



RENEWABLE ENERGY & POWER CONVERSION

CP7128

Inspiring The Next
Generation Of Engineers

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Contents

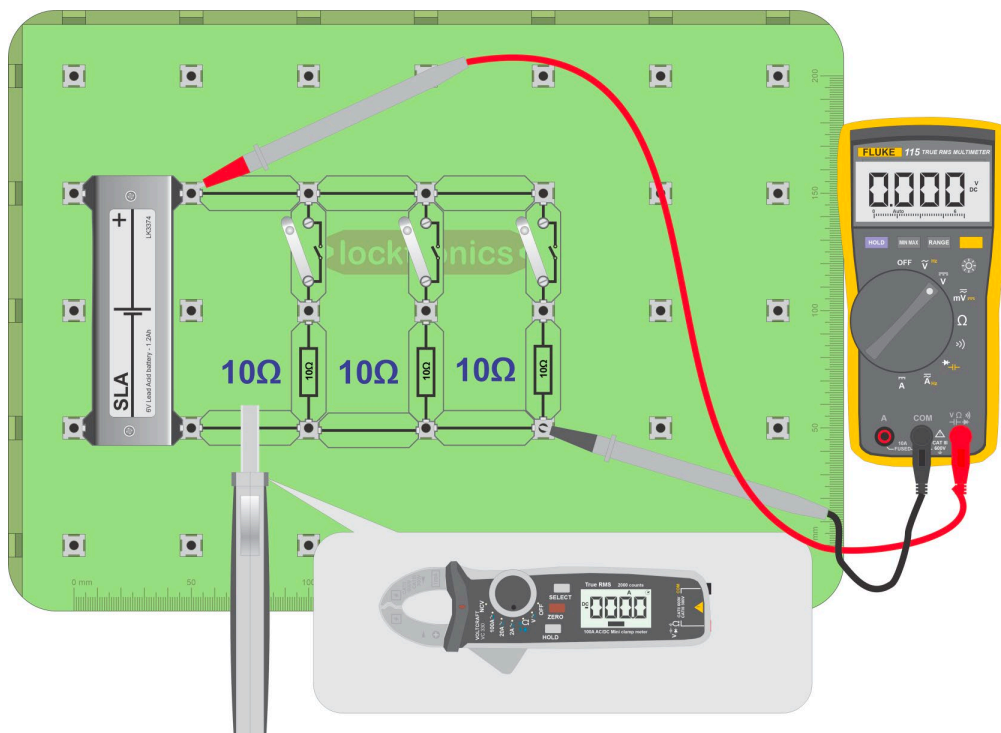
Worksheet 1	Testing Sealed Lead Acid Batteries	3
Worksheet 2	Charging Sealed Lead Acid Batteries	5
Worksheet 3	Testing Li-ion Cells	7
Worksheet 4	Charging Li-ion Cells	9
Worksheet 5	Building Larger Batteries	11
Worksheet 6	Li-ion Battery Faults	16
Worksheet 7	SLA Battery Faults	18
Worksheet 8	Battery Management	19
Worksheet 9	Voltage Converters	23
Worksheet 10	Voltage Inverters	25
Worksheet 11	Solar Panels	26
Worksheet 12	Wind Turbines	28
Worksheet 13	Three Phase Rectifiers	30
Worksheet 14	Using Wind Power to Provide AC	32
Worksheet 15	Using Solar Power to Provide AC	34
Worksheet 16	Using Solar Power to Charge Batteries	36
	Student Handout	37

WORKSHEETS

Worksheet 1 - Testing Sealed Lead-Acid Batteries

There are number of ways to test a battery, but, ultimately, the only sure way is to test its energy-storage capacity. This involves charging it and then discharging it, making measurements of energy intake and output as you do so. The Sealed Lead-Acid battery (SLA) provided is a small one but it behaves just like the larger lead-acid batteries you find in vehicles.

The photograph shows a Voltcraft battery tester.



Over to you

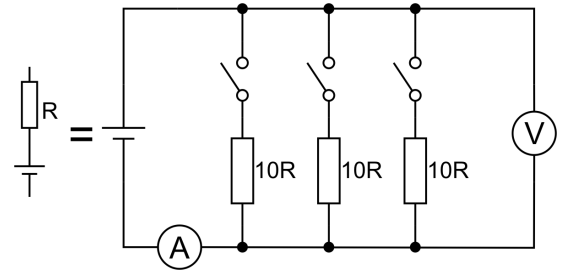
- Build the circuit shown above but leave the switches open for now.
- Configure the multimeter to measure DC volts.
- Configure the current clamp to measure DC amps and 'zero' it.
- Connected as shown, the meters measure the output voltage and current of the battery.
- Measure these and record them in the table in the Student Handout.
- Close the first switch briefly and measure output voltage and current again.
- Close the second and then third switch, briefly, and repeat the process.
- Note down all readings in the Student Handout.

WORKSHEETS

Worksheet 1 - Testing Sealed Lead-Acid Batteries

So what

- You made a battery tester and used it to measure elements of the performance of the SLA battery. The circuit diagram for this tester is shown opposite.
- Batteries are more complex than they may appear. To understand their behaviour, it helps to think of them as a combination of a battery and a series resistor, **R**. **R** is called the 'internal resistance'.
- For lead-acid cells the internal resistance of a battery becomes higher when the battery '**state of charge**' (SOC) is low and as the battery ages.
- Many simple lead-acid battery testers show you the effects of this internal resistance.
- As the internal resistance increases, more of the voltage is dropped across it and the battery output voltage falls eventually to below an acceptable level.



Over to you

- Using the same circuit with all switches open, measure the initial output voltage.
- Close two switches and measure battery output voltage and current.
- Repeat this process after five minutes and then after ten minutes.
- Record your results in the table in the Student Handbook.

So what

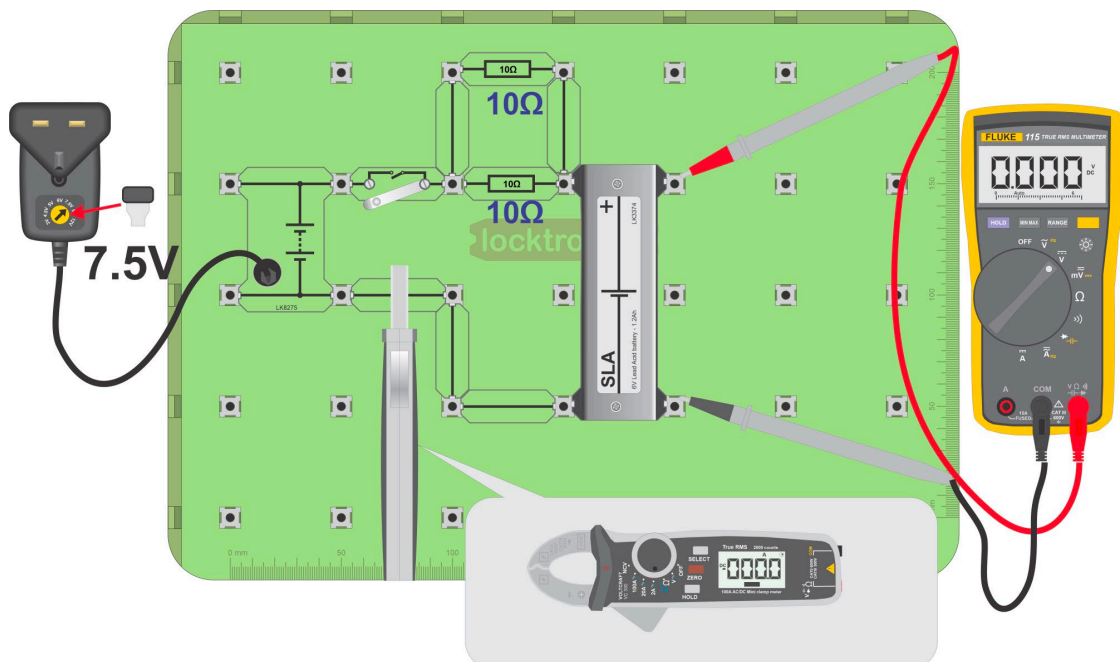
- The energy capacity of the battery, *C*, indicates how much energy it can store. It is measured in units called 'amp.hours, (Ah). This battery is rated at '6V 1.2Ah', meaning that, when fully charged, it should deliver a current of approximately 1.2A at 6V for 1 hour.
- As a rule of thumb, if this battery is fully charged, when you draw 1.2A for 10 minutes (i.e. two switches closed) the battery is probably satisfactory if the voltage stays above 5.5V.
- Simply measuring the output under no load is not a good enough test for lead-acid batteries.
- Using a quick and simple load test, like the one above, allows you to say with some degree of certainty that a battery is satisfactory.
- The only real way to test a battery with 100% certainty is to discharge it, charge it fully, and then discharge it whilst making sure that it supplies the rated current for the rated time.

WORKSHEETS

Worksheet 2 - Charging Sealed Lead Acid Batteries

The car alternator is continually charging the lead-acid battery whilst, at the same time, its output is also used by the car's electrical system. Just like when testing lead-acid batteries, the proper charging process is more complex than it may at first seem. The current needed and charging time depend on the battery's initial SOC.

For this SLA battery, one recommended method is to charge it at 10% of its amp.hour rating for 24 hours. The amp.hour rating for the SLA used here is 1.2Ah, implying a charging current of 0.12A for 24 hours. The photograph shows a garage-based battery charger.



Over to you

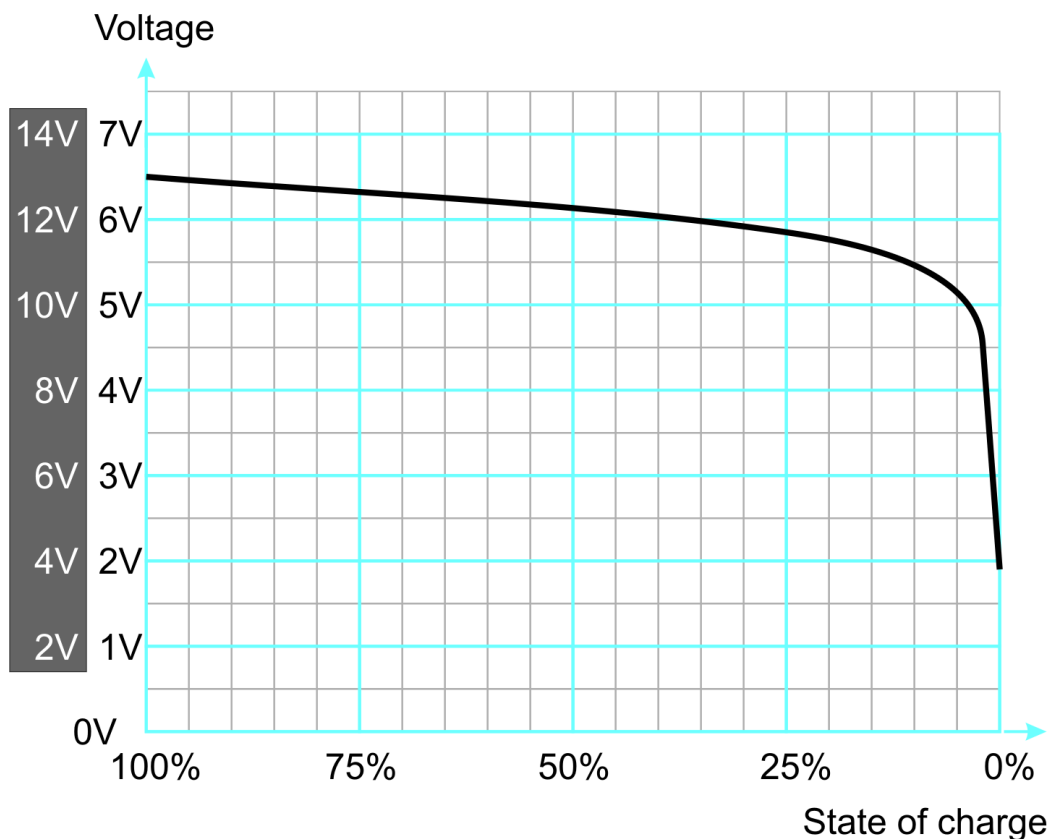
- Construct the circuit shown above.
- Measure the initial battery voltage with the switch open.
- Close the switch.
- Measure the charging current from the power supply and battery voltage.
- After five minutes, note the battery voltage and charging current again.
- Briefly, open the switch and measure the open-circuit voltage again.
- Close the switch and continue charging the battery.
- After ten minutes, and then after 15 minutes, repeat this process.
- Complete the table in the Student Handout with your measurements.

WORKSHEETS

Worksheet 2 - Charging Sealed Lead Acid Batteries

So what

- As the **State of Charge** (SOC) increases, the open-circuit battery voltage rises. (It may be difficult to see much of a change in such a short time.) This voltage will also change as the battery settles once charging is finished.
- With a simple voltage source power supply, like the one used here, the current reduces as the SOC increases. (SLA batteries are quite robust and withstand erratic charging like this.)
- The graph gives typical SOC voltages for 6V and 12V SLA batteries.
- It shows how SOC changes with battery voltage and can be used to predict SOC from battery voltage.
- In practice, a 12V SLA battery usually reads an output voltage of around 12.7V and a 6V SLA battery around 6.4V.

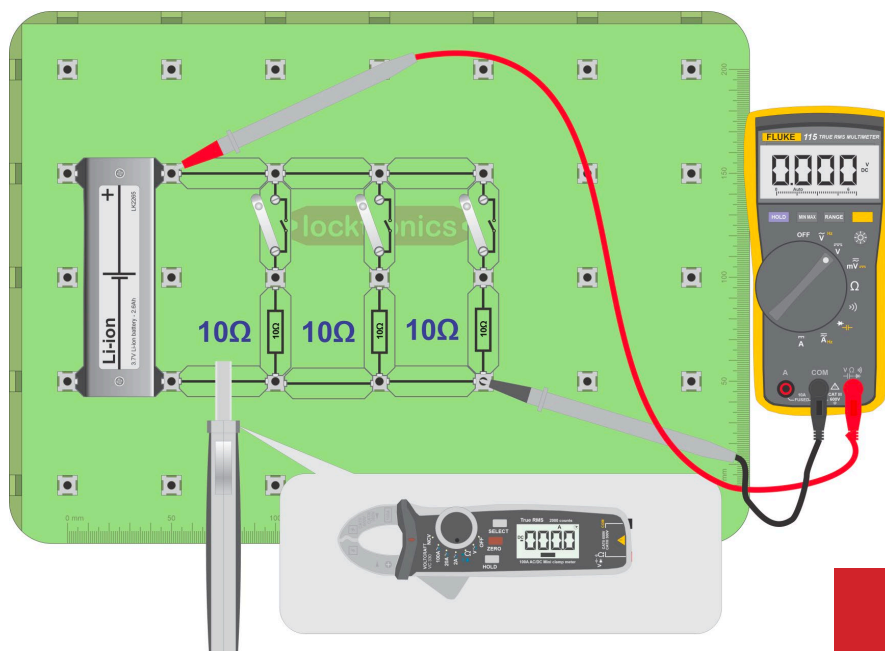
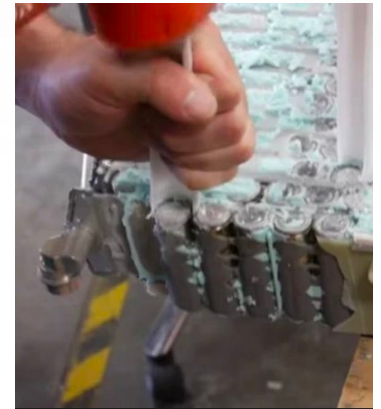


WORKSHEETS

Worksheet 3 - Testing Li-ion Cells

In practice, lithium-ion (Li-ion) battery packs are made up of a large number of 'cells'. Testing the whole battery is difficult and so each cell, or group of cells, is monitored separately by the battery management system.

The photograph shows the interior of a Tesla battery with hundreds of small Li-ion cells identical to those in your kit. They are known as '18650' cells. In the kit, they are housed in a metal case because they can catch fire or explode if mistreated.



**Do not
discharge
the batteries
below 3.2V**

Over to you

- Construct the circuit shown above but leave the switches open for now.
- Configure the multimeter to measure DC volts.
- Configure the current clamp to measure DC amps and 'zero' it.
- Measure the battery output voltage and current as shown.
- Close the first switch briefly and measure output voltage and current again.
- Close the second and then third switch, briefly, and repeat the process.
- Note down all readings in the Student Handout.

WORKSHEETS

Worksheet 3 - Testing Li-ion Cells

So what

You should have noticed two obvious differences between the Li-ion and SLA batteries:

- Their output voltage is very different - around 3.7V for the Li-ion cell compared to around 6.3V for the SLA battery;
- Li-ion cells have a much smaller internal resistance than the SLA batteries, allowing them to deliver huge power for their small volume.

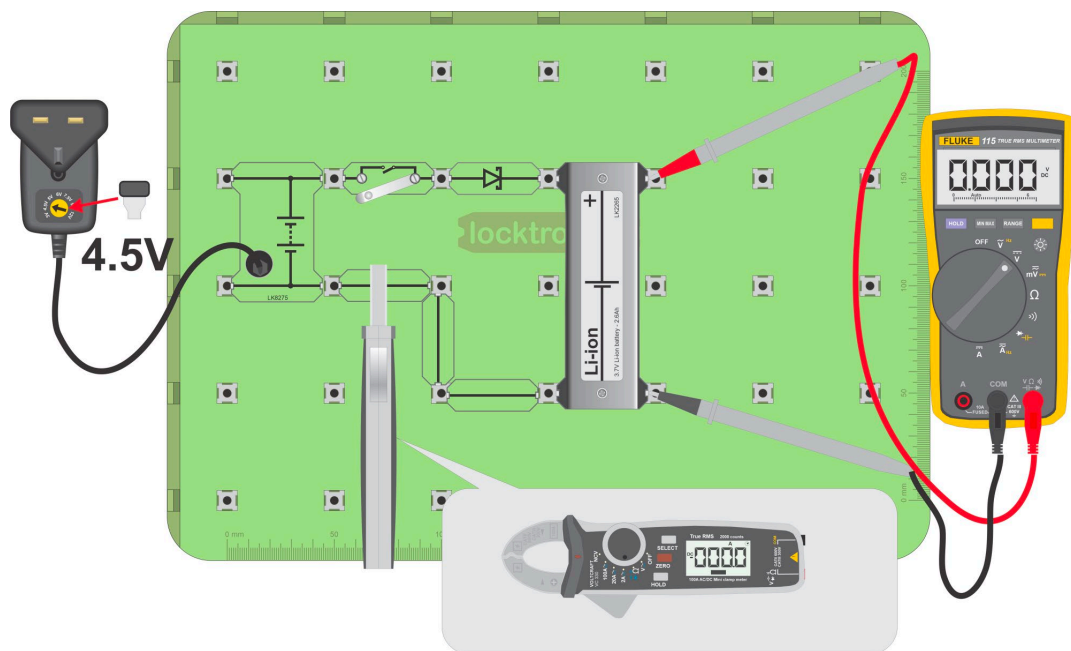
WORKSHEETS

Worksheet 4 - Charging Li-ion Cells

Batteries convert chemical energy into electrical energy and vice-versa. They can be charged in a number of ways - slowly with a low current 'trickle' charge or quickly with a high current charge.

Charging time is becoming more important as the need to recharge cars mid-journey becomes a necessity.

The photograph shows a Tesla 2170 battery cell.



Do not charge the batteries above 4.2V

Caution: if you mistreat Li-ion batteries they can catch fire. Do not use any other charger than the one supplied with this kit and make sure you use the correct voltage and the Schottky diode in series.

Over to you

- Construct the circuit shown above.
- The circuit above delivers around 4.1V to the Li-ion battery. Check the voltage with your meter.

WORKSHEETS

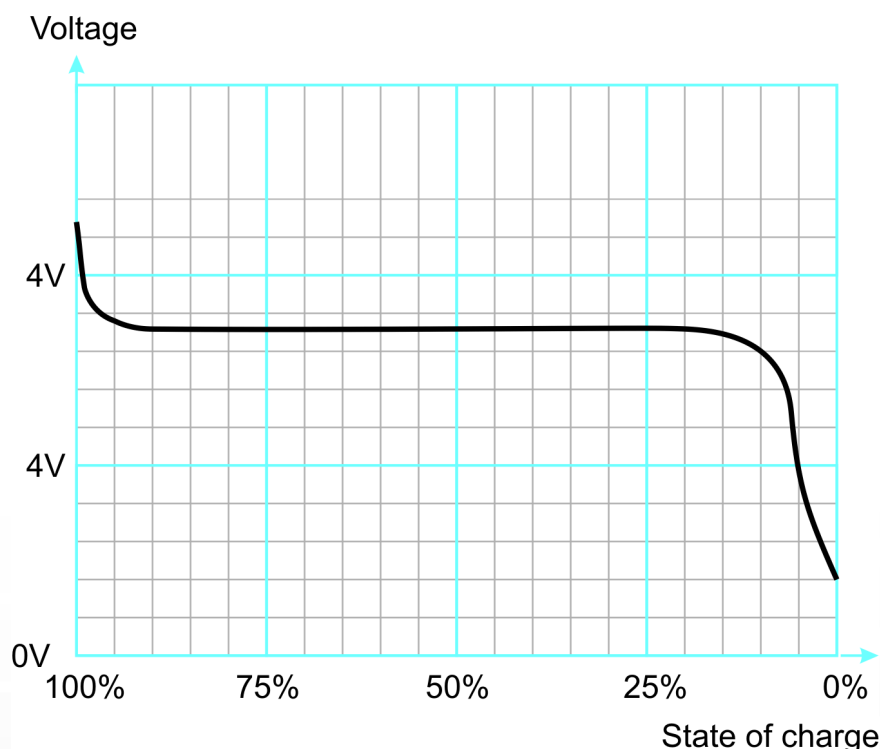
Worksheet 4 - Charging Li-ion Cells

Over to you

- Measure the initial output voltage with the switch open.
- Close the switch.
- Measure the charging current from the power supply and battery voltage.
- After five minutes, note the output voltage and charging current again.
- Briefly, open the switch and measure the open-circuit voltage again.
- Close the switch and continue charging the battery.
- After ten minutes, and then after 15 minutes, repeat this process.
- Complete the table in the Student Handout with your measurements.

So what

- The results depend on the state of charge of the cell.
- In general, the output voltage of a Li-ion cell varies less with SOC than it does for a SLA battery.
- The graph shows typical output voltage variation with SOC for Li-ion cells.
- At high SOC, the output voltage can be up to 4.5V.
- In the middle section, the curve is very flat at around 3.7V. This makes it impossible to deduce the state of charge from voltage alone.
- The voltage really tails off in the last 10% of SOC. In practice, we should not let Li-ion cells fall to below 20% of SOC.



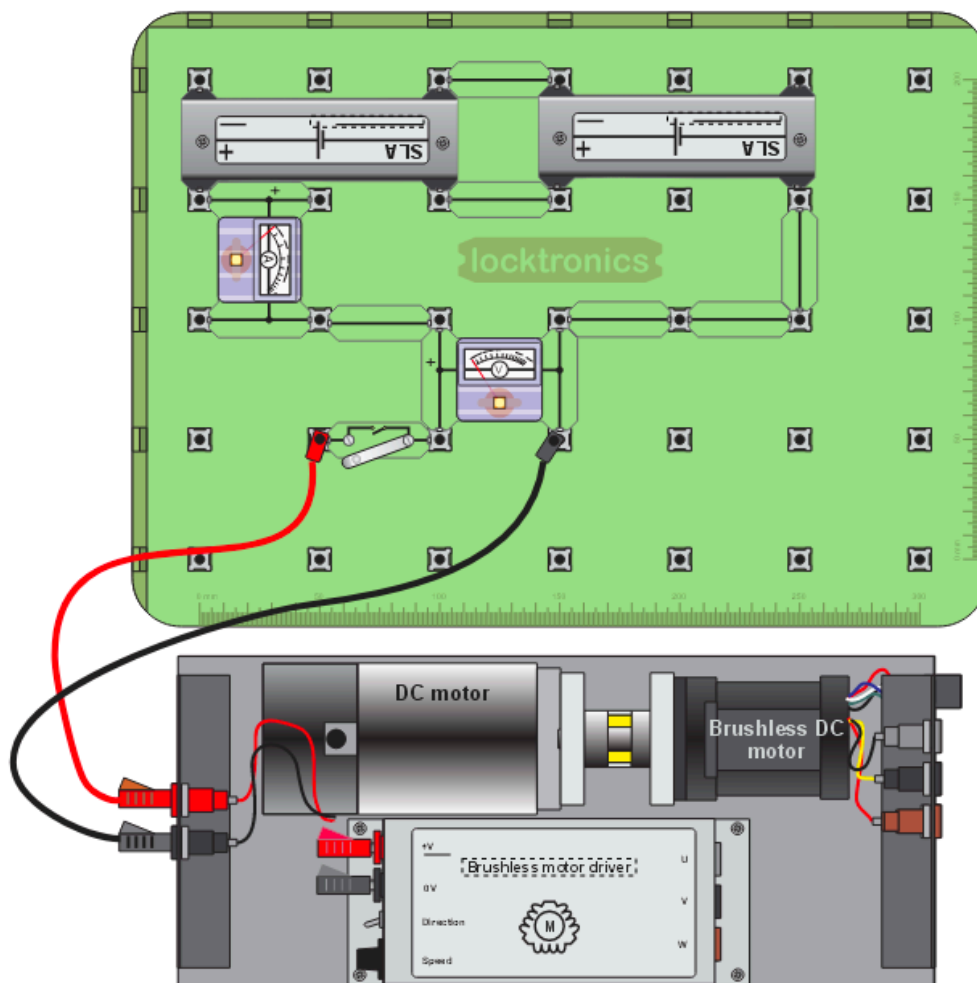
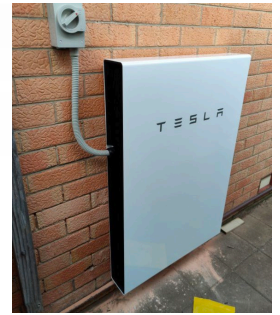
WORKSHEETS

Worksheet 5 - Building Larger Batteries

Larger batteries are made by connecting smaller batteries in series and / or parallel.

For example, a Tesla car battery is made up of 7,000 of the 18650 batteries like the one in your pack. The Tesla Powerwall uses the same batteries.

The photograph shows a Tesla powerwall.



Over to you

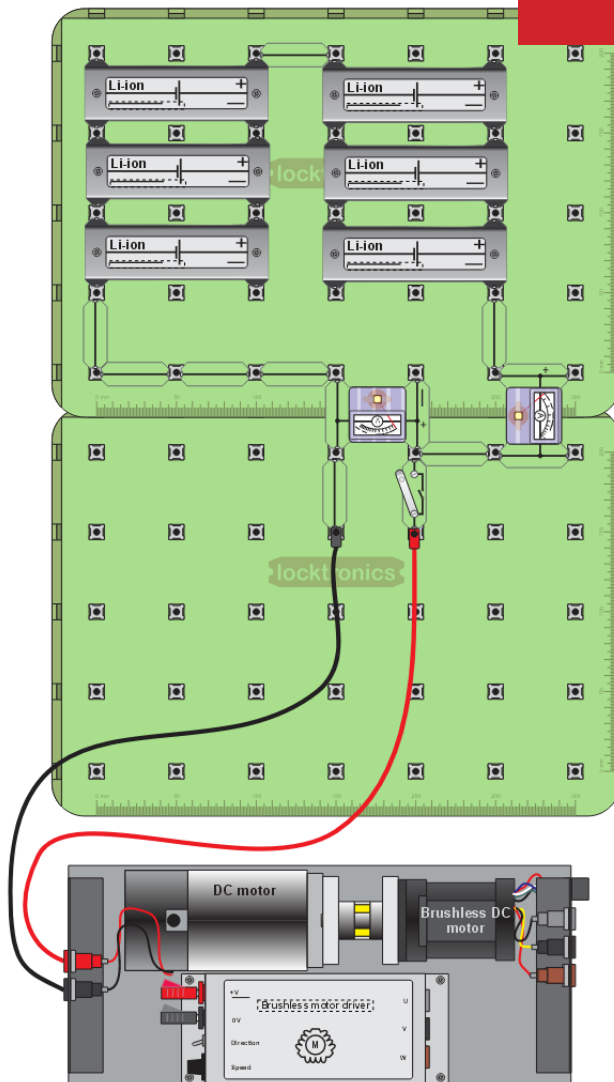
- Using two 6V SLA batteries, build the layout shown above.
- Close the switch - the DC motor/Brushless motor coupled pair should rotate.
- Measure the battery output voltage and current and record them in the Student Handout.
- Calculate the power delivered to the motor.

WORKSHEETS

Worksheet 5 - Building Larger Batteries

Try to match cells in parallel with others of a similar voltage: otherwise you just charge one cell with another.

Warning
Be careful to connect the cells the right way round!
Do not short-circuit them!



Over to you

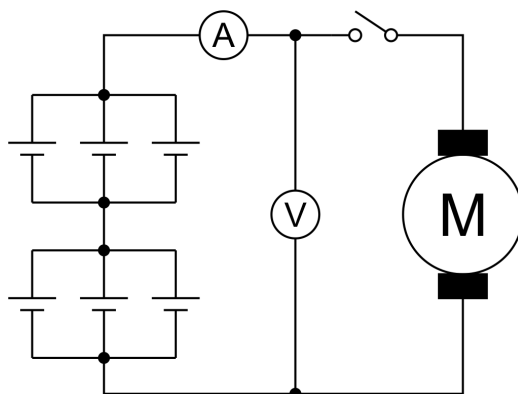
- Use six Li-ion cells, two sets of three, to build the battery shown above.
- Again, measure battery output voltage and current and calculate the power output.
- Record all your results in the Student Handout.

WORKSHEETS

Worksheet 5 - Building Larger Batteries

So what

- The circuit you built is shown in the circuit diagram below. It is known as a '2 by 3' battery or, simply, a 2,3 battery, meaning that it is made up of two sets of three parallel cells, connected in series. The output voltage is twice the cell voltage, i.e. $2 \times 3.7V = 7.4V$.



- The following table shows you how to calculate the power rating of the larger battery:

Cell voltage	A	3.7	V
Individual cell current rating	B	2.6	Ah
Cells in parallel	C	3	
Groups of cells in series	D	2	
Combined power rating	$A \times B \times C \times D$	57.72	Wh

So what

- Battery voltage and current capability can be changed by simply changing the number of batteries in series and parallel
- The Power rating of a battery is the voltage multiplied by the one hour current rating.
- Batteries are scalable. We can refer to a 2,3 battery as a 'module'. Then we can add other modules in series and parallel to build an even larger battery.

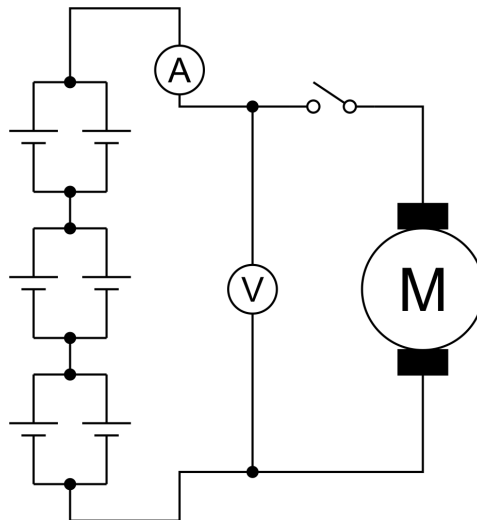
Warning - Be careful to connect the cells the right way round!

WORKSHEETS

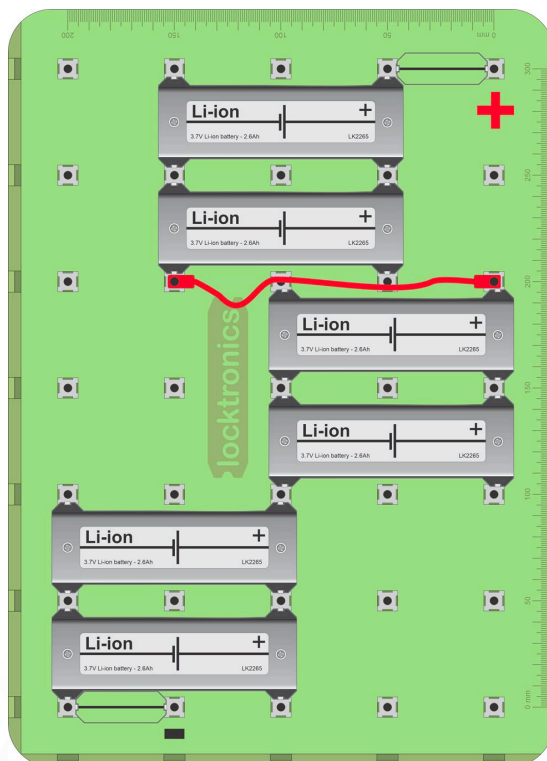
Worksheet 5 - Building Larger Batteries

Challenge 1:

- Build the 3,2 battery module shown in the circuit below. You can use the diagram to help you.



- Measure the battery module output voltage and current and calculate the power delivered to the motor.
- Use the current clamp meter and multimeter to improve accuracy.
- Record all your results in the Student Handout.
- Calculate the power rating for the 3,2 battery using the table in the 2,3 calculation above.



A 3,2 battery module

WORKSHEETS

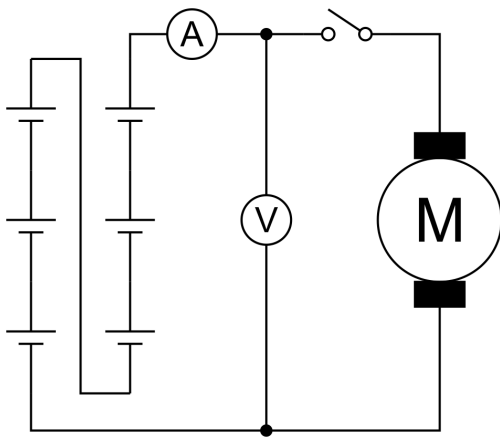
Worksheet 5 - Building Larger Batteries

Challenge 2:

- Build the 6,1 battery module shown in the circuit below.

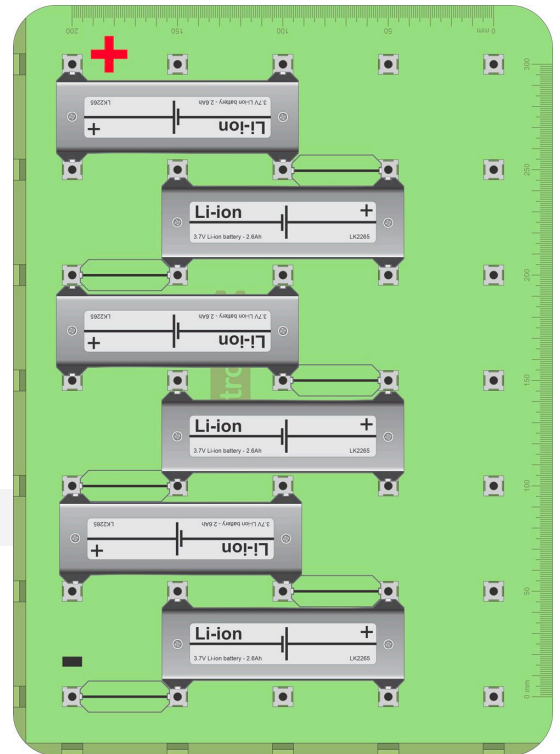
Warning - Be careful to connect the cells the right way round!

- Measure the battery output voltage and current and calculate the power delivered to the motor.
- Again, use the current clamp meter and multimeter to improve accuracy.
- Record all your results in the Student Handout.
- Calculate the power rating for the 6,1 battery.



So what

- You can build batteries with different output voltages, current and power capacities by varying the number of cells and their series / parallel configuration.
- You can keep the assembly in place as you will be using this for the next few experiments.



Challenge 3:

A Tesla model S battery pack contains 6,912 '16850' cells.

These are arranged in sixteen modules, or bricks, each containing 432 cells arranged with 72 cells in parallel, 6 groups of 72 batteries in series.

- What is the voltage of each brick?
- What is the total battery output voltage?
- What is the theoretical total power rating, in watt.hours, of the whole battery?
- Record your answers in the Student Handout.

WORKSHEETS

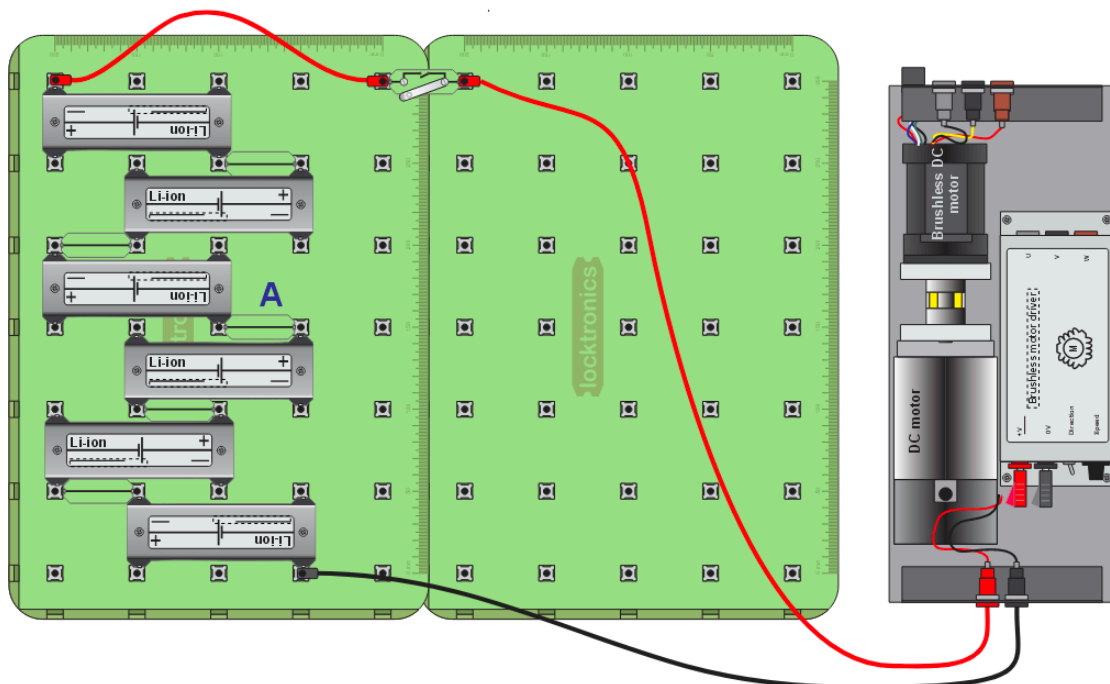
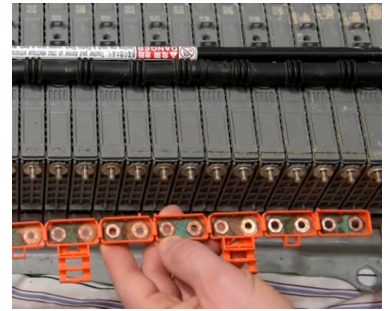
Worksheet 6 - Li-ion Battery Faults

Resolving faults in battery packs is made easier by the reports (or clues) that on-board computers give.

There are two main causes of failure in a battery pack:

- Bad cells;
- Bad links between cells.

The photograph shows corrosion on the battery links in a Toyota Prius.



Over to you

- Build the 6,1 battery as shown above but with the switch open for now.

Warning - Be careful to connect the cells the right way round!

- Measure the battery output voltage.
- Turn on the switch to power the motor.
- Measure the battery output voltage again.

WORKSHEETS

Worksheet 6 - Li-ion Battery Faults

Over to you

- Open the switch.
- Change the central link **A** for the fault component 'corrosion'.
- Measure the battery output voltage again.
- Turn on the switch to power the motor.
- Measure the battery output voltage again.
- Measure the voltage across the corrosion component.
- Record all your results in the Student Handout.

So what

- The 'corrosion' component was used to simulate a fault. Corrosion on contact terminals adds resistance to the circuit. Bad or loose contacts can also behave like added resistance.
- Testing for corrosion or bad contacts is difficult in isolation. Battery voltages appear normal when tested with a multimeter. The effects are noticed only when a large current is drawn.
- In an electric vehicle, the battery management system constantly tests the voltage from battery cells.

Over to you

- There are six Li-ion cells in your kit. The nominal output voltage for each is around 3.7V for SOC values between 15% and 90%.
- Measure the output voltage of each with a multimeter and record your results in the table in the Student Handout.
- If you see a voltage above 3.85V then the cell is likely to be in the top 5% of SOC. Discharge it for 10% of its SOC (see Appendix 3) and remeasure it.

So what

- Battery voltages vary a great deal. In the case of the '18650' battery, the output voltage for a good cell can vary from 3.5 to 4V.
- An output voltage of below 3.5V for a charged Li-ion cell means that it is defective.

WORKSHEETS

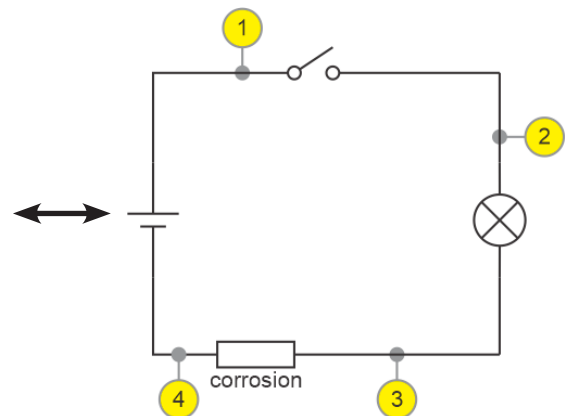
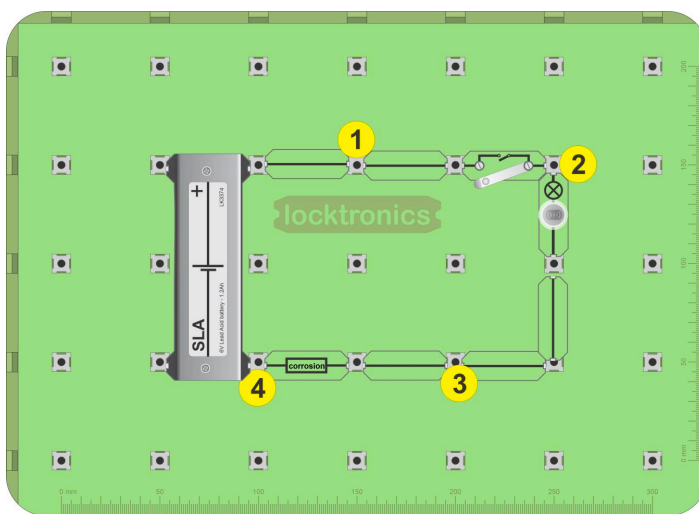
Worksheet 7 - SLA Battery Faults

When chemicals from the battery leak onto the terminals, they can cause corrosion.

Corrosion on the negative terminal is often a sign of undercharging.

Corrosion on the positive side is often a sign of overcharging.

The photo shows a car battery with bad corrosion on one terminal.



Over to you

- Build the layout shown above. It includes a 12V 0.1A filament lamp. The circuit diagram for this is shown alongside. The effect of corrosion is simulated by adding the 'corrosion' component in the earth path of the battery.
- Set up a multimeter to measure DC voltages.

WORKSHEETS

Worksheet 7 - SLA Battery Faults

Over to you

Part 1:

- Connect the multimeter COMmon terminal to node 4.
- Measure the voltage across the battery, between nodes 4 and 1, with the switch open and then closed.
- Record the readings in the table in the Student Handout.

Part 2:

- Move the COMmon connection to node 3 .
- Measure the voltage across the battery between nodes 3 and 1, with the switch open and then closed again.
- Record the readings in the table in the Student Handout.
- Now answer questions 1 and 2.

Part 3:

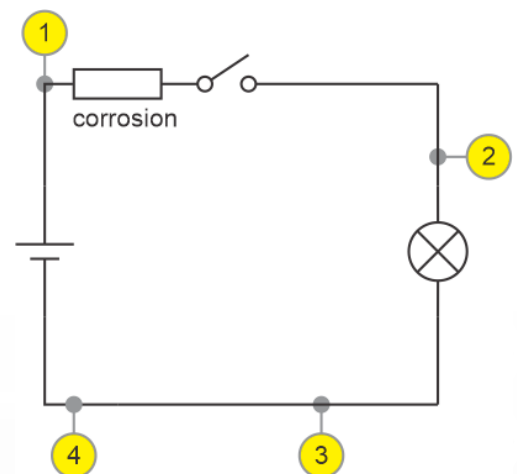
- With the switch closed, measure the voltage dropped across the bulb.
- Open the switch and replace the 'corrosion' link with a normal link.
- With the switch closed, measure the voltage dropped across the bulb again.
- Record the readings in the table in the Student Handout and answer question 3.

So what

- Corrosion is the equivalent to a resistor in the circuit.
- You need to be careful about what you assume is the 0V line or earth.
- Always make sure you know what the exact battery voltage is.
If you know that the battery voltage is 12.7V and you see under 12V in a circuit then it could be a sign of problems.

Challenge:

- Build the circuit opposite, which has corrosion in the 6V line.
- Use a multimeter to investigate the effect of corrosion.
- Record the results of your investigation in the Student Handout.
Describe how you would check whether there is corrosion on the battery?



WORKSHEETS

Worksheet 8 - Battery Management

Batteries are all different, physically and therefore electrically. That's the result of a manufacturing process which is not exact. This raises problems that need managing by the electronics systems that supervise charging.

The photograph shows the insides of a Tesla Powerwall.



Over to you

There are six Li-ion cells in your kit. The nominal voltage is around 3.7V for each, provided that the SOC is between 15% and 95%.

- Measure the output voltage of each with a multimeter and record your answers in the table in the Student Handout.
- If you see a voltage above 3.8V then that cell is likely to have a SOC above 95%. Discharge it until the SOC falls by around 10%, (see Appendix 3). The measure its voltage again.

So what

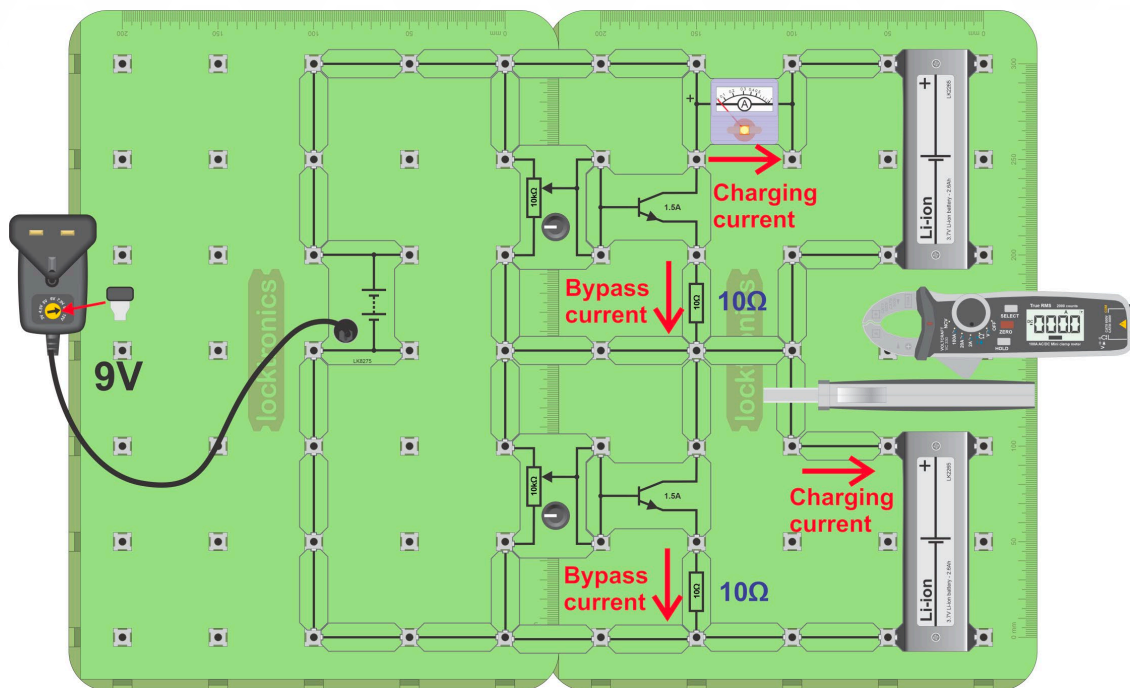
- The actual output voltage of a Li-ion '18650' cell will vary between 3.5 and 3.9V.
- Providing that it is properly charged, with a SOC between 5% and 95%, any cell with an output voltage outside this range can be assumed to be out of specification.
- One bad cell in a battery pack can affect the performance of the entire battery pack.
- Where it is necessary to charge many batteries connected in parallel, batteries of similar output voltages are chosen.

Over to you

- Select two cells from your collection, one with high voltage and one with low voltage.
- Note their voltages in the Student Handout.
- Build the circuit shown on the next page.
- Using the current clamp meter to monitor performance, adjust each potentiometer until the current charging each cell is 0.7A.
- Measure the bypass current in each circuit.

WORKSHEETS

Worksheet 8 - Battery Management

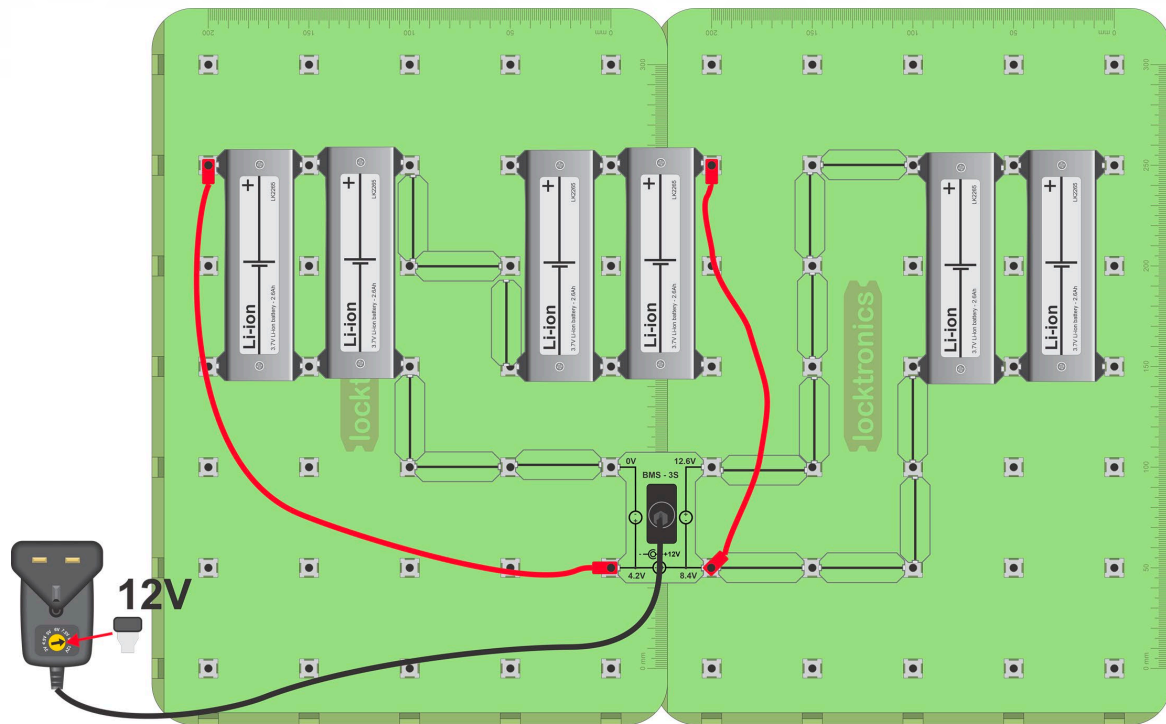


So what

- This circuit allows you to vary the charging current for each cell.
- In a battery management system, a computer measures the voltage and current for each battery - or for each set of batteries in parallel. The computer then uses a transistor to bypass current for batteries that are fully charged so that they do not overcharge.
- It then uses a similar circuit to vary the amount of current charging each battery to ensure that the batteries are not over or under charged.

WORKSHEETS

Worksheet 8 - Battery Management



Over to you

- Build the circuit shown above. The Battery Management System (BMS) allows you to charge three pairs of batteries together.
- Measure the voltage and current of each pair of batteries and make a note in the handout.

So what

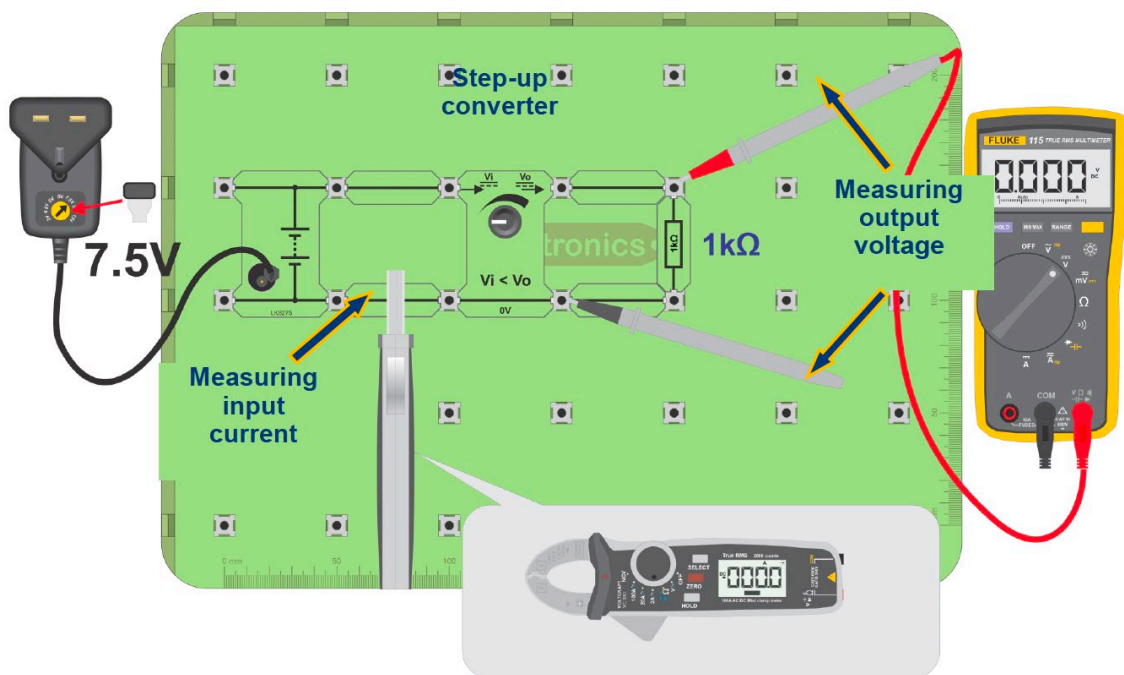
- Battery Management Systems vary in their complexity. The Locktronics BMS charges all batteries at the same rate until the voltage across one pair of batteries reaches 4.2V. Then it stops charging all batteries.
- This unsophisticated system is safe, but it does not allow all batteries to reach their maximum capacity.

WORKSHEETS

Worksheet 9 - Voltage Converters

A key difficulty in green energy system is that wind turbines, solar panels, batteries and the energy grid all operate at different voltages. To get round this modern energy systems make use of voltage upconverters and down converters. These are blocks of electronics that efficiently convert one voltage to another.

The photograph shows a domestic solar panel inverter.



Over to you

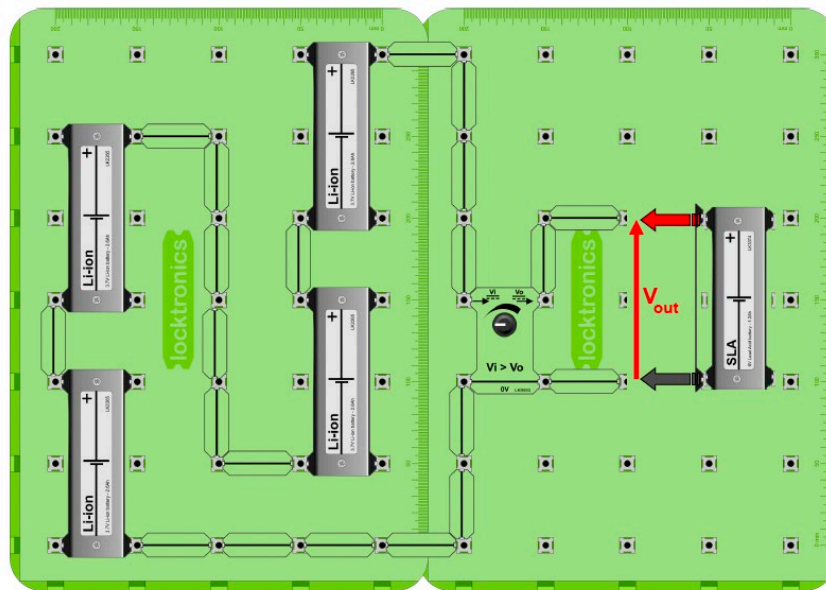
- Build the layout shown above.
The circuit converts the 7.5V output of the power supply to a voltage between 12V and 20V, depending on the position of the step-up converter potentiometer.
- Rotate the potentiometer fully anti-clockwise.
- Use the multimeter to measure the input and output voltages of the step-up converter.
- Use the current clamp-meter to measure input and output currents of the step-up converter.
- Rotate the potentiometer half way round and measure the same quantities again.
- Then do the same when the potentiometer is rotated fully clockwise.
- Calculate the power in and out of the step-up converter for all three positions.

WORKSHEETS

Worksheet 9 - Voltage Converters

So what

A 'DC-to-DC converter' or 'inverter' converts one DC voltage to another and can reverse its polarity. The voltage conversion inevitably includes a loss of energy, i.e. an efficiency of less than 1. This circuit has high losses. In domestic installations, the loss would be less than 5%.



Over to you

- Build the circuit shown above using four Li-ion cells in series.

Warning - Be careful to connect the cells the right way round!

- Adjust the potentiometer in the step down-converter so that its output voltage, V_{OUT} , is 7V.
- Now connect a single SLA battery to the output.
- This circuit converts the 15V or so output of the Li-ion battery to a voltage suitable for charging the SLA battery. In the same way as before, take measurements to allow you to calculate the power in and out of the step-down converter.
- Hence, calculate the efficiency of the step-down converter.

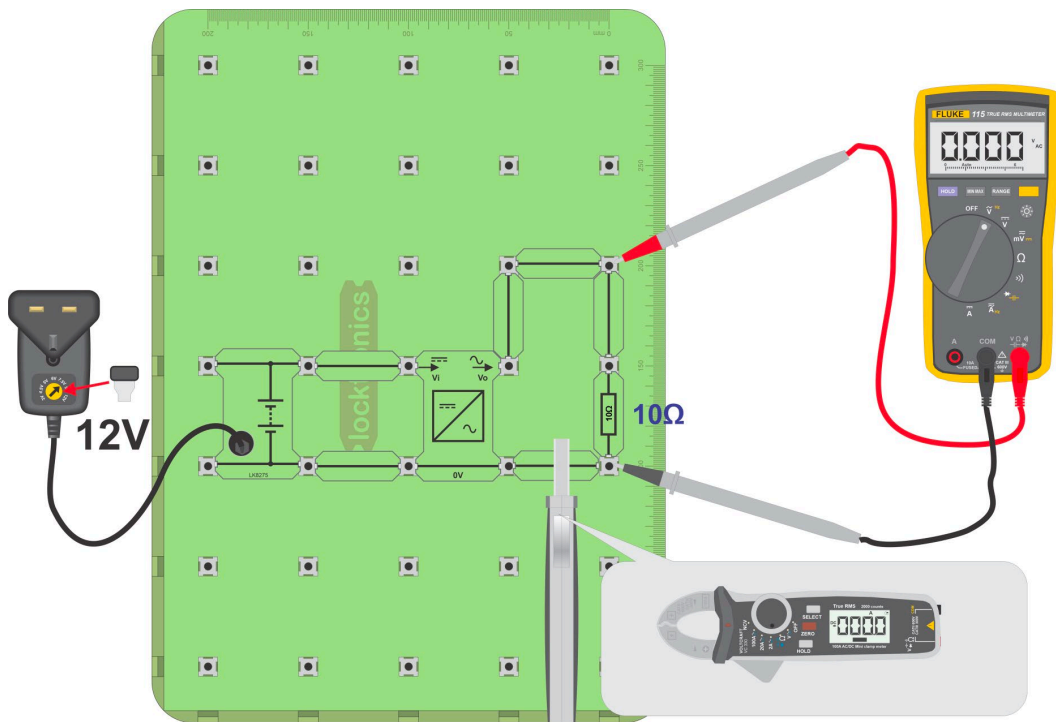
So what

- Modern electric systems make use of upconverters and downconverters.
- In every stage efficiency of conversion of energy is less than 100%.

WORKSHEETS

Worksheet 10 - Voltage Inverters

Solar panels give out direct current (DC) energy. The electricity from a wind turbine is converted from three phase Alternating Current (AC) to DC by the bridge rectifier. The power from the electricity grid is AC and most domestic appliances use AC. What is needed is a unit that converts DC to AC - the inverter. The photograph shows a 24V DC to 240V AC inverter.



Over to you

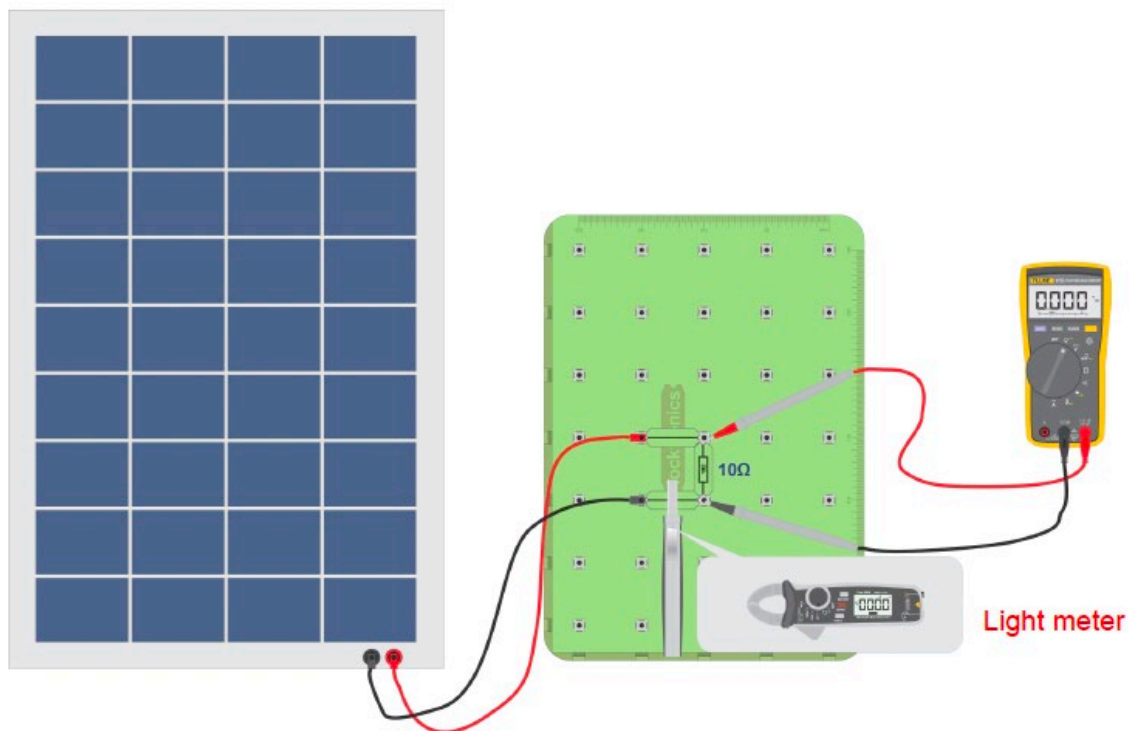
- Build the layout shown above.
The circuit converts the 12V power supply output to AC.
- Use the multimeter to measure the input and output voltages of the inverter.
- Use the current clamp-meter to measure input and output currents of the inverter.
- Calculate the power in and out of the inverter.
- Look at the output on an oscilloscope. What frequency does it produce?
- What is the efficiency of modern domestic 240VAC inverters?

WORKSHEETS

Worksheet 11 - Solar Panels

Solar panels give out direct current (DC) energy. Like batteries the voltage and current that a bank of panels produces can be customised by wiring them in series and in parallel. To be useful they need to integrate into the AC network in the home or office.

The photograph shows a domestic solar panel installation.



Over to you

- Build the layout shown above. This is simply the solar panel feeding a 10ohm resistor.
- Use the light meter, the current clamp meter and the multimeter to investigate the performance of the solar panel.
- Fill in the table below with your findings.

WORKSHEETS

Worksheet 11 - Solar Panels

Inside

Make the following measurement of the solar panel's performance by measuring the luminous flux per unit area (lux), the voltage and the current produced in each situation

- With the solar panel in the lab, flat on the bench,
- With the solar panel facing the window
- With the solar panel outside flat on the floor
- With the solar panel at 90 degrees to the Sun's rays.

	Luminous flux (lux)	Voltage (V)	Current (I)	Power (W)
On the bench				
Facing the window				
Outside				
Outside at 90 degrees to sun's rays				

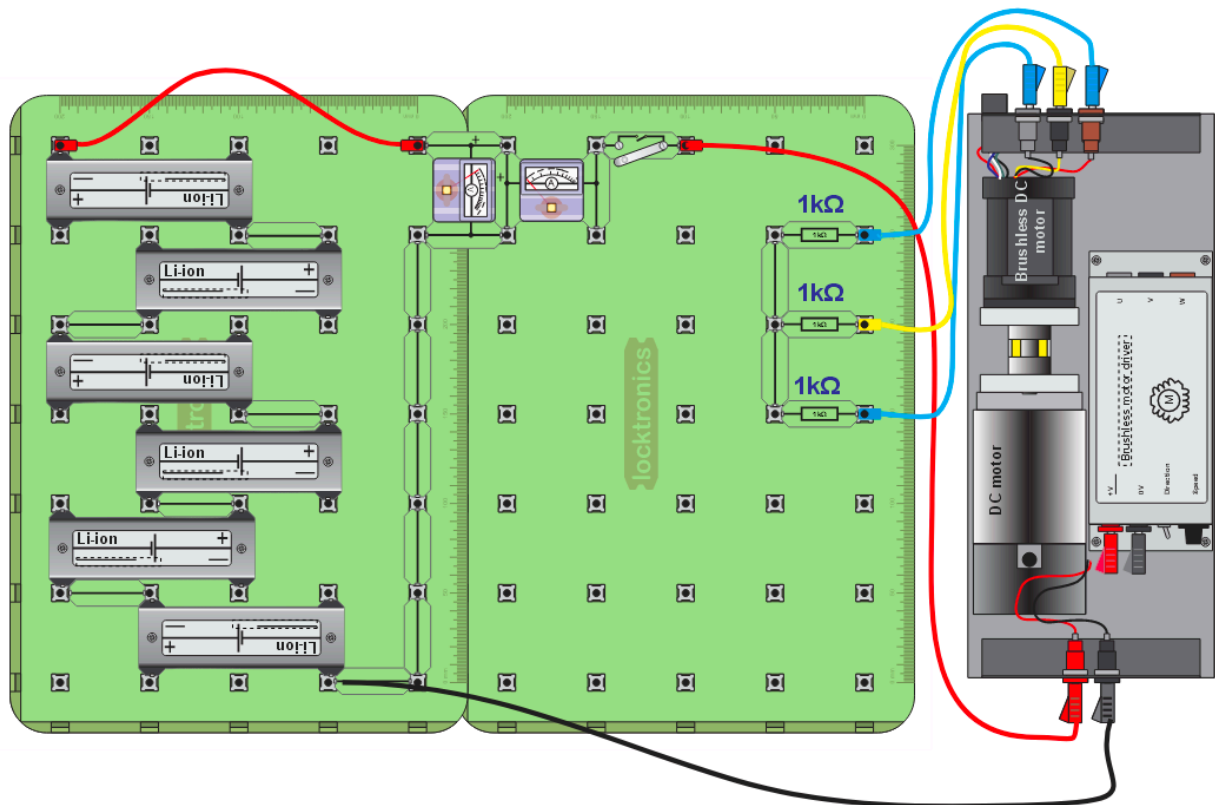
So what

- Solar panels generate electricity by converting light energy to electrical energy.
- The factors that affect the amount of energy are the light intensity and the angle of the light on the panel surface.
- Our eyes are not always good at resolving the amount of light energy around us.
- The panels are optimised for sunlight.
- Sunlight has much greater energy than room lighting.
- To get a really good performance from the panel you will need to be outdoors.

WORKSHEETS

Worksheet 12 - Wind Turbines

Wind turbines are actually three-phase AC generators. Smaller turbines use a permanent magnet rotor and a three phase wound stator to produce electricity. Three phase is used because it is more energy efficient than single phase. Photograph shows a small three phase wind turbine with nacelle and blades removed.



Over to you

Build the circuit shown above. Here we are powering the three phase generator with 24V.

Warning - Be careful to connect the cells the right way round!

WORKSHEETS

Worksheet 12 - Wind Turbines

Over to you

- Use an oscilloscope to look at the waveforms coming from the three-phase generator. Your oscilloscope probably has only two inputs. To see the relative timing of the three waveforms, keep one waveform on channel 1 all the time and use channel 2 to examine the other two waveforms, in turn. Connect the oscilloscope probe across one of the 1k Ω resistors with the ground connection of the oscilloscope attached to the connecting links.

Oscilloscope settings:

Timebase - 10ms/div

Voltage range - $\pm 10\text{V DC}$

Trigger mode - Auto

Trigger channel - ch A

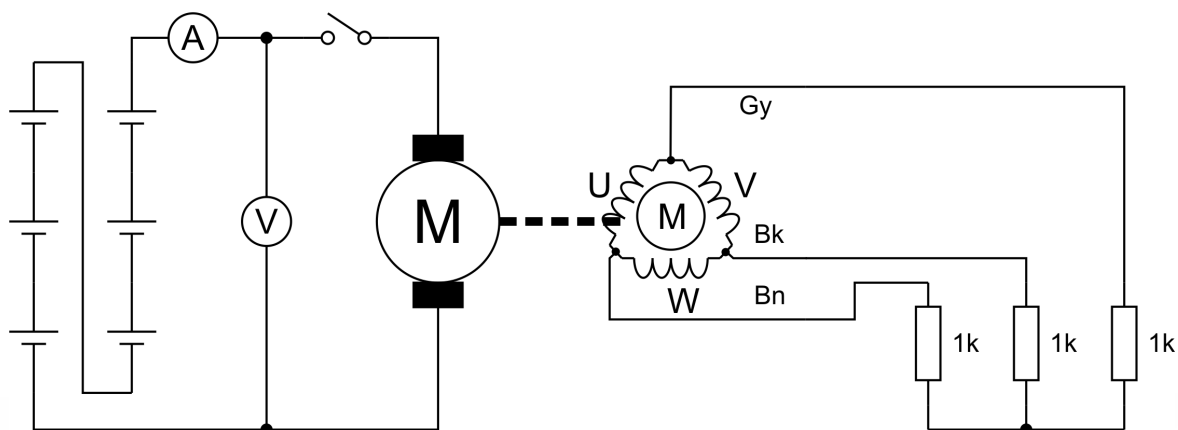
Trigger direction - Rising

Trigger threshold - 5V

- Use the axes provided in the Student Handout to sketch the waveforms across the three resistors.
- Reduce the supply voltage to the DC motor by using just three Li-ion batteries.
- Sketch one of the waveforms again.

So what

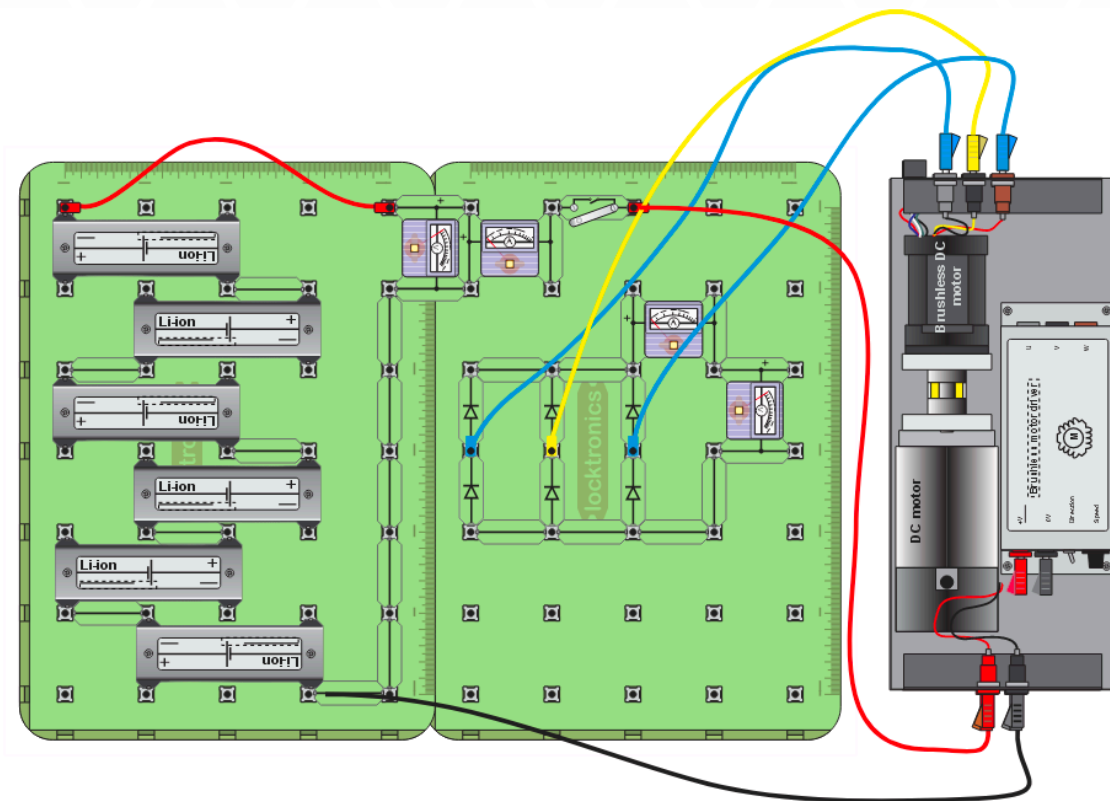
- The three-phase outputs all have different timings on the oscilloscope. The windings in the three-phase generator are spaced 120 $^\circ$ apart. The peaks of the waveforms occur spaced at 33% of the time period of the waveform. Hence we say that "the waveforms are 120 $^\circ$ apart".
- The output of the three-phase generator depends on the speed of the DC motor.



You built the circuit shown in the diagram above. In reality, it is two separate circuits. Each has its own earth or ground. They are not connected and can be at different voltages.

WORKSHEETS

Worksheet 13 - Three-Phase Rectifiers



Over to you

- Build the circuit shown above.

Warning - Be careful to connect the cells the right way round!

- Use an oscilloscope to look at the waveforms coming from the three-phase generator.

Oscilloscope settings:

Timebase - 10ms/div

Voltage range - $\pm 10V$ DC

Trigger mode - Auto

Trigger channel - ch A

Trigger direction - Rising

Trigger threshold - 5V

- Use the axes provided in the Student Handout to sketch the waveforms across the banks of diodes.

WORKSHEETS

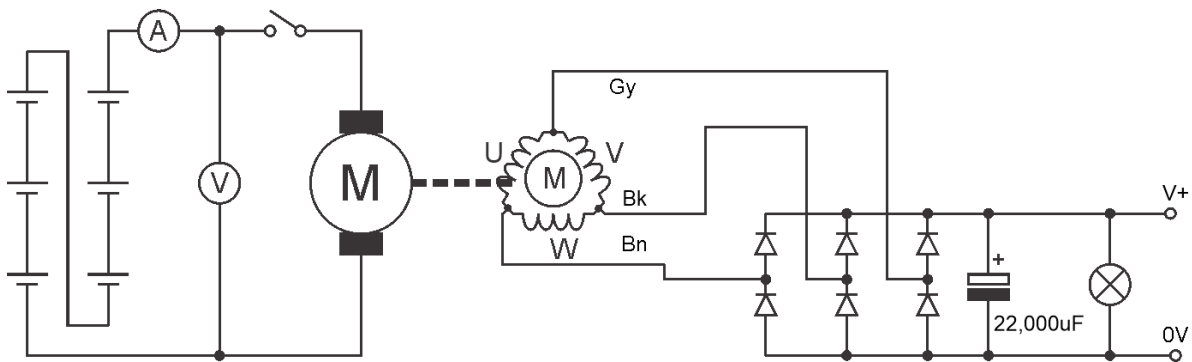
Worksheet 13 - Three-Phase Rectifiers

So what

- The diodes rectify the three phase voltage signal into a single DC waveform.
- The DC waveform has some ripple on it. When the output of a bridge like this is connected to a battery, the battery removes the ripple.

Over to you

- Add a large 2200 μ F capacitor to the rectifier output.
- Connect a LED bulb across the rectifier output. The circuit looks like the one below.



- Close the switch and run the DC motor.
- Open the switch to stop the DC motor.
- How long does the bulb stay lit?
- With a multimeter on DC voltage setting, measure the initial voltage between the two earths - this voltage will decline rapidly.

So what

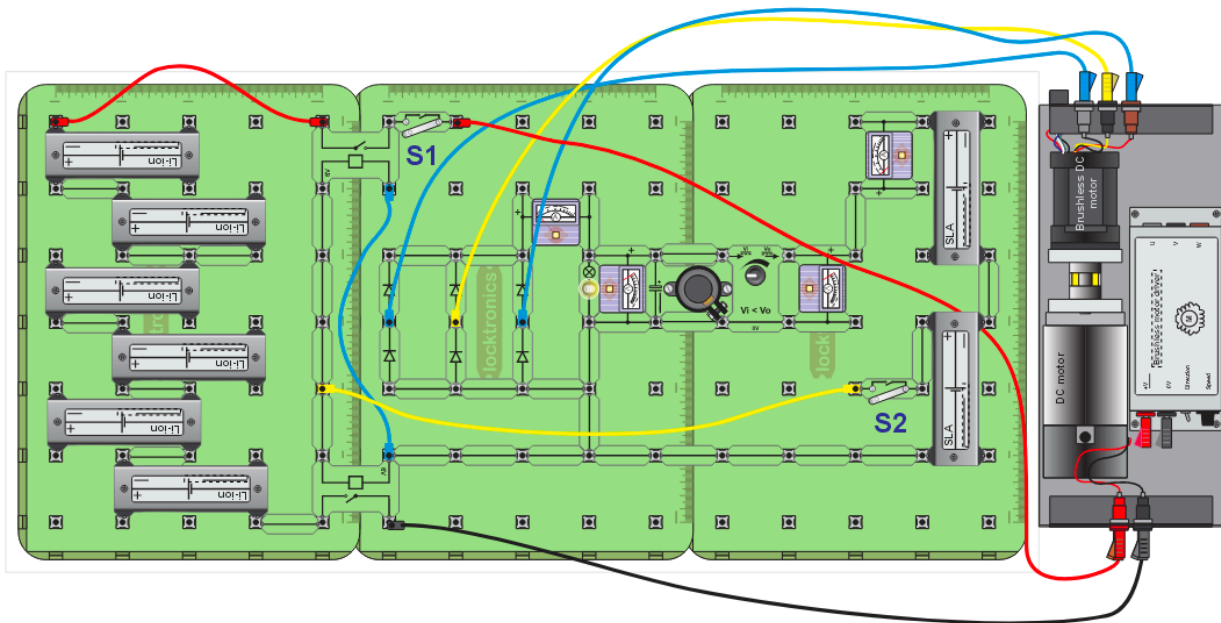
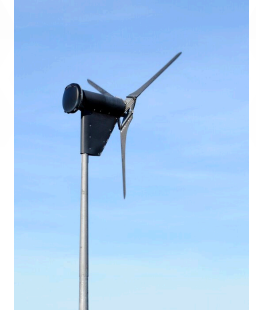
- The capacitor is discharging because of only one LED bulb. Without that in place it would stay charged for much longer.
- You need to be very careful of capacitors in the high voltage side of electric vehicles - even when batteries are removed they may still contain enough charge to kill.
- There is no electrical link between the ground of each side of the circuit. That means there could be a significant voltage between the two grounds.

WORKSHEETS

Worksheet 14 - Using Wind Power to Provide AC

The output from wind turbines varies in amplitude and frequency - we can't just connect it to the domestic AC system. First we rectify it to DC, then smooth it with a large capacitor, then we use an up converter or down converter to regulate its voltage, then we create AC. In practice each module is computer controlled with a feedback system to cater for variations in output.

The photograph shows a small domestic wind turbine.

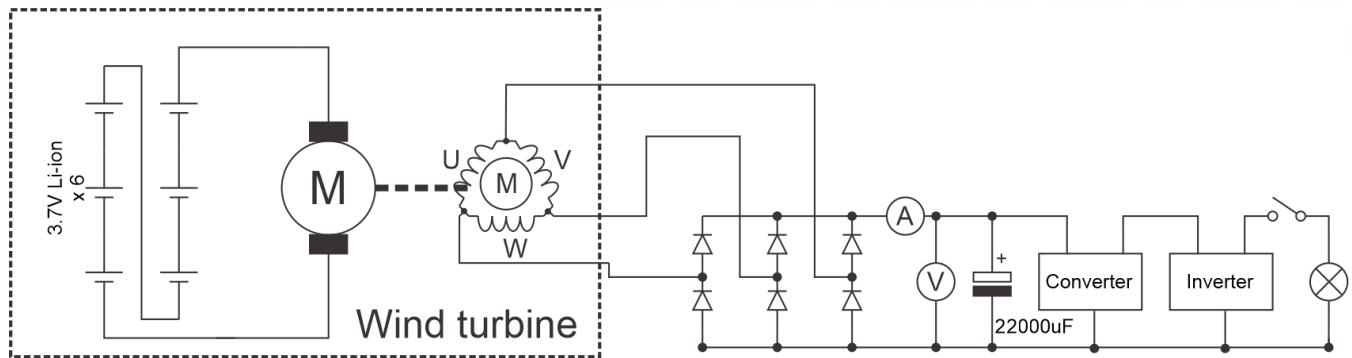


Over to you

- Build the layout shown above. The six Li-ion batteries produce around 24V when charged. This powers a DC motor mechanically coupled to a brushless DC motor which makes three phase electricity. You can vary the speed of the DC motor / brushless DC motor by tapping into the battery chain at different points.
- This battery/DC motor / brushless DC motor allows you to mimic the action of a wind turbine.
- You should get around 6V RMS across the large capacitor.
- Adjust the potentiometer on the voltage up converter until current starts to flow. This should be when the DC output from the up converter is around 12V.

WORKSHEETS

Worksheet 14 - Using Wind Power to Provide AC



So what

The diagram above shows you the schematic of your system. To create AC the voltage needs to first be rectified, then regulated to a set voltage, then inverted to AC.

Over to you

Calculate the efficiency of the system at each stage:

- Power in to the motor DCV in DCI in
- Power generated after the rectifier ACV AC I
- Power into and out of the voltage converter DC Vin DC I in DC Vout DC I out
- Power into and out of the inverter DC Vin DC I in AC Vout AC I out

Research what typical efficiencies you would find in commercial units.

When you switch the bulb on what happens to the speed of the motor generator pair?

So what

There are losses at each stage in the energy conversion.

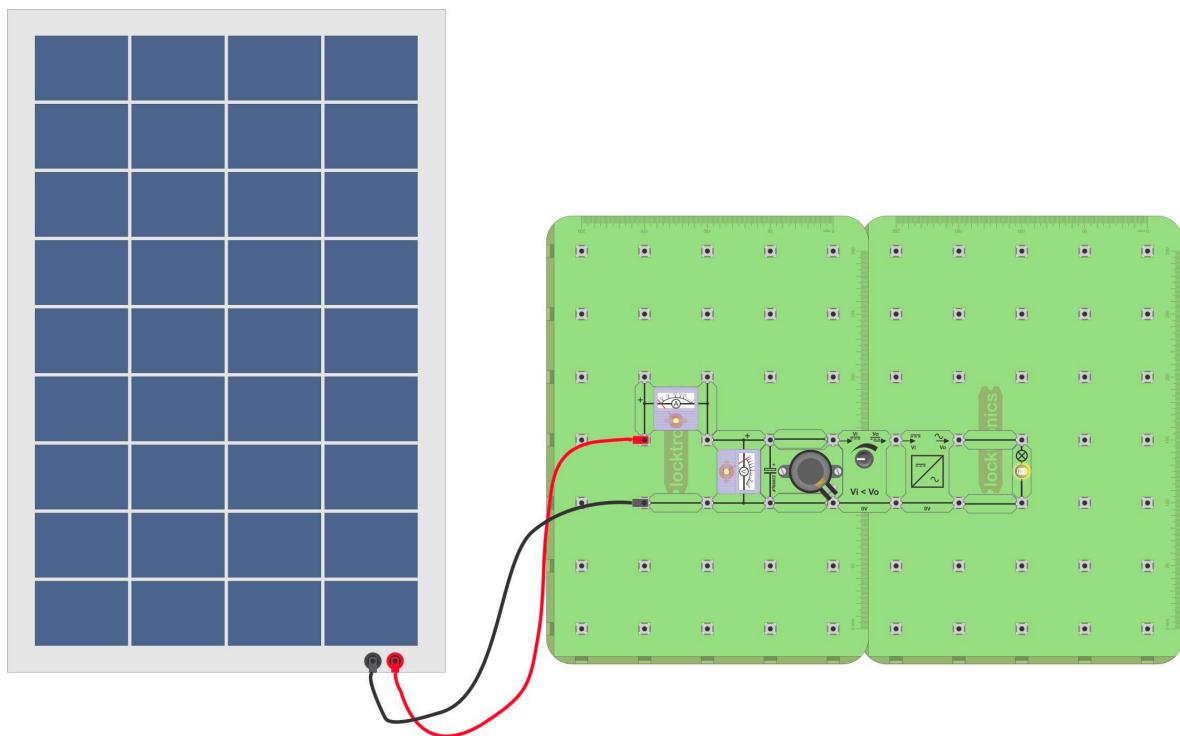
The losses in commercial systems will be lower than in this system.

Putting an electrical load on the system puts a mechanical load on the motor generator pair which slows it down. A significant problem for wind farms is that in high winds the rotating speed of the windmills needs to be slowed down by having a load on the electrical system at all times - even when energy is not needed. Dumping this excess electricity is a significant problem for wind energy generating companies.

WORKSHEETS

Worksheet 15 - Using Solar Power to Provide AC

The output from solar panels is DC. It varies depending on the brightness of the sun, the angle of the incident rays on the surface of the panels, and the time of day. The DC energy is first passed to a DC to DC converter and then to a DC to AC inverter before the energy can be distributed in the home or through the electricity grid. The photograph shows a solar farm with power management units.

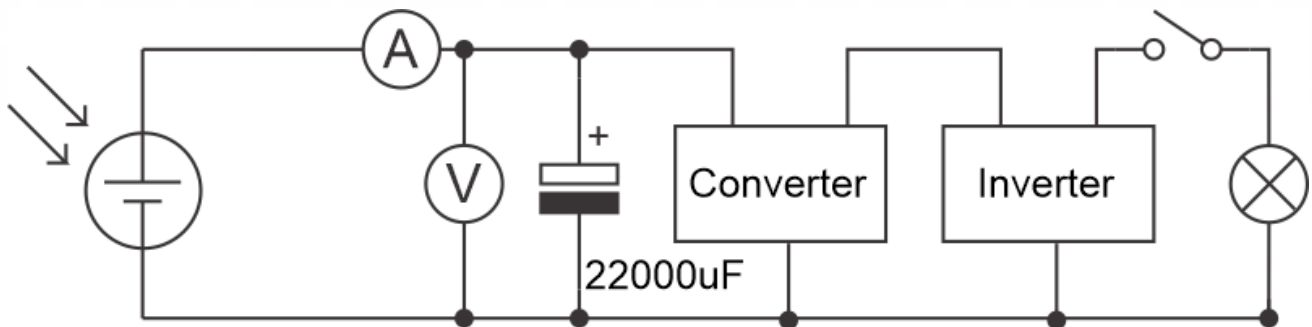


Over to you

- Build the layout shown above. The solar panel will produce around **12V at 0.5 Amps** (6 watts) when in reasonably bright light. You will need to place the panel outdoors to achieve this level of power - indoor lights will not produce enough electricity.
- You will get around **12V** across the large capacitor.
- Adjust the potentiometer on the up converter until current starts to flow. This should be when the DC output from the up converter is around 12V.

WORKSHEETS

Worksheet 15 - Using Solar Power to Provide AC



So what

The diagram above shows you the schematic of your system.
To create AC the voltage needs to first be regulated to a set voltage, then inverted to AC.

Over to you

Calculate the efficiency of the system at each stage:

- Power into and out of the voltage converter DC Vin DC I in DC Vout DC I out
- Power into and out of the inverter DC Vin DC I in AC Vout AC I out

Research what typical efficiencies you would find in commercial units.

So what

Solar power has fewer problems than wind power. It is cheaper to install and maintain in term of cost per kilowatt hour generated.

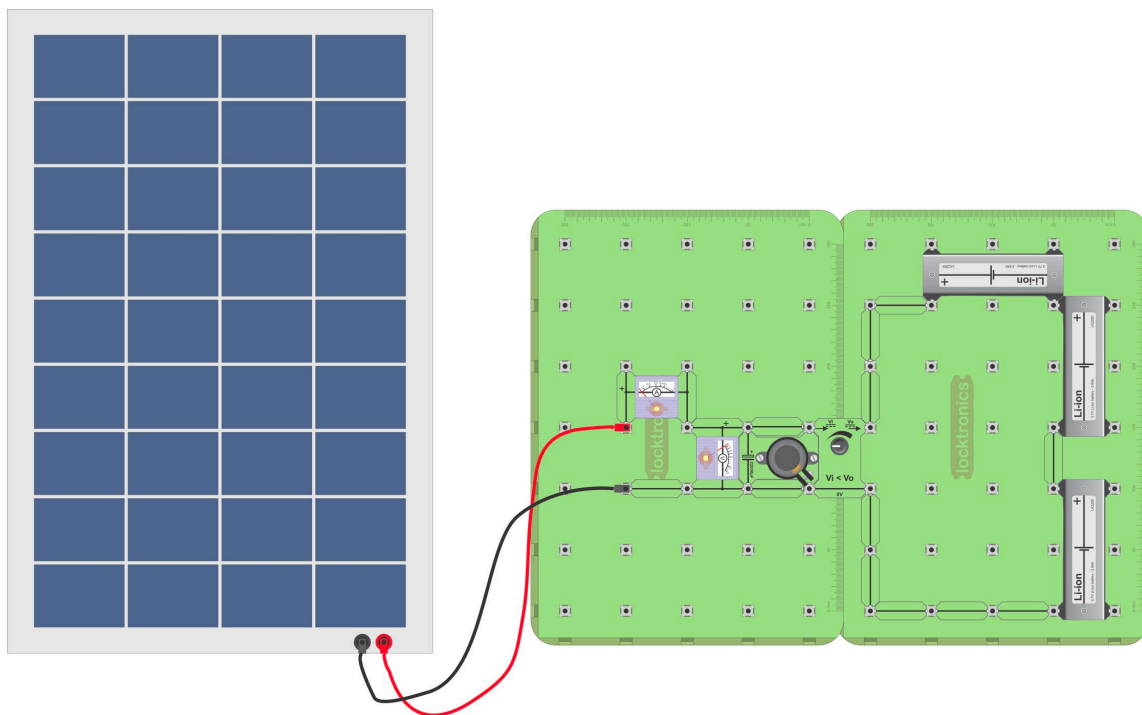
But it does not generate much electricity at night

WORKSHEETS

Worksheet 16 - Using Solar Power to Charge Batteries

Solar and wind power have one significant problem: the output varies so much in any one day and from day to day. We can get round that by storing energy in batteries. This means that we need to use an inverter to convert the voltage from the solar panel to a suitable voltage for the battery pack.

The photograph shows one of Tesla's power banks in Australia.



Over to you

- Build the layout shown above. The solar panel will produce around **12V at 0.5 Amps** (6 watts) when in reasonably bright light. You will need to place the panel outdoors to achieve this level of power - indoor lights will not produce enough electricity.
- You will get around **12V** across the large capacitor.
- Adjust the potentiometer on the up converter until current starts to flow. This should be when the DC output from the up converter is around 11V.



STUDENT HANDOUT



STUDENT HANDOUT

Worksheet 1 - Testing Sealed Lead-Acid Batteries

Effect of load on output voltage:

Switches closed	None	1st only	1st and 2nd	1st, 2nd and 3rd
Battery voltage				
Total current	0			

Effect of discharge time on output voltage:

Time in mins	0	5	10	15
Battery voltage				
Battery current				

Worksheet 2 - Charging SLA Batteries

Time in mins	0	5	10	15
Battery voltage				
Battery current				
Battery voltage open-circuit				

Worksheet 3 - Testing Li-ion Batteries

Effect of load on output voltage:

Switches closed	None	1st only	1st and 2nd	1st, 2nd and 3rd
Battery voltage				
Total current	0			

Worksheet 4 - Charging Li-ion Batteries

Time in mins	0	5	10	15
Battery voltage				
Battery current				
Battery voltage open-circuit				

For two Li-ion batteries in series:

Initial charging current = A

Voltage across battery 1 = V

Voltage across battery 2 = V

STUDENT HANDOUT

Worksheet 5 - Building Larger Batteries

Two 6V SLA batteries in series:

Voltage (V)	Current (A)	Power delivered (W)

Six Li-ion cells in a 2,3 battery:

Voltage (V)	Current (A)	Power delivered (W)

Challenge 1: six Li-ion cells in a 3,2 battery:

Voltage (V)	Current (A)	Power delivered (W)

Cell voltage	A	3.7	V
Individual cell current rating	B		Ah
Cells in parallel	C		
Groups of cells in series	D		
Combined power rating	A x B x C x D		Wh

Challenge 2: six Li-ion cells in a 6,1 battery:

Voltage (V)	Current (A)	Power delivered (W)

Cell voltage	A	3.7	V
Individual cell current rating	B		Ah
Cells in parallel	C		
Groups of cells in series	D		
Combined power rating	A x B x C x D		Wh

STUDENT HANDOUT

Worksheet 5 - Building Larger Batteries

Challenge 3: Tesla model S battery

For one brick:

Cell voltage	A	3.7	V
Individual cell current rating	B		Ah
Cells in parallel	C		
Groups of cells in series	D		
Combined power rating	A x B x C x D		Wh

For 16 bricks the total power rating is 16 times this number or 66.5kWh.

Worksheet 6 - Li-ion Battery Faults

No load output voltage

Output voltage when connected to motor:

Output voltage with corrosion at point A

Output voltage with corrosion at point A - with load

Voltage across the corrosion component

Battery 1 (V)	Battery 2 (V)	Battery 3 (V)	Battery 4 (V)	Battery 5 (V)	Battery 6 (V)
(V)					

STUDENT HANDOUT

Worksheet 7 - SLA Battery Faults

Part 1 - COMmon connected to node 4:

Switch	Voltage across battery (between nodes 1 and 4)
Open	
Closed	

Part 2 - COMmon connected to node 3:

Switch	Voltage across battery (between nodes 1 and 3)
Open	
Closed	

Question 1: Why are both readings the same when the switch is open?

.....
.....

Question 2: In part 1, why does the reading change when the switch is closed?

.....
.....

Part 3 - Effect of corrosion on load voltage:

Switch	Voltage across battery (between nodes 1 and 3)
Open	
Closed	

Question 3: What is the effect of corrosion in the cables and connectors on the brightness of the bulb?

.....
.....

Challenge:

Results of the investigation:

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

Describe how you would check whether there is corrosion on the battery.

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

STUDENT HANDOUT

Worksheet 8 - Battery Management

Battery 1 (V)	Battery 2 (V)	Battery 3 (V)	Battery 4 (V)	Battery 5 (V)	Battery 6 (V)
(V)					

Battery	Initial voltage (V)	Charge current (A)	Bypass current (A)
1		0.7	
2		0.7	

BMS system

	Pair 1	Pair 2	Pair 3
Voltage V			
Current I			

Worksheet 9 - Voltage Converters

Pot position	Fully anticlockwise	Half way	Fully clockwise
Input current			
Input voltage			
Input power			
Output current			
Output voltage			
Output power			
Efficiency			

	Reading
Input current	
Input voltage	
Input power	
Output current	
Output voltage	
Output power	
Efficiency	

STUDENT HANDOUT

Worksheet 10 - Voltage Inverters

Input voltage DCV	Input current DCA	Input power W	Output voltage ACV (rms)	Output current AV A (rms)	Output power W

Frequency:

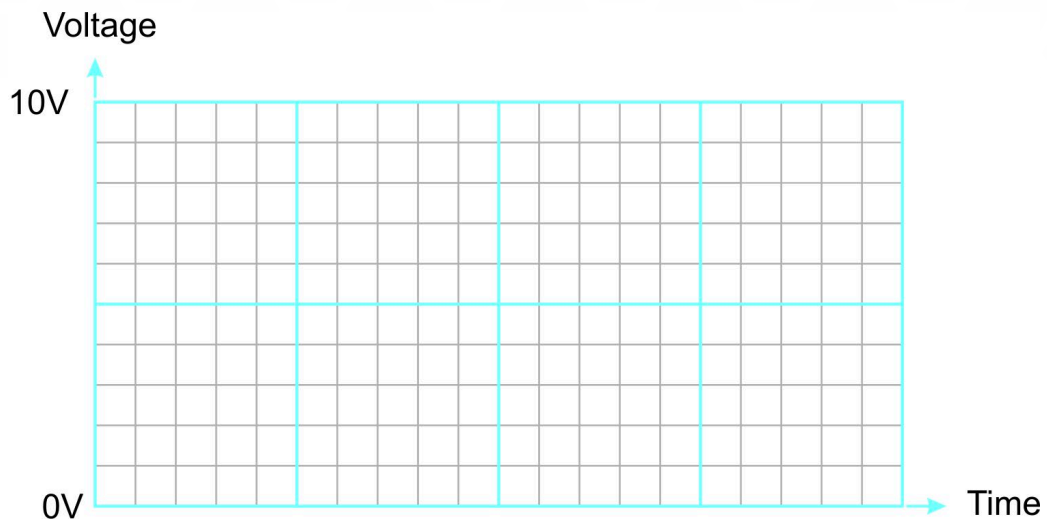
Worksheet 11 - Solar Panels:

	Luminous flux (lux)	Voltage (V)	Current (I)	Power (W)
On the bench				
Facing the window				
Outside				
Outside at 90 degrees to sun's rays				

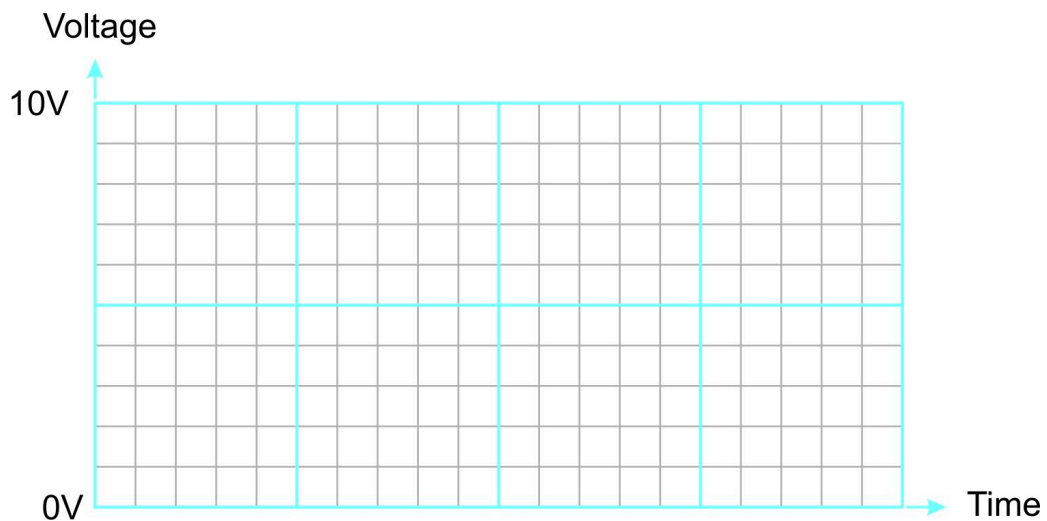
STUDENT HANDOUT

Worksheet 12 - Three-Phase Generators

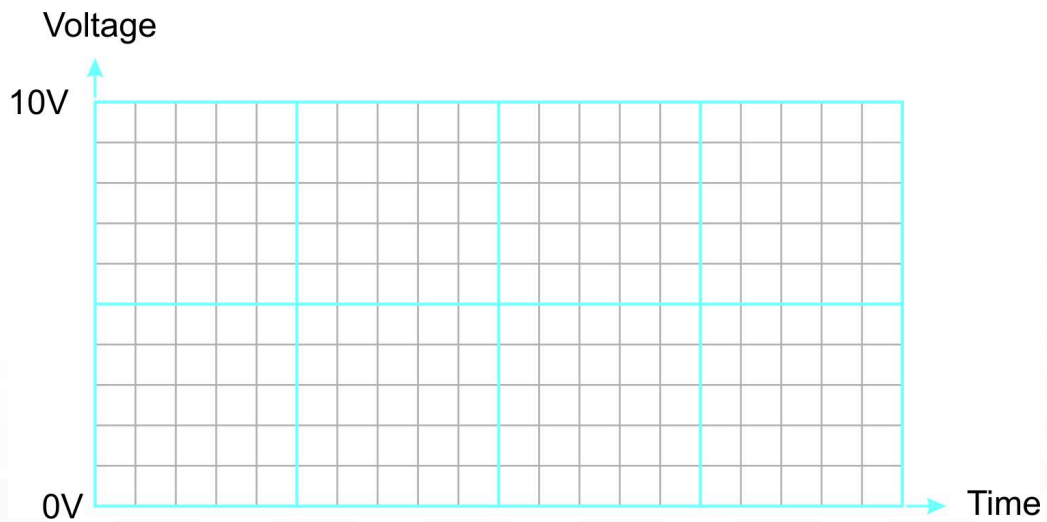
Phase 1:



Phase 2:



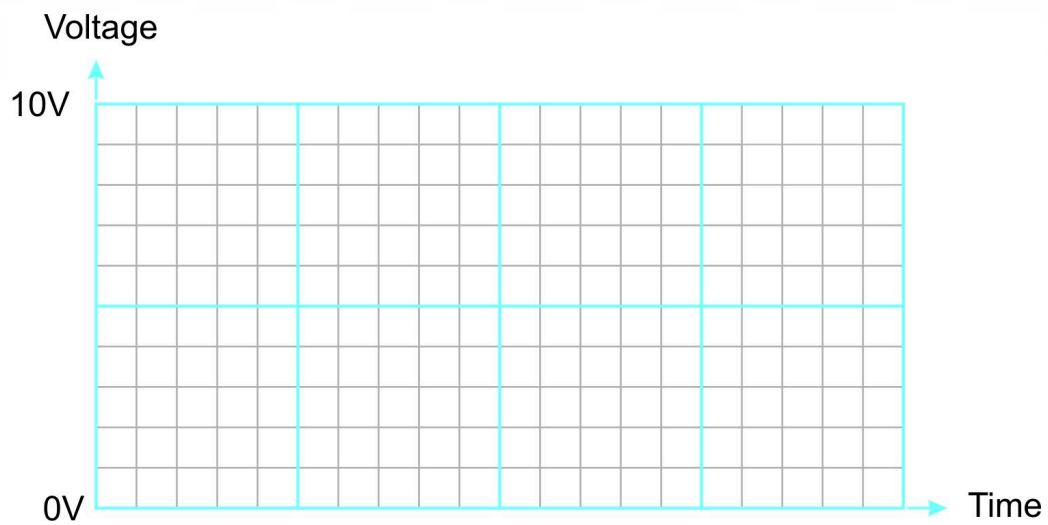
Phase 3:



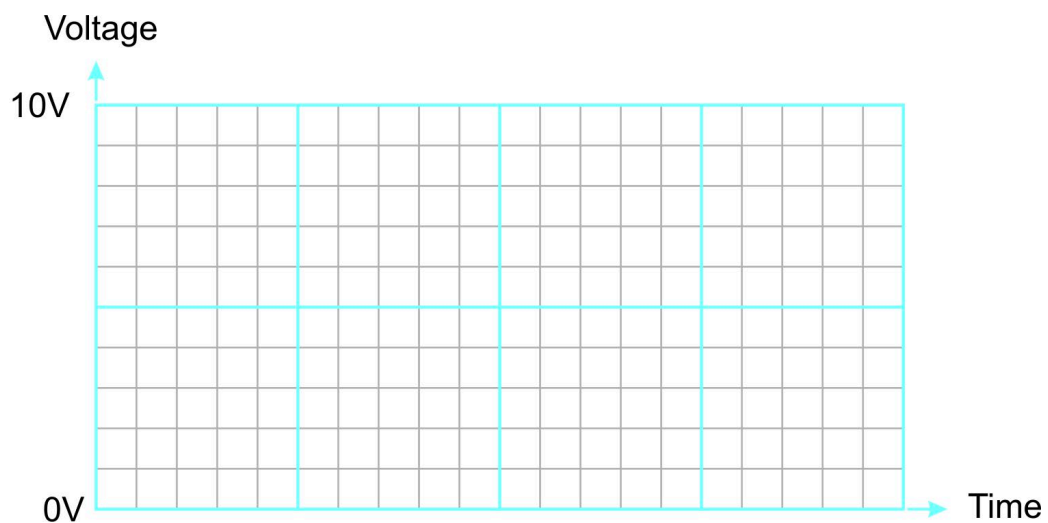
STUDENT HANDOUT

Worksheet 13 - Three-Phase Rectifiers

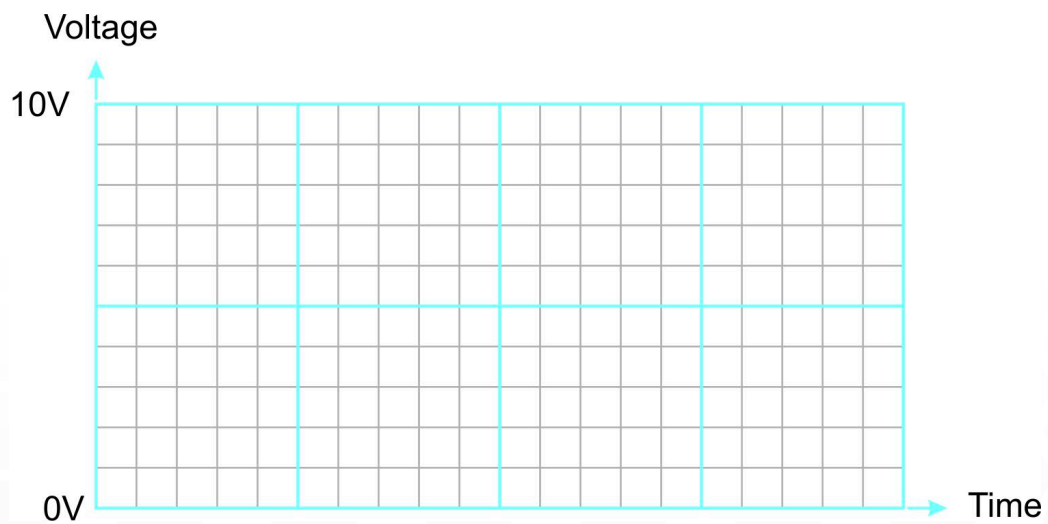
Phase 1:



Phase 2:



Phase 3:



STUDENT HANDOUT

Worksheet 14 - Using Wind Power to Provide AC:

Power in to the motor

Power into voltage converter

Power into the inverter

Power into the load

Worksheet 15 - Using Solar Power to Provide AC:

Power from the solar panel

Power out of the inverter

Worksheet 16 - Using Solar Power to Charge Batteries

No written tasks.

[illegible]

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