locktronics

Simplifying Electricity

Aircraft Maintenance - Electrical Fundamentals 2

CP7381

MATRIX

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Contents

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Worksheet 1

Resistors and resistance

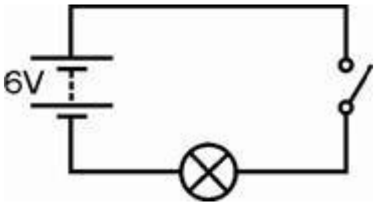
In a metal conductor, electric current is the movement of electrons subjected to a difference of electric potential. Each electron carries a single unit of negative electric charge. In constant random motion anyway, these tiny charge carriers drift when an external electric field is applied from a point of negative electric potential to one having a positive potential.

When a battery is connected to a copper wire, electrons will move through the wire until they reach the positive pole of the battery. Further electrons will be liberated from the negative pole of the battery to replace them.

This flow of these electrons (i.e. the **current**) can be reduced by adding more resistance to the circuit (for example, by making the conductor longer, thinner, or both). Using a tap, we can change the flow of water from fast to slow. With electricity, we change the flow using a resistor.

Over to you:

- Make your own resistor by clamping a piece of thin pencil lead (a mixture of carbon and clay) between the terminal posts of the Sampler, as shown.
- Set up the circuit shown in the diagram, using a 6.5V 0.3A bulb. The bulb 'rating' is stamped onto the metal casing of the bulb.
- Make sure that the power supply is set to 6V!
- Close the switch and notice how bright the bulb looks. Remember – the brighter the bulb, the greater the current flowing through it.

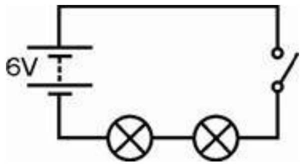


- Next, swap your pencil lead resistor for one of the connecting links.
- Close the switch again. What do you notice about the bulb? What does this tell you about the new electric current?

- To check the effect of the resistor, try 'short-circuiting' it, by plugging in a wire into both ends, as shown in the picture.

Worksheet 1
Resistors and resistance

Over to you:



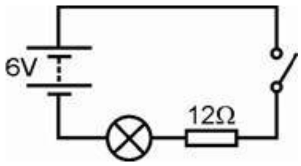
- Now set up the circuit shown in the diagram, using two 6.5V 0.3A bulbs and close the switch.
- What do you notice about the brightness of the two bulbs compared with the brightness of the single bulb in the first circuit (before you add-

So what?

A resistor can be simply a long piece of wire, made from a metal that does not conduct very well. This type is often wound as a coil around an insulating core.

It can also be made by coating an insulating core with a thin layer of carbon, or by mixing carbon with a ceramic substance (like clay).

- Adding more resistance to a circuit makes the electric current smaller.
- It is not only 'resistors' that have resistance – pencil lead, bulbs, even the wires themselves and the power supply have some resistance.
- Swap one of the bulbs for a 12Ω resistor. The circuit diagram for this arrangement is shown opposite:



Notice the brightness of the remaining bulb. What does this tell you?

(Once again, try 'short-circuiting' your resistor, by plugging in a wire into both ends, to check what is happening.)

For your records:

- A resistor limits the flow of electricity.
- The bigger the resistance, the smaller the electric current.
- Resistance is measured in ohms. Usually, we use the Ω sign to mean 'ohms'.

Answer the following questions:

1. In the previous module, you used Ohm's Law to calculate the value of voltage and current in a circuit of a given resistance. How could you use a *voltage* measurement to calculate the current flowing in the second circuit?
2. An aircraft battery has a voltage of 24V and is to be discharged at a nominal current of 4A. What value of load resistance is required to do this?
3. Electric charge is measured in units called coulombs (C). Find out how much charge is present on an just one single electron and also how many electrons are needed to carry a charge of 1 C.

Compare your answers with those given at the end of the module.

Worksheet 2

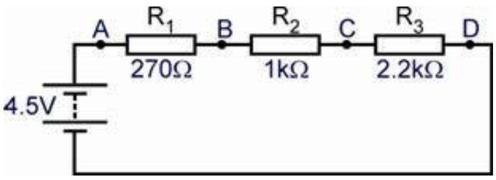
Resistors in series

Resistors are basic components in electrical and electronic systems. A series connection is one of the simplest ways to join them.

w2a

In a series connected circuit there are no alternative routes and no junctions for the current. The same current flows through each of the series-connected resistors.

Over to you:



w2b

- Connect a 270Ω resistor, a 1kΩ resistor and a 2.2kΩ resistor in series with the power supply, as shown in the circuit diagram. Use extra connecting links so that the current can be measured easily at points A, B, C and D.
- Set the power supply to give a 4.5V output.
- Remove the connecting link at A, and connect a multimeter, set to read up to 2mA DC, in its place. Record the current flowing at point A in the left-hand table.
- Remove the multimeter and replace link A.
- Remove the connecting link at B, and use a multimeter to measure the current at this point. Record the current flowing at point B, in the table.
- Measure and record the current at points C and D.
- Set up the multimeter to read DC voltages of about 5V and connect it in parallel with resistor R_1, as shown in the picture. Record the voltage in the table.
- Measure and record the voltages across R_2 and R_3, in the same way.

w2c

- Now change the power supply voltage to 9V and repeat the whole process . Record your results in the right-hand table.

Power supply = 4.5V	
Current at A in mA	
Current at B in mA	
Current at C in mA	
Current at D in mA	
Voltage - R_1 (270Ω)	
Voltage - R_2 (1kΩ)	
Voltage - R_3 (2.2kΩ)	

Power supply = 9V	
Current at A in mA	
Current at B in mA	
Current at C in mA	
Current at D in mA	
Voltage - R_1 (270Ω)	
Voltage - R_2 (1kΩ)	
Voltage - R_3 (2.2kΩ)	

Worksheet 2
Resistors in series

So what?

- You probably noticed that the current readings at A, B, C and D are virtually identical. They should be, as there is only one route for the current to flow down.
- Use your four current readings to obtain an average value for the current. Write down this value, as **I**, in the next table.

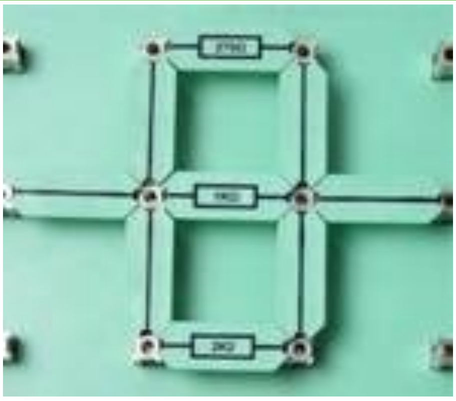
Power supply voltage	**4.5V**	**9V**
Average current I in mA		
Total voltage V_S across all resistors		
Total resistance $R_T = V_S / I$		
Total resistance $R_T = R_1 + R_2 + R_3$		

- Add together the voltages across the three resistors and write that in the table. You should find that this total voltage, V_S, is equal to the supply emf.
- There are two ways to calculate the total resistance, R_T, of the resistors:
  - We can use I and V_S in the formula $R = V/I$, from Ohm's Law.
    Calculate the total resistance in this way, and enter the result in the table.
  - The total resistance of three resistors connected in series is equal to the sum of their resistance.
    Calculate the total resistance in this way, and write the result in the table.
- Compare these values for total resistance. Think of reasons why these might be different.

For your records:

- In a series circuit, the power supply voltage is shared between all components connected in series.
- As a result, in this case, when you add together the voltages across the three resistors, the total is equal to the power supply voltage.
- In a series circuit, there is only one pathway for the electrons to flow from one terminal of the power supply to the other.
- As a result, the same current flows in all parts.
- The effective resistance of three resistors connected in series is the sum of their individual resistances: $R_T = R_1 + R_2 + R_3$

Worksheet 3
Resistors in parallel



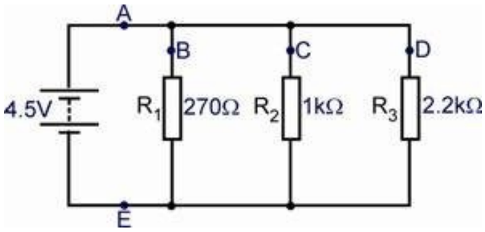
w3a

When resistors are connected in parallel, they offer different routes for the electric current. An easier route will pass a greater current.

The same effect is seen with traffic. When a bypass (parallel connection) opens, more vehicles pass along it than struggle to go along the original route.

Combining resistors in parallel reduces the total resistance of a circuit, allowing more current to flow than before.

Over to you:



w3b

- Connect a 270Ω resistor, a 1kΩ resistor and a 2.2kΩ resistor in parallel, as shown in the circuit diagram.
- Again, use extra connecting links so that the current can be measured easily at points A, B, C and D.
- Set the power supply to give a 4.5V output.
- Remove the connecting link at A, and connect a multimeter, set to read up to 2mA DC, in its place. The photograph shows the multimeter in position to do this. Record the current flowing at point A in the table.
- In the same way, measure and record the current at points B, C, D and E.
- Set up the multimeter to read DC voltages of about 5V and connect it in parallel with resistor R_1, as shown.
- Measure and record the voltage across R_1.
- Then measure and record the voltages across R_2 and R_3.

w3c

Power supply voltage = 4.5V	
Current at point A in mA	
Current at point B in mA	
Current at point C in mA	
Current at point D in mA	
Voltage - R_1 (270Ω resistor)	
Voltage - R_2(1kΩ resistor)	
Voltage - R_3(2.2kΩ resistor)	

Worksheet 3

Resistors in parallel

So what?

- The current readings at B, C and D are different, as there are three different routes the current can take. The current through R_1, the smallest resistor, should be the biggest as it offers the easiest route. As R_1 is about four times smaller than R_2, the current at B should be about four times bigger than the current at C. Similarly, the current at C should be about twice as big as the current at D.

- The current from the power supply divides up between the three possible routes, and then joins back up again. So, when you add together the currents at B, C and D, the total should equal the current at A. The current at A should be virtually the same as the current at E. Complete rows 1, 2 and 3 of the following table.

Power supply voltage = 4.5V	
Average of currents at A and E in mA	
Total of currents, I, at B, C and D in mA	
Average voltage across resistors, V_S	
Total resistance $R_T = V_S / I$	
Total resistance from $1/R_T = 1/R_1 + 1/R_2 + 1/R_3$	

- The voltage readings across the three resistors should be virtually the same, and should equal the power supply voltage. Enter the average of these readings, V_S, in the table.

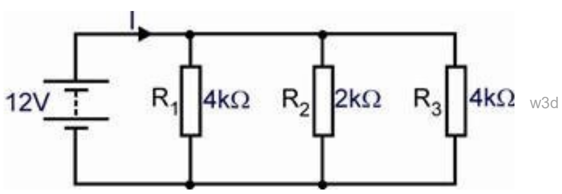
- Calculate the total resistance R_T of the three resistors, in two ways, as before:
  - Use I and V_S in the formula $R = V / I$, from Ohm's Law and enter the result in the table.
  - Use the formula $1/R_T = 1/R_1 + 1/R_2 + 1/R_3$, and write the result in the table.

- Compare these two values for total resistance. Again, why might these be different?

For your records:

Answer the following questions:

1. Use Ohm's Law to calculate the current flowing in each of the resistors shown in the circuit on the right.
2. What current is supplied by the battery?
3. What single resistor carrying the same current could be used to replace the three individual resistors?



Compare your answers with those given at the end of the module.

Worksheet 4

Series/parallel networks

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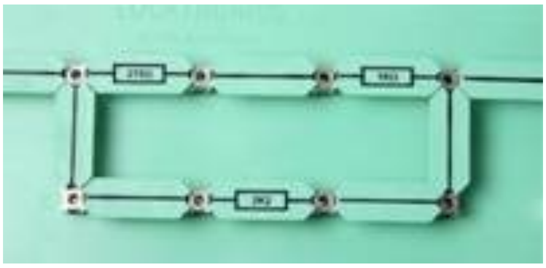
w4a

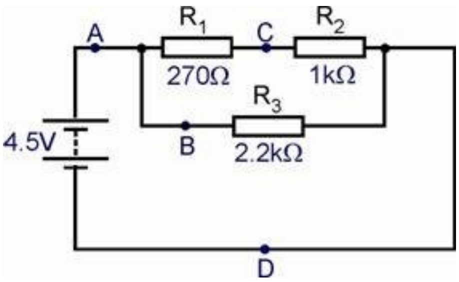


In most electrical circuits, some components are connected in series, while others are in parallel.

The rules developed in the previous worksheets still apply, but only to the appropriate parts, instead of the whole circuit.

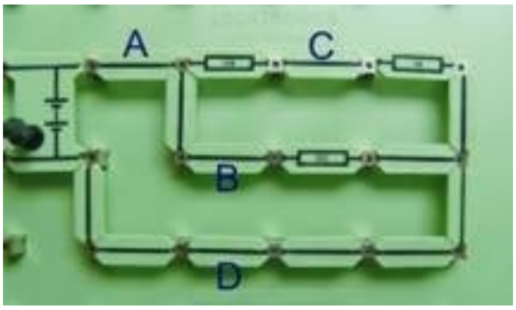
In a complex circuit, components in parallel have the same voltage across them but may carry different currents, while components in series have the same current flowing through them but may have different voltages across them.

Over to you:



w4b

- Connect a 270Ω resistor, a 1kΩ resistor and a 2.2kΩ resistor, as shown in the circuit diagram. The 270Ω and 1kΩ resistor are in series, while the 2.2kΩ resistor is in parallel with the combination.
- Use extra connecting links so that the current can be measured easily at points A, B, C and D.
- The picture shows one way to do this.
- Set the power supply to give a 4.5 V output.
- Remove the connecting link at A, and connect a multimeter to read the current at A. Record it in the table.
- .In the same way, measure and record the current at points B, C, and D.



w4c

- Set up the multimeter to read the voltage across resistor R_1. Record it in the table.
- Then connect it to read the voltage across R_2 and R_3, in turn, and record them in the table.

Power supply voltage = 4.5V	
Current at point A in mA	
Current at point B in mA	
Current at point C in mA	
Current at point D in mA	
Voltage - R_1 (270Ω resistor)	
Voltage - R_2(1kΩ resistor)	
Voltage - R_3(2.2kΩ resistor)	

Worksheet 4

Series/parallel networks

So what?

- The same current flows through R_1 and R_2, as they are in series. This is the current you measured at point C.
- The current readings at A and D should be the same, as these measure the total current leaving and returning to the power supply.
- The current from the power supply splits, with part going through R_1 (and then R_2), while the rest flows through R_3. In other words, adding together the readings at B and C should give a total equal to the reading at A (and D).
- The full power supply voltage appears across R_3, but is split between R_1 and R_2.
- Complete rows 1, 2 and 3 of the following table.

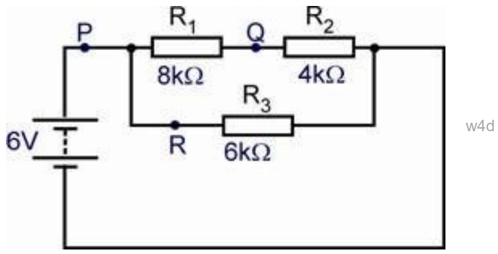
Power supply voltage = 4.5V	
Average of currents at A and D in mA (= I)	
Sum of currents at B and C in mA	
Sum of voltages across R_1 and R_2 ($=V_S$)	
Total resistance $R_T = V_S / I$	
Combined resistance of R_1 and R_2 (in series) ($=R_C$)	
Total resistance of all three resistors $R_T = R_C \times R_3 / R_C + R_3$	

- Complete the table by calculating the total resistance R_T of the three resistors by:
  - using I and V_S in the formula $R = V / I$;
  - adding together the resistance of R_1 and R_2, as these are in series, to give R_C, their combined resistance, and then using $R_T = R_C \times R_3 / R_C + R_3$.
- Think of reasons why these two approaches might give different values for R_T. Which, do you think, gives the more reliable result?

For your records:

For the circuit shown opposite, calculate:

1. The total resistance;
2. The current at P;
3. The voltage across R_3, the 6kΩ resistor;
4. The current at R;
5. The current at Q;
6. The voltage across R_1, the 8kΩ resistor.



Compare your answers with those given at the end of the module.

Worksheet 5

Voltage dividers

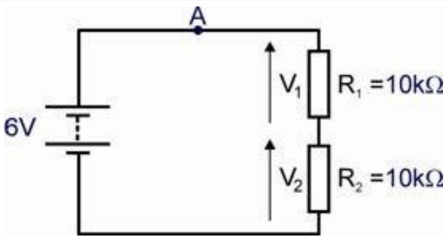
w5a

Resistors can protect other components from excessive currents.

They can also be used in voltage dividers to reduce the voltage from a power supply into smaller predictable portions. This is particularly useful when one of the resistors is a sensing component, such as a LDR (light-dependent resistor,) or a thermistor, (temperature-dependent resistor.)

Voltage dividers form the basis of many aircraft sensors. The output voltage can represent temperature, light-level, pressure, humidity, strain or other physical quantities.

Over to you:



w5b

- Connect two 10kΩ resistors in series, as shown in the circuit diagram.
- Set the power supply to give a 6V output.
- Remove the connecting link at A, and connect a multimeter to measure the current. Record the value in the table.
- Remove the multimeter and replace link A.
- Set up the multimeter to read DC voltages of about 5V, and connect it to read first, the voltage across resistor R_1, and then across R_2.
- Record these in second column of the table.

R_1 = 10kΩ, R_2 = 10kΩ		
Power supply voltage	6V	9V
Current at point A in mA		
Voltage V_1 across R_1		
Voltage V_2 across R_2		

- Next, set the power supply to 9 V, and repeat the measurements. Record them in the third column of the table.

- Now, swap resistor R_1 for a 1 kΩ resistor. Repeat the process and record the results in the table on the left, below.

- Finally, replace both resistors, with a 2.2 kΩ resistor for R_1, and a 22 kΩ resistor for R_2.
  Re-
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right.

R_1 = 1kΩ, R_2 = 10kΩ	
Power supply voltage	9V
Current at point A in mA	
Voltage V_1 across R_1	
Voltage V_2 across R_2	

R_1 = 2.2kΩ, R_2 = 22kΩ	
Power supply voltage	9V
Current at point A in mA	
Voltage V_1 across R_1	
Voltage V_2 across R_2	

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Worksheet 5
Voltage dividers

So what?

- First of all, look at the theoretical behaviour of this circuit -
  - Resistors R_1 and R_2 are connected in series. Their total resistance, is given by:

$$R_T = R_1 + R_2$$

  - The full power supply voltage, V_S, appears across this total resistance, R_T, and so the current **I**, flowing through the two resistors is given by:

$$I = V_S / R_T$$

  - The voltage across resistor R_1 is given by:

$$V_1 = I \times R_1$$

  - The voltage across resistor R_2 is given by:

$$V_2 = I \times R_2$$

- Calculate R_T, I, R_1 and R_2 for each circuit, and complete the next table with your results:

Circuit	**R_T**	**I**	**V_1**	**V_2**
R_1 = 10kΩ, R_2 = 10kΩ, Vs = 6V				
R_1 = 10kΩ, R_2 = 10kΩ, Vs = 9V				
R_1 = 1kΩ, R_2 = 10kΩ, Vs = 9V				
R_1 = 2.2kΩ, R_2 = 22kΩ, Vs = 9V				

- Compare the values of V_1 and V_2 with those you measured for each circuit.
  Why might you expect the experimental values to be different?

For your records:

Here is a straightforward way to view these results:

- The voltage from the power supply is shared between the resistors,
  so that $V_1 + V_2 = V_S$
- The bigger the resistor, the bigger its share of the voltage.

In the first circuit, $R_1 = R_2 = 10k\Omega$ so $V_1 = V_2 = ½V_S$.

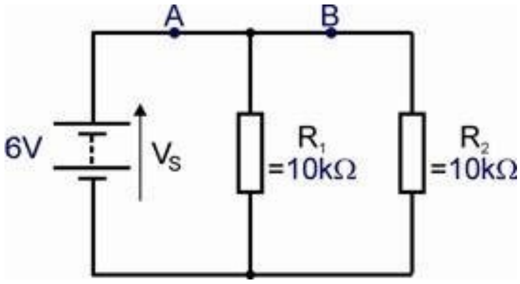
In the second and third circuits, $R_2 = 10 \times R_1$, and so $V_2 = 10 \times V_1$.

The second and third circuits seem to perform in the same way, except for the current. Sometimes it is best to use big resistor values, to reduce battery drain and power dissipation.

However, using lower resistor values allows us to draw current from the voltage divider without appreciably affecting voltages V_1 and V_2.

Worksheet 6

Current dividers



w6a

Voltage dividers:

use resistors connected in **series** to divide up a **voltage** into predictable components.

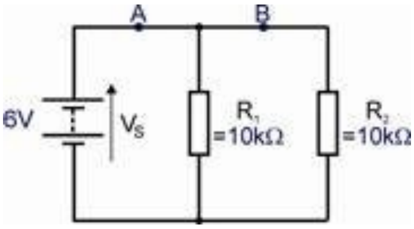
Current dividers:

use resistors connected in **parallel** to divide up a **current** into predictable components.

Current dividers are used in ammeters. A known fraction of the total current passes through the meter and is measured. From that the total current can be calculated .

Over to you:

- Connect two 10kΩ resistors in parallel, as shown in the circuit diagram.
- Set the power supply to give a 6V output.
- Measure current I_1, at A, in the usual way, and record it in the first table.
- Measure current I_2, at B, similarly, and record that result in the first table.
- Set the multimeter to read DC voltages of about 10V, and connect it across the power supply to read V_S. Record it in the table too.



w6b

R_1 = 10kΩ, R_2 = 10kΩ **Power supply set to 6V**	
Power supply voltage, V_S	
Current at point A, I_1, in mA	
Current at point B, I_2, in mA	

- Next, set the power supply to 9V,
- Repeat the measurements.
- Record them in the second table.

R_1 = 10kΩ, R_2 = 10kΩ **Power supply set to 9V**	
Power supply voltage, V_S	
Current at point A, I_1, in mA	
Current at point B, I_2, in mA	

- Lastly, swap resistor R_1 for a 1kΩ resistor.
- Repeat the process, with the multimeter set to the 10mA range when measuring currents.
- Record the results in the third table.

R_1 = 1kΩ, R_2 = 10kΩ **Power supply set to 9V**	
Power supply voltage, V_S	
Current at point A, I_1, in mA	
Current at point B, I_2, in mA	

Worksheet 6

Current dividers

So what?

First of all, the theoretical behaviour:

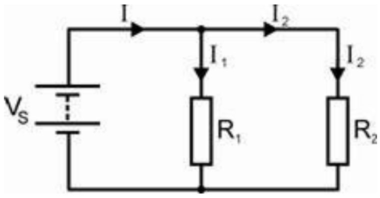
- The voltage across resistor $R_1 = V_S$, and so:

  $V_S = I_1 \times R_1$

- Similarly, $V_S = I_2 \times R_2$

  so that: $I_1 \times R_1 = I_2 \times R_2$

- or $I_1 = I_2 \times (R_2 / R_1)$



w6c

The current I from the power supply splits into I_1 and I_2 at the junction.

In other words: $I = I_1 + I_2$

Using the equation for I_1 given above: $I = I_2 \times (R_2 / R_1) + I_2$

$= I_2 (1 + R_2 / R_1)$

Re-arranging this gives $I_2 = I \times \left(\frac{R_1}{R_1 + R_2} \right)$

This can be used to calculate the current I_2 flowing in the branch of the circuit.

- Use this formula to calculate I_2 in the three cases you investigated.
  Write your results in the following table:

Circuit	I_2 in mA
R_1 = 10kΩ, R_2 = 10kΩ Power supply set to 6V	
R_1 = 10kΩ, R_2 = 10kΩ Power supply set to 9V	
R_1 = 1kΩ, R_2 = 10kΩ Power supply set to 9V	

- Compare the calculated values of I_2 with those you measured for each circuit.
  Once again, why might you expect the experimental values to be different?

For your records:

As with voltage dividers, there is a straightforward way to view these results:

- The current from the power supply is shared between the resistors,

  so that $I = I_1 + I_2$

- The *bigger* the resistor, the *smaller* its share of the current.

In the first and second circuits:

$R_1 = R_2 = 10\text{k}\Omega$ so $I_1 = I_2 = ½ I$.

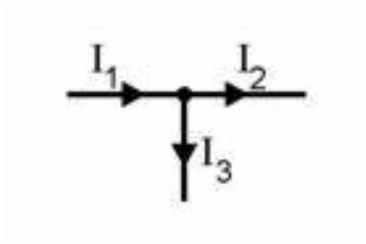
In the third circuit:

$R_2 = 10 \times R_1$, and so $I_1 = 10 \times I_2$.

Worksheet 7

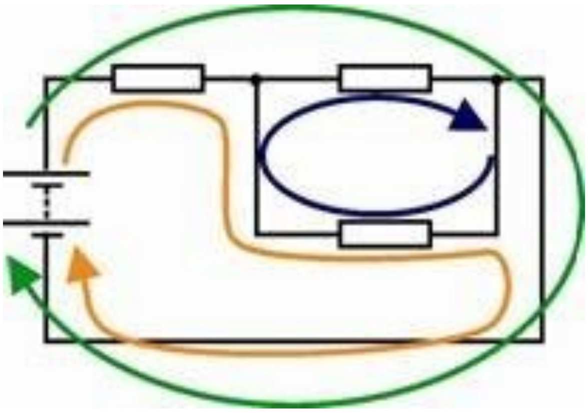
Using Kirchhoff's Laws

- **Kirchhoff's Current Law** - 'What flows in must flow out'
  The algebraic sum of all currents at any junction is zero.
  In other words, $I_1 = I_2 + I_3$



w7a

- **Kirchhoff's Voltage Law** -



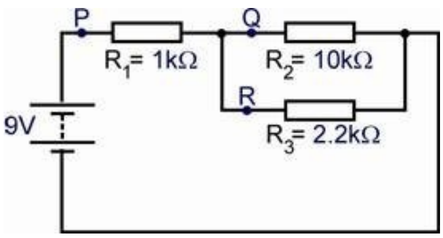
w7b

Around any loop in the circuit, the algebraic sum of voltages is zero.

The expression 'algebraic sum' simply means that we must take the direction of current flow into account.

There are three loops in the circuit you will investigate. These are shown in different colours in the diagram.

Over to you:



w7c

- Connect a 1kΩ, a 2.2kΩ and a 10kΩ resistor, as shown in the circuit diagram.
- Set the power supply to give a 9V output.
- Measure the current at P, (the total current leaving the power supply.) Record the value in the table.
- Measure the current at Q and then R in the same way, and record the results in the table.
- Measure the voltages across the three resistors. Record them in the table.

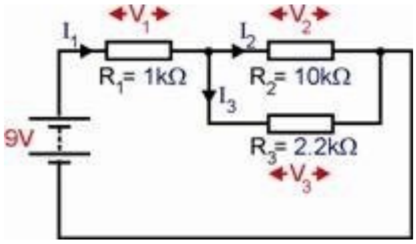
	Value
Current at point P in mA	
Current at point Q in mA	
Current at point R in mA	
Voltage across R_1	
Voltage across R_2	
Voltage across R_3	

Worksheet 7
Using Kirchhoff's Laws

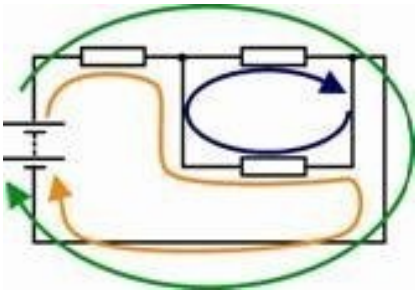
So what?

- Kirchhoff's current law gives us the relationship:

$$I_1 = I_2 + I_3$$



w7d



w7e

- Now apply Kirchhoff's voltage law to each of the three loops.
  - The green loop: $9 = V_1 + V_2$ equation 1
  - The orange loop: $9 = V_1 + V_3$ equation 2
  - The blue loop: $0 = V_2 + V_3$
- Ohm's law gives us the relationships:

$$V_1 = I_1 \times R_1 = (I_2 + I_3) \times R_1$$
$$V_2 = I_2 \times R_2$$
$$V_3 = I_3 \times R_3$$

- Inserting the values of the resistors (in kΩ) gives:

$$V_1 = (I_2 + I_3) \times 1 = (I_2 + I_3)$$
$$V_2 = I_2 \times 10$$
$$V_3 = I_3 \times 2.2$$

- Using these, equation 1 becomes $9 = (I_2 + I_3) + (10 \times I_2)$
  or $9 = 11I_2 + I_3$
  which means that $I_3 = 9 - 11I_2$
  and equation 2 becomes $9 = (I_2 + I_3) + (2.2 \times I_3)$
  or $9 = I_2 + 3.2I_3$
  Inserting the value of I_3 gives $9 = I_2 + 3.2(9 - 11I_2)$
  so $(35.2 - 1)I_2 = 28.8 - 9$
  which gives $I_2 =$ **0.58 mA**
  Substituting this in earlier equations $I_3 = 9 - 11I_2 = 9 - 11 \times 0.58 =$ **2.63 mA**
  and so $I_1 = 0.58 + 2.63 =$ **3.21 mA**
  In turn, these values give $V_1 = 3.21 \times 1 = 3.2$ V
  $V_2 = 0.58 \times 10 = 5.8$ V
  $V_3 = 2.63 \times 2.2 = 5.8$ V (not surprisingly!)
- Check your measured values against these results!

For your records:

- Kirchhoff's Current Law - 'What flows in must flow out'
  The algebraic sum of all currents at any junction is zero.
- Kirchhoff's Voltage Law -
  Around any loop in the circuit, the algebraic sum of voltages is zero.

Worksheet 8

Power in DC circuits

Electrical power is vital to the operation of an aircraft. Without it, the aircraft simply couldn't fly!

w8a

Being able to generate and make efficient use of electrical power is an important consideration in the design of any modern aircraft, where weight, fuel efficiency and operating cost are very closely linked.

Because of this, you need to have a good grasp of electrical power and of what happens when energy is converted from one form to another.

A reminder:

Electric current is a measure of how many electrons are passing per second.

Voltage is a measure of the energy the electrons gain or lose as they pass through an electrical component.

A few relationships that you need to know:

First: **Number of coulombs Q = Current I x time t**

(Common sense - current is a measures of how many electrons pass per second, so to find out how may have passed in 10 seconds, for example, you simply multiply the current by 10!)

Second: **One volt = one joule of energy given to or lost by a coulomb of charge**

(A 12 V battery gives each coulomb of charge that passes through it 12J of energy. If the voltage dropped across a resistor is 2V, every coulomb that passes through it loses 2J of energy (i.e. converts 2J to heat energy. It's the electrons struggling to squeeze past the atoms in the resistor - it makes them hot!)

Third: **Power is the rate at which energy is converted.**

(A power rating of one watt of means that one joule of energy is converted from one form to another every second. The old style of domestic light bulbs had power ratings of about 60W. Newer energy-saving types have a rating of 15W for the same brightness, because they waste less electrical energy as heat!)

Formula juggling - ignore all but the result if you wish:

P = E / t *from fact 3* and E = Q x V *from fact 2* so P = Q x V / t

but Q = I x t *from fact 1* so P = I x t x V / t

or, cancelling out the 't' **Result** **P = I x V**

The cast:

P = power in watts **E** = energy converted in joules **Q** = charge in coulombs

I = current in amps **V** = voltage dropped (in volts!) **t** = time in seconds to convert energy

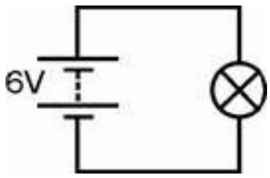
Worksheet 8

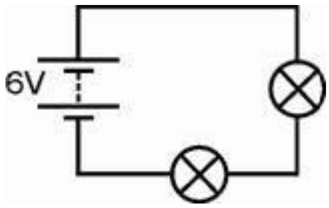
Power in DC circuits

Over to you:

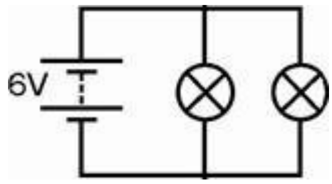
- Set up each the circuit in turn, using 6.5V 0.3A bulbs.
- For each bulb, measure the current through it, and the voltage across it.
  (First of all, decide where to connect the ammeter and voltmeter!)

w8b





w8c



w8d

So what?

- Calculate:
    - the power dissipated in each bulb (using the formula P = I x V)
    - how long it takes each bulb to take 1J of energy from the electrons;
    - how much energy (in joules) the power supply is losing each second.
- Each of these three circuits uses a different amount of energy. The amount of energy used will depend on not only how many loads there are but also how the loads are connected.
- Think about the energy that is dissipated as power in each of the three circuits. Which circuit will use the least energy and which will use the most? Why is this?
- Which battery will 'go flat' first? Explain your answer in terms of the amount of energy consumed.

For your records:

- Power is the rate at which energy is being used.
- When a component has a voltage V across it, and a current I flowing through it, it is
- converting energy from one form to another at a rate given by the power formula

$$P = I \times V$$

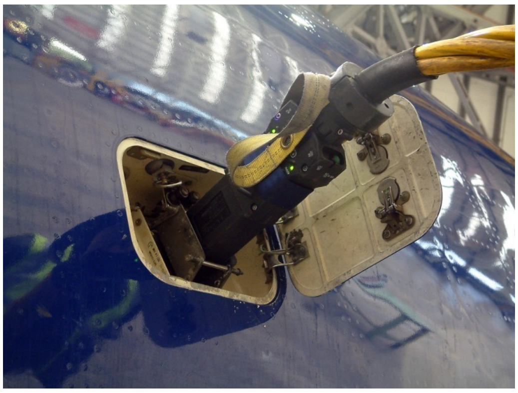
- Answer the following questions:
    1. An aircraft DC bus supplies 28V to two loads, each rated at 288W. What current is supplied to each load, and what energy is supplied by the bus if the loads remain connected to it for a total of 10 minutes?
    2. The battery in an emergency radio beacon can supply 480 kJ of energy. If the battery is rated at 12V 1A, for how long will the beacon operate?

Compare your answers with those given at the end of the module.

Worksheet 9

Power transfer

w9a



There are two common requirements when an electrical source is connected to a load.

Often we simply want to pass on voltage from one system to another (for example, from an external AC or DC supply to the aircraft's internal power bus).

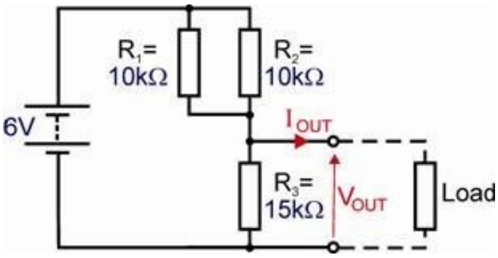
In other situations, we need to transfer as much electrical power as possible from a source to a load, (for example, from a VHF aircraft radio to an antenna, so that as much energy as possible can be radiated into space surrounding the aircraft).

w9b

In this situation, we are primarily concerned with transferring as much power as possible from one system to another. This requires a matched configuration, where the output resistance (or impedance) of the source matches that of the load. This important principle is known as the **maximum power transfer theorem**.

Over to you:

- Connect two 10kΩ resistors and a 15kΩ resistor, as shown in the circuit diagram. We will use this combination as a voltage source to deliver electrical energy to a load attached to its output. This source has an internal resistance of 3.75kΩ.
- Set the power supply to 6V.
- Connect a 1kΩ resistor as a load .
- Measure the output voltage V_{OUT} and the output current I_{OUT}. Record your measurements in the table.
- Repeat this procedure for each load resistor in turn.



w9c

- Use a multimeter to set a 10kΩ variable resistor to a resistance of 3.75 kΩ, (the equivalent resistance of the circuit.)
- Use it as the load. As before, measure the current through it and voltage across it.

Load Resistor	V_{OUT}	I_{OUT}
1kΩ		
2.2kΩ		
5.6kΩ		
10kΩ		
22kΩ		
3.75kΩ		

Worksheet 9

Power transfer

locktronics

So what?

- Power dissipated = current x voltage.
  To dissipate a lot of power, both the current through the load and the voltage across it must be as large as possible.
  Look at your table of results.
    - The voltage across the load is big when the load resistance is high.
    - However, the current through the load is big when the load resistance is small!

- Use your measurements to calculate the power dissipated in the load, using $P = I_{OUT} \times V_{OUT}$ for each value of load resistor .
  Complete the table with your results.

Load Resistor	Power transferred = V_{OUT} x I_{OUT}
1kΩ	
2.2kΩ	
5.6kΩ	
10kΩ	
22kΩ	
3.75kΩ	

- Plot a graph of your results, with 'Load' on the x-axis, and draw a smooth curve through your plotted points.

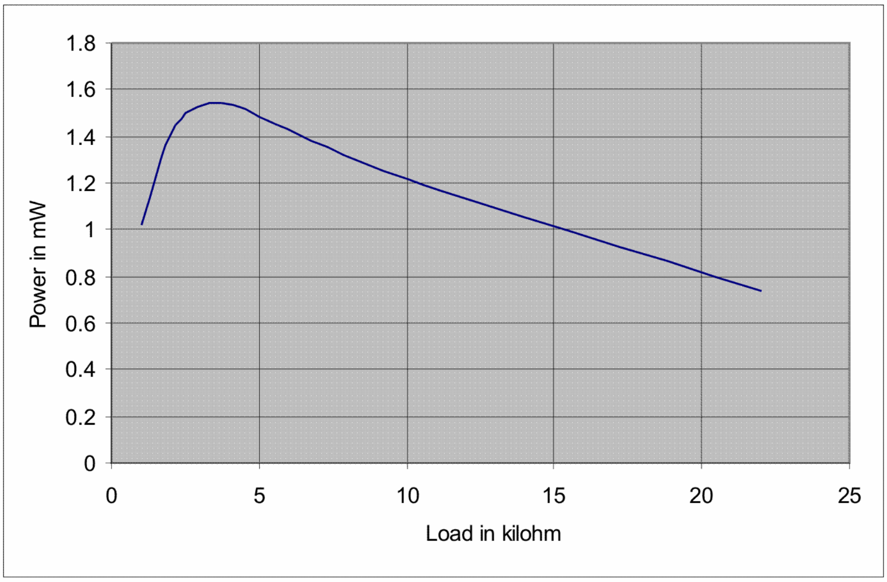
w9d

Worksheet 9

Power transfer

Your graph should like the one shown below.

(Note - the maximum value of power transfer occurs when the system is matched):



w9e

For your records:

- Maximum power is transferred when the current through the load and the voltage across it are both big.
- However, the current is big when the load resistance is small, and the voltage across the load is big when the load resistance is big.
- These conflicting requirements lead to the maximum power transfer theorem:
    - **The maximum amount of power is transferred from a source to a load when the resistance of the load is equal to that of the source.**

Questions

About these questions

These questions are typical of those that you will be required to answer in the EASA Part-66 examination.

You should allow 15 minutes to answer these questions and then check your answers with those given at the end of the module.

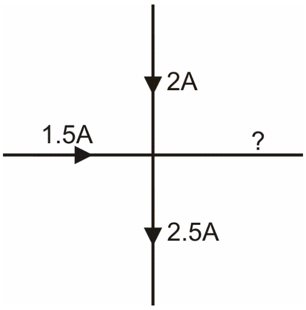
Please remember that **ALL** these questions must be attempted **without** the use of a calculator and that the pass mark for all Part-66 multiple-choice examinations is 75%!

1. The resistance of a circuit can be determined from:
(a) $R = V \times I$
(b) $R = V / I$
(c) $R = I / V$

2. A potential difference of 7.5V appears across a 15Ω resistor. Which one of the following gives the current flowing:
(a) 0.25A
(b) 0.5A
(c) 2A

3. A DC supply has an internal resistance of 1Ω and an open-circuit output voltage of 24V. What will be the output voltage when the supply is connected to a 5Ω load?
(a) 20V
(b) 22V
(c) 28V

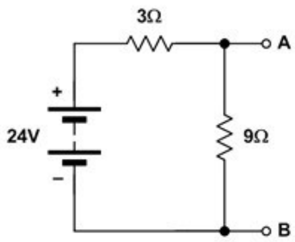
4. The unknown current shown in the figure will be:
(a) 1A flowing towards the junction
(b) 1A flowing away from the junction
(c) 4A flowing towards the junction .



p22a

5. The resistance of a wire conductor of constant cross-section:
(a) decreases as the length of the wire increases
(b) increases as the length of the wire increases
(c) is independent of the length of the wire.

6. The voltage dropped between A and B in the figure will be:
(a) 9V
(b) 18V
(c) 21V



p22b

7. A 20 m length of cable has a resistance of 0.02Ω.
If a 100 m length of the same cable carries a current of 5A flowing in it, what voltage will be dropped across its ends?
(a) 0.02V
(b) 0.1V
(c) 0.5V

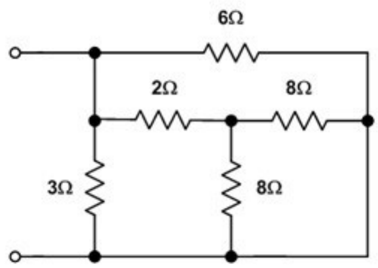
8. A generator with an output of 28V is connected to a load by a cable having a total resistance of 0.01Ω. If a current of 140A is supplied by the generator, what proportion of the generator's output voltage reaches the load?

(a) 85%
(b) 90%
(c) 95%

9. Three pilot lamps each rated at 24V are connected in parallel. If the parallel combination draws a current of 0.3A what power is delivered to each lamp?
(a) 0.8W
(b) 2.4W
(c) 7.2W

10. Four 15Ω resistors are connected in parallel. Which one of the following gives the effective resistance of the parallel combination?
(a) 3.75Ω
(b) 5Ω
(c) 60Ω

11. Which one of the following gives the effective resistance of the circuit?
(a) 1.5Ω
(b) 2Ω
(c) 27Ω



p23a

12. The relationship between power, P, voltage, V, and current, I, is:
(a) $P = I \times V$
(b) $P = V / I$
(c) $P = V / I$

13. An aircraft fuel heater consists of two parallel-connected heating elements each rated at 28V, 10A. What total power is supplied to the fuel heating system?
(a) 140W
(b) 280W
(c) 560W

14. A generator delivers 250W of power to a 10Ω load. The current flowing in the load will be:
(a) 2.5A
(b) 5A
(c) 25A

15. A VHF radio rated at 250W input operates for 20 minutes. How much energy has been consumed?
(a) 4.8kJ
(b) 5kJ
(c) 300kJ.

Answers are provided at the end of the module

Tutor’s notes

About this course

Introduction

This workbook is intended to reinforce the learning that takes place in the classroom or lecture room. It provides a series of practical activities and investigations that complement syllabus sections 3.3 to 3.6 of EASA Part-66 Module 3, Electrical Fundamentals.

Locktronics equipment makes it simple and quick to construct and investigate electrical circuits. The end result can look exactly like the circuit diagram, thanks to the symbols printed on each component carrier.

Aim

The workbook aims to introduce students to the basic underpinning principles and concepts of aircraft electrical and electronic equipment. Is also provides a useful introduction to electrical measurements and the use of ammeters and voltmeters.

Prior Knowledge

Students should have previously studied (or should be concurrently studying) Module 1 (Mathematics) and Module 2 (Physics) or should have equivalent knowledge at Level 2.

Learning Objectives

On successful completion of this course the student will have learned:

- the relationship between current, charge and electron flow
- the effect of resistance on the current flowing in a circuit;
- to distinguish between series and parallel connected resistors;
- that the same current flows in all parts of a series combination of resistors;
- that the voltages across the resistors in a series combination add up to the total voltage across the combination;
- that the resistors in a parallel combination have the same voltage across them;
- that the currents through the resistors in a parallel combination add up to the total current through the combination;
- to analyse currents and voltages in a voltage divider made from two series resistors;
- to analyse currents and voltages in a current divider made from two parallel resistors;
- to solve problems using Kirchhoff’s Current and Voltage Laws;
- the relationships between energy, power, voltage and current and time;
- to solve problems involving energy, power, voltage, current and resistance.

Tutor's notes

locktronics

What students will need:

To complete this course, students will have access to the Locktronic parts and equipment listed opposite:

Note that the Aircraft Maintenance Kit contains many other parts that are used in the other workbooks that together cover aspects of Module 3 and 4.

Students will also need:

- either two multimeters, such as the LK1110, capable of measuring currents in the range 0 to 100mA, and voltages in the range 0 to 15V;
- or an ammeter with a range of 0 to 100mA, and a voltmeter with a range 0 to 15V.

For other modules in the series, they will need:

- a function generator, such as the LK8990, or equivalent;
- and an oscilloscope capable of monitoring the signals it produces, such as the LK6730 Pico 4000 virtual oscilloscope.

If you are missing any components, or need additional items, please contact Matrix or your local dealer.

Code	Description	Qty
LK2340	AC voltage source carrier	1
LK2347	MES bulb, 6V, 0.04A	3
LK2350	MES bulb, 6.5V, 0.3A	3
LK4025	Resistor, 10 ohm, 1W 5% (DIN)	1
LK4065	Resistor, 47 ohm, 1/2W, 5% (DIN)	1
LK4100	Resistor, 12 ohm, 1W, 5% (DIN)	1
LK4102	Motor, 6V, open frame	1
LK4123	Transformer, 2:1 turns ratio	1
LK5202	Resistor, 1k, 1/4W, 5% (DIN)	1
LK5203	Resistor, 10k, 1/4W, 5% (DIN)	2
LK5205	Resistor, 270 ohm, 1/2W, 5% (DIN)	1
LK5208	Potentiometer, 250 ohm (DIN)	1
LK5209	Resistor, 5.6k, 1/4W, 5% (DIN)	1
LK5221	Capacitor, 10 uF, Electrolytic, 25V	3
LK5250	Connecting Link	14
LK5291	Lampholder, MES	3
LK5607	Lead - yellow - 500mm, 4mm to 4mm stackable	2
LK5609	Lead - blue - 500mm, 4mm to 4mm stackable	2
LK6205	Capacitor, 1 uF, Polyester	1
LK6206	Capacitor. 4.7uF, electrolytic, 25V	2
LK6207	Switch, push to make, metal strip	1
LK6209	Switch, on/off, metal strip	1
LK6211	Resistor, 22k, 1/4W, 5% (DIN)	1
LK6213	Resistor, 15k, 1/4W, 5% (DIN)	1
LK6214R1	Choke, 10mH	3
LK6214R2	Choke, 47mH	1
LK6214R3	Choke, 5mH	1
LK6217	Capacitor, 2.2 uF, Polyester	2
LK6218	Resistor, 2.2k, 1/4W, 5% (DIN)	1
LK6482	Left hand motor rule apparatus	1
LK7409	AA battery holder carrier	3
LK7483	1:1 transformer with retractable ferrite core	1
LK7485	Alnico Rod Magnet	1
LK7487	Lenz's law kit	1
LK7489	Faraday's law kit	1
LK7746	Solar cell	1
LK7936	Fuse/universal component carrier	1
LK8275	Power supply carrier with battery symbol	2
LK8900	7 x 5 metric baseboard with 4mm pillars	1
LK8988	Thermocouple and carrier	1
LK9381	Ammeter, 0mA to 100mA	1

Power source:

The larger baseboard is appropriate for use with this power supply, which can be adjusted to output voltages of either 3 V, 4.5 V, 6 V, 7.5 V, 9 V or 13.5 V, with currents typically up to 1 A. The voltage is changed by turning the selector dial just above the earth pin until the arrow points to the required voltage.

The instructor may decide to make any adjustment necessary to the power supply voltage, or may allow students to make those changes.

Each exercise includes a recommended voltage for that particular circuit.

p25b

Tutor’s notes

Using this course:

It is expected that the worksheets are printed / photocopied, preferably in colour, for the students’ use. Students should retain their own copy of the entire workbook.

Worksheets usually contain:

- an introduction to the topic under investigation and its aircraft application;
- step-by-step instructions for the practical investigation that follows;
- a section headed ‘So What?’ which aims both to challenge learners by questioning their understanding of a topic and also provides a useful summary of what has been learned. It can be used to develop ideas and as a trigger for class discussion.
- a section headed ‘For Your Records’ which provides important summary information that students should retain for future reference.

This format encourages self-study, with students working at a rate that suits their ability. It is for the tutor to monitor that students’ understanding is keeping pace with their progress through the worksheets and to provide additional work that will challenge brighter learners. One way to do this is to ‘sign off’ each worksheet, as a student completes it, and in the process have a brief chat with the learner to assess their grasp of the ideas involved in the exercises that it contains.

Finally, a set of examination ’Revision Questions’ has been provided to conclude the work on each topic. These questions are of varying difficulty and are typical of those that students will face when they sit their Module 3 CAA examinations. It is recommended that students should attempt these questions under examination conditions and without the use of notes or calculators.

Time:

It will take most students between four and six hours to complete the full set of worksheets. It is expected that a similar length of time will be needed to support the learning in a class, tutorial or self-study environment.

Tutor’s notes

Worksheet	Notes for the Tutor	Timing
1	In the first worksheet, students investigate the current flow in a simple circuit. Light bulbs are used as simple indicators of current flow and the effect of introducing resistance into the circuit is demonstrated by temporarily shorting the resistance by plugging a wire into both ends. Students then continue their investigation by connecting two bulbs in series and then adding a fixed resistor of known value in place of one of the bulbs. Once again, students can introduce a temporary short-circuit link in order to observe the effect of the addition of series resistance into the circuit. Students should be reminded of the work that they previously carried out in Worksheet 7 of Electrical Fundamentals 1, where they first met Ohm’s Law. This will allow them to quantify the current flowing in the circuit by measuring the voltage drop across the fixed resistance. The questions provided as extension activities should prompt further discussion and also provide an opportunity for some additional library/internet research.	30 - 45 minutes
2	The aim of the investigation is to justify the formula for series combinations of resistors. Students will have met series connections before, but it may be worth the instructor reminding them of equivalent transport phenomena, such as the flow of water, to drive home the issues involved. A series circuit has no junctions and no alternative routes from one terminal of the power supply to the other. As a result, the same current flows everywhere in that circuit, as it has nowhere else to go. As this may be the student’s first experience of using the adjustable power supply, the tutor should check that it is set to the correct voltage, 4.5 V. For those returning to electrical studies after a break, it is an opportunity to revisit the skills involved in using multimeters to measure current and voltage. In particular, students should be reminded that voltage measurements can be made without interrupting the circuit, as the multimeter is then connected in parallel with the resistor under investigation. On the other hand, to measure current at a point in the circuit, the circuit must be broken at that point and the multimeter inserted there to complete the circuit. Instructors need to be aware that the low current ranges on most multimeters are protected by internal fuses. If a student is having difficulty in getting readings from a circuit, it may be that this internal fuse has blown. It is worth having some spare multimeters available, and the means to change those fuses, to streamline the lesson. The students use their readings to measure the total resistance of the circuit and compare this with the value obtained from the series resistor formula.	30 - 45 minutes

Tutor’s notes

Worksheet	Notes for the Tutor	Timing
3	This is the equivalent to Worksheet 2 but for parallel connections. Again, the vast majority of students will have already met the idea of parallel connections. These involve junctions in the circuit, allowing different currents to follow different routes from one terminal of the power supply to the other. It is worthwhile preparing students for this exercise by comparing the behaviour of water in an equivalent arrangement, where junctions in the pies allow water to flow by different routes. Similarly, for traffic flow, a by-pass allows motorists to avoid narrow roads (high resistance) by choosing a dual-carriageway (low resistance.) Some will still prefer to miss the bustle of the busy by-pass by taking the narrow route. The activities are similar to those in Worksheet 1, and require similar multimeter skills. As before, the instructor should verify that the correct voltage has been selected on the power supply, and be prepared for multimeter problems resulting from a blown internal fuse. The measurements are processed in a similar way to that followed in Worksheet 1. The total resistance is obtained from the total current flowing, and the total voltage. The result is compared with that from the formula for parallel resistors. The summary gives two such formulae, one for combining just two resistors, and the other for combining any number. It may be worth setting the task of deriving the first of these from the second. The tutor should contrast the results with those from Worksheet 2. This time, the current through each resistor varies, but the voltage across each is the same. Previously, the current was the same, with different voltages across the resistors.	20 - 30 minutes
4	This investigation combines the results developed in Worksheets 2 and 3, and applies them to a network which contains some resistors in series and others in parallel. As before, this involves similar multimeter skills, and pitfalls. Instructors should again be aware of the internal fuse issue. The treatment compares measured values with calculated ones. Instructors might decide at this point to discuss component and instrument tolerance at this point. Inspection of the resistors beneath the carriers will show them to have either 5% or 1% tolerance. Measuring instruments have a range of accuracies, depending on what scale they are on. Where available, students could be directed to manufacturer’s data. The worksheet ends with a network for students analyse. The outcome of their calculations will indicate how well they have assimilated the contents of the first three worksheets.	30 - 45 minutes

Tutor's notes

Worksheet	Notes for the Tutor	Timing
5	Voltage dividers are a very important in electricity and electronics as they form the basis for many sensing subsystems, such as light-sensing units. They can also appear difficult to students. The aim here is to overcome that aura of difficulty by reducing the treatment to two simple stages: • the sum of the voltages across the components equals the supply voltage; • the bigger the resistance of a component, the bigger its share of the supply voltage, so that if one resistor has four times the resistance of the other, it gets four times as much voltage. This approach is tested with three different pairs of resistors, and using two supply voltages. The output voltage depends only the supply voltage and the relative size of the resistors, (not their absolute resistance,) so that a voltage divider made from a 2Ω and a 1Ω resistor behaves like one made from a 2MΩ and a 1MΩ resistor. However, the absolute values of resistance are important in two ways. 1. Using very low values of resistance increases the current flowing through the voltage divider, and increases the power dissipation in the resistors. This is usually undesirable. 2. When another subsystem is connected to the voltage divider output, and draws an appreciable current, this extra loading can change the output voltage of the voltage divider. This extra current flows through the upper resistor but not the lower resistor in the voltage divider. A useful rule of thumb says that the current flowing through the unconnected voltage divider should be at least ten times bigger than the current that will be drawn from it when the next subsystem is connected to its output. It may be worth discussing these points with the students once they have completed this exercise.	25 - 40 minutes
6	This worksheet investigates current divider circuits, and compares and contrasts their behaviour with that just studied for voltage dividers. Current dividers do not have as many obvious applications as voltage dividers, though they are used in current measurement. It is often useful to measure only a fixed portion of the total current, and from that deduce the total current flowing. For example, if a current divider sends 10% of the total current through an ammeter, which then registers a current of 2.5A, then the total current flowing was 25A. In an approach parallel to that used for voltage dividers, the treatment looks at two simple ideas: • the sum of the currents through the components equals the supply current; • the bigger the resistance of a component, the smaller its share of the current, so that if one resistor has four times the resistance of the other, it passes a current four times smaller.	25 - 40 minutes

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7	This worksheet looks at two very important, but straightforward, rules of electricity, known as Kirchhoff's laws. In the light of modern knowledge about electricity, these are less impressive than they would have appeared in 1845 when they were first formulated. Nevertheless, they offer valuable tools for analysing networks of components. The current law states that the (vector) sum of the currents at any point in a circuit is zero, or in other words, the total current flowing out of any junction is equal to the total current flowing into the junction. It may need to be stressed t students that it is vital to take into account the direction in which a current is flowing, as well as its magnitude, when applying Kirchhoff's rule. We can now say that it is a consequence of the conservation of charge, or, in other words, that electrons are neither created nor destroyed as they flow around a circuit. The voltage law says that around any loop in a circuit (any possible path that an electron may flow around,) the sum of the emf (giving energy to the electrons,) is equal to the sum of the pd (taking energy from the electrons). In other words, in a series circuit consisting of a 6V battery and two resistors, (so that there is only one possible loop,) the sum of the voltages across the resistors (which take energy from the electrons and heat up in the process, - the pd's) is equal to 6 V (the battery gives energy to the electrons - the emf.) In reality, this rule is a restatement of the conservation of energy. The investigation looks at both these aspects, and takes measurements to justify them.	25 - 40 minutes
8	Students need to have an appreciation of the relationship between energy, power (as the rate at which energy is used), voltage, current and time. The introduction leads to three key facts (definitions), and uses them to arrive at the relationship P = I x V. The investigation into three circuits is designed to give students experience of electrical calculations in the context of actual circuits. The questions will provide students with practice in applying the principles of power and energy in relationship to practical aircraft systems.	25 - 40 minutes

Tutor's notes

Worksheet	Notes for the Tutor	Timing
9	It is important that students can distinguish between the two different situations that can arise when a voltage source is connected to a load. The first is when the impedance (resistance) of the source is equal to that of the load (as is the case with most instrumentation and communication systems) and the second is when the impedance (resistance) of the source is very much lower than that of the load (as it is with most AC and DC power supplies). In the first situation, the aim is that the source passes on as much electrical power as possible to the load. Since power = current × voltage, the ideal is to pass as high a current as possible, and as high a voltage as possible. These are conflicting requirements. For maximum current, the input and output resistances should be as small as possible. For maximum voltage, the input resistance should be as high as possible. The result is a compromise – in order to achieve maximum power transfer the source and load resistances should be identical. Examples of aircraft applications in which this is important includes radio equipment (where the antenna impedance is matched to that of the feeder cable and transmitter/receiver) and ARINC databus systems (where the cables are terminated with resistances that accurately match the impedance of the twisted pair wiring and the transceivers fitted in the avionic equipment). In the second situation, the source impedance (resistance) is made very small in comparison with that of the load, so that the voltage drop across the load can be maintained over a wide range of load currents. Ideally, the output impedance (resistance) of the source should be zero but in practice this is unachievable. Examples of aircraft applications where this is important is AC and DC power generation. The investigation uses a range of resistors as loads for the circuit. For each load, students measure the voltage across and current flowing through the resistor, and use them to calculate the power dissipated (and so transferred) to the load. A graph of the results should confirm the maximum power transfer when the load resistance is equal to R_{EQ}. Where a variable resistor is available, this can be set to a value of R_{EQ} and used as one of the loads. This should correspond to the maximum value of transferred power.	30 - 45 minutes

Answers

Worksheet 1

1. The current is found by first measuring the voltage drop across the 12 Ω resistor and then dividing the measured voltage by 12 (i.e. by using *I* = *V* / *R*)
2. 6 Ω
3. A single electron has a charge of $1.60217733 \times 10^{-19}$ coulombs.
   A collection of 6.2415×10^{18} electrons has a charge of one coulomb
   (i.e. $1 / 1.60217733 \text{x} 10^{-19}$).

Worksheet 3

1. I_1 = 3 mA; I_2 = 6 mA; I_3 = 3 mA
2. $I_1 + I_2 + I_3$ = 12 mA
3. 1 kΩ

Worksheet 4

1. 4 kΩ
2. 1.5 mA
3. 6 V
4. 1 mA
5. 0.5 mA (or 500 µA)
6. 4 V

Worksheet 8

1. 10.3 A, 345.6 kJ
2. 11 hours (approx.)

Revision question paper

1.	(b)	2.	(b
3	(a)	4.	(b)
5.	(b)	6.	(b)
7.	(c)	8.	(c)
9.	(b)	10.	(a)
11.	(a)	12.	(a)
13.	(c)	14.	(b)
15.	(c)		