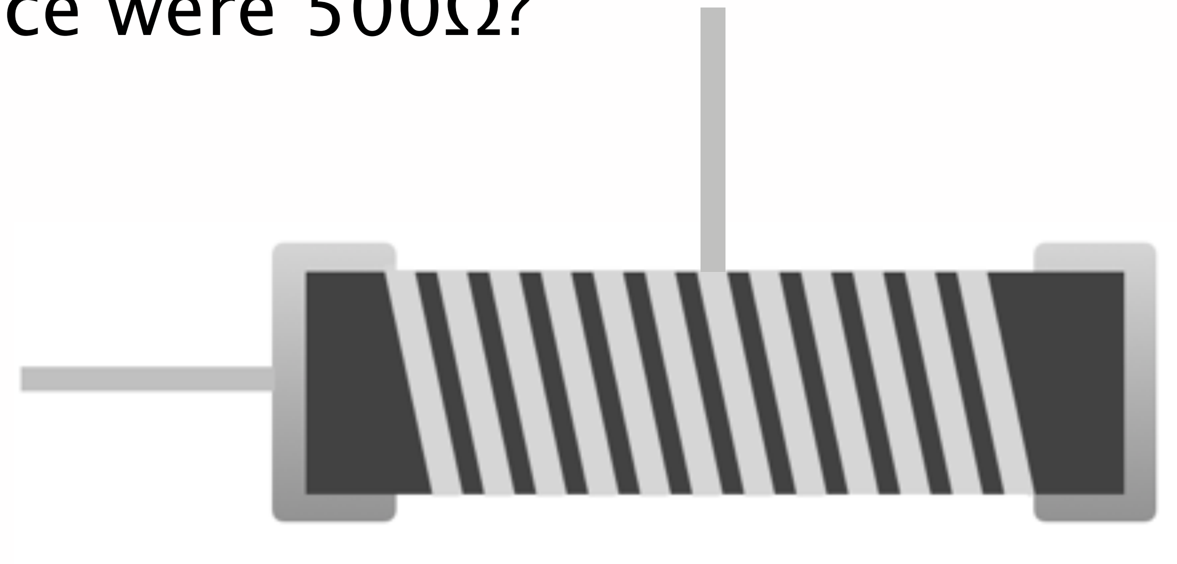
{Variable Resistors}

{Questions}

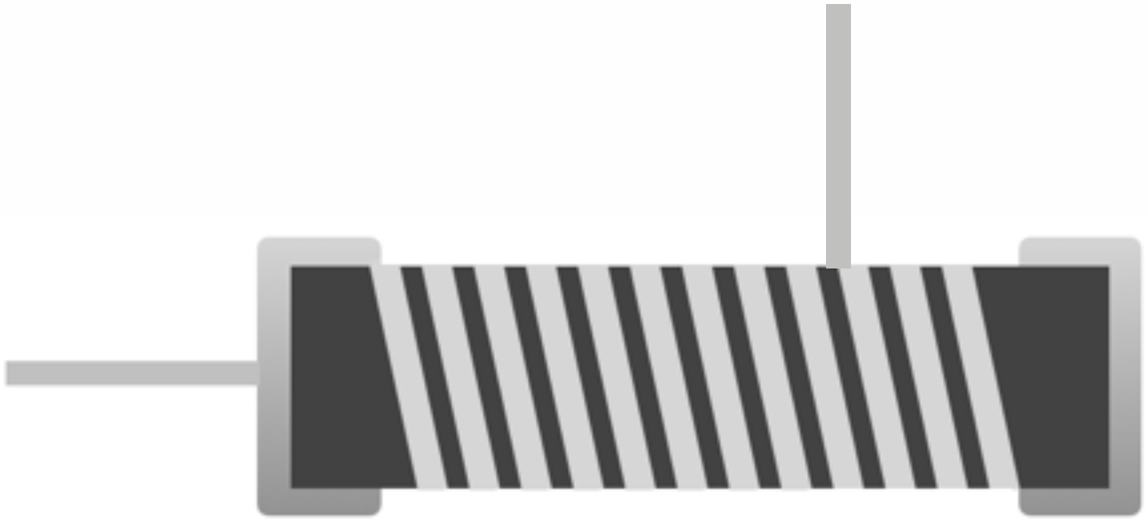
5. What is the minimum and maximum value of this variable resistor?



6. What is the resistance of the following if the maximum resistance were 500Ω?



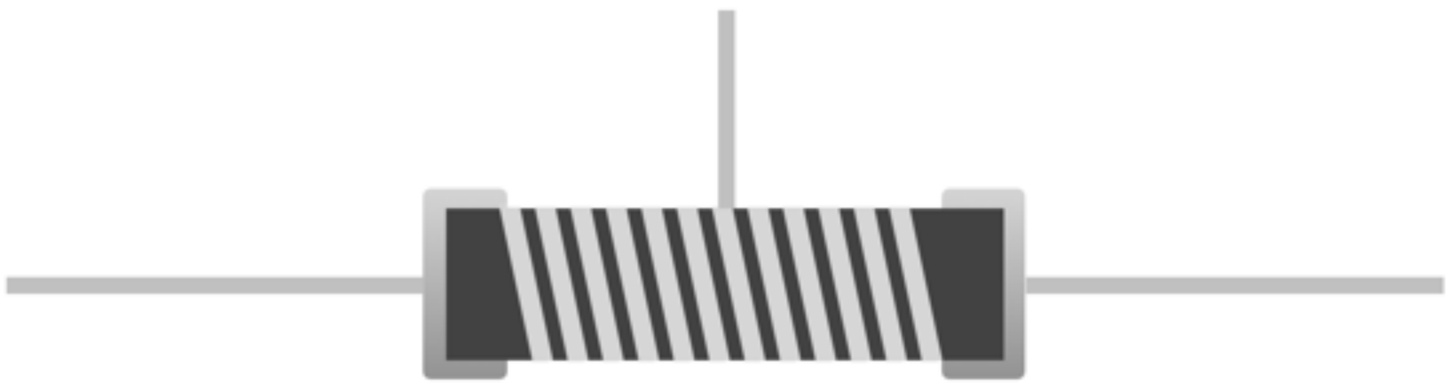
7. What is the (approximate) resistance of the following if the maximum resistance were 250kΩ?



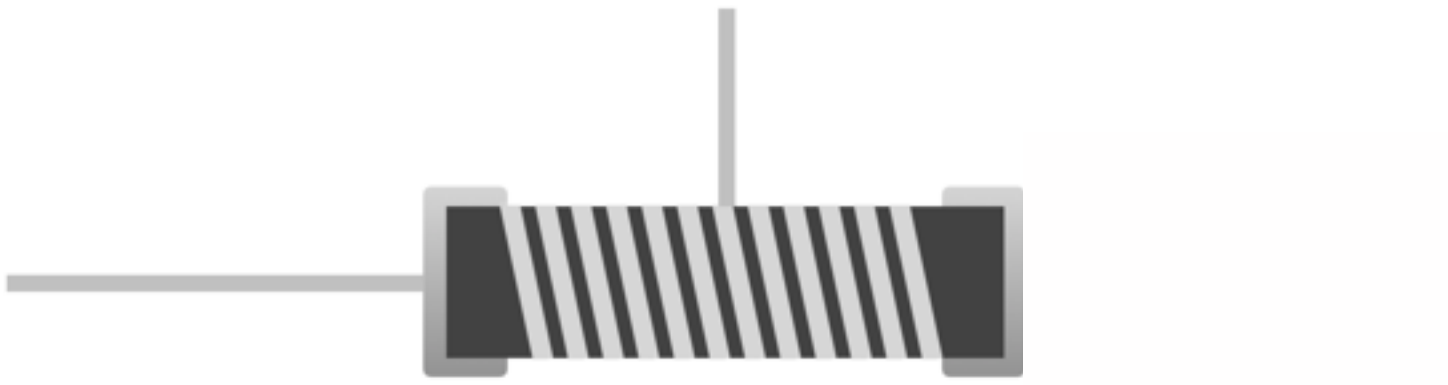
{Variable Resistors}

{Questions}

8. What type of variable resistor does the following image represent?



9. What type of variable resistor does the following image represent?



10. Are there more variable resistor tutorials including practical circuit tasks coming up in later chapters?