Pearson BTEC Levels 4 and 5 Higher Nationals in Engineering (RQF)

Unit 3: Engineering Science (core)

Unit Workbook 4

in a series of 4 for this unit

Learning Outcome 4

Circuit Theory and Electromagnetic Principles

Contents

INTRODUCTION

Analyse applications of electromagnetic principles and properties

D.C. circuit theory:

Voltage, current and resistance in D.C. networks.

Exploring Ohm's law and Kirchhoff's voltage and current laws.

A.C. circuit theory:

Waveform characteristics in a single-phase A.C. circuit.

RLC circuits.

Magnetism:

Characteristics of magnetic fields and electromagnetic force.

The principles and applications of electromagnetic induction.

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose

Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory

Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example

The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question

Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner, it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge

You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

4.1 DC Electrical Principles

4.1.1 Review of Resistors in Series and Parallel

Series Resistors

When resistors are connected in series then each resistor contributes its own barrier to the flow of electrons in a circuit. This is much akin to placing weights along the length of a garden hosepipe: the more weights there are along the length of the hose, and the heavier they become, will collectively contribute to constricting the overall flow of water in the pipe.

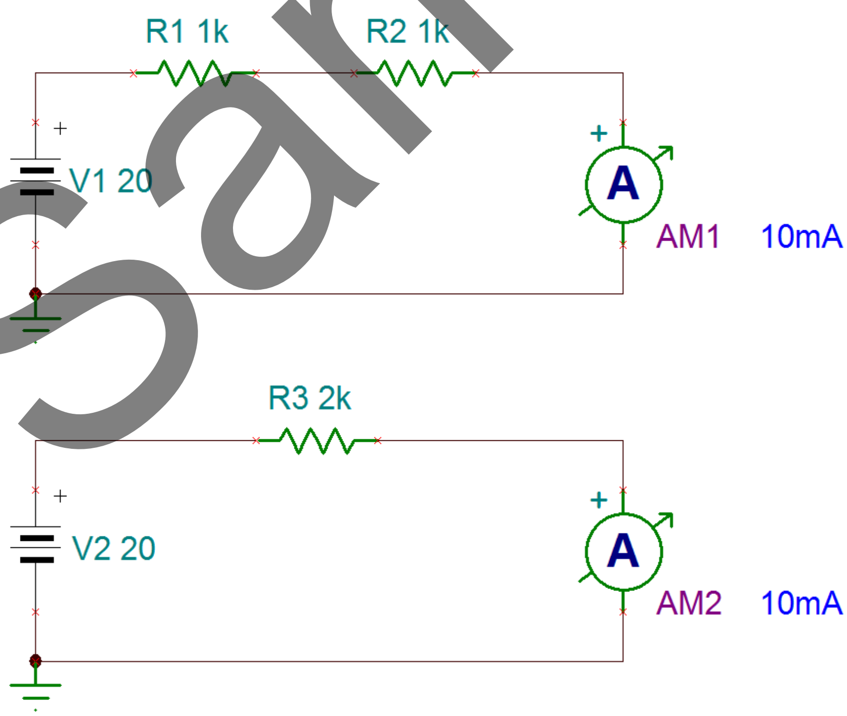
The simple rule for resistors in series is therefore to add their values to find the overall resistance.

$$\boldsymbol{R_T} = \boldsymbol{R_1} + \boldsymbol{R_2} + \cdots \quad [\Omega]$$

Very straightforward. The first circuit below is drawn in the TINA-TI simulator. It has two 1kΩ resistors connected in series to a 20V DC source. The total resistance is 2kΩ and therefore, from Ohms Law…

$$I = \frac{V}{R_T} = \frac{20}{2000} = 0.01A = 10mA$$

The simulation in the first circuit clearly shows 10mA on the Ammeter.



The second circuit lumps together the two 1kΩ resistors, making a 2kΩ resistor, with exactly the same result. Try it yourself (notice that the earth is needed to reduce errors/warnings in the simulator).

Parallel Resistors

The picture is a little more involved when we come to consider resistors in parallel. The parallel arrangement provides 'alternative paths' for the electrons to negotiate. The more alternative paths there are will mean an easier route for the electrons. A good analogy might be to think of multiple hosepipes connected to a single tap: there will be an increased water flow compared to the single hose arrangement.

To evaluate the overall resistance of a parallel arrangement of resistors we need to consider these multiple paths and use the equation…

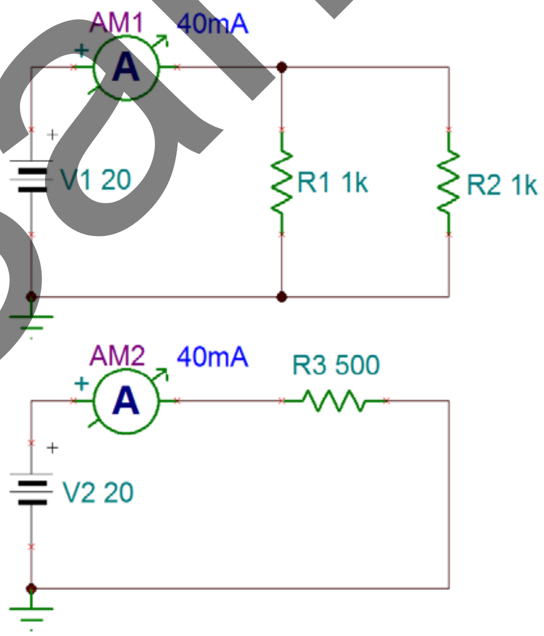
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \quad [S]$$

Notice the units used in the equation. They are Siemens (reciprocal of resistance) which is the unit used for Conductance. This equation must be used for all cases where there are three or more resistors in parallel. When there are only two resistors in parallel then we may take a common denominator and end up with the product over sum for the overall resistance…

$$R_T = \frac{R_1 R_2}{R_1 + R_2} \quad [\Omega]$$

The first circuit below shows two 1kΩ resistors in parallel, connected to a 20V DC source. Using the product over sum formula for the overall resistance yields…

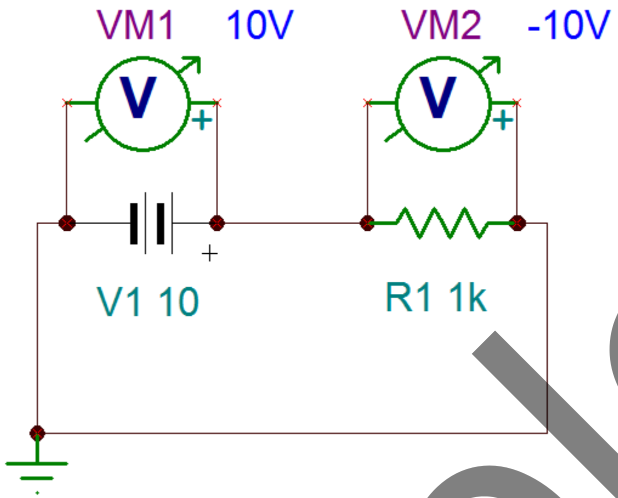
$$R_T = \frac{1000 \times 1000}{1000 + 1000} = \frac{1000000}{2000} = 500\Omega$$



The lower circuit shows that the same current flows using the equivalent resistance of 500Ω.

4.1.2 Kirchhoff's Voltage Law (KVL)

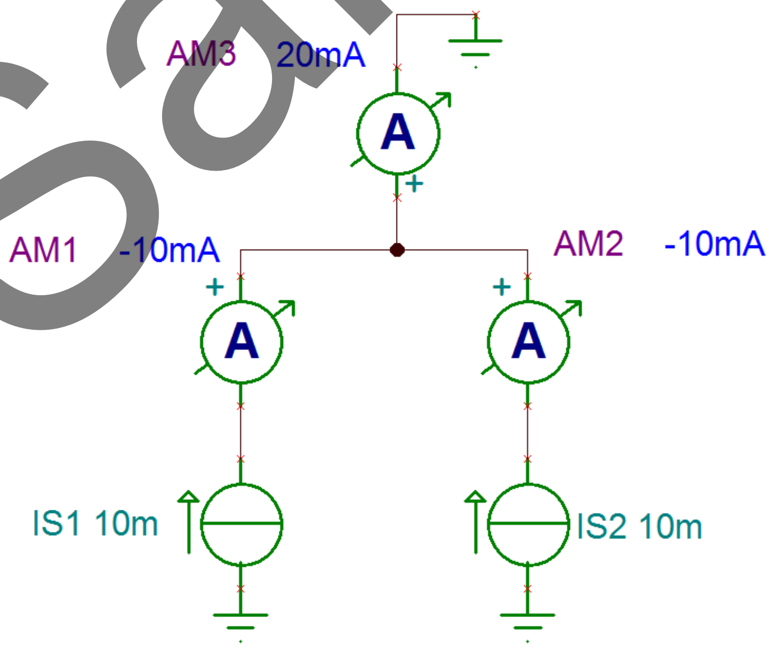
This states that the ***algebraic*** sum of voltages in any closed loop is zero. For a very simple circuit that means that if we place a resistor across a battery then the algebraic sum of voltages in the closed loop will be zero. Let's have a look at this arrangement…



The crucial part in this circuit is that we have connected the voltmeters in such a way that their '+' terminals both face the same way. Adding +10V and -10V gives us zero volts. This proves KVL in this simple case. Perhaps you would like to construct an arrangement with more resistors and prove that KVL still applies?

4.1.3 Kirchhoff's Current Law (KCL)

This states that the ***algebraic*** sum of currents at a junction is zero. Let us again use the TINA simulator to prove this…



Here we have ensured that the Ammeters measure current leaving the junction in each case (notice all the Ammeter '+' terminals are connected to the junction). Adding those three currents gives zero. This proves KCL in a simplistic case. Perhaps you would like to construct a more involved arrangement and prove that KCL still applies?

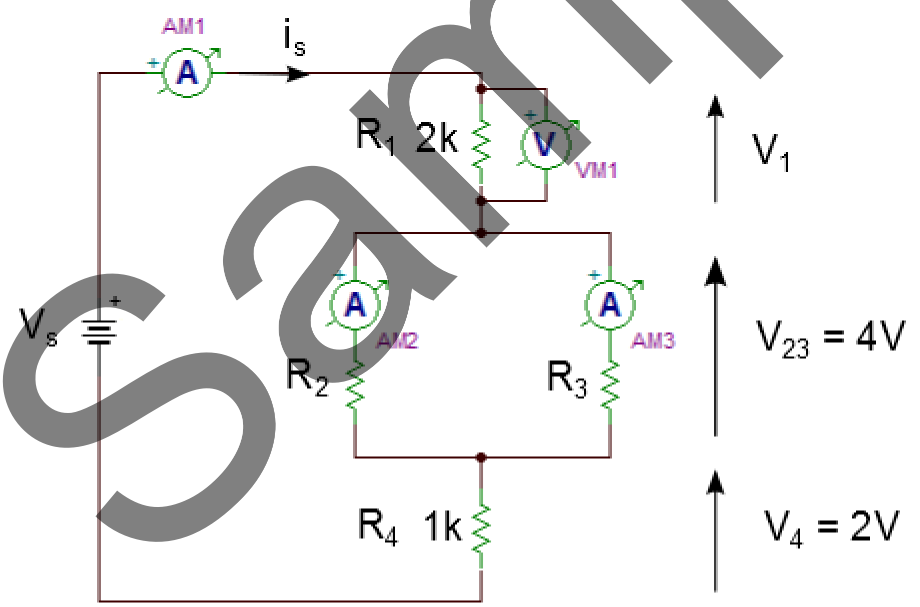
NOTE: *The two symbols at the bottom of the above diagram (marked IS1 and IS2) are constant current generators. They do what their title suggests: provide a constant current.*

Now that KVL and KCL have been reviewed we are in a position to look through a couple or worked examples.

Worked Example 1

For the DC network given below:

- **a) Calculate the value of the supply current (i_s).**
- **b) Determine V_1.**
- **c) Given that $R_2 = R_3$ calculate the current through each of these two resistors.**
- **d) Determine the value of the supply voltage (V_s).**



a) We can see that the value of R_4 is known, as is the voltage across R_4. The current i_s must therefore be $2/1000 = 2mA$.

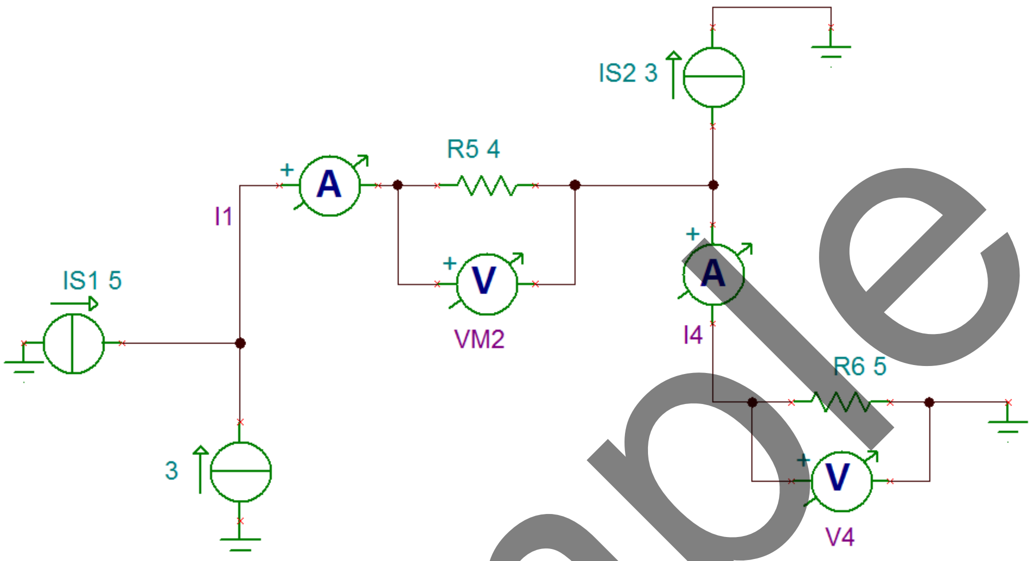
b) The supply current also flows through R_1 therefore the voltage V_1 must be $2mA \times 2000 = 4V$.

c) Since $R_2 = R_3$ then i_s must split evenly between these two resistors. These currents are therefore 1mA each.

d) Knowledge of KVL tells us that the supply voltage V_s must be equal to the sum of V_1, V_{23} and V_4, which is 10V.

Worked Example 2

Consider the circuit below:



a) Calculate the value of i_1 and hence V_1
b) Calculate the value of i_4 and hence V_4

a) Knowledge of KCL tells us that on the lower left of the circuit there are two constant current generators feeding a junction. Since each of these currents must emerge from that junction then the current i_1 must be (5 + 3) = 8A.

b) Looking at the junction to the top right of the circuit we see that 8A (i_1) goes in and 3A comes out at the top. Therefore the current coming out at the bottom of this junction must be (8 – 3) = 5A. Since 5A flows through R_6 (which is given as 5Ω) then V_4 must be (5 x 5) = 25V.

4.1.4 Voltage Divider

A voltage divider 'divides' a supply voltage across series connected resistors according to the proportion of each resistor to the total resistance seen by the voltage source. Here's the picture…