

LEVEL 4 ASSESSMENT SPECIFICATION

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Programme:	HNC Electrical/Electronic Engineering & Instrumentation Engineering		
Module:	Electrical Principles		
Module code:	PCEE4001	Contribution to Overall Module Assessment (%):	100%
Lecturer:	Jason Pointer	Internal Verifier:	Lance Rutherford
Assignment Title:	Electrical Principles	Word count (or equivalent):	2000
Submission deadline:	15/01/20	Return date of provisional marks & written feedback:	29/01/21
Submission method:	All written assessments, where practical and possible, must be submitted via Turnitin unless otherwise instructed by the Lecturer. (Please DO NOT put this assessment specification into Turnitin or it will match many similarities with other students' submissions.) Alternative submission method (if applicable): Late submission of the assessment will result in a late penalty mark. Penalties for late submission: Up to one week late, maximum mark of 40%. Over one week late, 0%. Only the Extenuating Circumstances Panel may approve a change to submission dates.		
Academic honesty / referencing:	Academic honesty is required. In the main body of your submission you must give credit to authors on whose research and ideas your work is based. Append to your submission a reference list that indicates the books, articles, etc. that you have used, cited or quoted in order to complete this assessment.		

Module Learning Outcomes (from module syllabus)

1. Produce routine solutions to typical electrical problems.
2. Relate and apply basic electrical theory to collected data.

STUDENT FEEDBACK FORM

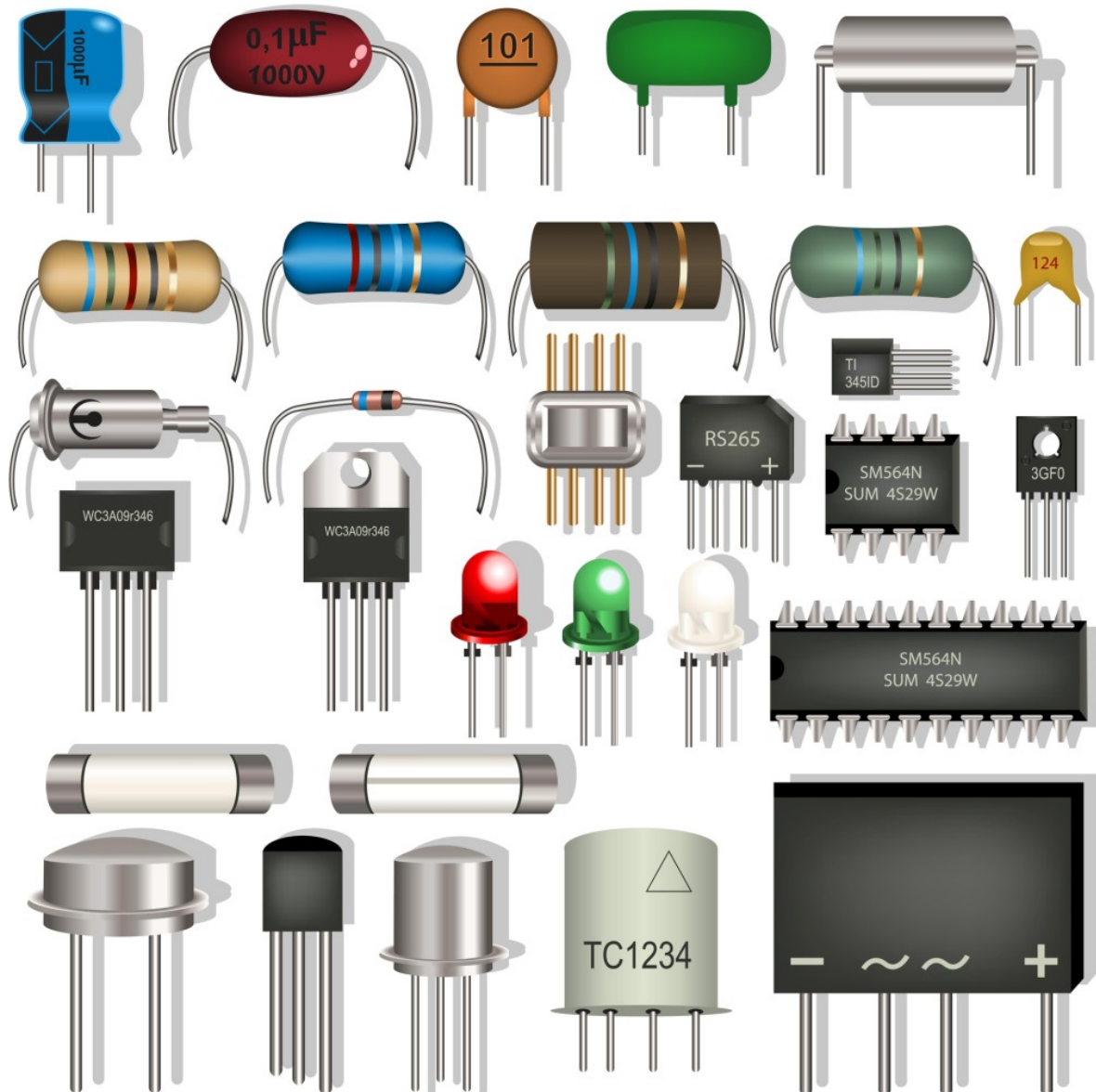
This section details the *extent* to which the assessment criteria are demonstrated by you, which in turn determines your mark. The marks available for each category of skill are shown. Lecturers will use the space provided to comment on the achievement of the task(s), including those areas in which you have performed well and areas that would benefit from development/improvement.

Generic Assessment Criteria	Marks available	Marks awarded
1. Engagement with Literature Skills	15	10.2
Engagement with a wide range of literature sources, including sources retrieved independently. Generally sound referencing, with no inaccuracies or inconsistencies.		
2. Knowledge and Understanding Skills	25	17.4
Task 1 achieved 72%. Task 2 achieved 77%, Task 3 achieved 52%. Task 4 achieved 78%. Competent knowledge of the basic underlying concepts and principles is accurate with a good understanding in most areas. You have shown a very good understanding of the requirements for the calculation work in each task but need to be careful with the engineering prefixes.		
3. Cognitive and Intellectual Skills	15	9.5
Task 1 achieved 65%. Task 4 achieved 62%. Very good evaluation of the underlying concepts and principles, have include key concepts in the discussion.		
4. Practical Application Skills	35	27.5
Task 1 achieved 75%. Task 4 achieved 82%. An excellent application of practical work for Task 1 and 4, very good use of the test equipment to obtain all of the required results.		
5. Transferable Skills for Life and Professional Practice	10	6.5
Mostly coherent, organised and accurate work, in a suitable structure and is for the most part clearly expressed.		

Assessment Mark (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)	Late Submission Penalties (tick if appropriate)		71%
	Up to 1 week late (40% Max)		
	Over 1 week late (0%)		

HNC Electrical and Electronic Engineering

PCEE4001 Electrical Principles



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Abstract

An assessment set as part of a Higher National Certificate (HNC) part time course in Electrical and Electronic Engineering designed to improve the candidate's understanding of basic electrical theories and components. Four separate tasks set to introduce the following general themes; DC Circuits; Capacitors; Magnetism, and; AC Circuits. Topics explored using a mix of theory and practical demonstrations. Used as a forum to demonstrate the ability to research required theory to the HNC syllabus, apply this to practical demonstrations, and to critically analyse the findings using the knowledge of the applicable theories. ✓

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Cover image courtesy of <https://predictabledesigns.com/how-to-develop-and-prototype-a-new-product/>, viewed 17th January 2021

Task 1 – DC Circuits

Task 1 required the construction of a basic circuit, to include a 12 volt power supply and resistors of various values placed in series and parallel. Figure 1 is a pictorial representation of the circuit as assembled and tested.

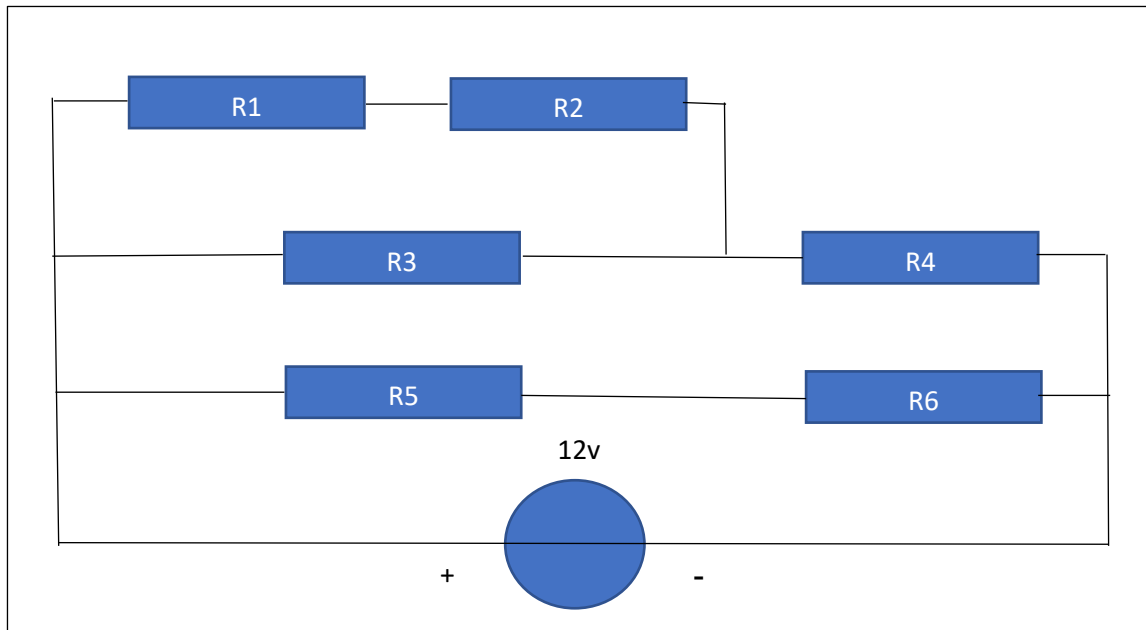


Figure 1 – Representation of the resistive circuit as tested.

The following values were provided for the resistors used in this demonstration:

R1 (Ω)	R2 (Ω)	R3 (Ω)	R4 (Ω)	R5 (Ω)	R6 (Ω)
220	560	330	470	220	680

Table 1 – Values of resistors used in Task 1

Background Theory

Before undertaking the experiment, it is important to lay out some of the key concepts applicable to this demonstration and electronics generally. All elements are constructed of atoms. Atoms are in turn formed of three major components, those being protons, neutrons, and electrons. According to the Bohr model of atoms, at the

core of each atom is the proton and neutron which form the nucleus (Robertson 2008, p7). Surrounding the nucleus are said be to electrons which are arranged in 'shells' in orbit around the nucleus. The proton is said to have a positive charge (Q), as measured in coulombs (C), where electrons are said to have an equivalent negative charge. Where the number of electrons and protons are equal, the atom is said to be in a steady state.

Robertson ((2008), p9) states that atoms may be categorised into three sub-divisions, those being conductors, insulators and semiconductors. These are defined by how many "free" electrons are available for displacement. Good conductive elements have many more free electrons than insulators, thus being ideal candidates for use in transferring charge from one location to another. ✓

This transition of charge from one location to another within a given timeframe is referred to as current (I) (Bird (2007), p4), the unit being referred to as the ampere or amp (A). This can be described mathematically as:

$$\text{Current (I)} = \frac{\text{Charge (Q)}}{\text{Time (t)}}$$

The movement of electrons within a conductor is not always random. It is possible to manipulate the flow of electrons within a conductor by applying an electro motive force (*emf*) in the form of a power source. The unit of an *emf* is referred to as the volt (V), where the volt is defined as being one joule per coulomb. The volt is also referred to as an electrical potential (Robertson (2008), p11). This potential is formed where there is a difference of voltage in two areas of a conductor, thus causing the flow of charge. ✓

A conductor may allow the flow of charge (I) and this charge may carry energy (V), but conductors do not provide the free flow of current and *emf*. The physical composition of the conductor may restrict the flow of electrons. This resistive effect is expressed as a unit in terms of ohms (Ω) and is expressed most clearly by Ohm's Law, which states that a current flowing through a conductor is directly proportional to the voltage and inversely proportional to the resistance. Mathematically, this is expressed as:

$$\text{Current (I)} = \frac{\text{Voltage (V)}}{\text{Resistance (Ω)}} \quad \checkmark$$

This experiment also requires knowledge of resistors placed in series and in parallel in a d.c. circuit. There are several consequences following the logic of Ohm's Law in the context of a circuit constructed with resistors in parallel. When altering the value of the resistance in a closed circuit, the current will remain constant across all components where the voltage will be altered by passing through the resistors. In the case of the voltage, the total voltage must equal the sum of the voltages as measured at each of the components (Bird (2008), p41). Therefore, in a circuit constructed with three resistors in series:

$$V_T = V_1 + V_2 + V_3 \quad \checkmark$$

And so where $V = IR$, the same three-resistor series circuit should be expressed as $IR_T = IR_1 + IR_2 + IR_3$. So to divide through by I , R_T could be expressed as:

$$R_T = R_1 + R_2 + R_3 \quad \checkmark$$

In the case of a circuit where the resistors are connected in parallel to each other, they in effect have an equal connection to the *emf*. It is possible to say, therefore, that the voltage will remain constant between all of the resistors. Using Ohm's Law, it follows that:

$$\text{Total Current } (I_T) = \frac{\text{Supply Voltage } (V)}{\text{Total Resistance } (R^T)} \quad \checkmark$$

And as the total charge must equal the sum of each of the parallel legs of the circuit, in a three resistor circuit this would be expressed as:

$$I_T = I_1 + I_2 + I_3 \quad \checkmark$$

Therefore, where $I = V/R$, applying this to the above expression leads to the following:

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \checkmark$$

So, to divide the above expression through by the supply voltage (V), an expression for the total resistance in a parallel resistive circuit is:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

These calculations are possible because of the work conducted by the German physicist Gustav Kirchhoff in 1845, which is now referred to as Kirchhoff's Laws. The

first law considers a current flowing through a junction in a circuit, and states that the sum of the currents flowing into the junction equals the current leaving that junction (Robertson (2008), p48). This is a clear and concise review of the above expression for current (I_T) that followed on from the logic of Ohm's Law. ✓

Kirchhoff's second law considers voltage within a circuit, and states that the sum of the *emf* is equal to the sum of the potential difference (Robertson (2008) p.49). This can be expressed mathematically as:

$$\Sigma E = \Sigma IR$$
 ✓

However, as we have seen that $V = IR$, the above expression could also be expressed as:

$$V_T = V_1 + V_2 + V_3$$
 ✓

Thus, an understanding of both Ohm's Law and Kirchhoff's Laws is critical for appropriate analysis of the experiment set within this task. ✓

Equipment Used

The outcomes of the experiment were achieved by utilising the following equipment:

- A step-down transformer, converting the 230v alternating current mains supply to 12v direct current;
- A bread board, allowing for rapid construction and testing of the circuit;
- Six resistors of various values (See Table 1)
- Connecting leads
- A high impedance digital multimeter

Special note should be made of some of the basic functions of the multimeter used in this experiment. The selected unit functioned by passing a small current through the circuit when applied at various points around the circuit. This made it possible to obtain fair measurements of actual values for both resistance and voltage by placing the multimeter in parallel with the circuit. However, Kirchhoff's first law indicates that attempting to measure the current in the same manner would increase the overall current of the circuit, thus providing false readings. To remedy this, any readings for

current were obtained by placing the multimeter in series with the measured component. ✓

The Practical Experiment

Task 1 was divided into the following sub-tasks:

1. *Construct the circuit and measure the total resistance (R_T) before connecting the power supply.*

R_T measured on the breadboard displayed 0.391 when using the 2k multimeter setting, the value therefore being 391Ω. ✓

2. *Connect a 12V supply and measure the p.d. value across each resistor, the supply current and the current in each resistor.*

V_T measured at the breadboard displayed 11.76 on the 20V multimeter setting, the value therefore being 11.76V.

I_T measured at the breadboard displayed 30.4 on the 200μA multimeter setting, the value therefore being 30.4μA.

R_T	V_T	I_T
391Ω	11.74V	30.4μA

Table 2: Total values derived from practical experiment

The voltage value measured across each resistor was completed using the 20V multimeter setting, and rendered the following results:

V_1	V_2	V_3	V_4	V_5	V_6
1.09V	2.81	3.91V	7.87V	2.88V	8.91V

Table 3: Values for voltage across each resistor from practical experiment

The current measured across each resistor was completed using the 20μA setting on the multimeter, and rendered the following results:

I ₁	I ₂	I ₃	I ₄	I ₅	V ₆
5.01μA	5.01μA	11.90μA	16.88μA	13.24μA	13.24μA

Table 4: Values for current across each resistor from practical experiment

You used the wrong prefix for the current should be "m"

Calculations

Task 1 then required the reworking of the experiment by using calculations only:

3. Calculate the

- total resistance, R_T
- supply current, I
- current in each resistor
- and the p.d. value across each resistor.

All formulas and workings must be shown.

In considering R_T :

$$R_{123} = \frac{R_{12} \times R_3}{R_{12} + R_3} = \frac{(220+560) \times 330}{(220+560)+330} = 231.89\Omega$$

$$R_{1234} = R_{123} + R_4 = 231.89 + 470 = 701.89\Omega$$

$$R_T = \frac{R_{1234} \times R_{56}}{R_{1234} + R_{56}} = \frac{701.89 \times (220+680)}{701.89 + (220+680)} = 394.35\Omega$$

In considering I_T :

$$I_T = \frac{V_T}{R_T} = \frac{12}{394.35} = 30.43\mu A$$

Again wrong prefix.

In considering the current and voltage in each resistor:

$$I_T = \frac{V_T}{R_T} = \frac{12}{394.35} = 30.43\mu A \quad \leftarrow \text{why have you state this again?}$$

$$I_{56} = \frac{V_T}{R_{56}} = \frac{12}{(220+680)} = 13.33\mu A$$

$$V_5 = I_5 \times R_5 = 0.01333 \times 220 = 2.93V$$

$$V_6 = I_6 \times R_6 = 0.01333 \times 680 = 9.06V$$

$$I_4 = \frac{V_T}{R_{123} + R_4} = \frac{12}{(231.89+470)} = 17.10\mu A$$

$$V_4 = I_4 \times R_4 = 0.0171 \times 470 = 8.04V$$

$$V_3 = V_{12} = V_T - V_4 = 12 - 8.04 = 3.96V$$

$$I_3 = \frac{V_3}{R_3} = \frac{3.96}{330} = 12.00 \mu A$$

$$I_{12} = \frac{V_{12}}{R_{12}} = \frac{3.96}{(220+560)} = 5.08 \mu A$$

$$V_2 = I_2 \times R_2 = 0.00508 \times 560 = 2.84V$$

$$V_1 = I_1 \times R_1 = 0.00508 \times 220 = 1.12V$$

R_T	V_T	I_T
394.35Ω	12.00V	30.43μA

Table 5: Calculated values for total resistance, voltage and current

V_1	V_2	V_3	V_4	V_5	V_6
1.12V	2.84V	3.96V	8.04V	2.93V	9.06V

Table 6: Calculated values for voltage across each resistor

I_1	I_2	I_3	I_4	I_5	V_6
5.01μA	5.01μA	11.90μA	16.88μA	13.24μA	13.24μA

Table 7: Calculated values for current across each resistor

Multisim Test

Task 1 further required the use of the circuit simulation software Multisim to verify the results of the experiment and the calculations.

4. Use Multisim to also produce a set of test results for the voltages and currents.

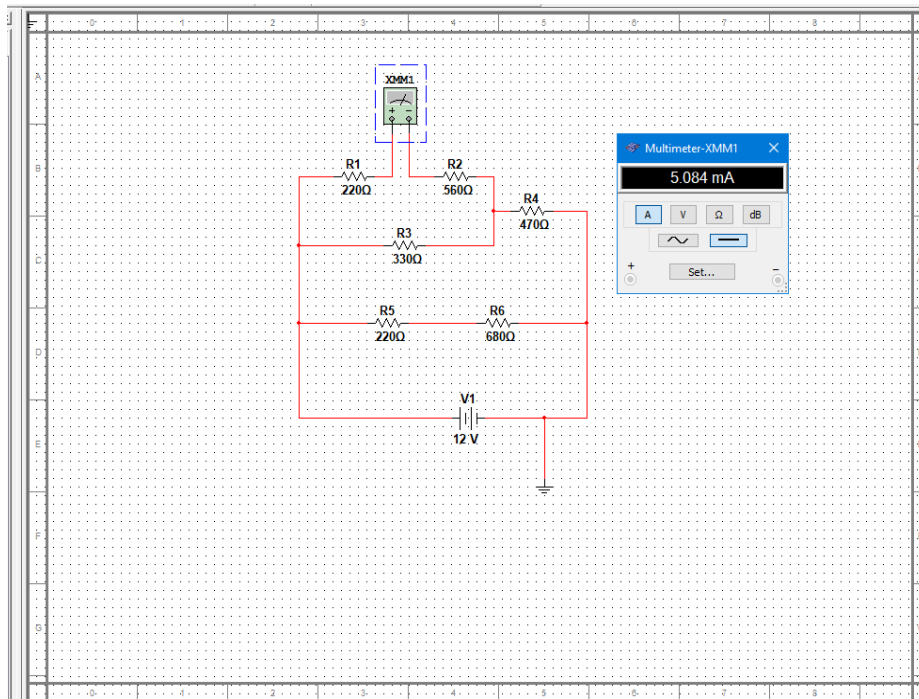


Figure 2: Screenshot of measuring the current in series with R₁ using Multisim

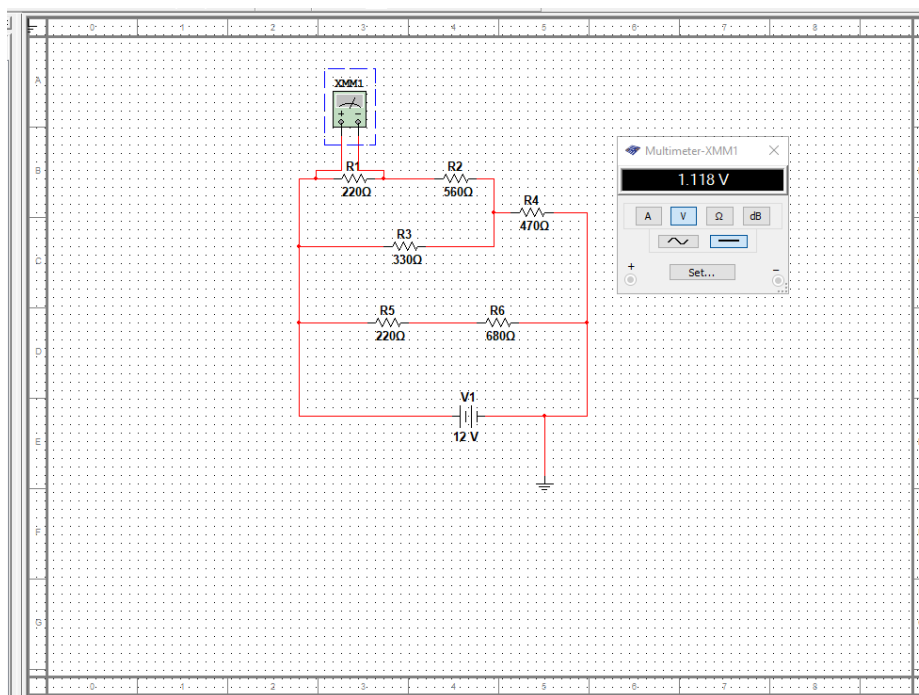


Figure 3: Screenshot of measuring the voltage in parallel with R₁ using Multisim

The following tables evidence the results of the simulation run on the Multisim software.

R_T	V_T	I_T
394.348 Ω	12.00V	30.43 μ A

Table 8: Values derived from Multisim for total resistance, voltage and current

V_1	V_2	V_3	V_4	V_5	V_6
1.118V	2.846V	3.965V	8.035V	2.933V	9.067V

Table 9: Values derived from Multisim for voltage across each resistor

I_1	I_2	I_3	I_4	I_5	V_6
5.084 μ A	5.082 μ A	12.014 μ A	17.097 μ A	13.333 μ A	13.333 μ A

Table 10: Values derived from Multisim for current across each resistor

Analysis of Results

Task 1 is concluded by the following sub-task:

5. Comment on the practical, calculation and simulation results, discussing any variations when comparing these results and make reference to relative theories such as Kirchhoff's laws.

There is significant variance between the values sets collected during the practical, calculations and simulation. This can be easily demonstrated, for example, by applying Kirchhoff's second law to the values obtained for the leg described by V_1 , V_2 and V_4 during the practical: ✓

$$\Sigma E = \Sigma IR = V_1 + V_2 + V_4 = 1.09V + 2.81V + 7.87V = 11.77V \quad \checkmark \quad \text{Good.}$$

When considering that the observed value for V_T as produced by the power source was 11.78V, a variance of 0.01V is an undesirable component of this data. ✓

Several reasons may be adduced for these differences. In the case of the practical, all of the components used had a design tolerance which necessarily meant that they were operating to levels other than those stated in the calculations and simulation. For example, the resistors used had a design tolerance of some 5%. ✓

Similarly, each of the components used in the practical had its own internal resistance, which was not taken into account in the calculations or simulations. This

may have been inherent in the manufacture process of the components or, alternatively, caused by wear or damage that was not evident upon use. This is perhaps the most likely reason, for example, for the power source used during the practical providing a voltage less than the stated 12V. ✓

Human error cannot be discounted in determining factors effecting the reliability of the data gathered by the various methods. In the case of the calculations, error will have been introduced during the process of rounding to two decimal figures. This is most apparent in the data collected on the current, where due to the very small sizes of current involved, any rounding has a significant effect on the final value. This is then compounded when the rounded figure is used to derive another figure which, in turn, is also rounded. ✓

In the practical, the only testing tool used to collect the data was the digital multimeter. These devices are not immune from various errors. They are, for example, powered by their own internal source (a 9V battery cell). This battery over time will degrade and fail to produce the required voltage. This will affect the test current emitted by the multimeter which, in turn, will alter the readings provided by the device. ✓

It should be noted that the values obtained through the Multisim software were used as a baseline comparator for the other data sets. This was based on the assumption that calculations provided through the software would be as near to the theoretical ideal values as possible. However, in measuring the values for I_1 and I_2 , where I_1 should be equal in value to I_2 , a variance of $0.002\mu\text{A}$ was noted. From this it is necessary to state that no assumptions should be made regarding the reliability of data. All data must be tested and compared wherever possible with other similar data to ascertain its efficacy. ✓

Good.

Task 2: Capacitors

Would be better to start this on a new page.

Task 2 is divided into several sub-tasks, such as the following:

1. Explain the construction and function of a capacitor, listing some of the different types that are available and typical values. Include methods that could be used to alter the value of the capacitor.

Capacitors are a common electrical device used for the storage of electrical charge. Capacitors take advantage of the fact that, when two conductors are placed in parallel to each other and a positive charge is applied to one conductor and a negative charge is applied to the other, an electrostatic field is formed. ✓

Within this electrostatic field, the field strength is effected by the potential difference between the two conductors and their relative distance from each other. This may be expressed mathematically as:

$$\text{Electric Field Strength, } E = \frac{V}{d} \quad \checkmark$$

From this it can be adduced that the efficient working of a capacitor will be affected by the distance between the two conductors and the voltage applied across it (Bird (2007), p57). ✓

It is stated that between one positive charge and one negative charge there exists one field line (Bird (2007), p57). In any field, therefore, the number charges dictates the scale of the field. Within this field charge (Q) will be retained based on the magnitude of the potential difference (V) applied. This ratio between charge and voltage is determined by the physical parameters of the two conductors and is a constant that is referred to as the capacitance (C) (Robertson (2008), p83). The unit of capacitance is the farad (F). This may be expressed mathematically as: ✓

$$\text{Capacitance, } C = \frac{Q}{V} \quad \checkmark$$

With the above theory in mind, in it's most basic form a capacitor is a device constructed of two plates separated by an insulative material. This insulator is described as a dielectric (Bird (2007), p 58). Dielectrics are graded and selected based on their insulative properties, which is referred to as it's permittivity. ✓

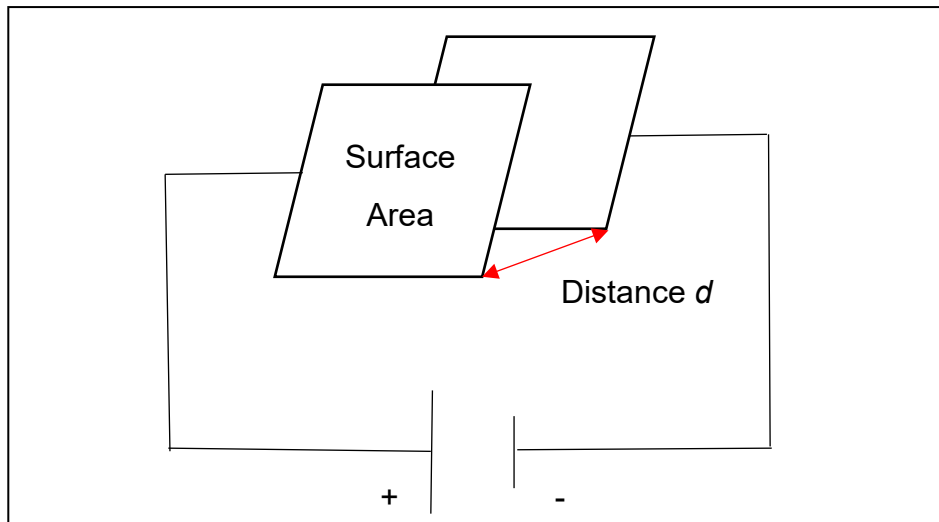


Figure 4: Pictorial representation of basic capacitor

The amount of charge held by a capacitor can, therefore, be affected by the following factors:

- Surface area of the plates (this can be achieved by increasing the surface area of one plate, or placing a number of interleaving plates in proximity) ✓
- Altering the distance between the plates ✓
- Selecting a dielectric with a different permittivity ✓
- Changing the voltage applied across the capacitor ✓ *Good.*

Common types of capacitor include units defined by the material used in the dielectric, such as paper (or film), ceramic, mica, silicon, or air-gap (vacuum) capacitors. They may also be classed by the material used in the construction of the conductive material, such as aluminium, silver, tantalum or niobium electrolytic capacitors. Electrolytic capacitors function in a similar manner to a multi-plate capacitor, except that the anode (positively charged conductor) is served by a liquid or liquid-impregnated layer surrounding the cathode (negatively charged conductor). The dielectric barrier is formed of an oxide coating of the cathode. ✓

One of the most common types of capacitors used is the single-layer ceramic capacitor. As its name suggests, it provides relatively small capacitance values, and can range from as little as 100pF to 4.7nF (<https://uk.rs-online.com/web/c/passive-components/capacitors/ceramic-single-layer-capacitors/?pn=2>, viewed 17th January, 2021). ✓

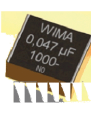
Type ⊕ = polarized	Pic	Cap Range	ESR	Leakage	Voltage Rating	Temp Range	Gen Notes
Ceramic		pF - μF	low	med	high	-55° to +125°C	Multipurpose Cheap
Mica (silver mica)		pF - nF	low 0.01-0.1Ω	low	high	-55° to +125°C	For RF filters Expensive Very stable
Plastic Film (polyethylene polystyrene)		few μFs	med	med	high	varies	For low freq Cheap
Tantalum ⊕		μFs	high 0.5-5.0Ω	low	lowest	-55° to +125°C	Expensive Nonlinear (bad for audio)
OSCON ⊕		μFs	low 0.01-0.5Ω	low	low	-55° to +105°C	Best quality Highest price
Aluminum Electrolytic ⊕		high μFs	high 0.05-2.0Ω	med	low	-40° to +85°C	For low-med frequencies Cheap Hold charge for long time – not for production test

Table 2. Common Capacitor Specifications and Trade-offs

Figure 5: Table comparing six types of capacitor

It is also important to understand the effect of placing capacitors in series and in parallel. When a circuit constructed solely of capacitors placed in parallel, the capacitance of the circuit equals the sum of the values of those capacitors. This may be represented mathematically as:

$$Q_T = Q_1 + Q_2 + Q_3 + Q_4 \dots + Q_n \quad \checkmark$$

It also follows, therefore, that:

$$C = C_1 + C_2 + C_3 + C_4 \dots C_n \quad \checkmark$$

Where capacitors are placed in series, the charge on each interconnected capacitor is the same. But consider the following:

$$V = \frac{Q}{C} \quad \checkmark$$

That is to say that the potential difference of a circuit is proportional to the charge and inversely proportional to the capacitance. Therefore, where the charge remains constant the capacitance must be altered to achieve a certain potential difference.

$$\text{Also, where } V = \frac{Q}{C} \quad \text{then} \quad \frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} + \frac{Q}{C_4} \dots + \frac{Q}{C_n} \quad \checkmark$$

This can be restated as:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} \dots + \frac{1}{C_n} \quad \checkmark$$

In the special circumstance of there being two capacitors in series (Bird (2007), p62):

$$C = \frac{C_1 \times C_2}{C_1 + C_2} \quad \checkmark$$

Calculations

Task 2 further requires the analysis of a circuit (Figure 6) by the application of calculations derived from the underpinning theory.

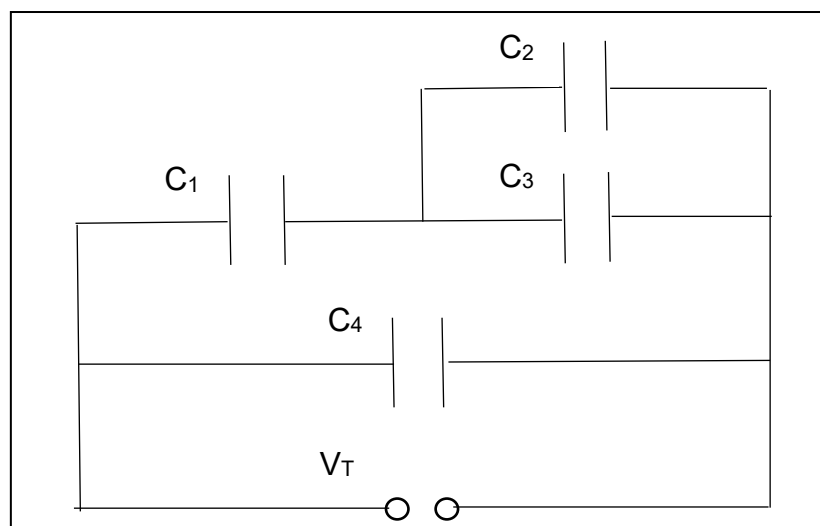


Figure 6: Circuit to be analysed

C_1	C_2	C_3	C_4	V_T
$12\mu\text{F}$	$22\mu\text{F}$	$33\mu\text{F}$	$4.7\mu\text{F}$	20V

Table 11: Values applied to Figure 6 and subsequent calculations

Task 2 states:

Using the values stated in Table [11], determine:

a) *the equivalent circuit capacitance*

$$C_{23} = C_2 + C_3 = 22 + 33 = 55\mu\text{F} \quad \checkmark$$

$$C_{123} = \frac{C_1 \times C_{23}}{C_1 + C_{23}} = \frac{12 \times 55}{12 + 55} = 9.851 \mu\text{F}$$

$$C_T = C_{123} + C_4 = 9.851 + 4.7 = 14.551 \mu\text{F}$$

b) the total charge

$$Q_T = C_T \times V = 14.551 \times 10^{-6} \times 20 = 291.02 \mu\text{C}$$

c) the charge in each capacitor

$$Q_4 = C_4 \times V_T = 4.7 \times 10^{-6} \times 20 = 94 \mu\text{C}$$

$$Q_{123} = C_{123} \times V = 9.851 \times 10^{-6} \times 20 = 197.02 \mu\text{C}$$

And $Q_1 = Q_{123}$ as it is placed in series

$$\text{Therefore } Q_1 = 197.02 \mu\text{C}$$

$$\text{So } V_1 = \frac{Q_1}{C_1} = \frac{197.02}{12} = 16.418 \text{V}$$

$$V_{23} = \frac{Q_1}{C_{23}} = \frac{197.02}{55} = 3.582 \text{V}$$

$$Q_2 = C_2 \times V_{23} = 22 \times 10^{-6} \times 3.582 = 78.804 \mu\text{C}$$

$$Q_3 = C_3 \times V_{23} = 33 \times 10^{-6} \times 3.582 = 118.206 \mu\text{C}$$

Q_1	Q_2	Q_3	Q_4
197.02 μC	78.804 μC	118.206 μC	94 μC

Table 12: Statement of charge at each capacitor

d) the energy stored in each capacitor

$$\text{Where } W = \frac{1}{2} CV^2$$

$$W_1 = \frac{1}{2} C_1 V_1^2 = \frac{1}{2} \times 12 \times 10^{-6} \times 16.418^2 = 1.617 \text{mJ}$$

$$W_2 = \frac{1}{2}C_2V_{23}^2 = \frac{1}{2} \times 22 \times 10^{-6} \times 3.582^2 = 0.141 \text{mJ} \checkmark$$

$$W_3 = \frac{1}{2}C_3V_{23}^2 = \frac{1}{2} \times 33 \times 10^{-6} \times 3.582^2 = 0.212 \text{mJ} \checkmark$$

$$W_4 = \frac{1}{2}C_4V_T^2 = \frac{1}{2} \times 4.7 \times 10^{-6} \times 20^2 = 0.940 \text{mJ} \checkmark$$

e) *the total energy stored in the circuit.*

$$W_T = \frac{1}{2}C_TV_T^2 = \frac{1}{2} \times 14.551 \times 10^{-6} \times 20^2 = 2.910 \text{mJ} \checkmark$$

Alternatively $W_T = W_1 + W_2 + W_3 + W_4 = 1.617 + 0.141 + 0.212 + 0.940 = 2.910 \text{mJ} \checkmark$
Very well done.

Task 3 – Magnetism

1. *Explain the principles of permanent magnets including the distribution of magnetic fields.*

A permanent magnet is an object made of a ferrous (containing iron) material that is able to attract other objects of the same material. A permanent magnet will have a 'north' and a 'south' pole, which can be identified by noting it's orientation when free-floating in relation to the Earth's axis (i.e. the North pole of the magnet will align with Magnetic North) (Bird (2007), p72). $\checkmark$

The area surrounding a permanent magnet that is influenced by it's force is known as the magnetic field. Lines of force, referred to as magnetic flux, will pass from one pole to the other (Robertson (2008), p112). These lines will never cross and will always form a loop. They may be deformed by the introduction of the similar pole of another permanent magnet. They will, however, attempt to reform to their original position, thus causing the two magnets to repel one another. Dissimilar poles will attract, and strong magnets will have magnetic fields with a greater number of lines of flux (Denton (2009), p15) $\checkmark$

The strength of a magnet, or the magnetic flux density (the unit of measure being the tesla (T)), may be determined by taking the value for the particular magnetic flux (Φ) and dividing this by the surface area of the magnet that is perpendicular to

the flux. The units of magnetic flux are the weber (Wb). This is expressed mathematically as:

$$\text{Magnetic Flux Density (B)} = \frac{\text{Magnetic Flux } (\Phi)}{\text{Area (a)}} \quad \checkmark$$

Could have included diagrams to show the fields.

2. Solve the following problems:

- a) A magnetic pole face has a rectangular section having dimensions 220mm by 120mm. If the total flux emerging from the pole is 130μWb, calculate the flux density.

$$\text{Area (a)} = 0.22 \times 0.12 = 0.0264\text{m}^2 \quad \checkmark$$

$$B = \frac{\Phi}{a} = \frac{130 \times 10^{-6}}{0.0264} = 4.92\text{mT} \quad \checkmark$$

- b) The maximum working flux density of a lifting electromagnet is 1.9T and the effective area of a pole face is circular in cross-section. If the total magnetic flux produced is 611mWb determine the radius of the pole face.

Where $B = 1.9\text{T}$ and $\Phi = 611\text{mWb}$

$$B = \frac{\Phi}{a} \quad \text{therefore } a = \frac{\Phi}{B} = \frac{611 \times 10^{-3}}{1.9} = 0.322\text{m}^2 \quad \checkmark$$

$$\text{and where } a = \pi r^2 \quad \checkmark \quad \text{therefore } r^2 = \frac{a}{\pi} \quad \checkmark \quad \text{therefore } r = \sqrt{\frac{a}{\pi}} = \sqrt{\frac{0.322}{\pi}} = 0.092\text{m} \quad \checkmark$$

where did this come from?

3. Explain the principle operation and construction of an electromagnet including the distribution of magnetic fields.

The noted scientist Michael Faraday discovered that an *emf* could be induced within a conductor by moving a magnet next to the conductor (Robertson (2008), p141). The magnitude of the *emf* is directly proportional to the rate of change of magnetic flux. In other words, by moving the magnet faster past the conductor, the size of the *emf* is increased.

You have not explained an electromagnet.

Fleming's Righthand Rule (Bird (2007), p97) was established to identify the direction of an induced *emf* based on the motion of the magnetic flux lines relative to the conductor. The first finger is used to indicate the direction of flow of the magnetic flux. At 90° to the first finger along the x-axis, the second finger represents the direction of the *emf*. And at 90° to the first finger along the y-axis, the thumb indicates the direction of movement of the magnet.

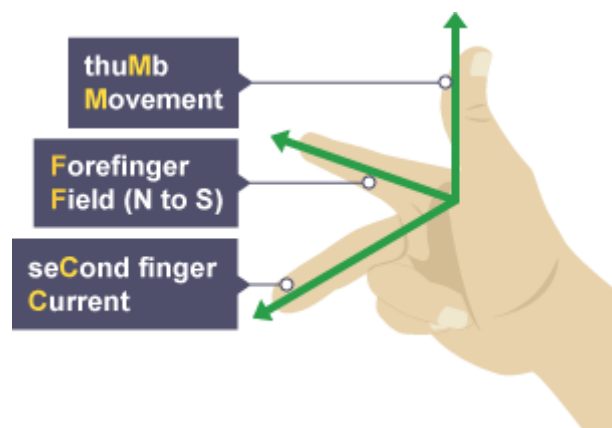


Figure 7: Diagram representing Fleming's Righthand Rule

Faraday's discovery of the link between magnetism and *emf* has had far reaching consequences. When applying the corollary of this theory, it was established that any *emf* applied to a conductor will induce an electromagnetic force. Field lines of magnetic flux form perpendicular to the direction of *emf* flow. Direction of flow of flux is dictated by the direction of flow of the *emf*. When viewing the conductor in line with the flow of *emf* (Bird (2007), p86):

- Flow of flux is clockwise when the flow of current is away from the viewer
- Flow of flux is anticlockwise when the flow of current is towards the viewer

When the conductor is coiled around a core material, the field formed appears similar to that of a permanent magnet, in that the field flows along the axis of the core material from one 'pole' to the other. The direction of flow of flux (and orientation of the poles) is dictated once again by the direction of flow of the current. ✓

4. *A transformer is a device that uses some of the principles associated with electromagnetism. Explain the operation and construction of transformer, include methods to reduce power loss within the transformer.*

A transformer is a device that relies on the joined concepts that a magnetic field is formed by the passing of an *emf* through a conductor, and that a conductor may have an *emf* induced within it by the application of a passing magnetic field. A transformer is manufactured from an iron core with two separate windings which are electrically insulated from one another. ✓

An alternating current will be placed through one of the windings (termed the primary) (Robertson (2008), p187). This will generate an alternating magnetic field. The iron core of the transformer is used to unify the magnetic field, combating a phenomenon known as reluctance. Reluctance is a form of 'resistance' to a magnetic flux and is an undesirable consequence of the unstable field created using a pulsating or alternating current. ✓

The other coil (termed the secondary), in the presence of the pulsing magnetic flux of the primary, will have an *emf* induced within itself. The scale of the inductance (L) (where the unit is the henry (H)) is defined by the number of turns within the secondary coil, the change in flux ($d\Phi$) as measured in webers, and the time taken for the flux to change (dt) as measured in seconds. Expressed mathematically, the induced *emf* may be represented by the following: ✓

$$E = -N \frac{d\Phi}{dt} \quad \checkmark$$

The *emf* may also be explored in terms of the current applied to the coil instead of the number of turns:

$$E = -I \frac{d\Phi}{dt}$$

The inductance of a coil may be established using the following expression:

$$L = \frac{N\Phi}{I} \quad \checkmark$$

The efficiency of a transformer will be affected by the following factors:

- The number of turns in each coil ✓
- The cross-sectional area of the wire used in each coil ✓
- The type of material used in the core, some being more effective at combating reluctance and hysteresis losses (losses of electrical efficiency caused by the friction of electrons passing through the conductor) ✓
- Lamination of the core material, to reduce the negative affects of eddy losses (caused by an induced *emf* within the core itself; lamination prevents escalation of the *emf*) ✓

- Effective methods for dissipating heat generated as a byproduct of hysteresis losses; common methods include heat sinks with large surface areas and immersion in coolant liquids ✓

Again could have included some diagrams

5. Solve the following problems:

- a) A 700 turn coil of inductance 2.5H carries a current of 1.6A. Calculate the flux linking the coil and the e.m.f. induced in the coil when the current collapses to zero in 20ms.

Where $N = 700$, $L = 2.5\text{H}$, $I = 1.6\text{A}$, and $dt = 20\text{ms}$

$$\text{Coil Inductance } L = \frac{N\Phi}{I} \quad \text{so } \Phi = \frac{L \times I}{N} = \frac{2.5 \times 1.6}{700} = 5.714\text{mWb} \quad \checkmark$$

$$\text{EMF } E = -N \frac{d\Phi}{dt} = -700 \frac{5.714 \times 10^{-3}}{20 \times 10^{-3}} = 199.99\text{V} \quad \checkmark$$

- b) A rectangular coil of sides 10cm and 6cm is rotated in a magnetic field of flux density 1.2T, the longer side of the coil actually cutting this flux. The coil is made up of 70 turns and rotates at 1200rev/min.

(i) Calculate the maximum generated e.m.f.

Where $N = 70$, $B = 1.2\text{T}$, $l = 0.10\text{m}$, and $v = 1200\text{rpm}$

And where $v = \omega t$, and angular velocity $\omega = 2\pi r \quad \checkmark$

$$\text{So } v = \left(\frac{1200 \times 2\pi}{60} \right) \times \left(\frac{0.06}{2} \right) = 3.770\text{m/s} \quad \checkmark$$

$$\text{Generated EMF } E = 2 \times NBlv \sin\theta \quad \checkmark$$

For maximum emf, $\theta = 90^\circ$, and $\sin 90^\circ = 1 \quad \checkmark$

$$\text{So } E = 2 \times 70 \times 1.2 \times 0.10 \times 3.770 \times 1 = 63.335\text{V} \quad \checkmark$$

(ii) If the coil generates 80V, at what speed will the coil rotate?

Where $E = 80\text{V}$

$$v = \frac{E}{2NBl} = \frac{80}{2 \times 70 \times 1.2 \times 0.10} = 4.761\text{m/s} \quad \checkmark$$

$$\text{SO } V_{\text{rpm}} = \left(\frac{v \times 60}{2\pi}\right) \times \left(\frac{2}{0.06}\right) = \frac{4.761 \times 60 \times 2}{2\pi \times 0.06} = \frac{571.32}{0.377} = 1515.44\text{rpm} \quad \checkmark \quad \text{Good.}$$

Task 4 – A.C. Circuits

Oscilloscope Settings		Grid Spacing	
Volts/Division	Timebase (m/s/Div)	Vertical (Peak to Peak)	Horizontal (1 Cycle)
2	20	5.2	5.2

Table 13: Values for Task 4

- Using the oscilloscope measurements for a sine wave stated in table [13], perform the following calculations:

- Peak voltage

$$\text{Peak Voltage } V_P = \frac{(\text{Volts/division} \times \text{Pk to pk})}{2} = \frac{(5.2 \times 2)}{2} = 5.2\text{V} \quad \checkmark$$

- Frequency

$$\text{Frequency } F = \frac{1}{t} = \frac{1}{\text{Timebase} \times \text{Horizontal Grid}} = \frac{1}{(20 \times 10^{-3} \times 5.2)} = 9.62\text{Hz} \quad \checkmark$$

- Average voltage

Average Voltage V_{AV} (using average sine waveform constant 0.637) $\checkmark$

$$V_{\text{AV}} = 0.637 \times V_P = 0.637 \times 5.2 = 3.31\text{V} \quad \checkmark$$

- Root mean square (rms) voltage

$$V_{\text{RMS}} = \frac{V_P}{\sqrt{2}} = \frac{5.2}{\sqrt{2}} = 3.68\text{V} \quad \checkmark$$

2. Measure and record the value of each of the components

L =	0.99 mH	R =	18.02 Ω	R _L =	2.45 Ω	✓
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Frequency (kHz)	CH1 (V) pk to pk Voltage (V)	CH2 (V) pk to pk Voltage (V)	Time Difference (between peaks) (μ S)
1	1	0.66	38.1
2	1	0.77	37.4
3	1	0.82	34.2
4	1	0.86	31.2
5	1	0.89	28.4
6	1	0.93	26.8
7	1	0.94	24.5
8	1	0.95	22.9
9	1	0.95	20.5

Table 14: Table of results from experiment

3. Produce a table of measurements as shown below:

Frequency (f) (kHz)	CH1 (V) pk to pk Voltage	CH2 (V) pk to pk Voltage	Time Difference (between peaks) (T2-T1) (μ S)	Calculated values		
				Time for 1 cycle (T) (mS)	Fraction of Cycle (T2-T1)/T	Phase Angle ($^{\circ}$) (fraction x 360)
1	1	0.66	38.1	1.000	0.0381	13.716
2	1	0.77	37.4	0.500	0.0748	26.928
3	1	0.82	34.2	0.333	0.1026	36.936
4	1	0.86	31.2	0.250	0.1248	44.928
5	1	0.89	28.4	0.200	0.142	51.12
6	1	0.93	26.8	0.167	0.1608	57.888
7	1	0.94	24.5	0.143	0.1715	61.74
8	1	0.95	22.9	0.125	0.1832	65.952
9	1	0.95	20.5	0.111	0.1845	66.42

Table 15: Calculations derived from practical experiment

4. Produce a table of calculations as shown below:

Frequency (f) (kHz)	Reactance (X _L) (Ω) (2πfL)	Total Resistance (R _T) (R + R _L)	Impedence (Z) (Ω)	Current (mA)	Phase Angle (°)
1	6.22035345	20.47	21.394244	46.74154	16.9028
2	12.4407069	20.47	23.953958	41.74675	31.28927
3	18.6610604	20.47	27.699388	36.10188	42.35323
4	24.8814138	20.47	32.219647	31.03696	50.55579
5	31.1017673	20.47	37.233598	26.85746	56.64861
6	37.3221207	20.47	42.567142	23.4923	61.25663
7	43.5424742	20.47	48.114114	20.78392	64.82105
8	49.7628276	20.47	53.808549	18.58441	67.64012
9	55.9831811 ✓	20.47 ✓	59.6082 ✓	16.77622 ✓	69.91529 ✓

Table 16: Values derived from calculations of each frequency

No need for so many decimal places.

For the proceeding calculations, **3kHz** as a frequency a has been used as an exemplar:

$$\text{Reactance } X_L = 2\pi fL = 2 \times \pi \times 3 \times 0.99 = 18.6610604\Omega \quad \checkmark$$

$$\text{Total Resistance } R_T = R + R_L = 18.02 + 2.45 = 20.47\Omega \quad \checkmark$$

$$\text{Impedance } Z = \sqrt{R_T^2 + X_L^2} = \sqrt{20.47^2 + 18.6610604^2} = 27.699388\Omega \quad \checkmark$$

$$\text{Current } I = \frac{V}{Z} = \frac{1000}{27.699388} = 36.10188\text{mA} \quad \checkmark$$

$$\text{Phase Angle } \theta = \tan^{-1}\left(\frac{X_L}{R_T}\right) = \tan^{-1}\left(\frac{18.6610604}{20.47}\right) = 42.35323^\circ \quad \checkmark$$

Frequency	Phase Angle Derived from Experiment	Phase Angle Derived from Calculations	Angle Difference Derived from Experiment	Angle Difference Derived from Calculations
1	13.716	16.902798		
2	26.928	31.2892738	13.212	14.3864758
3	36.936	42.3532312	10.008	11.0639573
4	44.928	50.5557852	7.992	8.20255407
5	51.12	56.6486084	6.192	6.09282317
6	57.888	61.256628	6.768	4.60801965
7	61.74	64.8210468	3.852	3.56441877
8	65.952	67.6401243	4.212	2.81907746
9	66.42	69.9152866	0.468	2.27516236

Table 17: Direct comparison of results from experiment and calculations

5. Comment on the practical and calculation results, discussing any variations when comparing these results.

When reviewing the values in Table 17, it is clear that there are discrepancies between the two data sets. As the initial measurements for L, R_L and R are the same between the two sets, and as the calculations are derived from a significant body of scientific research, it must be assumed that errors have affected the experimental data set.

This is also corroborated by the consistent exponential pattern of the difference between consecutive angles within calculated data set (marked in Table 17 as "Angle Difference Derived from Calculations"). In comparison, the experimental values fail to consistently adhere to this pattern. This is particularly apparent when considering the final three angle differences, where the pattern momentarily inverts for the difference between 7kHz and 8kHz.

In considering the reliability of the experimental data set, due consideration must be made of possible errors that have likely affected the results. For example, the oscilloscope has several possible errors associated with its use. As the oscilloscope provides a visual representation of the sine wave, optical errors from the observer may place the point of intersection between the wave and the relevant division out of position. This is often referred to as a parallax error.

The resolution selected for use on the oscilloscope will also have bearing on the accuracy of readings obtained. Selecting the inappropriate resolution may make it appear to the observer that the sine wave is in a different position to that which it is in fact placed. The observer may also be required to make an estimation of the true position of the sine wave if the observed line is viewed with too great a magnification. In other words, the sine wave may overlap too many lines of the divisions of the oscilloscope. This also introduces the concept of rounding errors that may be introduced by the observer where it is challenging to obtain an exact measurement. ✓

Other errors to be considered may include where the tolerance inherent within the components have not been assessed correctly. All components have operating values other than those stated as it is recognised that minor variations will occur in the mass-manufacturing processes. ✓

It is also possible that internal faults or errors may be present in the components of the circuit, and also in the measuring devices. Internal damage, degradation or wear may not be apparent to the observer but may serve to alter the outcomes of the experiment. ✓

Another factor that may have caused an erroneous experimental data set may have been the performance of the circuit itself. As the frequency input was altered, the current applied to the circuit was also affected. This will have had an effect on the performance of the components of the circuit through the extra heat and resistance that this will have generated. ✓

It should not be overlooked that placing the oscilloscope within the circuit will have also affected the load on the circuit. This will have further altered the performance of the circuit, which in turn may have affected the gathered data. ✓

Finally, although it is assumed that the calculated data set is of greater reliability because of the reliability of the underlying theory, human error may still affect the reliability of this data set. Rounding errors, errors caused by inputting and transferring long sequences of numbers, and misunderstanding of the underlying theory may all serve to affect the data set. ✓

In in most parts you have produce a very good assignment.

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Figure 3 courtesy of

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