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Simplifying Electricity

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Contents

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Motors, generators and charging systems

Worksheet 1
**Generating electricity**

A vehicle's electrical system obtains energy from a combination of the battery and the alternator. The output of the alternator delivers electrical energy to peripheral units, like headlamps, and keeps the lead-acid battery charged.

This investigation uses an oscilloscope to study the electricity generated when a magnet is dropped through a coil. Using an oscilloscope is a key skill that you will need to master.

You start to learn that here!

The photograph shows an alternator and drive belt in a vehicle.
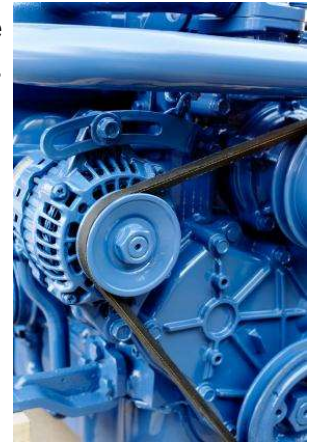
The investigation uses a device known as 'Faraday's law apparatus', shown below, and an oscilloscope, used to 'see' the time-varying signals produced.

Over to you:

- Connect the Faraday's law apparatus to an oscilloscope.
  Typical settings are given below.
- Drop the magnet through the coil.
- Sketch the resulting oscilloscope trace in the Student Handout.
- Reverse the magnet and do the same thing again.
- Answer the question in the Student Handout.

Oscilloscope settings:

Timebase - 1s/div

Voltage range - ±500mV DC

Trigger mode - Auto

Trigger channel - ch A

Trigger direction - Rising

Trigger threshold - 10mV

So what?

A typical trace obtained in this investigation is shown below.

The spikes are produced by pulses of current generated as the magnet falls through the coil.

The bipolar nature of the pulses (i.e. above and below the centre axis,) is the result of the magnet first approaching and then leaving the coil, generating a current first in one direction and then in the other.

This demonstrates Faraday's law of electromagnetic induction.

31May2010 21:28
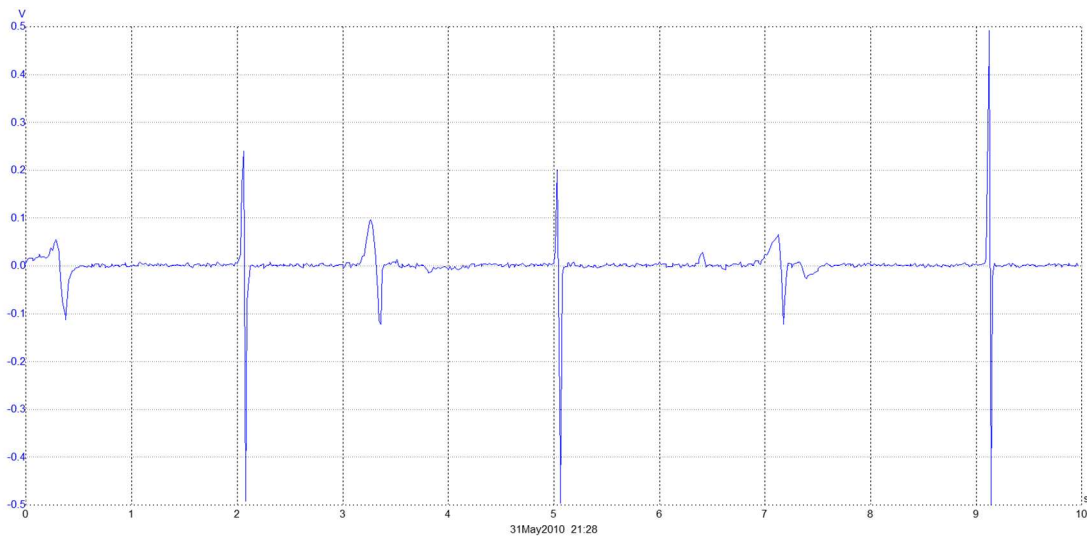
Worksheet 2
Understanding AC

It is important to understand the difference between direct current (DC) and alternating current (AC) and how they relate to each other.

Both are used in modern vehicle electrical systems. Both produce the same effects - heat, light and motion.

Photograph shows AC charge post.
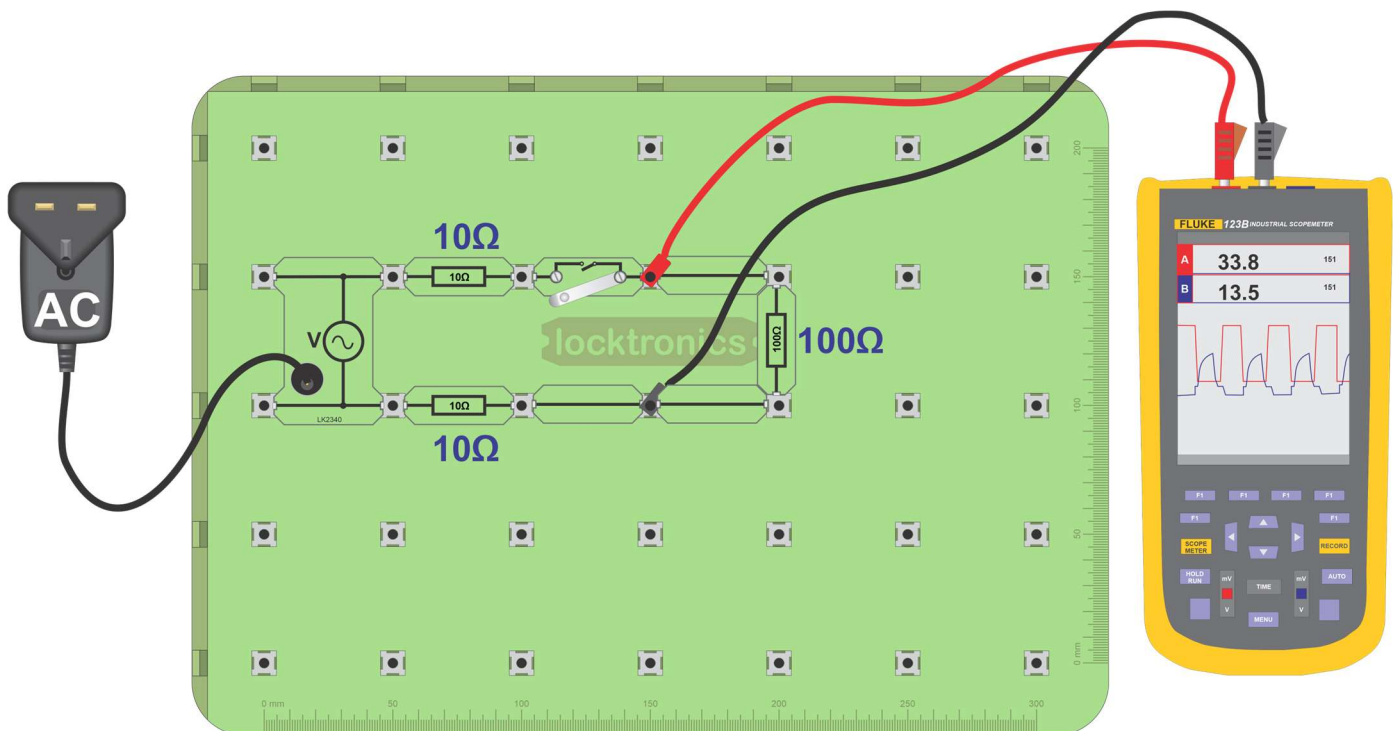
Over to you:

- Build the circuit above using the AC power supply.
- Connect an oscilloscope as shown.
- Typical oscilloscope settings are given below.
- Close the switch, and study the AC trace seen on the screen.
- Sketch it using the axes provided in the Student Handout.

Oscilloscope settings:

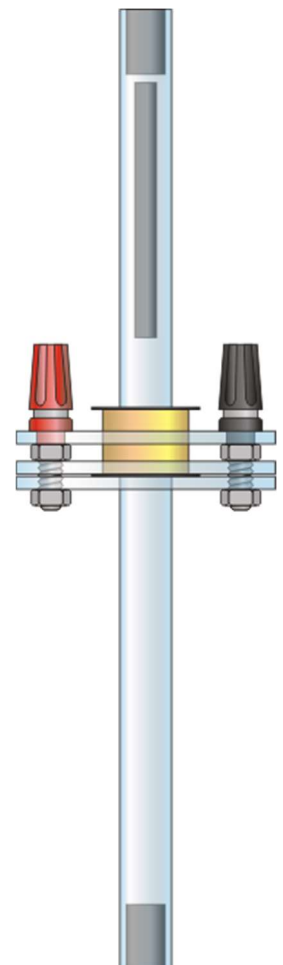**Timebase** -5ms/div   **Voltage range -** ±20V DC   **Trigger mode** - Auto

Trigger channel - ch A   **Trigger direction** - Rising   **Trigger threshold** - 200mV

(You may need to use the 'x10' setting on the oscilloscope probe.)

Worksheet 2
Understanding AC

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Motors, generators and charging systems

So what?

A DC trace is undramatic - just a voltage level that doesn't change over time.

The images below show an AC trace. This shape is known as a **sinusoidal** (or sine-wave) signal.
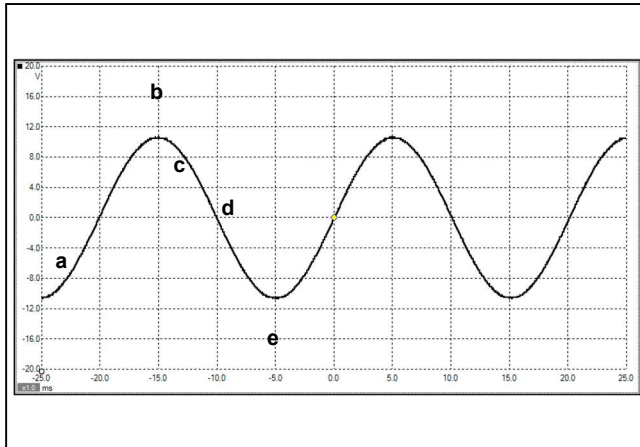
a	Voltage increasing
b	Maximum positive voltage
c	Voltage decreasing
d	Voltage changes direction
e	Maximum negative voltage

- The voltage changes direction when the trace crosses 0V.
- The time taken to produce one cycle (i.e. one peak plus one trough) is called the ***period*** of the AC signal, and is measured in seconds.
- The number of cycles produced per second is known as the ***frequency*** of the AC signal, and is measured in hertz (Hz). 1Hz means one cycle produced every second.

    Frequency and period are connected by the relationship:

$$\text{Frequency} = 1 \,/\, \text{period}$$

- The second picture shows the meaning of the terms ***peak voltage*** (or ***amplitude***), **A**, and ***period* P** of the signal .

    Use the trace to measure these quantities and record the results in the table in the Student Handout.

    Use this value of period to calculate the AC frequency, and record that too.
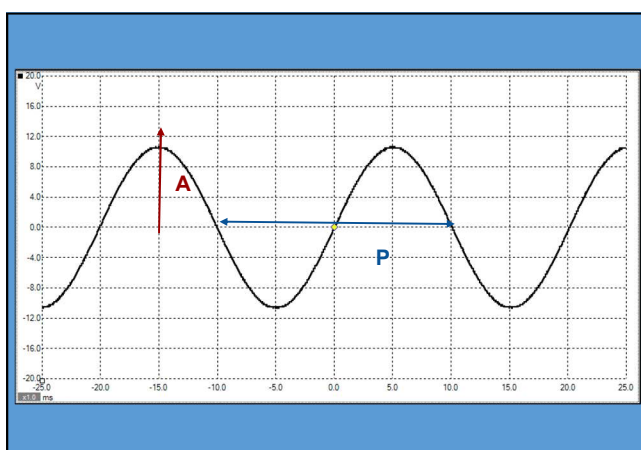
A	Amplitude
P	Period

Worksheet 3
AC vs DC

Most of the auto electrical system uses DC, i.e. current always flows in the same direction and one terminal of a device is always more positive than the other.

The alternator, however, generates AC - current flows first one way and then the other through the device.

Does this mean that the effects cancel out? The answer - a definite 'no'. How do AC and DC compare? That is the task for this worksheet. Photograph shows a typical 12V car battery: all batteries are DC.
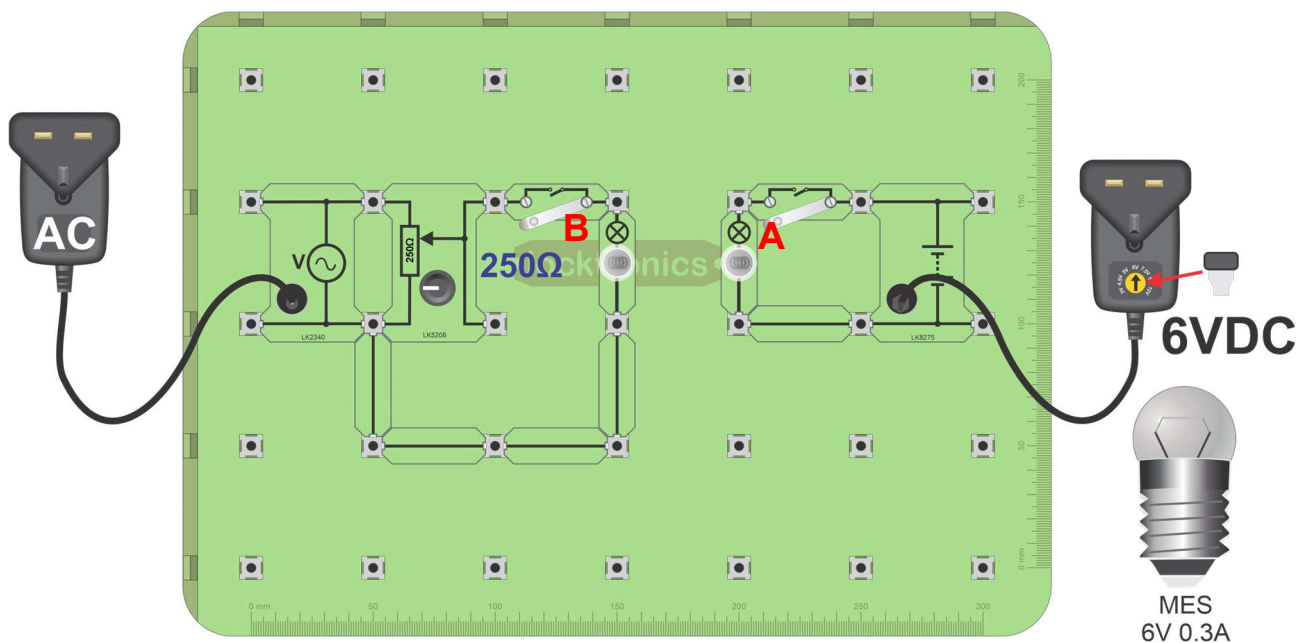
Over to you:

- Set up the **two** circuits shown in the diagram.
  Lamp **A** is powered by the 6V **DC** source, and lamp **B** by an **AC** power supply.
- Adjust the 'pot' until the two bulbs have the same brightness.
  Now, the AC voltage across lamp **B** has the same effect as the DC voltage across lamp **A**.
- Connect a multimeter, set to the 20V DC range, to read the voltage across lamp **A**.
- Record the measurement, known as the RMS value of the AC voltage, in the Student Handout.
- Now connect an oscilloscope across lamp **B**, and measure the peak AC voltage across it.
- Record this measurement in the Student Handout.

  (Note - the layout diagram shows a 'plug top' AC power supply powering lamp **B**.
  A conventional AC signal generator/power supply can be used instead.)

Worksheet 3
AC vs DC

So what?

The investigation you carried out showed that the AC supply to lamp **B** had the same effect as the 6V DC supply - both lamps had the same brightness.

We can put this another way: the **RMS** value of the AC supply was 6V. Although RMS stands for 'root-mean-square', it is more useful to consider it as the DC voltage that would produce the same effect as the AC supply.

The diagram shows a typical AC trace.
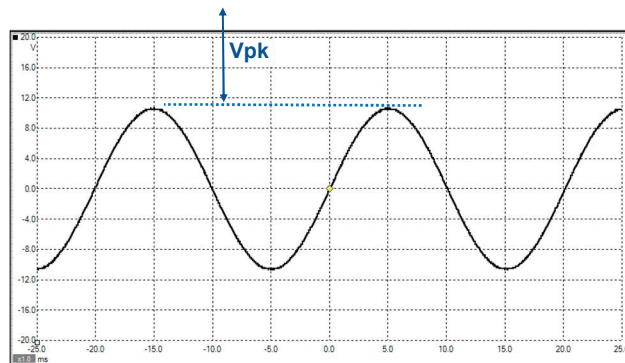
The RMS value, 6V, does not leap out as an obvious characteristic of this trace.

We obtain it in the following way:

- Measure the peak voltage (amplitude) **Vpk**, shown on the trace.
- Record it in the table in the Student Handout.
- Now, divide this peak value by the square-root of 2 (1.4 approximately.)
- Write your answer in the second row of the table.
- You should find that the result is very close to 6V.

This relies on the result, obtained using mathematics, that for a sinusoidal signal:

$$V_{RMS} = V_{pk} / \sqrt{2}$$

Worksheet 4
Half-wave rectifier

Motors, generators and charging systems

Most of a vehicle's electrical system runs on DC. The alternator, however, generates AC. We need to turn AC into DC so that the alternator can service the needs of the system.

This process is called rectification. The device needed is the diode, like that shown in the photograph.

There are several ways in which diodes can rectify AC. This worksheet looks at the simplest - the half-wave rectifier.

Over to you:

- Set up the first circuit, shown below, using the AC power supply.
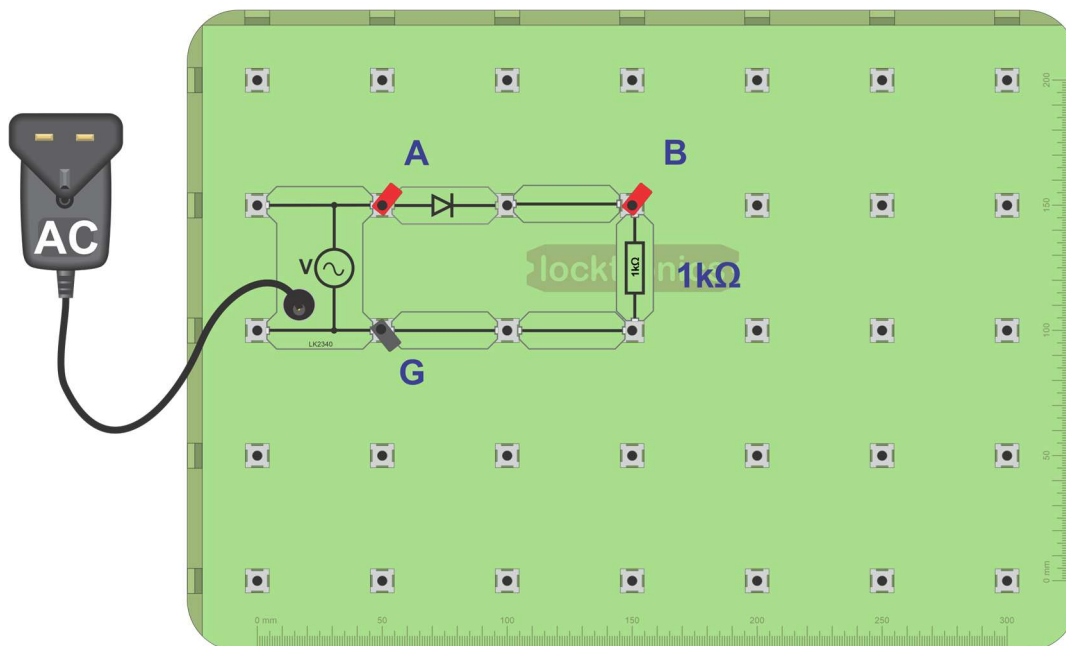
- Connect the oscilloscope earth to the point labelled '**G**'.
- Connect channel **A** to point '**A**' and channel **B** to point '**B**'.
  Suitable settings for the oscilloscope are shown below.

> **Oscilloscope settings**:
>
> **Timebase** -10ms/div   **Voltage range** - ±20V DC   **Trigger mode** - Auto
>
> **Trigger channel** - ch A   **Trigger direction** - Rising   **Trigger threshold** - 200mV
>
> (You may need to use the 'x10' setting on the oscilloscope probe.)

- The 1kΩ resistor represents the load, i.e. all the devices in the auto electrical system.
  Notice that that the voltage across this resistor is DC - it does not change direction.
  However, it is not **smooth** DC.

Worksheet 4

Half-wave rectifier

Over to you continued ...

The performance of the rectifier can be improved by adding a capacitor.
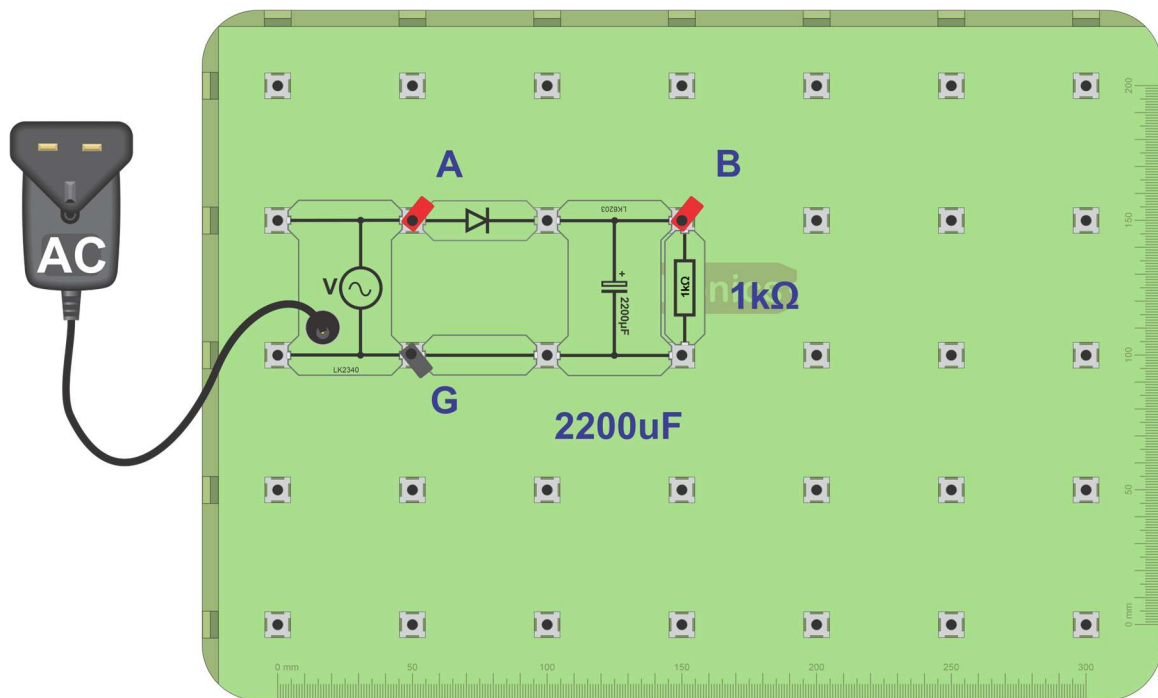
- Modify the circuit by adding a large value capacitor, (2200μF) called a smoothing capacitor, as shown in the diagram above.
- Connect the oscilloscope as before and, using the same settings, observe the waveform across the 1kΩ load.
- Compare your findings with the traces shown on the next page.

Worksheet 4
Half-wave rectifier

So what?

The diode allows current to flow through it (and the 1kΩ load,) in one direction only. More precisely, it acts as a small resistor for currents trying to flow in one direction (when it is 'forward-biased',) and as a very large resistor for currents trying to flow in the other direction, (when 'reverse-biased'.)

The top diagram shows a typical trace obtained from the first circuit.
At the points labelled '**A**', the input current from the AC supply changes direction.
At the points labelled '**B**', the output current does not change direction, i.e. is DC.
The AC input is turned into a DC output (rectified.)
Notice that while the output is DC (as it never crosses the 0V line,) it is not *steady* DC.

The second diagram shows the same signal, seen using a different timebase setting (2ms/div.)
Notice that the DC output, shown in red, is 0.7V (approximately) lower than the AC input.
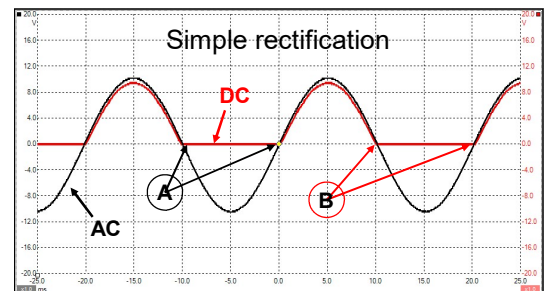The diode does not really conduct until the voltage across it reaches 0.7V. Once it starts, there is a 0.7V drop across the diode, leaving the DC output 0.7V below the AC input at all points.
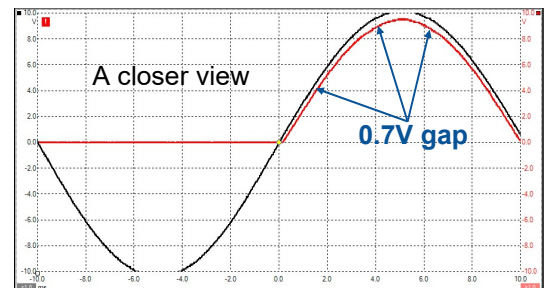
The third diagram shows the effect of adding a smoothing capacitor. The output voltage is now both DC and steady.
There are issues about the size of the capacitor. These will be explored later.
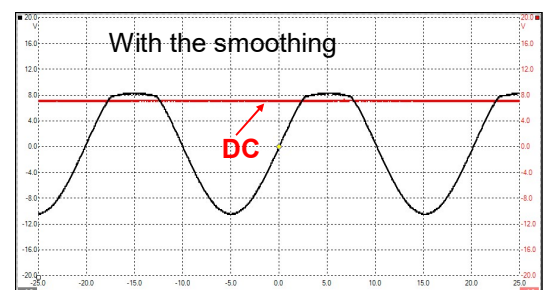
Summary:

- The process of turning AC into DC is called rectification. Half-wave rectification uses only one diode, but results in only half of the AC signal being turned into DC. No current at all flows for half of the time.

- The silicon diode conducts only when it is forward-biased, and there is a voltage of at least 0.7V across it. The output of this half-wave rectifier is 0.7V less than the AC input, and is not smooth DC.A large capacitor can be connected across the output of the half-wave rectifier to smooth the DC signal produced.

Worksheet 5
Full-wave rectifier

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A half-wave rectifier circuit does not make efficient use of the electrical energy on offer. For half of the time, no current flows through the load.

A full-wave rectifier overcomes this limitation, but uses several diodes to do so, and drops more of the AC voltage across them as a result.

Nevertheless, it is the most common solution to converting the output of the alternator from AC to DC.
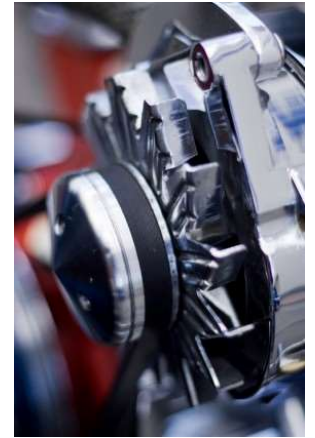
Over to you:

- Set up the circuit shown below.
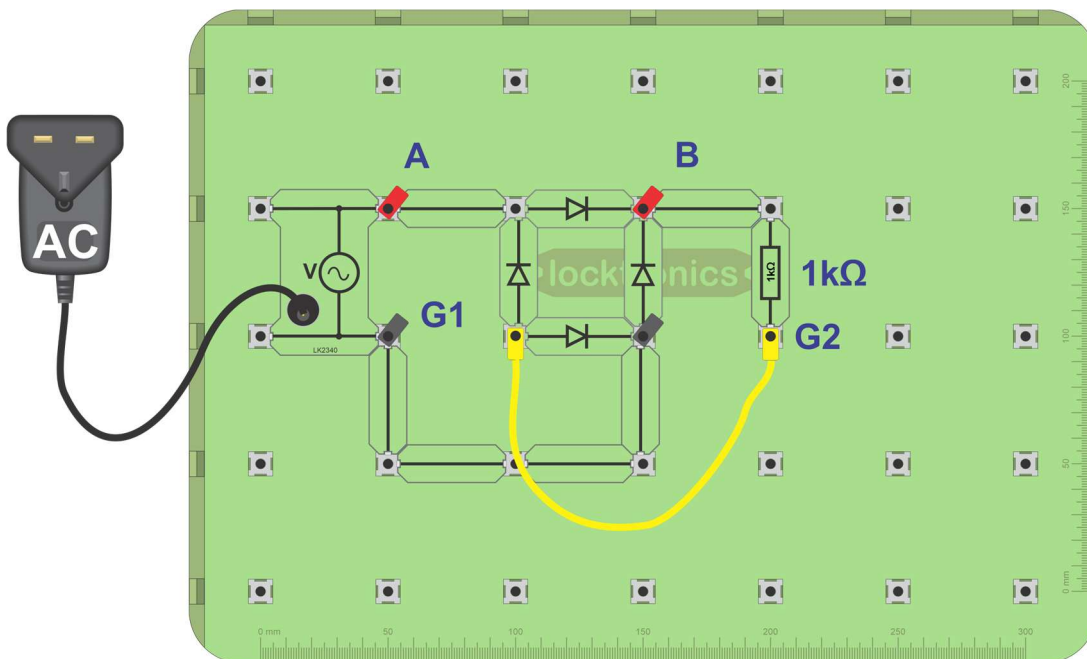
- Connect an oscilloscope to points **A** and **G₁** to monitor the AC input signal .
- **Then disconnect it.**
  Instead, connect it to points **B** and **G₂** to show the DC signal across the load.

> **Important: If the oscilloscope has two channels, DO NOT connect one to the points labelled 'AC', and the other to 'DC'. This will short-circuit one of the diodes.**

- The oscilloscope settings are the same as the ones used in the last investigation.
- Sketch both traces in the Student Handout.

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Over to you continued ...

- The DC output varies less than that in the half-wave circuit, but it is still not steady DC.

  Try the same remedy as before - a large capacitor connected across the output of the full-wave rectifier as shown in the layout below.
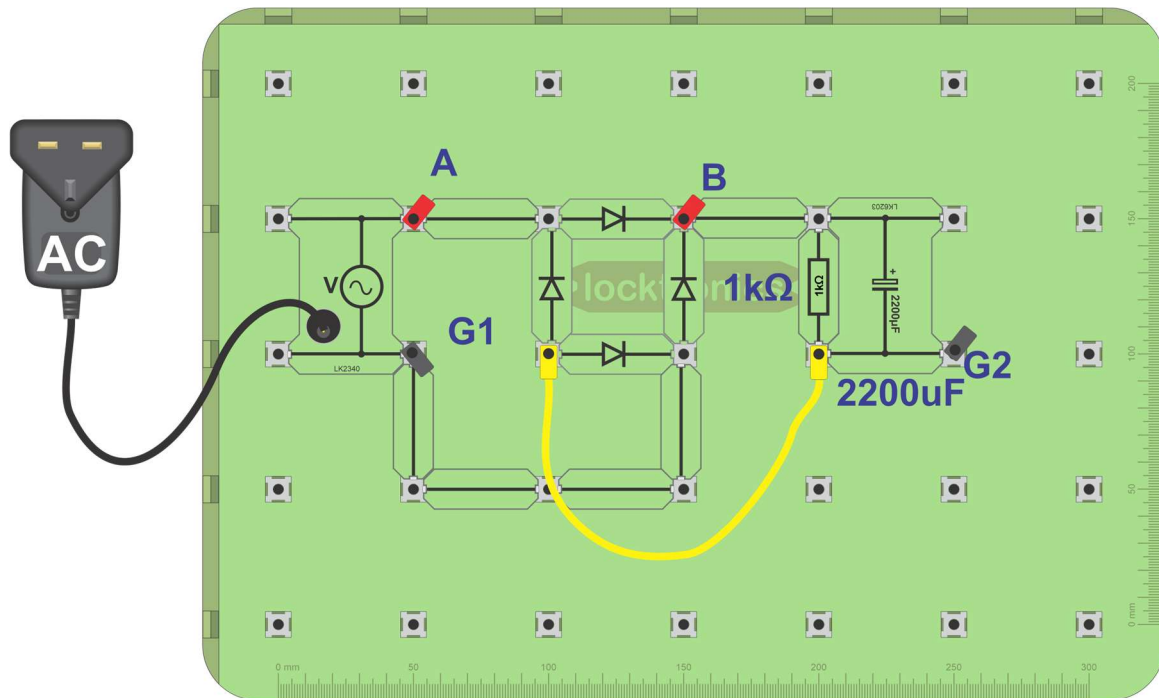
- Connect the oscilloscope to points **B** and **G$_2$**.
- Using the same settings as before, (given below,) view the signal across the 1kΩ load again.
- Sketch what you see, using the axes provided in the Student Handout.

Oscilloscope settings:

Timebase -10ms/div   **Voltage range -** ±20V DC   **Trigger mode** - Auto

Trigger channel - ch A   **Trigger direction** - Rising   **Trigger threshold** - 200mV

(You may need to use the 'x10' setting on the oscilloscope probe.)

Worksheet 5
Full-wave rectifier

So what?

The circuit diagram for the full-wave rectifier is shown opposite.

Earlier, it was stated that you cannot measure the AC and DC signals simultaneously, using two oscilloscope channels, in this circuit.

To do that, you would have to connect one channel to points **A** and **C**, to measure the AC signal, and the other to points **B** and **D**, to measure DC.

However, as the channels share a 0V connection, that would connect together points **C** and **D**, say, through this common connection, and short-circuit one of the diodes as a result.
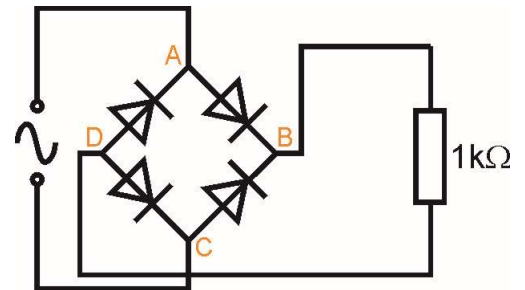
The three oscilloscope traces opposite show:
- the AC signal going into the full-wave rectifier;
- the DC output;
- and the effect of adding a smoothing capacitor.
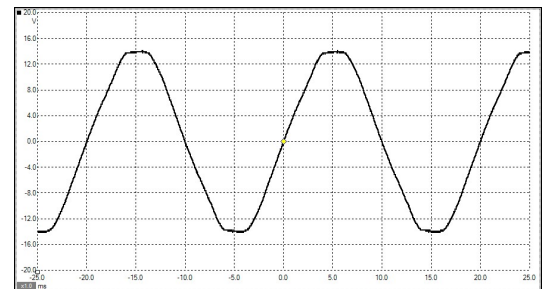
The DC output, shown in the middle trace, is an improvement on the half-wave output, as current flows through the load throughout the AC cycle. Again, the signal is DC , because the trace never crosses the 0V line.
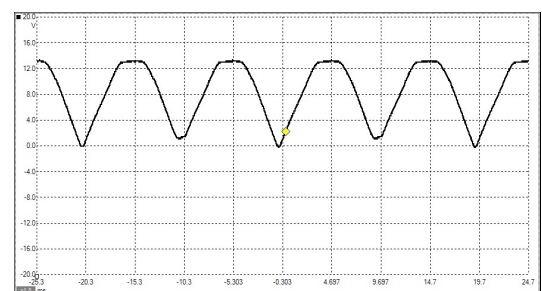
Notice that, after rectification, the peaks are spaced apart at half the signal period i.e. the full-wave signal has twice the frequency of the AC supply.

However, once again, a smoothing capacitor is needed to provide steady DC.
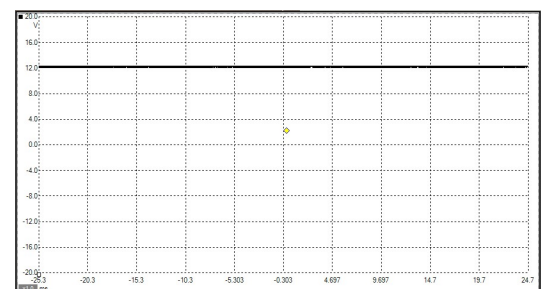
Worksheet 6
Ripple voltage

Many electronic devices require steady DC power and are unstable with 'noisy' supply voltages. A lead-acid car battery provides steady DC, but an alternator output is AC and so must be rectified and smoothed by connecting a large value capacitor across the output.

This worksheet investigates the link between the size of load and the size of capacitor needed to produce a steady DC voltage for that load.

The photograph shows capacitors connected to a Toyota ECU.
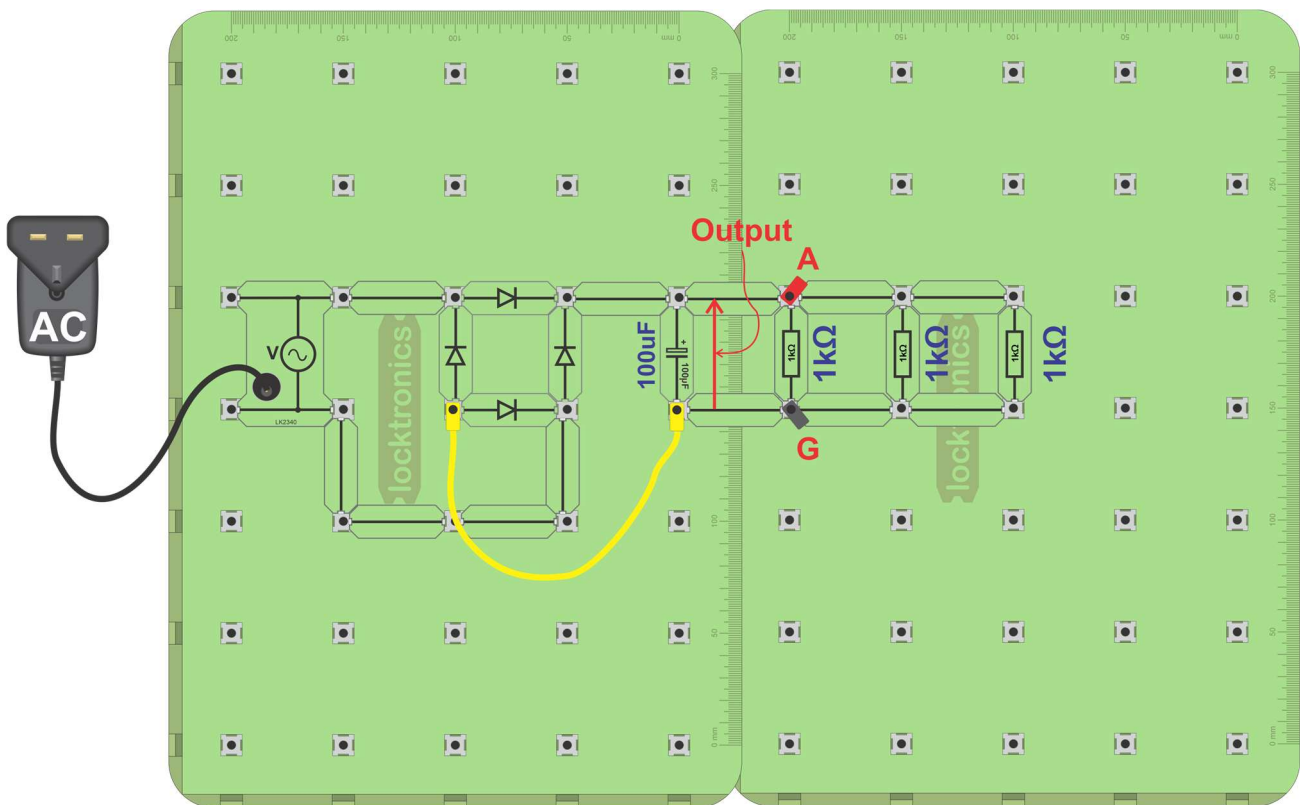
Oscilloscope settings:

Timebase -10ms/div	**Voltage range** - ±20V DC	**Trigger mode** - Auto
Trigger channel - ch A	**Trigger direction** - Rising	**Trigger threshold** - 200mV

Over to you:

- Build the layout shown above but using a load of only one 1kΩ resistor to begin with.
- Connect an oscilloscope to points 'A' and 'G' to monitor the output of the rectifier.
- Measure the ripple voltage present on the output, (illustrated on the next page.)
- Next, add a second 1kΩ resistor as shown in the layout. Repeat the measurement.
- Do the same for a third 1kΩ resistor and for both capacitor values shown in the table in the Student Handout. Enter all measurements in the table.

So what?

When the diodes are conducting sufficiently, the current drawn by the load (the 1kΩ resistors) comes from the AC power source. As the AC voltage falls, the current through the diodes drops.

The smoothing capacitor acts as a reservoir of electric charge. Increasingly, as the AC voltage falls, the load draws current from the smoothing capacitor instead. This discharges as a result and the voltage across it drops. The greater the current demanded, the faster it discharges, and the bigger the ripple voltage.

The diagrams show typical oscilloscope traces for this investigation. They show the varying degrees of success in achieving steady DC. The size of the ripple voltage is a measure of this success.

One 1kΩ resistor and 100uF capacitor

- The traces for the circuits that use a 100μF capacitor do not show steady DC at all for the currents demanded.

Two 1kΩ resistors and 100uF capacitor

- As more resistors are added, more current is drawn and the ripple voltage gets bigger (worse). The solution - use a bigger capacitor to smooth the supply voltage.

Three 1kΩ resistors and 100uF capacitor

- The effect of increasing the smoothing capacitor to 2200μF is shown in the bottom trace.

Three 1kΩ resistors and 2200uF capacitor
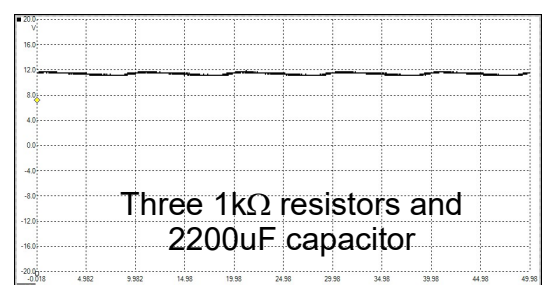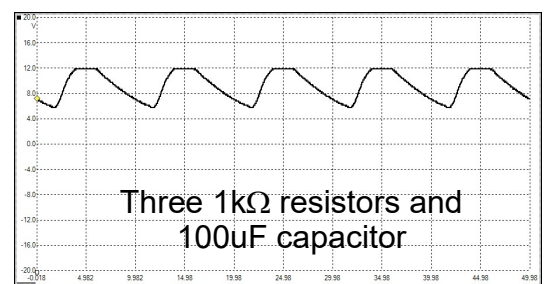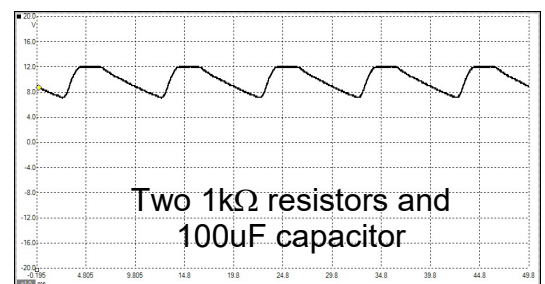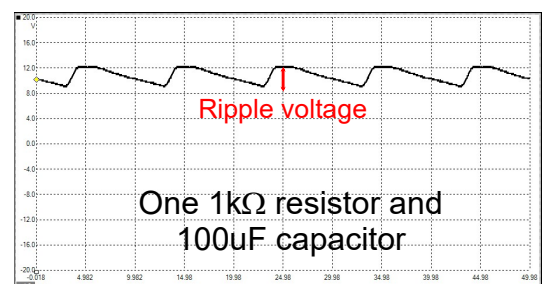
A battery behaves like a huge capacitor, which smoothes out the peaks and troughs from the rectifier.

Worksheet 7
Motor principles

Electric motors come in all shapes and sizes: from the small motors you find in toy trains to the large motors you find in lifts.

All work on the same principle:
electric currents create magnetic fields which attract and repel mechanical actuators to give movement.

The photograph shows an automotive electric motor.
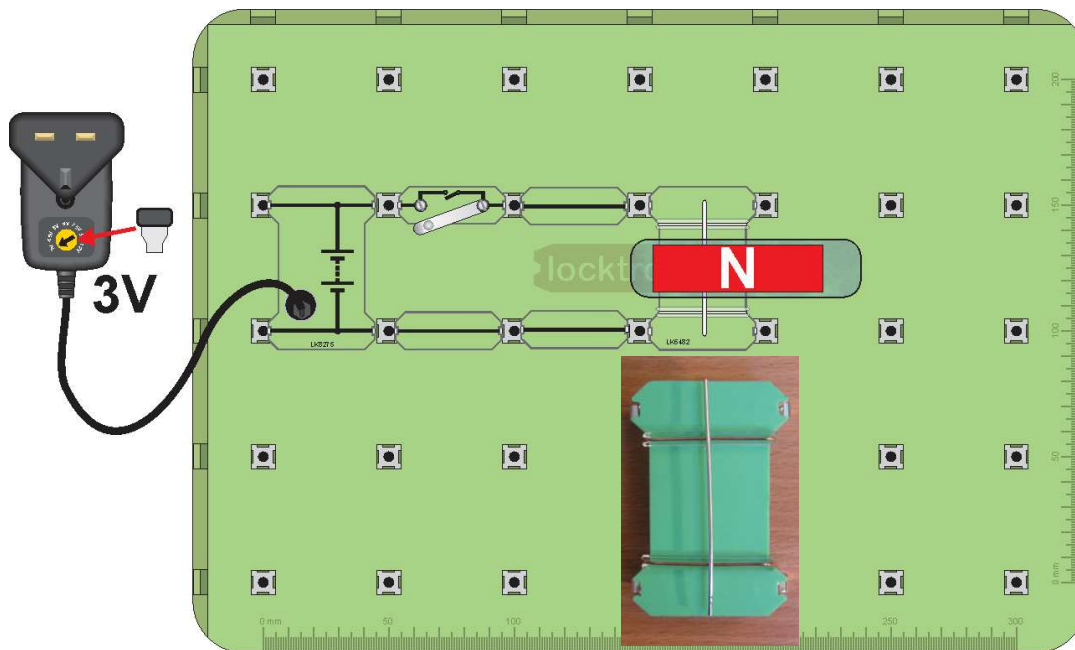
Over to you:

- This investigation uses the Motor-effect carrier, shown above.
  It has two fixed conductors, with a moveable metal rod sitting on top, across them.
  Build the system shown.
- For clarity, the magnet has not been pushed right over the metal rod. Push it right across, so that the moveable rod sits in the middle of its magnetic field.
- Set the power supply to 3V and switch it on.
- Press the push switch, and notice what happens.

Worksheet 7
Motor principles

Over to you continued ...

- Next, flip the magnet over so that the South pole is on top.
- Press the push switch again. What is the difference?
- Reverse the current direction by rotating the power supply carrier so that the negative end (short line on the symbol) is at the top.
- What happens now when you press the push switch?
- Change the power supply voltage to 12V to increase the current flowing through the rod.
- Can you see any difference when you close the push switch?
- Use your observations to complete the sentences in the Student Handout.

So what?

Here's the underlying theory:
- A current is a flow of electrons, tiny negatively-charged 'particles' found in all atoms.
- When electrons move, they generate a magnetic field.
- This interacts with the field of the magnets, causing attraction / repulsion, except that it acts at right-angles to both the current direction and the magnetic field.
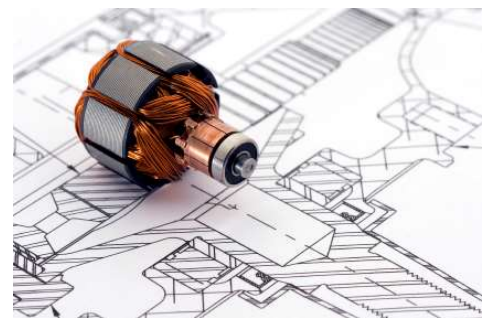
Fleming's Left-hand Rule:

John Ambrose Fleming devised a way to work out the direction a wire will move in (also known as the *motor rule*):

Clamp your **left**-hand to the corner of an imaginary box, so that thumb, fore finger and centre finger are all at right-angles to each other.

Then:
- line up the **F**ore finger so that it points along the magnetic **F**ield (from North pole to South pole);
- line up the **C**entre finger with the **C**urrent (flowing from the positive battery terminal to the negative);
- the thu**M**b now points in the direction of the resulting **M**otion.

Worksheet 8
The electric motor

Motors, generators and charging systems
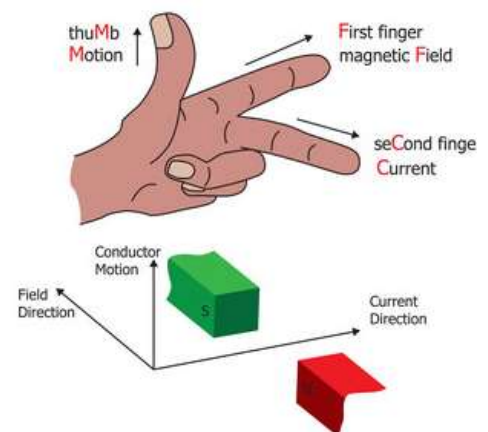
Electric motors usually consist of a coil rotating inside the magnetic field of either a permanent magnet or an electromagnet.

As the coil rotates, the current flowing in it must reverse periodically to reverse the magnetic field direction.

In PMDC (Permanent Magnet Direct Current) motors, this is achieved through a split commutator and brushes.

The photograph shows the miniature Locktronics open-frame motor.

6V
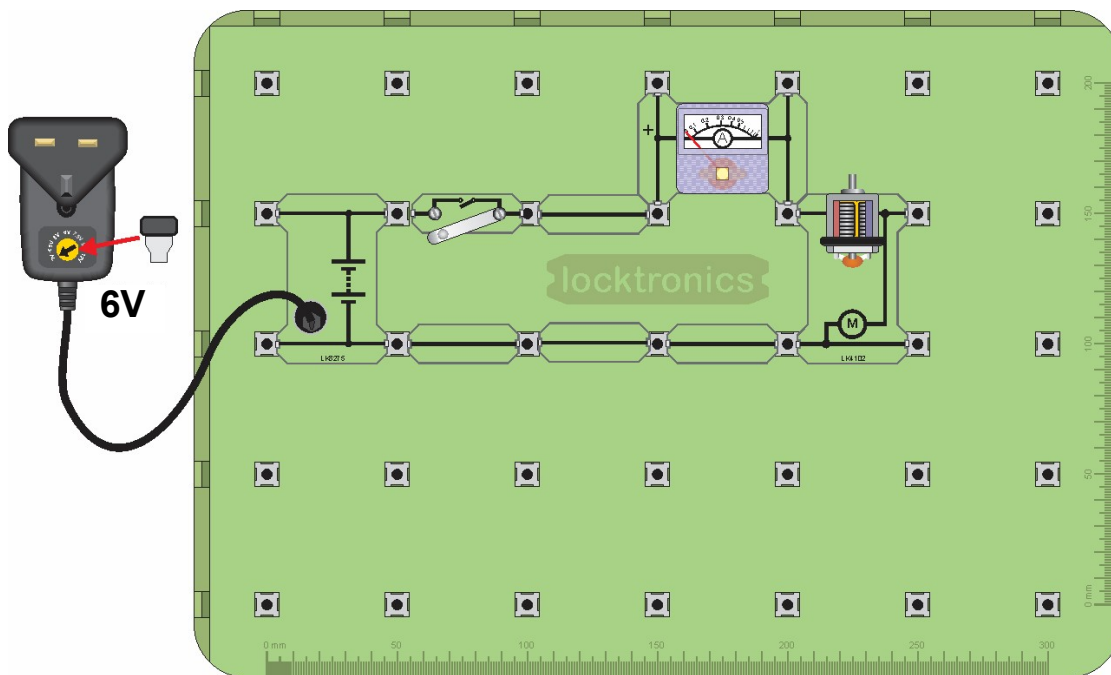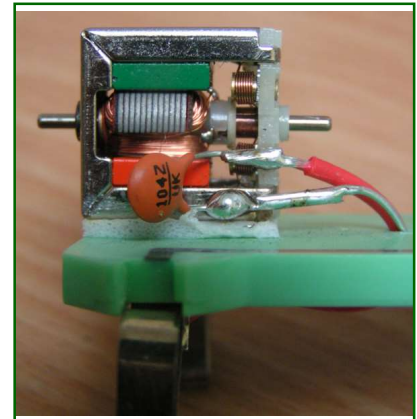
Over to you:

- Build the system shown above.
- Set the power supply to 6V and switch it on.
- Press the push switch, and watch the ammeter reading.
- Next, keeping the push-switch closed, press gently on the motor shaft to slow down the motor. Watch the ammeter reading as you do so.
- Keeping the push-switch closed, press harder on the shaft to stop the motor rotating at all, for a moment. Again watch the ammeter reading as you do so.
- Record your measurements in the table in the Student Handout and answer the question.

Worshseet 8
The electric motor

So what?

There are two ways to reverse the current in a motor .

1. For an AC motor we can use **slip-rings** with brushes:

   The picture shows one form of slip-ring.
   Each end of the coil is connected to its own full brass ring.
   Electrical contact is made to each ring with carbon brushes
   that mould themselves to the shape of the ring, reducing
   contact resistance.
   The coil is supplied with AC and so the current automatically
   changes direction in step with the mains supply.

2. For a DC motor we can use a **commutator** with brushes:

   The diagram shows the design of a simple commutator, a
   brass drum, split into two halves, separated by an insulator.
   Electrical contact is made by carbon brushes. The coil is
   connected to the two halves at **X** and **Y**. As the coil rotates,
   X is connected to the positive supply for roughly half of the
   time and then to the negative supply.
   At all times, **Y** is connected to the opposite supply to **X**.
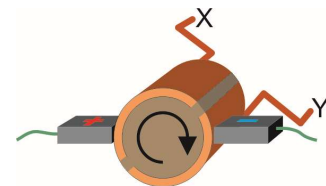
The pictures show a typical design of carbon brush, and a DC electric motor rotor with several windings. Its rotor contains a large number of coils, and so requires a more complicated commutator.
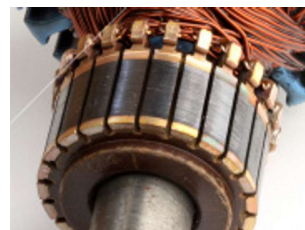
The current is a minimum when the motor is spinning fastest - why?

When a coil spins round inside a magnetic field, it generates a voltage. The faster it spins, the greater the voltage. This voltage opposes the external voltage producing the motion.
(Otherwise, we could switch off the external voltage, and have perpetual motion!)

As a result, at full speed, the overall voltage, and so the current, is reduced.

Putting it another way, when we ask the motor to do more work, spinning against the extra friction of us pressing on the axis, it needs more current.

Traditionally, DC motors are the most common type found in vehicles. They are used to drive fans, windscreen wipers, electric seats, etc.

However, they are rapidly being replaced by brushless DC motors, which are more efficient and weigh less.

The photograph shows a VW DC motor with an integrated gearbox.
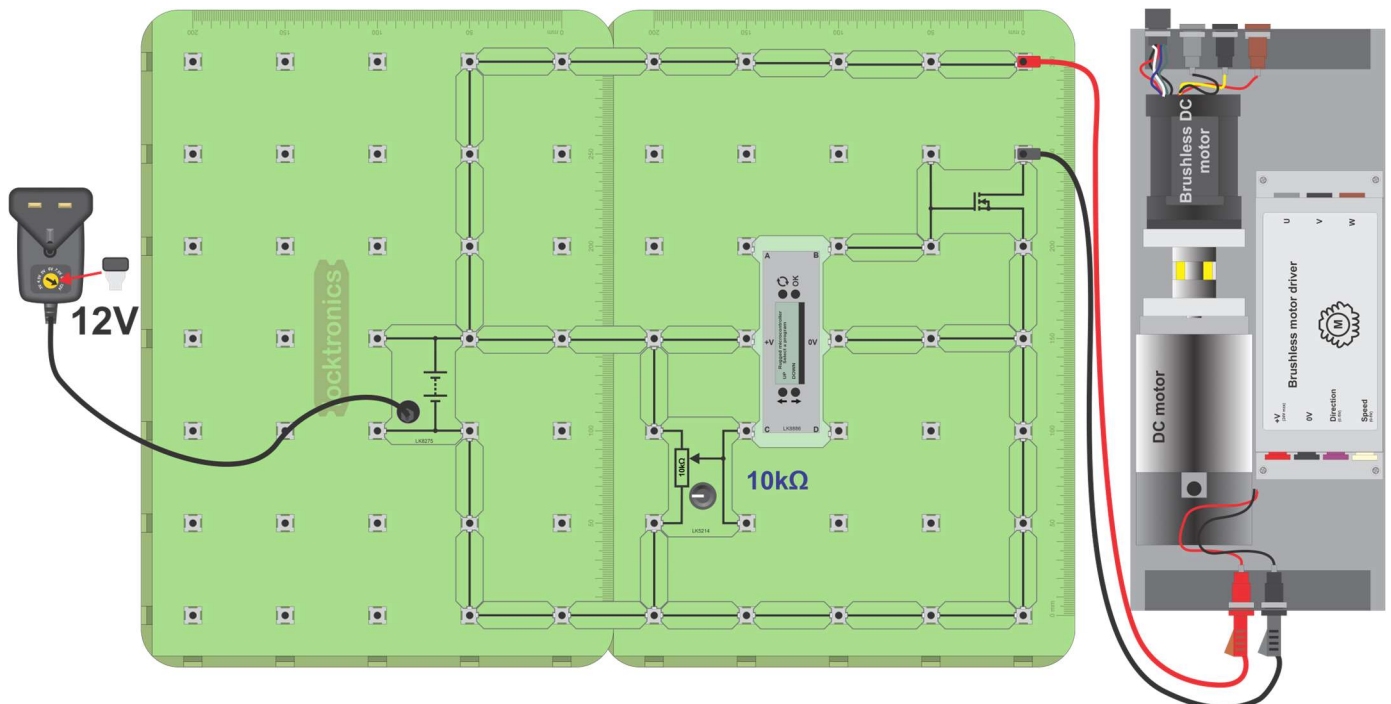
Over to you:

- Build the circuit shown in the layout above.
- Reset the Micro ECU and use the 'UP' and 'DOWN' keys to select program 14 - DC motor control. Press 'OK'.
- Adjust the 'pot' until the display on the ECU shows an output drive of 30%.
- Use an oscilloscope to view the output signal on terminal **B** of the ECU.

Oscilloscope settings:		
Timebase -500µs/div	**Voltage range -** ±20V DC	**Trigger mode** - Auto
Trigger channel - ch A	**Trigger direction** - Rising	**Trigger threshold** - 5V

- Sketch the waveform on the graph paper provided in the Student Handout.
- Adjust the 'pot' until the ECU display shows an output drive of 70% and do the same again.

Worksheet 9
The DC motor

So what?

- Typically, a 12VDC power supply uses PWM to vary the speed of DC motors in vehicles. A microcontroller in an ECU is used with a field-effect transistor (FET) to control this.

- Varying the mark:space ratio, the width of the PWM pulse from the DC power supply, has the same effect as varying the DC voltage. It alters the average power delivered to the motor and, as a result, its speed.

- In motor circuits, FETs are used to 'sink' current rather than supply current, i.e. they are used in the path from the motor to ground.

- The diode connected to the FET is called a 'suppression' diode. When the FET turns off, the DC motor produces a positive back-emf 'spike', which is clamped at 12V by the diode, protecting the circuitry from high voltages.

Over to you:

- The photographs below show a dissected DC motor, with the main parts labelled.

- In the Student Handout, explain the function of the split ring and the carbon brushes.

Commutator

Rotor windings

Magnets

Laminated iron rotor

Balance weight

Carbon brushes

Worksheet 10
The brushless DC motor

Motors, generators and charging systems
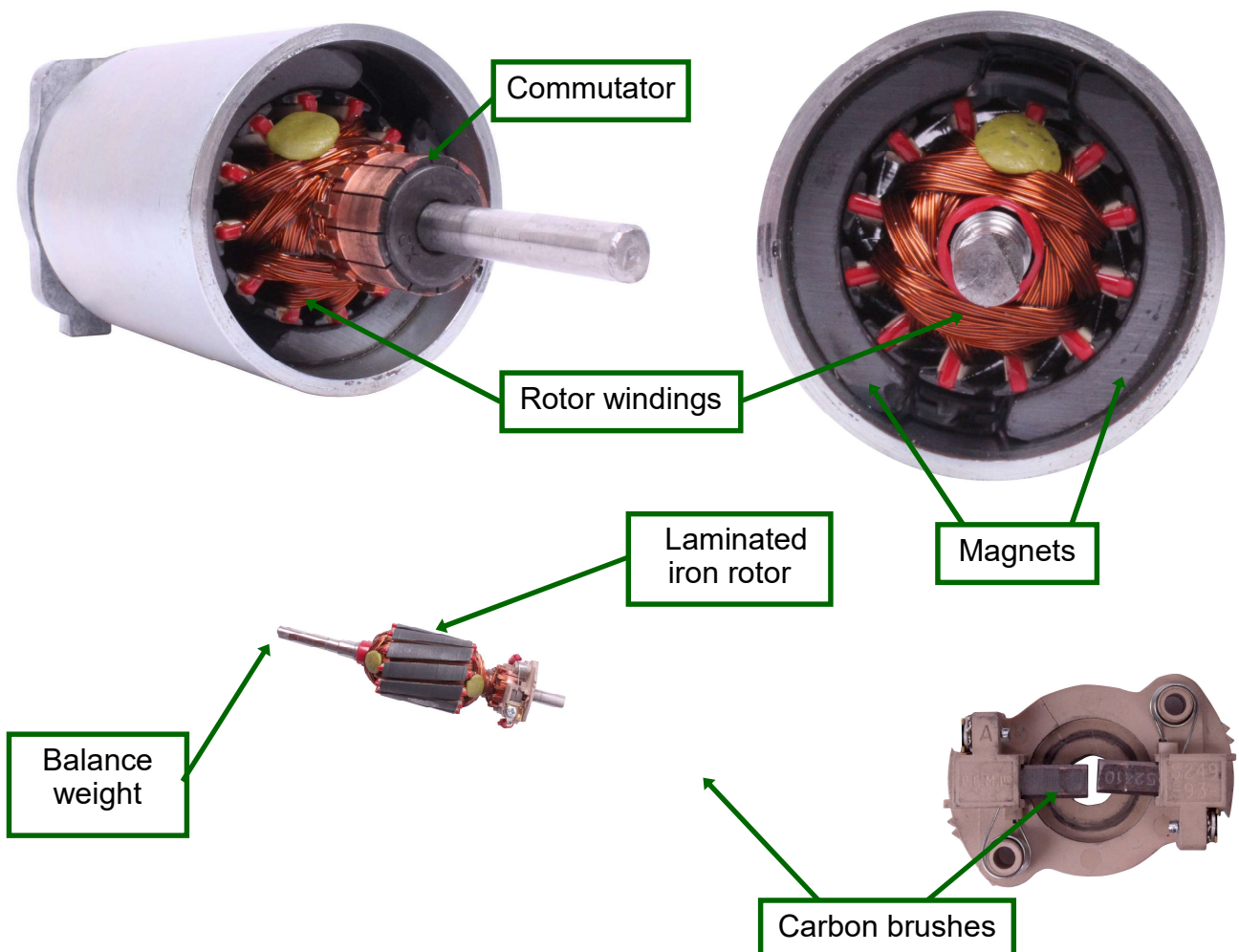
Brushless DC motors are lighter in weight than the normal DC motors. Compare the two motors on the 'DC motor /brushless motor' board - both rated at 50W. However, the brushless motor needs a complicated three-phase power supply to generate separate power signals for the three stator coils. It is so efficient and powerful that this complexity is worth it.

Photograph shows a brushless motor mounted on an axle.
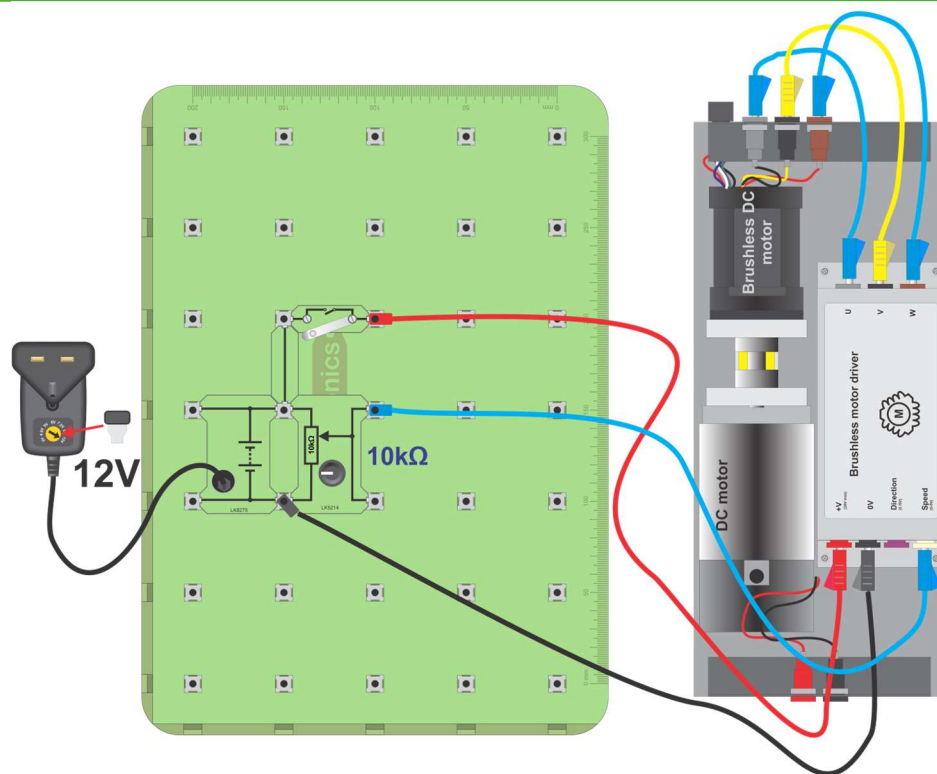
Over to you:

- Build the circuit shown above.
- Set the 'pot' to the minimum output position (fully anticlockwise).
- Close the switch.
- Brushless motors need to be started at a slow speed and then ramped up to full speed. Turn the 'pot' slowly to make the brushless motor start rotating and speed up.
- Use an oscilloscope to look at the waveform generated between sockets **U** and **V** on the 'Brushless motor driver' rotating at maximum speed. Suitable settings are shown above.
- Sketch the waveform on the graph in the Student Handout.

Oscilloscope settings:		
Timebase -2ms/div	**Voltage range** - ±5V DC	**Trigger mode** - Auto
Trigger channel - ch A	**Trigger direction** - Rising	**Trigger threshold** - 1V

Worksheet 10
The brushless DC motor

So what?

- The three-phase power supply is housed in the 'DC brushless motor driver' box in the HP2001 DC motor / Brushless motor module.
- It generates a complex three-phase waveform that includes 'gaps' where the controller takes voltage measurements to determine the position of the rotor and control the timing of the waveform. For this, this system uses a technique called 'back-emf sensing'.
- For this module a voltage varying between 0V and 5V controls the speed.

Over to you:

- On the page below, you can see photographs of the Brushless DC motor dissected with the main parts labelled. You can see the Hall-effect sensors used to sense rotor position.
- In the Student Handout, explain the key differences between this motor and the DC motor.

Stator coils

Hall-effect sensors

Magnetic rotor
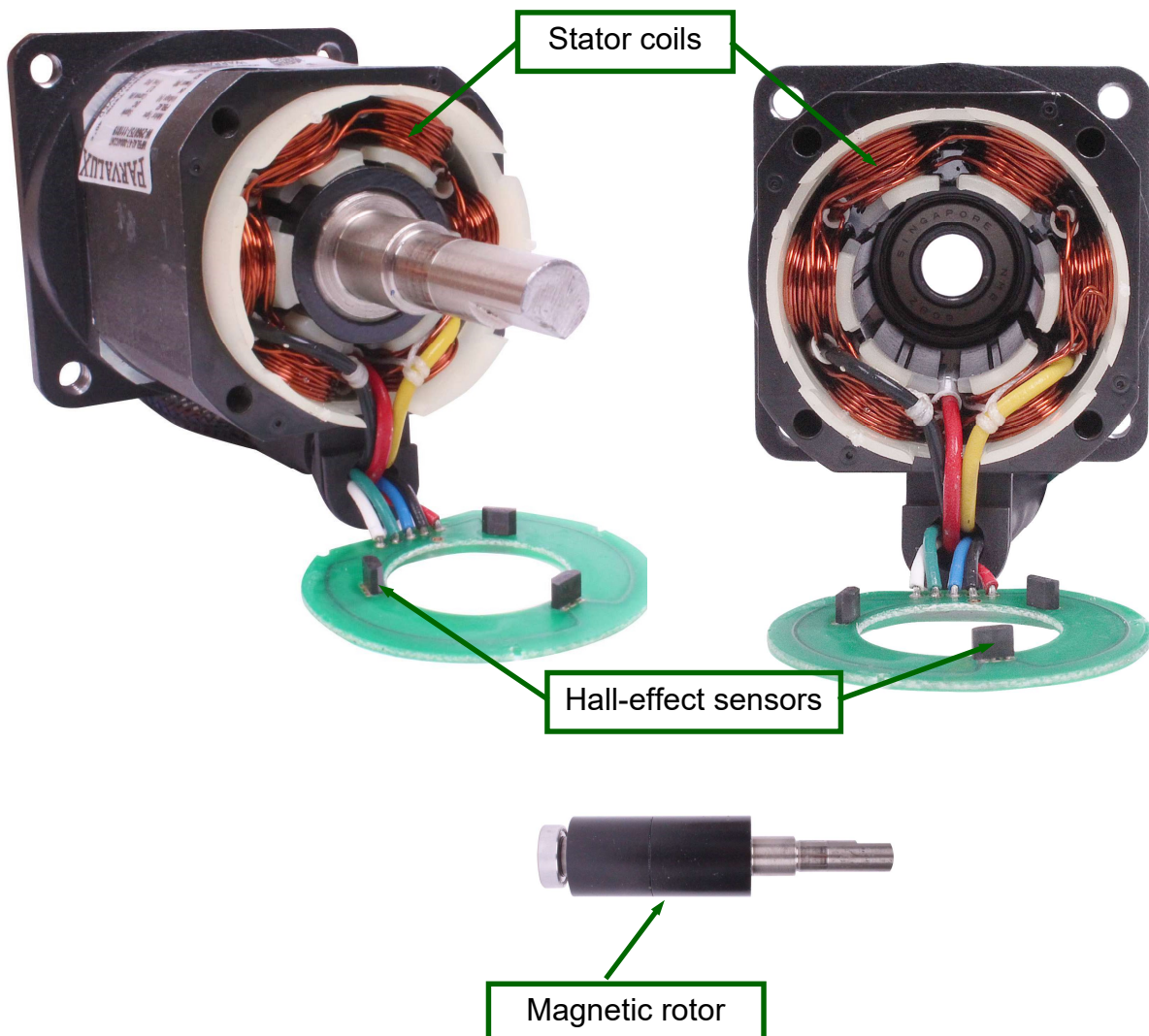
Worksheet 11

The AC generator

Three-phase systems - generators, motors, power transmission lines - are more energy efficient than their two-phase or single-phase equivalent.

In vehicle electrical systems, nearly all alternators and most motors are three-phase devices.

The photograph shows part of a Toyota Prius electric motor.
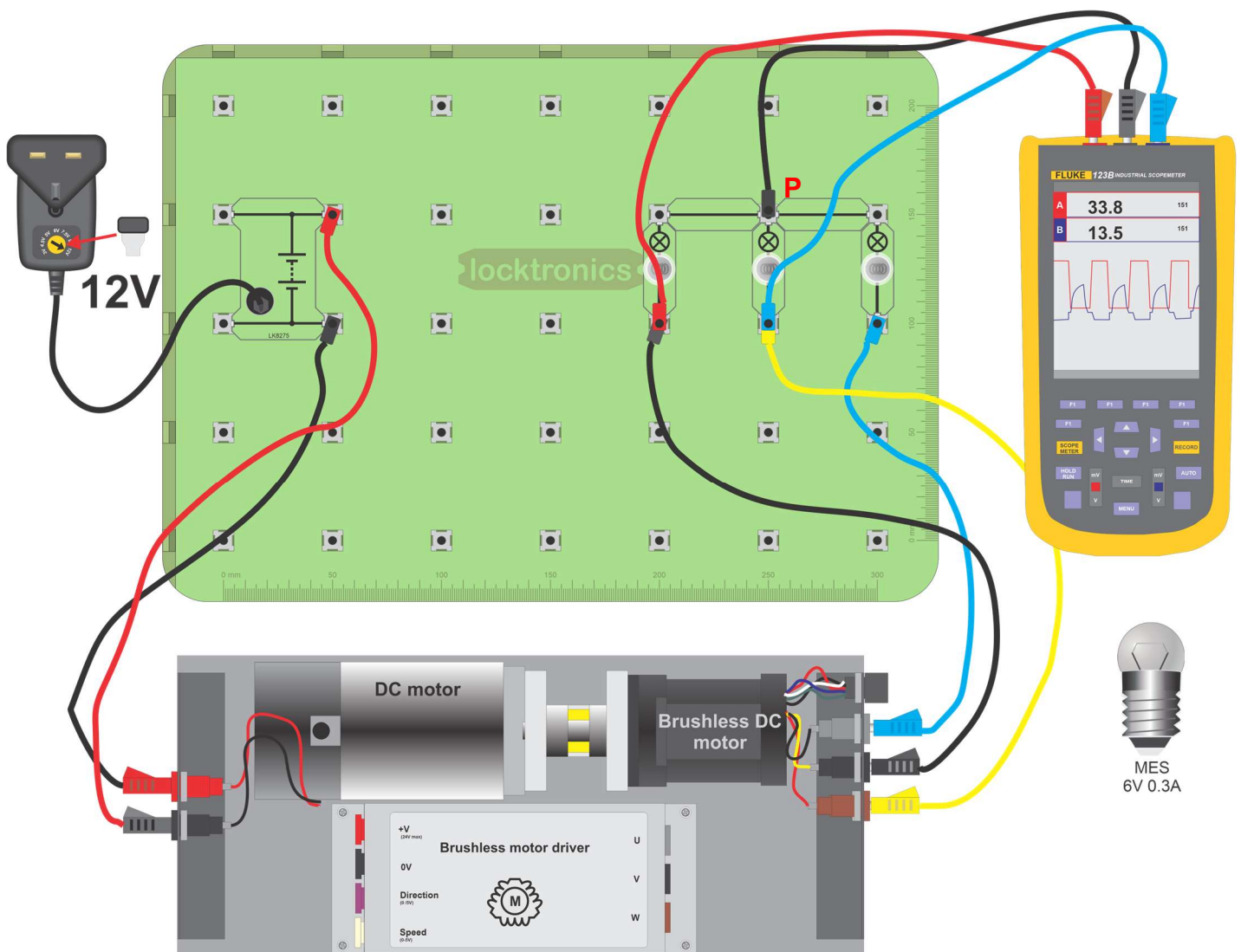
Worksheet 11
The AC generator

Over to you:

- Construct the system shown on the previous page, with three bulbs acting as loads for the brushless DC motor.

- Using a standard 12V power supply, drive the DC motor at a fixed speed.

- Use an oscilloscope to look at the three signals coming out of the brushless DC motor, with the oscilloscope earth connected to the point labelled **P**.

<div style="border:1px solid green; padding:10px">

Oscilloscope settings:

Timebase -5ms/div   **Voltage range -** ±5V DC   **Trigger mode** - Auto

Trigger channel - ch A   **Trigger direction** - Rising   **Trigger threshold** - 1V

</div>

- Use the axes in the Student Handout to sketch all three waveforms on the same graph.

- Reduce the power supply to output 9VDC. What effect does this have on the waveforms coming out of the brushless motor?

- What do you conclude about the link between power generated and rotational speed?

- Write your answers to these questions in the Student Handout.

So what?

The three signals are spaced equally in time.

The time between peaks and troughs is exactly one-third of the period of the waveform.

Sometimes we say that the signals are '120 degrees apart'.

(There are 360^0 in one cycle of the signal and the three waveforms are one-third of a cycle apart.)

The three-phase rectifier is very like the single-phase full-wave rectifier - it just has another two diodes in it.

The photograph shows a three-phase rectifier from an alternator, with diodes clearly visible.
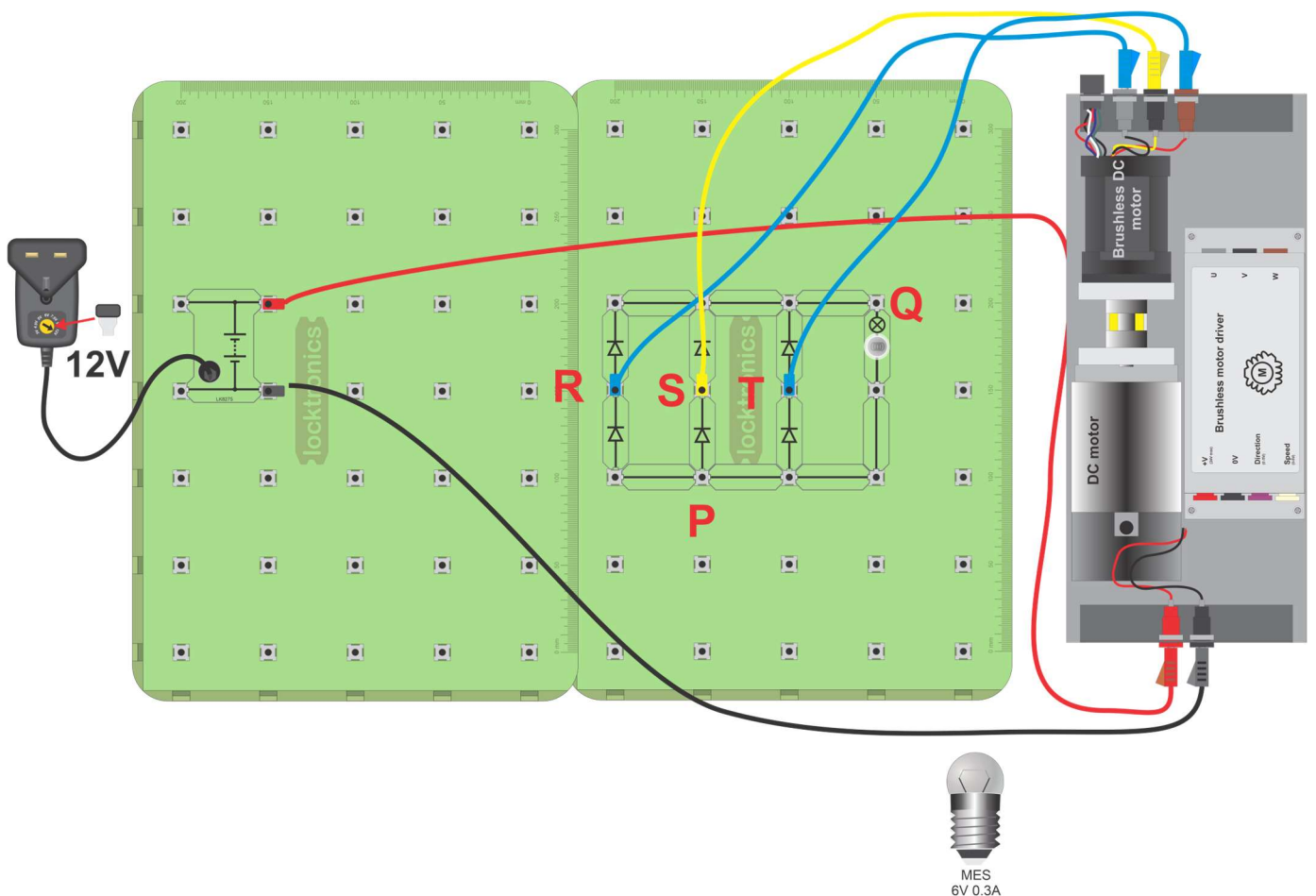
12V

R **S** **T**

Q

P

MES
6V 0.3A

Worksheet 12
Three-phase rectification

Over to you:

- Set up the circuit shown on the previous page.

  The bulb acts as a load so that some current flows.

- Using a two-channel oscilloscope, with the settings shown below:

  - connect the 0V terminal to the point labelled **P**.

  - connect oscilloscope channel **A** to the point labelled **R**.

  - connect channel **B** firstly to the point labelled **S** and then **T**.

  > **Oscilloscope settings**:
  >
  > **Timebase** - 5ms/div   **Voltage range -** ±5V DC   **Trigger mode** - Auto
  >
  > **Trigger channel** - ch A   **Trigger direction** - Rising   **Trigger threshold** - 200mV

- Using the axes in the Student Handout, sketch the signals seen at **R**, **S** and **T**.

  Don't worry too much about the size of the voltage - just try to get the timing relationships correct.

- Next, look at the voltage across the bulb, by connecting channel **A** to point **Q**.

  Explain the connection between this waveform and those seen at **R**, **S** and **T**.

- Add a 2200μF capacitor in parallel with the bulb. What happens to the oscilloscope traces?

So what?

- In worksheet 11,on AC generators, we said that the waveform peaks were 120^0 apart.

- You should now see that the rectified peaks, at **R**, **S** and **T**, are 60^0 apart. This compares to the single phase bridge rectifier where peaks were 180^0 apart.

The DC motor and DC generator are essentially the same electrical machine:

- Supply it with electric current and it becomes a motor.
- Drive the rotor around and it generates electricity.

The photograph shows a small DC dynamo on a bicycle wheel.

12V

10kΩ

100Ω

Brushless DC motor

DC motor

Brushless motor driver

direction of rotation
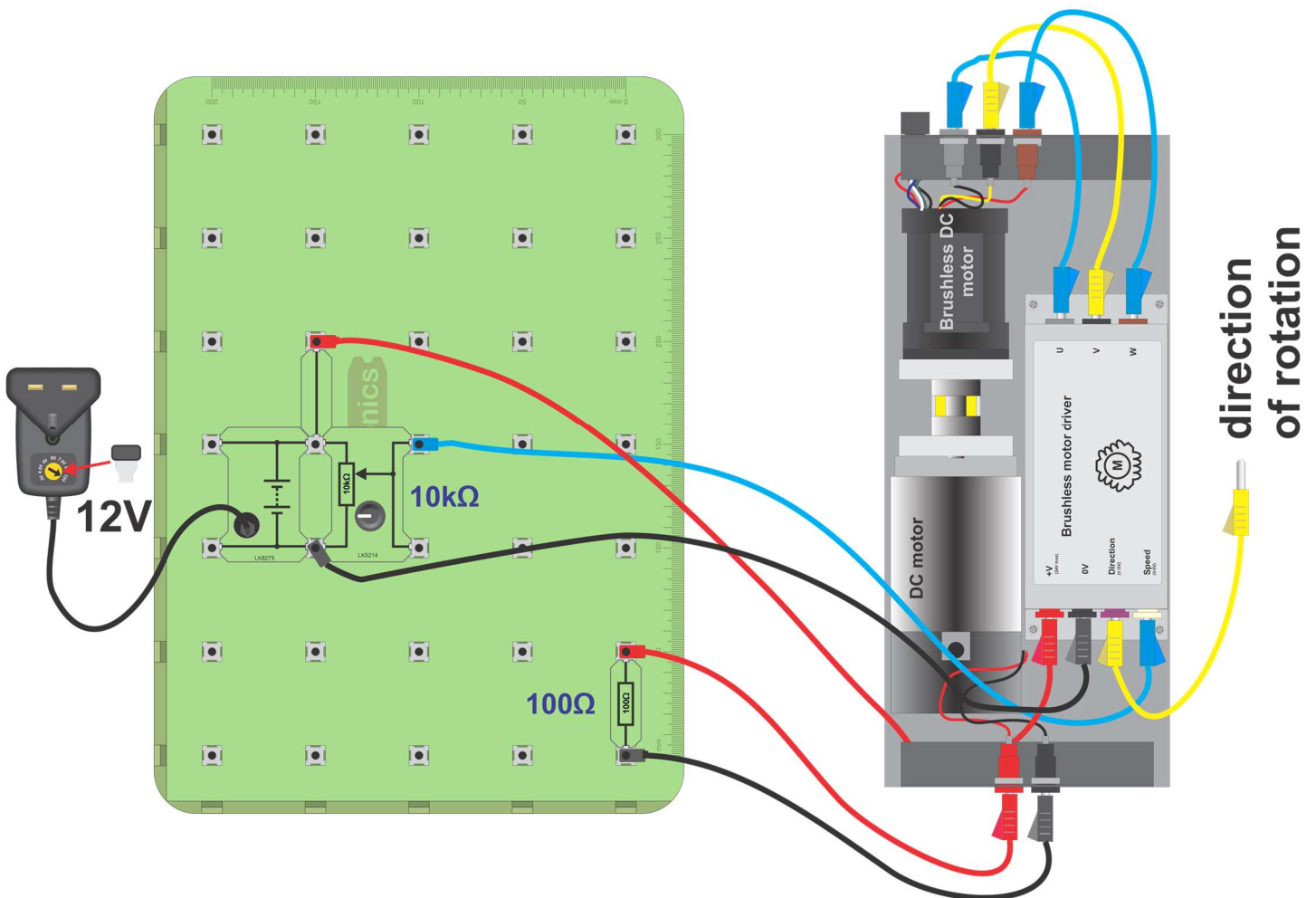
Worksheet 13
The DC generator or 'dynamo'

Over to you:

- Set up the circuit shown on the previous page.
  The 'pot' controls the speed of the brushless DC motor, which is driving the DC motor.
  The DC motor now acts as a DC generator or 'dynamo'.
  The resistor provides a small load for the DC generator.

- Use a multimeter to investigate how the output voltage from the dynamo changes with speed of rotation.

- Connect the 'Direction' terminal on the brushless motor driver to 0V to reverse the direction of rotation and switch on the power supply.

- How has the voltage from the dynamo changed?

- Report on all your findings in the Student Handout.

So what?

- The output voltage from a wire moving through a magnetic field is proportional to the rate of change of movement. This means that moving the wire faster, increases the size of the voltage generated.

- Fleming's **right**-hand rule states that when you change the direction of motion or the direction of the magnetic field, you change the polarity of the induced voltage.

  The diagram explains how to apply the rule, using your **right** hand.

- The **right**-hand rule applies to generators. It is the complement of Fleming's **left**-hand rule, which applies to motors.
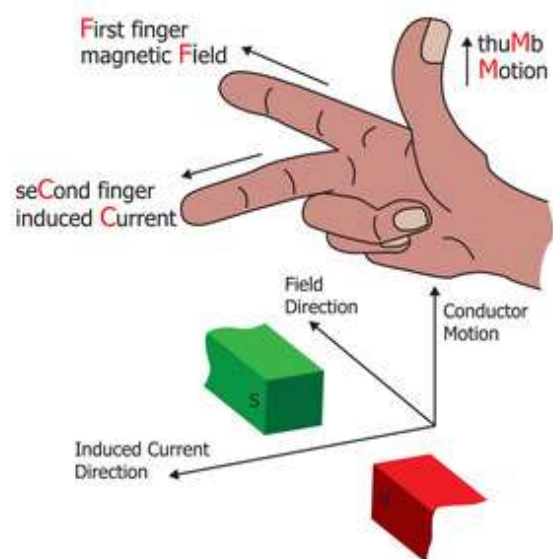
Worksheet 14

The zener diode

Like all diodes, the zener conducts in one direction only and that is when it is forward biased.

In use as a voltage regulator, however, it is connected in reverse bias and in 'zener breakdown', to control the voltage delivered to a circuit.

This worksheet investigates its behaviour, first in forward bias and then in reverse bias.
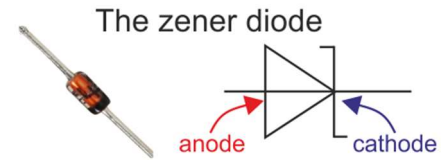
The zener diode

anode   cathode
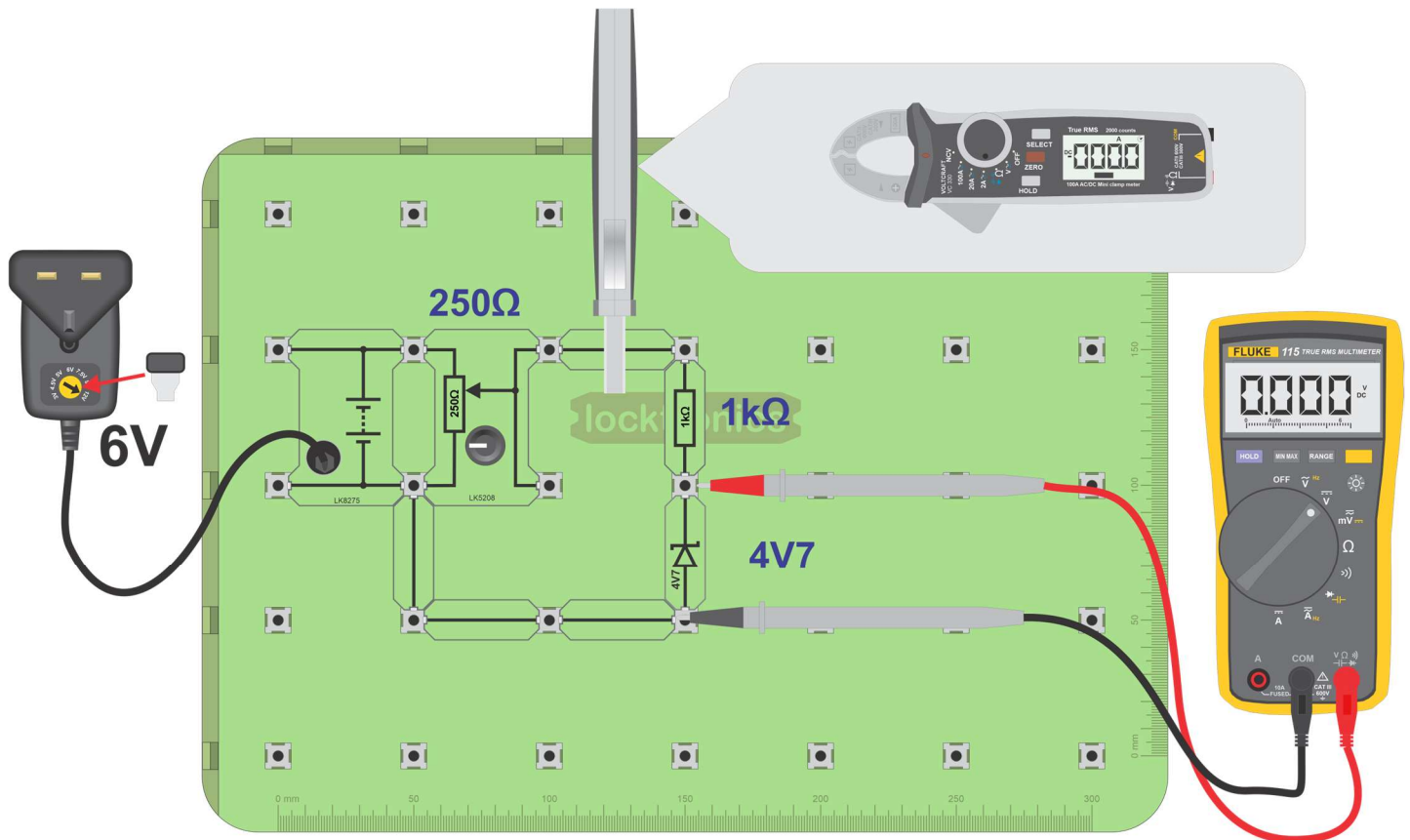
Over to you:

1. Forward bias:

- Set up the circuit shown on the previous page.
- Connect a multimeter, set as a voltmeter on the 2V range, to measure the voltage, V_Z, across the zener diode.
- Use a current clamp meter on the 20mA range, to read the zener current I_Z.
- The 'pot' allows us to vary the voltage applied to the zener diode.
  Turn the knob on the 'pot' fully anticlockwise, to set the applied voltage to zero.

- Turn the knob slowly clockwise until the current through the diode reaches 0.2mA.
  Then read the voltage across the diode.

- Increase the current in 0.2mA steps, up to 2.0mA, taking the voltage reading each time.

- Record all results in the table in the Student Handout.

2. Reverse bias:

- Switch off the power supply and change the setting to 9V.

- Swap the 1kΩ resistor for a 220Ω resistor.

- Invert the zener diode, so that it is reverse biased.

- Repeat the procedure outlined above, increasing the current through the zener in 0.2mA steps, up to 4.0mA, measuring the voltage across it each time.

- Record your results in the second table in the Student Handout.

3. The characteristic curve:

- Combine your results to plot a graph showing the behaviour of the zener diode in both forward and reverse bias conditions.
  Plot current on the vertical axis, and voltage on the horizontal axis.

- Draw a smooth curve through the points. The result should look like the graph shown opposite.

- The results show that once the zener breakdown voltage is reached, the voltage across the zener diode hardly changes as the current increases.

  This is ideal behaviour for a power source.
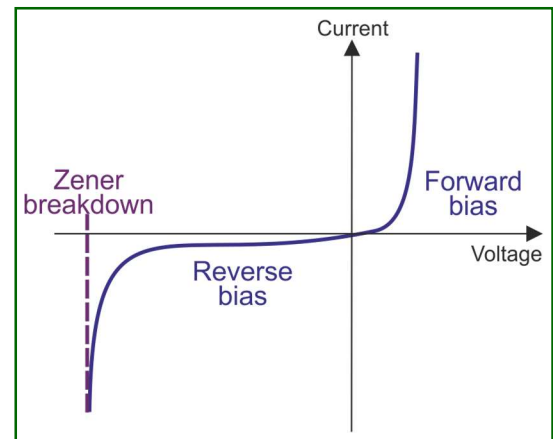
So what?

A zener voltage regulator:

The ideal voltage regulator offers a steady output voltage no matter what changes occur in either the output current or in the supply voltage. We have seen that a zener diode comes close to this behaviour.

The circuit diagram shows a simple zener voltage regulator in a single-phase AC circuit.

As the supply voltage, V_S, changes, the voltage across the zener, V_Z, stays steady and the voltage across the resistor, V_R, changes.

For example, when V_S = 8.5V, V_Z = 4.7V and so V_R = 8.5 - 4.7 = 3.8V.
If V_S then rises to 8.8V, V_Z = 4.7V and V_R = 8.8 - 4.7 = 4.1V.

Motors, generators and charging systems

When the current drawn by the output changes, the voltage across the zener remains steady, as the graph shows.

Power generators need to regulate their output power, which varies greatly with rotational speed.

There are three approaches:

- use electronics to regulate the output;
- dissipate excess power as heat;
- use an inverter to modify the output.

The first part of the worksheet shows the problem that the output voltage varies with motor speed.

The second part looks at an electronic solution.

The photograph shows a voltage regulator.

Over to you:

- Set up the circuit shown on the next page.

  The DC motor drives the brushless DC motor which generates three-phase electricity.

  The 1kΩ resistor represents the load on the system.

- Select program 14 - DC motor control, on the Micro ECU.
- Connect an oscilloscope to monitor the power supply to the DC motor.
  Suitable settings are given below.
- Adjust the 'pot' to control the speed of the DC motor.
- Observe the waveform applied to the DC motor as you do so.
- Use a multimeter to measure the voltage generated across   the load for drive levels of 20%, 40%, 60%, 80% and 90%, as indicated on the ECU display.
- Record your measurements in the table in the Student Handout.

Oscilloscope settings:

Timebase - 100µs/div   **Voltage range -** ±20V DC   **Trigger mode** - Auto

Trigger channel - ch A   **Trigger direction** - Rising   **Trigger threshold** - 11V

Worksheet 15

Voltage regulation

Motors, generators and charging systems

Program	Name	Input	Output
14	DC motor control	**C**	**B**

So what?

- The output depends on the speed of the DC motor. In a vehicle, this is a problem as the lead-acid battery needs a fixed charging voltage.
- The solution - add a feedback loop to control the speed of the motor at a set level. In the following circuit, this feedback signal is carried by the orange cable.

Program	Name	Input	Output
16	Motor feedback	C	B

Over to you continued ...

- Build the second circuit, shown on the previous page, but without any of the links coloured orange in the diagram.
  As before, the speed of the motor is determined by the voltage at the input, terminal **C**.
  This time, however, that voltage is fixed by the 2.2kΩ and 1kΩ resistors.
  Previously, it was variable, adjusted by the pot.

- Select program 16 - Motor feedback, on the Micro ECU.

- Connect an oscilloscope to monitor the power supply to the DC motor, using the same settings as before.

- Connect a multimeter to monitor the voltage across the output smoothing capacitor.

- Then, in turn, add the orange links to change the load by adding one 10Ω resistor at a time.

- Use your observations to answer the questions raised in the Student Handout.

So what?

- Here, the Micro ECU uses DC motor speed to control the voltage generated by the three-phase brushless DC motor.
  When this voltage falls, the Micro ECU increases the drive to the DC motor.
  When it goes up, the Micro ECU reduces the drive.
  This is a good example of a closed-loop feedback system.

- Car alternators achieve the same result by varying the field coil current in the alternator.

A challenge:

- Use the internet to investigate alternator regulator circuits. Write a summary to outline your findings to one of your fellow-students.

Worksheet 16
Fault-finding in charging systems

In the photograph, a technician is using a multimeter to test a battery.

Being good at fault-finding is about being systematic:

- understand the fault;
- gather information;
- formulate a theory and test it;
- repair and retest the circuit.

This investigation uses the same circuit as that in the second part of worksheet 15.

It maintains a voltage of around 1.5V at the system output (across the 1kΩ load), regardless, to an extent, of the load on the system.

Over to you:

- Build the circuit shown on the next page but, initially, without the three links which are coloured orange.

- Set up a multimeter to measure the voltage across the 1kΩ load.

- Set up the current clamp meter to read **DC** currents up to 2A and position it to measure the current delivered to the DC motor.

- Measure the load voltage (across the 1kΩ resistor) and DC motor current and record them in the Student Handout.

- Add the first (left-hand,) orange link and measure the voltage and current again.

- Add the second and then third orange link and repeat the measurements as you do so.

- Record all measurements in the Student Handout and answer the question about motor drive and speed.

- Remove one of the rectifier diodes to simulate a partial fault in the rectifier.

- Repeat the measurements and record them in the Student Handout.

- Remove another rectifier diode and do the same thing again.

- Now answer the second question about the effect of the faulty diodes.

Program	Name	Input	Output
16	Motor feedback	C	B
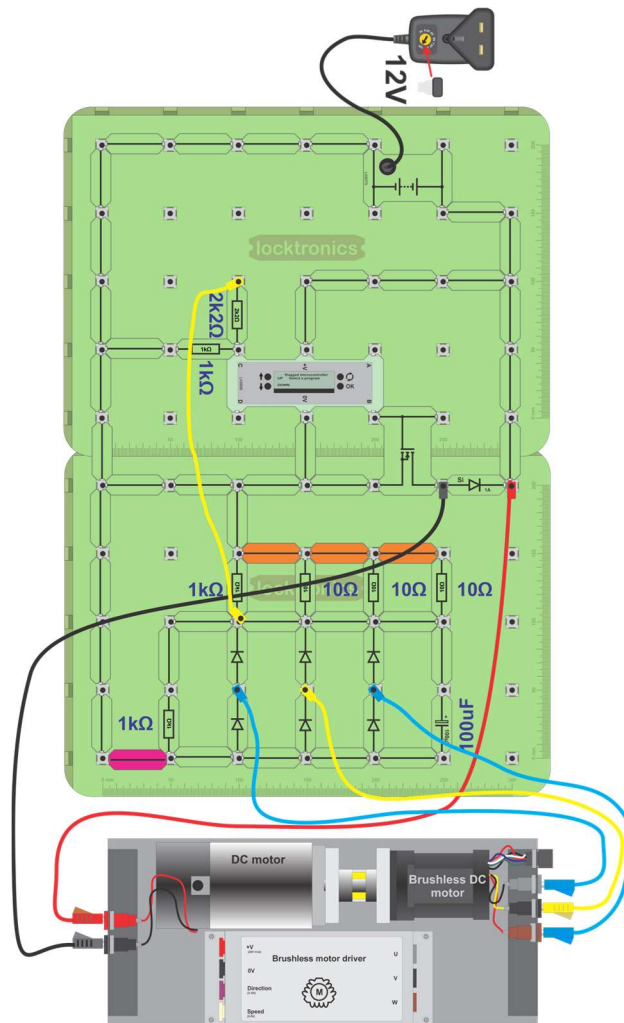
Worksheet 17
Generating high tension

The spark in a high-tension (HT) lead is used to ignite petrol vapour at the appropriate time in the engine firing cycle.

To generate the 25,000V needed, vehicles use the energy storage properties of inductors.

This worksheet investigates these properties.

The photograph shows an ignition coil used in VW group vehicles.

Over to you:

- Set up the circuit shown.
- Connect one channel of an oscilloscope between point **P** and 0V.
- Set the trigger of the oscilloscope to capture a single waveform over 10V. Suitable settings are given below.
- Close the switch for a moment and then release it.
- Using the axes provided in the Student Handout, sketch the waveform you see.
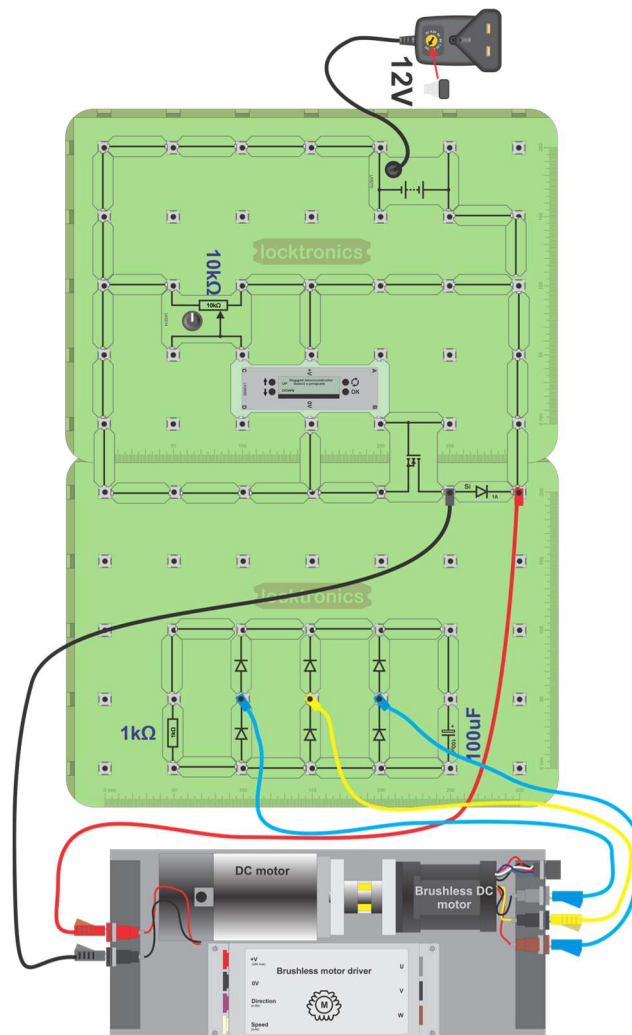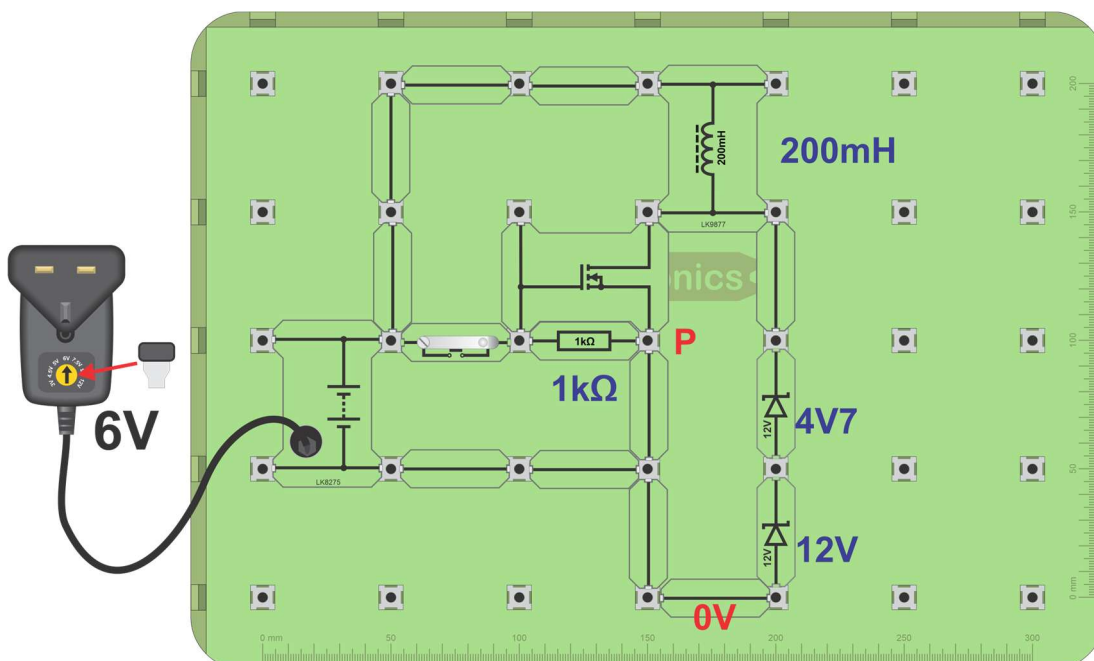
Oscilloscope settings:

Timebase - 100µs/div

Voltage range - ±20V DC

Trigger mode - Auto

Trigger channel - ch A

Trigger direction - Rising

Trigger threshold - 10V

(You may need to use the 'x10' setting on the oscilloscope probe.)

So what?

- As the transistor turns on, current flows in the coil, storing energy in its magnetic field.
- When the switch is released, the transistor turns off. The magnetic field collapses and the energy in it is released rapidly, generating a voltage much larger than the supply voltage.
- The zener diodes conduct at around 17V and clamp the inductor output voltage at this level. Without the zeners, the voltage at **P** would be much higher.
- The current through the zeners dissipates the energy stored in the inductor.
  Similarly, in an internal combustion engine, the spark dissipates the energy in the induction coil. This is known as the 'burn' part of the ignition cycle.
- After the energy in the coil has been dissipated, the zener diodes turn off and the voltage output oscillates as the coil finishes discharging.
- This circuit does not behave exactly like the circuit in a vehicle - but it is very similar.

Worksheet 18

Fault-finding in high tension systems

Motors, generators and charging systems

Faults that can occur in the high-tension circuit include:

- faulty spark plugs;
- faulty ignition coil;
- faulty high tension lead.

Here we look at the effects of resistance in the circuit.

The photograph shows a spark plug.

Over to you:

A. Working circuit:

- Set up the circuit shown on the next page.
- Close both switches **X** and **Y**.
- On the Micro ECU, run program 17 - Spark creator.
- Connect an oscilloscope as in the last worksheet. Suitable settings are given below.
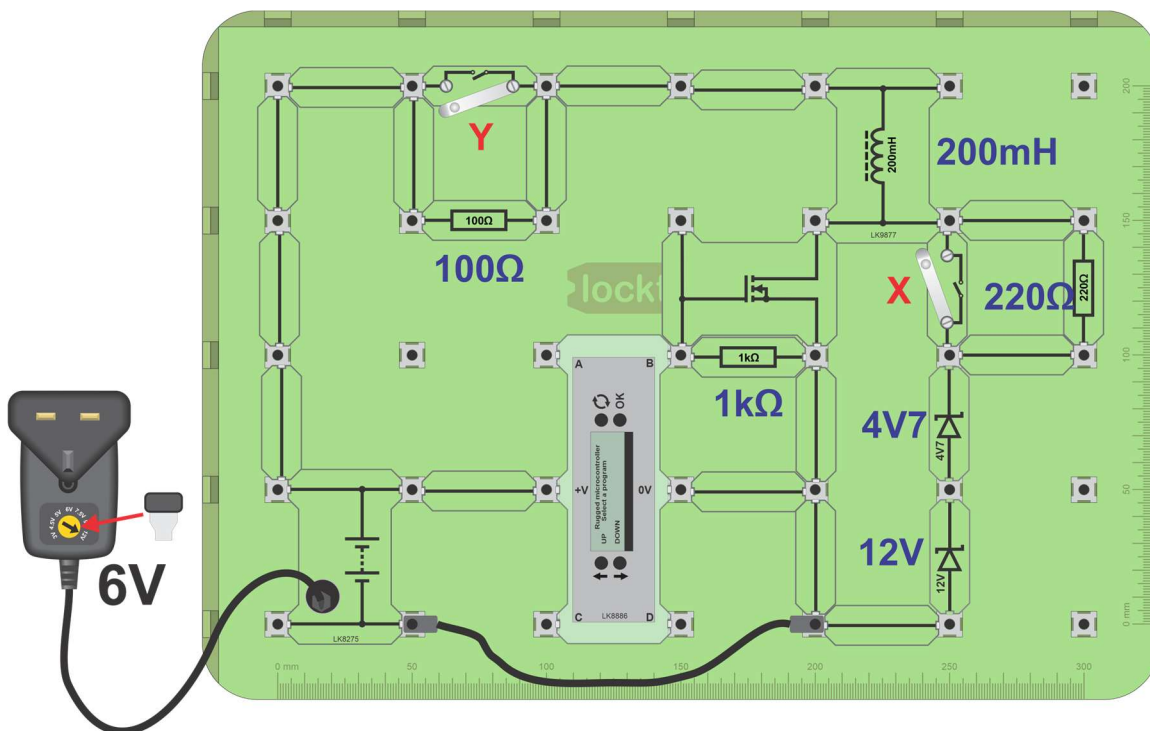
Oscilloscope settings:

Timebase - 100µs/div

Voltage range - ±20V DC

Trigger mode - Auto

Trigger channel - ch A

Trigger direction - Rising

Trigger threshold - 10V

(You may need to use the 'x10' setting on the oscilloscope probe.)

Program	Name	Input	Output
17	Spark creator	None	**B**

- Using a timebase setting of 50ms/div, confirm that you have a series of 'sparks' repeated at regular intervals.

- Change the timebase setting to 100μs/div and check that the 'spark' waveform is the same as in the previous worksheet.

- To see the role of the ECU, connect the oscilloscope to examine the signal from terminal B. (Change the timebase settings to 50ms/div again.)

B.   Extra resistance in the discharge section:

- Still on a timebase setting of 100μs/div, observe what happens to the 'spark' waveform when you open (and then close) switch **X**.
  This connects the 220Ω resistor into the discharge circuit.

- How does the oscilloscope trace change? Describe the change in the Student Handout.

C.   Extra resistance in the power supply section:

- On a timebase setting of 100μs/div, observe what happens to the 'spark' waveform when you open (and then close) switch **Y**.
  This adds 100Ω to the resistance of the cables in the power supply section of the circuit.

- Again, inspect the 'burn' part of the waveform on the oscilloscope .
  How is it affected by the increased resistance?
  Describe the change in the Student Handout.

So what?

- When the coil 'rings' it creates a high voltage. The coil discharges through the 'spark plug', (in this case the zener diodes).

Extra resistance in the discharge section:

- Increased resistance in the discharge section means that the voltage across that extra resistance rises during discharge.

- That leaves a smaller voltage across the spark plug (or zener).
  As a result, the zener turns off earlier in the waveform and so the 'burn' part of the   discharge gets shorter.

Extra resistance in the power supply section:

- The 100Ω resistor reduces the current in the coil in the transistor 'on' period. This in turn reduces the energy stored in the coil and so reduces the energy it can discharge.

- The reduction in energy means that the 'burn' part of the discharge waveform gets shorter and so the 'spark' is weaker.

- **Verdict:** The verdict - high tension leads with more resistance result in a weaker spark, (seen on the oscilloscope as a shorter 'burn'.)

Student
Handout

Worksheet 1 - Generating electricity

Voltage
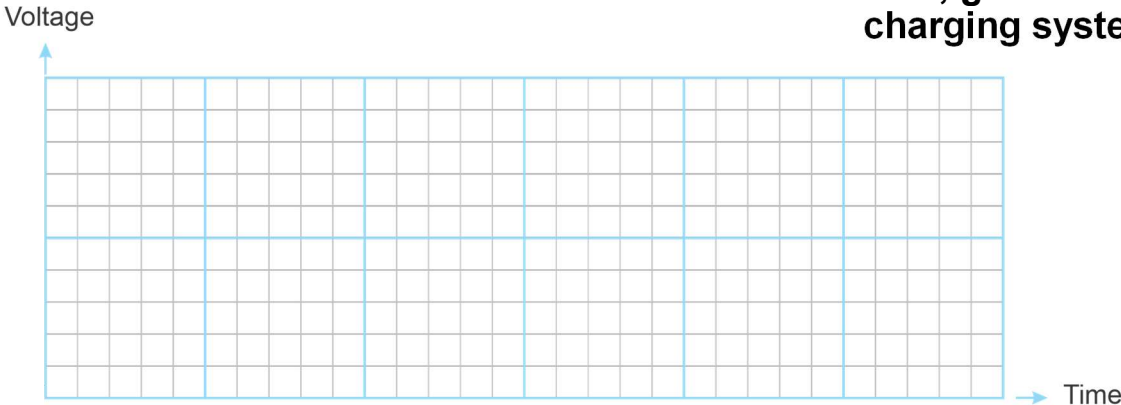
Time

What   is the effect of reversing the magnet?

....

Worksheet 2 - Understanding AC

Sketch the AC waveform and add the time-scale.

Voltage

20V

-20V

Time
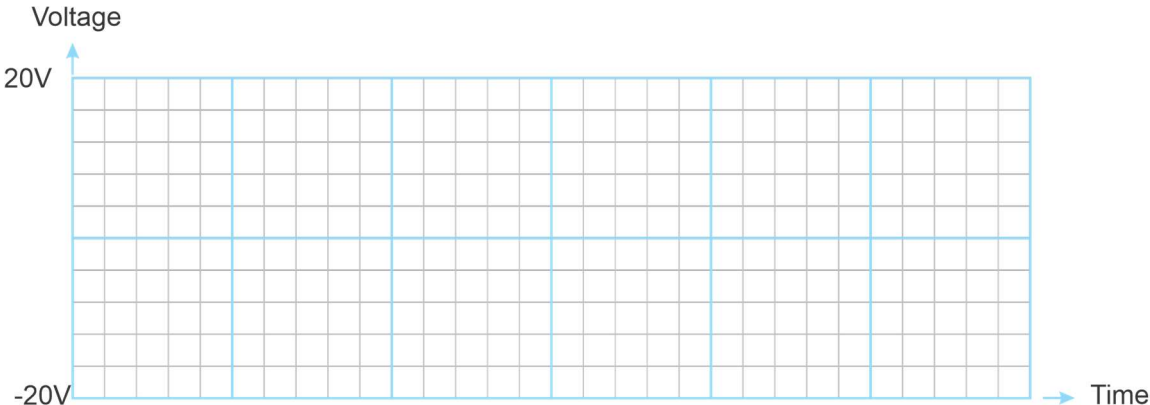
For the trace shown in the lower diagram on p.5:

AC signal	Measurement
Amplitude	V
Period	s
Frequency	Hz

Worksheet 3 - AC vs DC

Across lamp **B**:

Rms value of AC voltage = ...V

Peak AC voltage =................................V

For the trace shown on p.7:

	Value
Peak AC voltage Vpk	V
RMS voltage = Vpk / √ 2	V
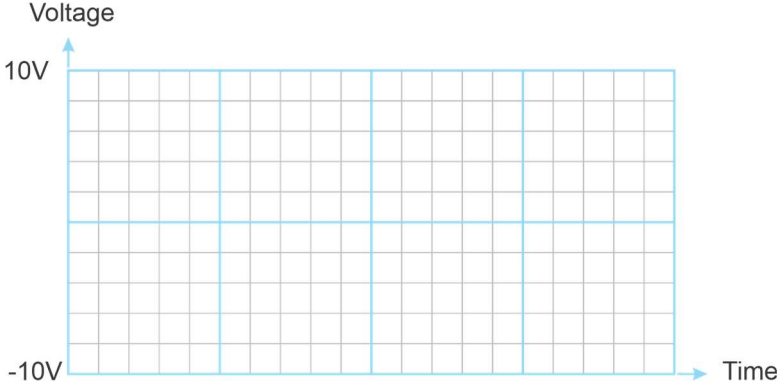
AC input:

DC output:

DC output smoothed:
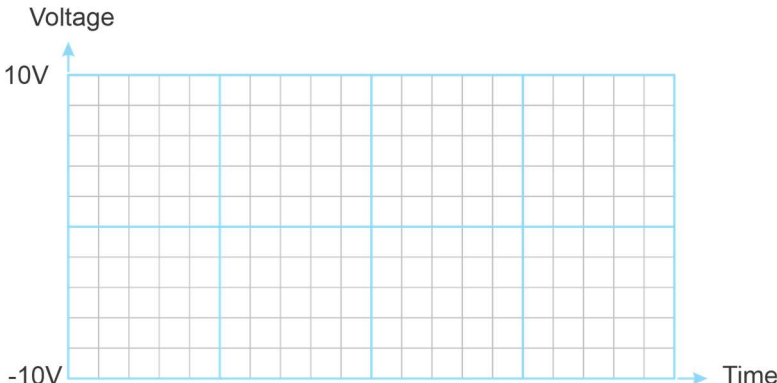
Load	Capacitor	Ripple voltage
1kΩ resistor	100µF	
Two 1kΩ resistors	100µF	
Three 1kΩ resistors	100µF	
Three 1kΩ resistors	2000µF	

Worksheet 7 - Motor principles

Using your observations, fill in the blanks:

• The magnetic field exerts a force on a conductor which is at ....-angles to the direction of the .... and to the direction of the ....

• When the magnetic field is reversed, the .... is reversed.

• When the current is reversed, the .... is reversed.

• Increasing the current, increases the ....

Complete the following version of Fleming's motor rule:

• Using the .... hand, hold the thumb, fore finger and centre finger at .... to each other.

• Keeping this shape, move the hand until the fore finger points in the direction of the ...., (from .... to ....) and the centre finger points in the direction of the .... (from .... to ....)

• The thumb now points in the direction of ....

Worksheet 8 - The electric motor

Speed	Current
Maximum	
Slow	
Zero	

What does this show about the current required by the motor?

....

Worksheet 9 - The DC motor

Sketch the waveform generated at terminal **B** and add a time scale on the X axis

Voltage

12V

70%

0V

12V

30%

0V ⟶ Time
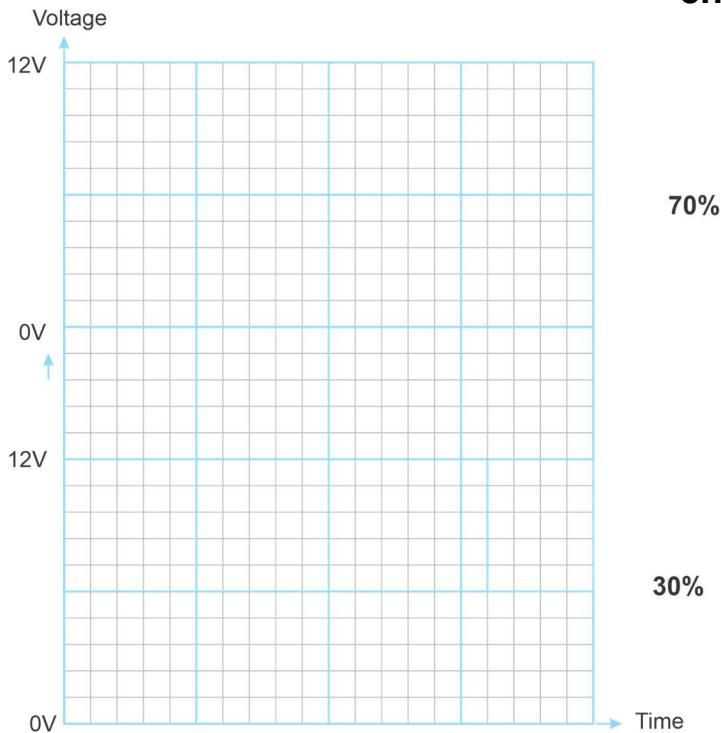
What is the function of the split ring and brushes?

....

....

....

Worksheet 10 - The brushless DC motor

Waveform between sockets **U** and **V**:

Voltage

20V

-20V ⟶ Time
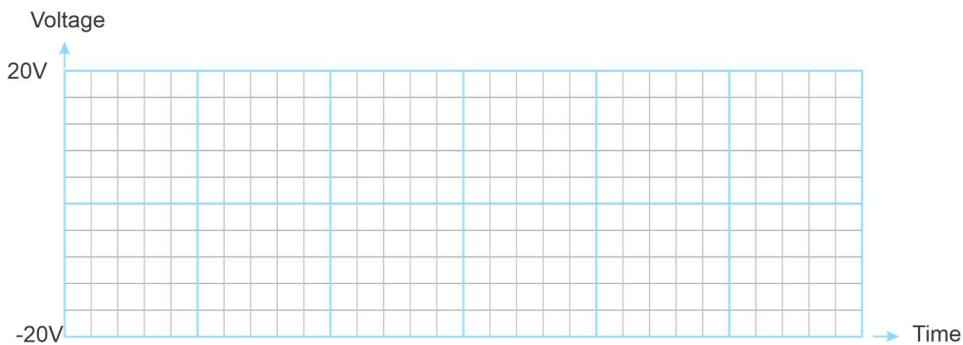
What are the key differences between this motor and the DC motor?

....

....

....

....

Worksheet 11 - The AC generator

Sketch the three voltages:
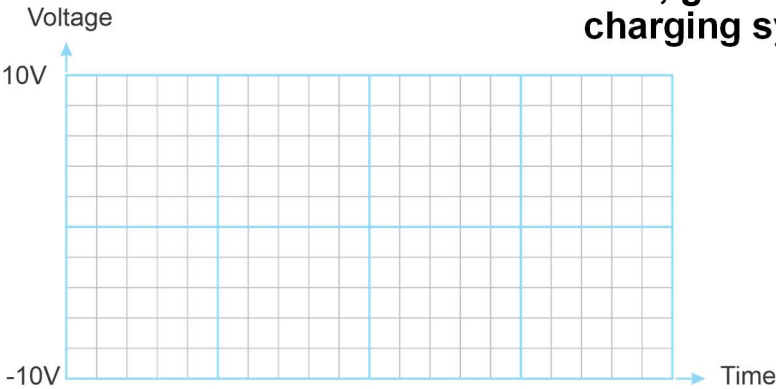
How do the waveforms change when the power supply is reduced?

....

....

What do you conclude about the relationship between power generated and rotational speed?

....

....

Worksheet 12 - Three phase rectification
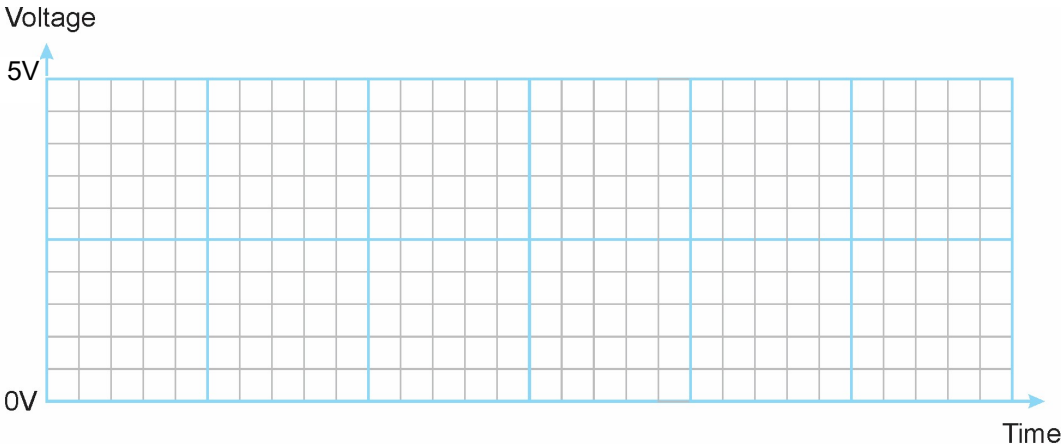
What is the connection between the waveform across the bulb and the waveforms at **R**, **S** and **T**?

....

....

What is the effect of a 2200μF capacitor connected in parallel with the bulb?

....

....

Worksheet 13 - The DC generator or 'dynamo'

How does the output voltage from the dynamo change with speed of rotation?

....

....

....

....

When the direction of rotation is reversed, what happens to the voltage from the dynamo?

....

....

....

Forward bias:

I$_Z$ in mA	V$_Z$ in V
0.2	
0.4	
0.6	
0.8	
1.0	
1.2	
1.4	
1.6	
1.8	
2.0	

Reverse bias:

I$_Z$ in mA	V$_Z$ in V	I$_Z$ in mA	V$_Z$ in V
0.2		2.2	
0.4		2.4	
0.6		2.6	
0.8		2.8	
1.0		3.0	
1.2		3.2	
1.4		3.4	
1.6		3.6	
1.8		3.8	
2.0		4.0	

Using all these results:
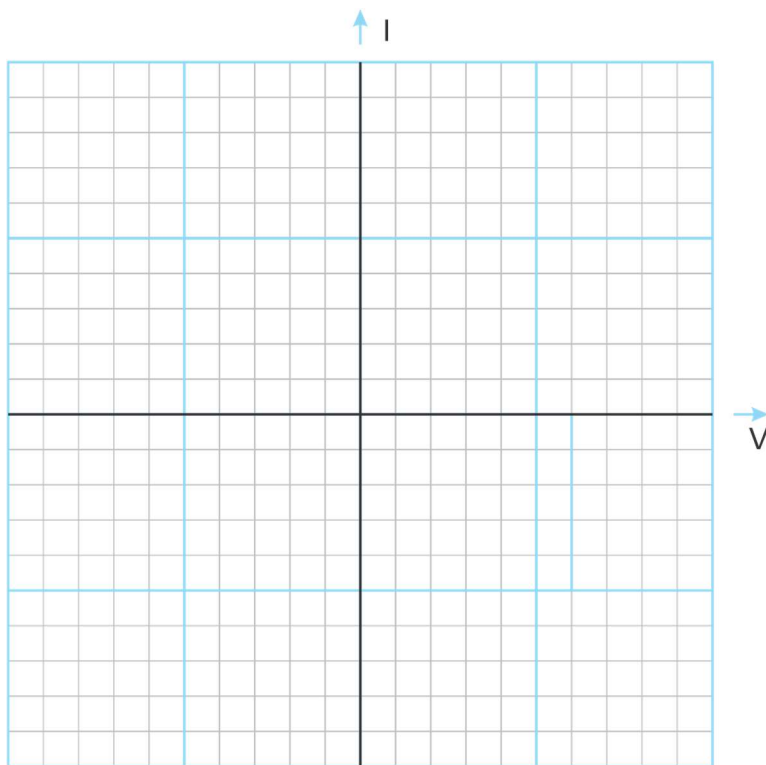
Optional extension:

Load	Output voltage

Motor drive	Voltage generated
20%	
40%	
60%	
80%	
90%	

As you change the load, by adding 10Ω resistors in parallel with the 1kΩ resistor:

- what do you think happens to the output current?

....

....

....

- what effect will this have on the output voltage, if unregulated?

....

....

....

- what is the effect of regulation on the mark:space ratio of the signal applied to the DC motor?

....

....

....

- what is the effect on the speed of the DC motor?

....

....

....

Worksheet 16 - Fault-finding in charging systems

Working circuit 1kΩ load:

Additional load	Output Voltage	Output Current
None		
one 10Ω resistor		
two 10Ω resistors		
three 10Ω resistors		

What happens to the drive (%) (shown on the ECU display) and the DC motor speed as extra load is added?

....

....

....

With one diode removed:

Additional load	Output Voltage	Output Current
None		
one 10Ω resistor		
two 10Ω resistors		
three 10Ω resistors		

With two diodes removed:

Additional load	Output Voltage	Output Current
None		
one 10Ω resistor		
two 10Ω resistors		
three 10Ω resistors		

How is the performance of the system affected by faulty diodes?

....

....

....

Worksheet 17 - Generating high tension

Generating high tension:
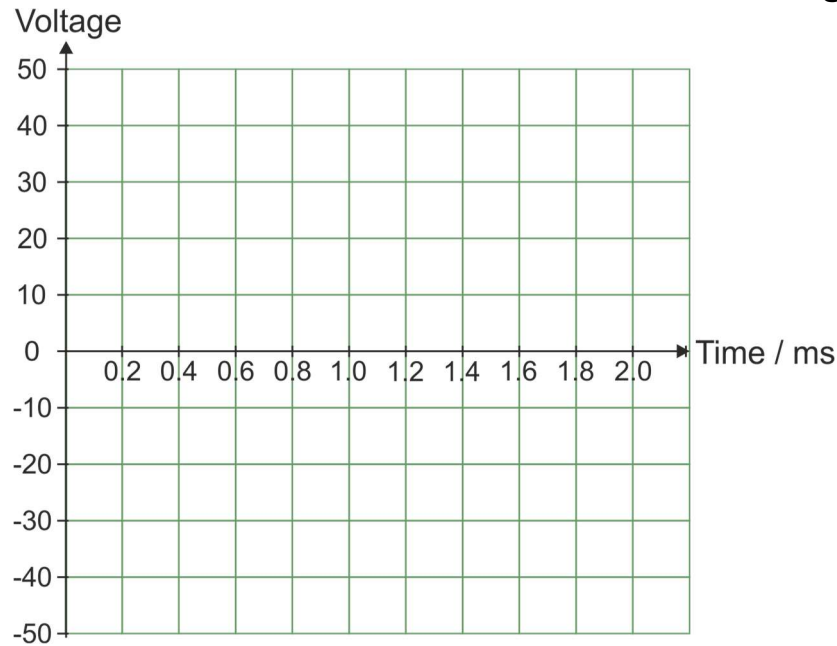
Worksheet 18 - Fault finding in high tension systems

How does the oscilloscope trace change when the 220Ω resistor is added?

_____

_____

How is the 'burn' part of the waveform affected when you ad the 10Ω resistor?

_____

_____

_____

Notes
for the
Instructor

Notes for the instructor

About this course

Introduction

This module allows students to develop an understanding of major electrical systems in modern vehicles.

The course is essentially a practical one. Using Locktronics equipment, students set up and test circuits that simulate the behaviour of important electrical systems found in automotive electrical circuits. They use multimeters, clamp meters and oscilloscopes, following guidelines set out in each worksheet, and analyse the results.

They study elements of fault-finding in two key areas, charging systems and HT systems.

Aims

The course gives students an overview of several key areas in vehicle electrical systems - electric motors, electric generators and the control of their output and HT systems.

In addition, it introduces techniques used to troubleshoot problem areas.

Prior Knowledge

It is recommended that students have followed the 'Automotive Electrics' course, or have equivalent knowledge and experience of building and testing simple circuits, of the meaning of electric current, voltage and resistance.

Using this course:

There are two main parts to the workbook: the worksheets and the Student Handout.

We envisage that you print (and bind) one copy of the workbook, for each set of Locktronics equipment. This stays with the equipment. You print a Student Handout for each student.

The worksheets are written in a student-centred way. The plan is that you give each pair of students a set of equipment, the bound workbook and a Student Handout each. You then allow them to work through the topics in the workbook, offering help and assistance where needed. Students should not write on the worksheets but instead record their measurements in the Student Handout.

The format encourages self-study, with students working at a rate that suits their ability. It is for the instructor to monitor that their understanding is keeping pace with their progress through the worksheets. The Student Handout is one element of this. The instructor can assess progress by looking at the quality of their entries. It can be the basis for the feedback given to the students.

Knowing that multidisciplinary teaching teams are increasingly popular, the 'Notes for the instructor' aims to help instructors for whom this topic is not their principal area of experience.

Time:

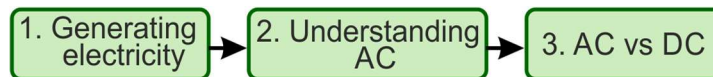It will take from ten to fifteen hours to complete the module.

Suggested curriculum path:

The course begins by exploring some basic concepts - generating electricity and its two common forms, AC and DC.

| 1. Generating electricity | → | 2. Understanding AC | → | 3. AC vs DC |

The next step is to look at rectification - how to convert AC into DC - and how to control the ripple voltage produced when it delivers a current.

| 4. Half-wave rectification | → | 5. Full-wave rectification | → | 6. Ripple voltage |

The course then turns to the 'other side of the coin', from generators to electric motors.

| 7. Motor control | → | 8. Electric motor | → | 9. The DC motor | → | 10. The brushless DC motor |
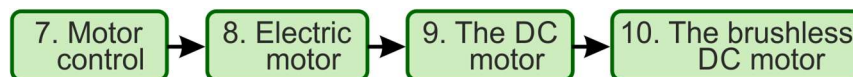
Now, a useful and common variant, 3-phase AC is introduced together with a technique for rectifying it.

| 11. The AC generator | → | 12. Three-phase rectification |
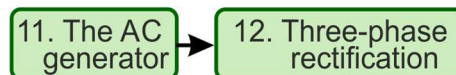
Then follows an investigation of DC generation with the dynamo.

| 13. The DC generator |
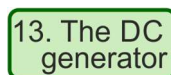
Having generated electricity, we now need to control the output produced. We look at voltage regulation and how to troubleshoot regulation systems.

| 14. The zener diode | → | 15. Voltage regulation | → | 16. Fault-finding in charging systems |

Finally, we touch on high-voltage generation and how to troubleshoot HT systems.

| 17. Generating high-tension | → | 18. Fault-finding in high-tension systems |

Notes for the instructor

Learning Objectives

On successful completion of this course the student will be able to:

- use an oscilloscope to monitor an alternating signal;
- adjust the settings on an oscilloscope to match the signal being monitored;
- state the conditions needed for the generation of a current in a conductor in a magnetic field;
- recall that the shape of AC signal delivered by AC power sources is called **sinusoidal**;
- define the term **period** of the signal, and know that it is measured in seconds;
- define the term **frequency** of the signal, and know that it is measured in hertz;
- use the formula: Frequency = 1 / period;
- obtain the amplitude, period and frequency of a sinusoidal signal from an oscilloscope trace;
- define the **RMS** value of a sinusoidal AC signal as the equivalent DC voltage;
- use the formula: Peak value = RMS value x $\sqrt{2}$;
- recognise the symbols for a diode and a LED;
- distinguish between forward and reverse bias;
- recall that a diode conducts when forward-biased, and does not conduct when reverse-biased;
- state that a silicon diode has a voltage drop of about 0.7V across it when conducting current;
- define **rectification** as the process of turning AC into DC;
- recall that half-wave rectification produces a DC output voltage which is ~0.7V less than the peak AC voltage;
- state that half-wave rectification uses only one diode, but outputs power for only half of the time;
- state that full-wave rectification uses at least four diodes, but produces an output throughout the full AC cycle;
- connect up a full-wave rectifier circuit consisting of four diodes, an AC power supply and a resistive load;
- recall that full-wave rectification produces a DC output voltage which is ~1.4V less than the peak AC voltage;
- know that a large value capacitor connected across the rectifier output smoothes the DC signal produced;
- describe the need to smooth the output of a DC power supply to an electronic circuit;
- measure the ripple voltage present in a DC power supply;
- state that capacitance is measured in farads (F), or microfarads (μF);
- relate the size of the capacitor, needed to produce smoothing, to the load current;
- use Fleming's left-hand rule to predict the direction of a force acting on a current-carrying conductor in a magnetic field;
- describe the effect on the current flowing of increasing the mechanical load on an electric motor;
- explain the need for a commutator in a DC motor;

Learning Objectives continued...

On successful completion of this course the student will be able to:

- describe the characteristics of PWM (pulse-modulated waveform) to control DC motor speed;

- explain why PWM is more energy-efficient than analogue motor control methods;

- distinguish between a traditional DC motor and a brushless DC motor;

- draw a voltage / time graph to illustrate what is meant by a three-phase AC supply;

- use the graph to explain the meaning of the term 'phase';

- state an advantage of using three-phase rather than a single phase AC supply;

- draw a circuit diagram for a three-phase rectifier using six diodes;

- use Fleming's right-hand rule to predict the direction of the current induced in a conductor moving in a magnetic field;

- sketch a graph showing the I / V characteristic of a zener diode and identify the forward-biased region, the reverse-biased region and the point at which zener breakdown occurs;

- explain why a reverse-biased zener diode has properties similar to those in an ideal power supply;

- explain the need to control the speed of a device used to generate electricity to charge the lead-acid battery in a motor vehicle;

- distinguish between positive and negative feedback and describe one likely benefit of negative feedback;

- describe the symptoms of a faulty diode in a three-phase rectifier;

- explain the conditions needed to generate high-tension (HT);

- state that inductance is measured in a unit called the henry, (H);

- describe the problems caused by increased resistance in cables in a HT system.

Notes for the instructor

Bill of materials:

To deliver this course you will need the following components in a Locktronics kit:

1	**HP2666**	**Adjustable DC power supply**
1	HP3728	12VRMS AC power supply
2	HP4039	Tray lid
2	HP5540	Deep tray
2	HP7750	Daughter tray foam cutout
2	HP8600	Crash foam
2	HP9564	Daughter tray
3	LK2350	6V, 0.35A MES bulb
1	LK2340	AC voltage source carrier
1	LK4002	Resistor, 100 ohm, 1W, 5% (DIN)
1	LK4102	Open frame motor
3	LK5202	1Kohm ressitor
1	LK5208	Potentiometer, 250ohm (DIN)
1	LK5214	Potentiometer, 10K ohm (DIN)
1	LK5215	Resistor 220ohm, 1/4 watt
7	LK5243	Diode, power, 1A, 50V
1	LK5247	Zener 4V7
45	LK5250	Connecting Link
1	LK5258	12V zener
3	LK5291	Lampholder, MES
2	LK5603	Red 4mm to 4mm lead, 1m
2	LK5604	Black 4mm to 4mm lead, 1m
3	LK5607	Yellow 4mm to 4mm lead, 1m
3	LK5609	Blue 4mm to 4mm lead, 1m
1	LK6202	100uF capacitor
1	LK6203	2200uF capacitor
1	LK6207	Switch, push to make, metal strip
2	LK6209	Switch, on/off, metal strip
1	LK6218	Resistor, 2k2, 1/4W, 5% (DIN)
1	LK6482	Fleming's motor rule apparatus carrier
1	LK7489	Faraday's apparatus
1	LK8011	Power MOSFET
1	LK8275	Power supply carrier with battery symbol
1	LK8397	Ammeter 0A to 1A
1	LK8886	Locktronics PIC II
2	LK8900	7 x 5 metric baseboard with 4mm pillars
1	LK9877	200mH inductor
3	LK4025	Resistor, 10R, 1/4W, 5% (DIN)

Updated 11 03 24

Notes for the instructor

Preliminary issue
Some groups may need initial guidance on using an oscilloscope. This could include an explanation of the significance of the various settings and help with interpreting and taking measurements from the oscilloscope trace.
General checks

- Is the correct type of plug-top power supply (AC or DC) being used?
  If not, the circuit will not function properly.

- Is the layout correct (including connections to potentiometer carriers)?
  If not, the circuit will not function properly.

- Are all components, including the power supply carrier, connected with the correct polarity?
  If not
  - components may be damaged;
  - the circuit will not function properly.

- Is the DC plug-top power supply on the correct voltage setting?
  If not:
  - components may be damaged;
  - the results in the Student Handout will be wrong.

Multimeter checks:

- Is the multimeter connected to the circuit correctly?
  If not, the '-' sign will appear in the wrong place.

- Are the leads connected to the correct sockets on the multimeter?
  If not, the student will not be able to take a reading.

- Is the multimeter set on the correct range?
  If not, the results in the Student Handout will be wrong.

- Some voltage readings are negative.
  The multimeter leads are the wrong way round.

Oscilloscope checks:

- Is the oscilloscope connected to the circuit properly?
  If not, the correct trace will not be created.

- Are the oscilloscope settings correct?
  If not, the correct trace will not be created. (Try the 'Auto' trigger mode / 'AC' coupling)

Worksheet	Notes

5
 	
Full-wave rectifier
	Specific problem:
	• In the event of a problem, check:
	   • that there is only one ground connection to the oscilloscope in use.
	   • see 'oscilloscope checks' in 'General checks'.
	   • that the diodes are connected with the right orientations - opposite diodes in the 'square' face the same way - the load is connected between the 'anode / anode' corner and the 'cathode / cathode' corner.
	   • that the diodes are not faulty, using a diode tester.
	
	Points for discussion:
	• Discuss the traces produced and point out the advantage of full-wave over half-wave rectification.
	• Outline the effect of the smoothing capacitor and discuss the effect of load current on capacitor size.
	• Explain the use of the two 10Ω resistors.

6
 	
Ripple voltage
	Specific problem:
	• In the event of a problem, check:
	   • that the diodes are connected with the right orientations - opposite diodes in the 'square' face the same way - the load is connected between the 'anode / anode' corner and the 'cathode / cathode' corner.
	   • that the diodes are not faulty, using a diode tester.
	
	Points for discussion:
	• Meaning of 'noisy' supply voltage in the introduction.
	• Meaning of ripple voltage and how to measure it from an oscilloscope trace.
	• The link between size of smoothing capacitor and ripple voltage.

7
 	
Motor principles
	Specific problem:
	• Nothing happens.
	  Is the movable rod in contact with both fixed conductors?
	  Is the switch closed fully?
	Points for discussion:
	• Revision of concept of a magnetic field.
	• Convention that current flows from positive to negative, whereas actually electrons flow from battery negative terminal to positive.
	• Practice with Fleming's Left-hand Rule.

Notes for the instructor

Worksheet	Notes
8 The electric motor	Points for discussion: • How to read analogue scales. • Structure of simple motor. • Need to reverse current in the coil to maintain rotation. (Hint - use Fleming's Left-hand Rule.) • How this is done by commutators and slip-rings.

9
 	
The DC motor
	Specific problem:
	• In the event of a problem, check:
	  • connections from the baseboard to the DC motor;
	  • the orientation of the transistor and the potentiometer;
	  • that the correct program has been selected and is running.
	
	Points for discussion:
	• PWM:
	  • show waveform and explain how to measure mark:space ratio;
	  • discuss connection between mark:space ratio and average voltage;
	  • discuss efficiency advantage of PWM compared with analogue methods.
	• Cause of back-emf, why it is a problem and how to guard against its effects.
	• Structure of the DC motor, using the photographs included in the worksheet.

10 The brushless DC motor	Specific problem: • No trace produced. See 'oscilloscope checks' in 'General checks'. Points for discussion: • Difference between DC motor and brushless DC motor; • What is a three-phase supply?
11 The AC generator	Specific problem: • No trace produced. See 'oscilloscope checks' in 'General checks'. Points for discussion: • Interpreting the waveforms. • Meaning of 'phase' and 'phase-difference'

Worksheet	Notes
1 Generating electricity	Specific problem: • No trace produced. See 'oscilloscope checks' in 'General checks'. Points for discussion: • Interpreting the trace. • Faraday's law of electromagnetic induction.
2 Understanding AC	Specific problem: • No trace produced. See 'oscilloscope checks' in 'General checks'. Points for discussion: • Interpreting the sinusoidal waveform. • Taking measurements from an oscilloscope trace. • Link between frequency and period. • Meaning of multipliers such as 'micro', 'milli', 'kilo' and 'mega'.
3 AC vs DC	Specific problem: • The crux of the investigation is that the two bulbs are electrically identical. To be sure of this, having completed the second bullet point in 'Over to you', swap them over and check that their brightness is similar. Points for discussion: • How to measure peak voltage from an oscilloscope trace. • Significance of RMS voltage. • Connection between RMS and peak voltage and practice calculations.

4
Half-wave rectifier
	Specific problem:
	• In the event of a problem, check:
	  • that the ground connection to the oscilloscope is in the correct place in the circuit.
	• If there is no DC trace on the oscilloscope,
	  • check that the oscilloscope is connected to the correct point in the circuit.
	  • see 'oscilloscope checks' in 'General checks'.
	  • the diode may be faulty. Check it on a diode tester.
	
	Points for discussion:
	• Discuss the traces produced. Distinguish between AC, DC and steady DC.
	• Explain the use of the two 10Ω resistors.

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Motors, generators and charging systems

Worksheet	Notes

12
 	
Three-phase rectification
	Specific problem:
	• In the event of a problem, check:
	  • that the ground connection to the oscilloscope is in the correct place in the circuit.
	  • see 'oscilloscope checks' in 'General checks'.
	  • a diode may be faulty. Check them on a diode tester.
	
	Points for discussion:
	• Discuss the traces produced.
	• Outline the advantage of three-phase rectification over full-wave rectification.
	• Phase relationships.

13
 	
The DC generator or 'dynamo'
	Specific problem:
	• The circuit does not work!.
	  Check the wiring to the motors.
	  Check that the pot is connected correctly.
	
	Points for discussion:
	• Faraday's law of electromagnetic induction.
	• Practice with Fleming's Right-hand Rule.
	• When to use the Left-hand Rule and when to use the Right-hand Rule.

14
 	
The zener diode
	Specific problem:
	• In the event of a problem, check:
	  • 'Multimeter checks' in 'General checks'.
	  • orientation of pot.
	  • power supply voltage.
	
	Points for discussion:
	• Meaning of voltage regulation.
	• Load and line regulation.
	• Meaning of 'forward' and 'reverse' bias.
	• Discuss significance of current / voltage graph for the zener diode.
	• Power rating calculation for a zener diode.
	• Go over calculations like that on p.27.

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Motors, generators and charging systems

| Worksheet	Notes
15 Voltage regulation	First part: Specific problem: - In the event of a problem, check: - that the diodes are connected with the orientations shown on the layout. - that the diodes are not faulty, using a diode tester. - that the correct program has been selected. - that the power supply voltage is correct. - that the orientation of the transistor, pot and capacitor are correct. - If there is no trace on the oscilloscope, - check that the oscilloscope is connected to the correct point in the circuit. - see 'oscilloscope checks' in 'General checks'. Points for discussion: - Higher rotation speed leading to higher output voltage is a consequence of Faraday's law of electromagnetic induction. - Examine the oscilloscope traces to see that PWM is used to vary DC motor speed. - Meaning of positive and negative feedback. Second part: Points for discussion: - Discuss the difference in the way the voltage is provided at terminal C. - Highlight the feedback mechanism. - Go over the results and oscilloscope traces. - Discuss the questions raised in the Student Handout. - Review methods used in alternator regulator circuits.
16 Fault-finding in charging systems	Specific problem: - See those listed for worksheet 15. - No readings (or unexpected readings) on the multimeter and clamp meter: - see 'multimeter checks' in 'General checks'. - check that the clamp meter is set to the correct scale and to DC. Points for discussion: - Discuss the effects of diode failure.

Worksheet	Notes

17
Generating high-tension
	First part:
	Specific problem:
	• If the trace has an unexpectedly small amplitude:
	  • check that the zener diodes are connected the right way round
	    - i.e. in reverse bias.
	• If there is no trace on the oscilloscope,
	  • check that the oscilloscope is connected to the correct point in the circuit.
	  • see 'oscilloscope checks' in 'General checks'.
	
	Points for discussion:
	• Health and safety in the investigation - need for zener diodes to limit voltage.
	• Meaning of 'back e.m.f' and its cause.
	• Go over the results and oscilloscope traces.
	• Compare this circuit with what happens in an internal combustion engine.

18 Fault-finding in high-tension systems	Specific problem: • The task requires changing the timebase in order to see multiple 'sparks' and then to see individual ones. • Can't see any difference in the traces when switches are opened. • watch the trace closely while a switch is opened and closed repeatedly. Points for discussion: • Discuss the effects of diode failure.

Reference

DC motor / brushless DC motor pair
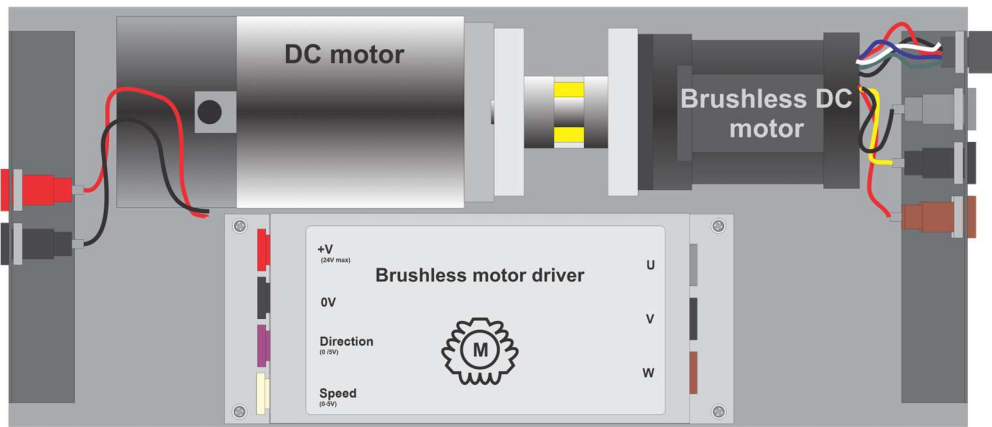
The HP2001 DC motor/brushless motor pair consists of two parts: the motors themselves, coupled together, and a brushless DC motor driver.
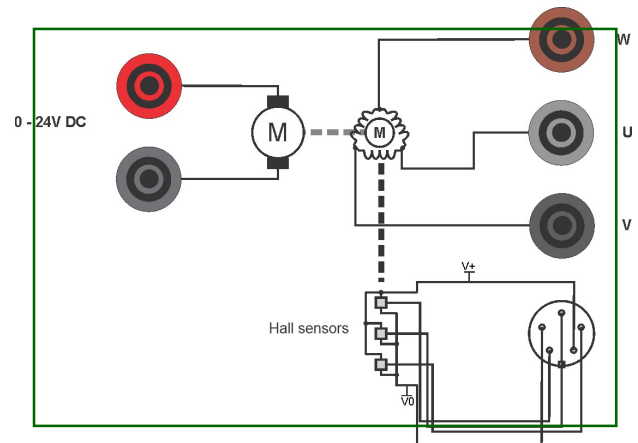
The coupled DC motor / brushless motor pair can be driven in two ways:

- the DC motor drives the brushless DC motor;
- the brushless DC motor drives the DC motor.

The DC motor supply voltage can be up to 24V.

With the Brushless DC motor unloaded the approximate speeds are:

Voltage	RPM
2.4	0
4.8	180
7.2	390
9.6	600
12.0	800
14.4	1000
16.8	1210
19.2	1410
21.6	1680
24.0	2010

Unloaded, the brushless DC motor will generate $6V_{RMS}$ between two phases at 2000 rpm.

When driving the DC motor with the brushless DC motor at 2000 rpm, the DC motor acts as a generator and generates 25VDC.

The polarity of the voltage generated on the terminals will depend on the direction of rotation. When driven clockwise with respect to the face of the motor the red terminal will be positive.

DC motor / brushless DC motor pair

When driven at full speed (speed input 5V) and unloaded, the DC motor speed of rotation is approximately 2000rpm.

The following table shows the relationship (approximate) between speed and generated voltage for the brushless DC motor for varying speed input voltages when a 24V DC power supply is used:

Speed rpm	Output V(DC)
1199	14
1795	21.5
2292	27
2565	29
2522	28
2631	30
3099	35

Brushless DC motor driver

The brushless DC motor driver board is housed in a rugged stainless steel casing. It should be supplied from a 24V power supply. This is included with HP2001.

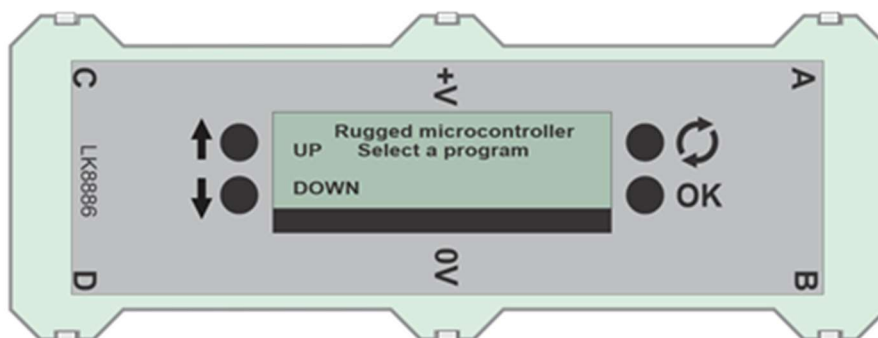The HP2001 has two additional inputs: a direction input and a speed input.

- The direction input should be 0V or +5V.
- The speed input should vary from 0V to 5V.

Micro ECU
User instructions

Motors, generators and charging systems

The LK8886 Micro ECU has six standard Locktronics legs that allow it to be inserted into the Locktronics base board.

The controls on the Micro ECU are:

UP: allows program selection and control from within a program.

DOWN: allows program selection and control from within a program.

RESET: resets the Micro ECU into program selection mode.

OK: confirms program selection; may also be used in a program.

To select a program: press the **RESET** switch and use the **UP** and **DOWN** buttons to navigate to the programme you want. Select the **OK** button to start the program.

Terminals **A**, **B**, **C**, **D** are input / output connections. Their function is dictated by the programme selected.

Each is fitted with series 220Ω resistors between the microcontroller and the output pin and will sink or source 20mA.

Terminals **B** and **D** can be programmed to deliver PWM output.

Max voltage at V+ is 12VDC.

The list of programs at date of publishing is as follows:

1. Logic NOT
2. Logic AND
3.
4. Logic OR
5. Slow PWM
6. Fast PWM
7. Temperature alarm B
8. Reverse alarm
9. Temperature alarm A
10. Heater fan control
11.
12. Auto headlights
13. Brake light alarm
14. DC motor drive
15.
16. Alternator feedback loop
17. Spark creator

Version control

First release   18 02 21

Reformatted to new style 02 08 23

11 03 24   Bom change on p60