

LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Heather Raymond	Student ID number:	
Programme:	HNC Electrical/Electronic Engineering & Instrumentation Engineering		
Module:	Electrical Principles		
Module code:	PCEE4001	Contribution to Overall Module Assessment (%):	100%
Lecturer:	Jason Pointer	Internal Verifier:	Nigel Richards
Assignment Title:	Electrical Principles	Word count (or equivalent):	2000
Submission deadline:	11/01/23	Return date of provisional marks & written feedback:	25/01/23
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	10.1
Engagement with a wide range of literature sources, including sources retrieved independently. Generally sound referencing, with very few inaccuracies or inconsistencies.		
2. Knowledge and Understanding Skills	30	22.6
Task 1 achieved 77%. Task 2 achieved 84%, Task 3 achieved 70%. Task 4 achieved 70%. Excellent knowledge and understanding of the basic underlying concepts and principles of the subject. Showed excellent understanding of the calculated requirements. The research work was very good that used a variety of source material.		
3. Cognitive and Intellectual Skills	10	6.2
Task 1 achieved 66%. Task 4 achieved 58%. Good evaluation of the underlying concepts and principles for Task 1 and 4.		
4. Practical Application Skills	35	28.9
Task 1 achieved 85%. Task 4 achieved 80%. 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	7.2
Work is coherent, very fluent and is presented professionally. Excellent layout making the assignment easy to read.		

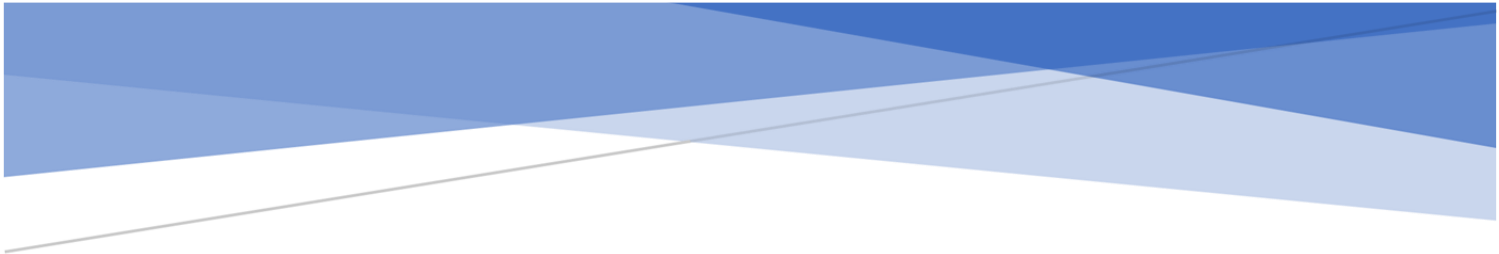
Assessment Mark (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)

Late Submission Penalties (tick if appropriate)

Up to 1 week late (40% Max)

Over 1 week late (0%)

75%



ELECTRICAL PRINCIPLES

Level 4 assignment 2022-2023

Abstract

The aim of this assignment is to develop an understanding of the fundamentals of electrical principles through theoretical and practical applications. The assignment will cover the following areas of Electrical Principles – DC circuits, Capacitors in DC circuits, magnetism and AC circuits. This will be achieved through a range of practical, calculation and research work.

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Task1 – DC Circuits

Figure 1 below shows a combinational arrangement of a DC circuit.

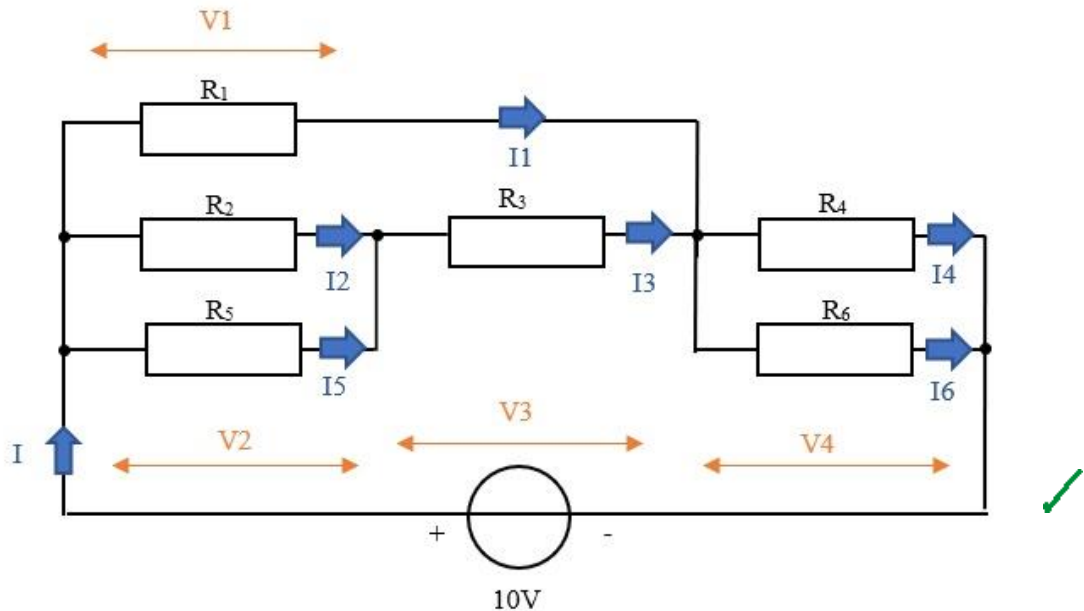


Figure 1, combinational DC circuit

R1	6800 Ω
R2	470 Ω
R3	220 Ω
R4	330 Ω
R5	180 Ω
R6	560 Ω

Figure 2, resistor values

Figure 1 shows the differing voltages within the combinational circuit, as well as, different currents as a result of the effects of different resistors within the circuit, both in parallel and series.

Given resistor values for the circuit are as per figure 2.

1. Total resistance (R_T) before connecting the power supply= 532 Ω as per figure 3. ✓

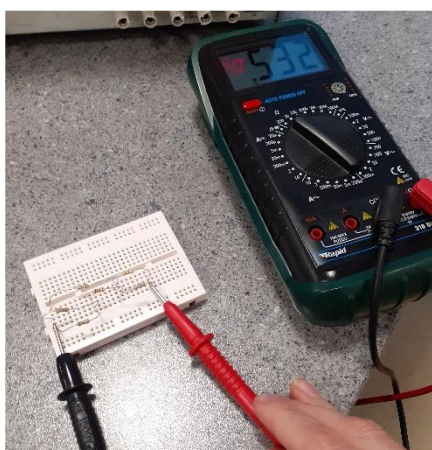


Figure 3, measuring total resistance

2. Upon Connecting a 10V supply, the p.d. value across each resistor, the supply current and the current in each resistor are as follows:

Resistor	Resistor value in ohms (actual)	Voltage values	Supply current	Current in each resistor	Power in each resistor
R1	6700Ω	V1= 6.06V	I=18.5mA	I1=0.9mA	5.48mW
R2	460Ω	V2= 2.26V		I2=4.85mA	11.20mW
R3	215Ω	V3=3.8V		I3=17.39mA	67.16mW
R4	322Ω	V4=3.79V		I4=11.52mA	44.61mW
R5	177Ω	V5= 2.26V		I5=12.46mA	28.86mW
R6	554Ω	V4=3.79V		I6=6.74mA	25.93mW

Table 1

Power calculations for practical results

$$P = \frac{V^2}{R}$$

$$P1 = \frac{V1^2}{R1} = \frac{6.06^2}{6700} = 5.48mW$$

$$P2 = \frac{V2^2}{R2} = \frac{2.27^2}{460} = 11.20mW$$

$$P3 = \frac{V3^2}{R3} = \frac{3.8^2}{215} = 67.16mW \quad \checkmark$$

$$P4 = \frac{V4^2}{R4} = \frac{3.79^2}{322} = 44.61mW \quad \checkmark$$

$$P5 = \frac{V2^2}{R5} = \frac{2.26^2}{177} = 28.86mW \quad \checkmark$$

$$P6 = \frac{V4^2}{R6} = \frac{3.79^2}{554} = 25.93mW \quad \checkmark$$

3. Theoretical calculations are as follows, see Appendix A for rough workings:

Total resistance (RT)

$$R25 = \frac{R2 \times R5}{R2 + R5} = \frac{470 \times 180}{470 + 180} = 130.15\Omega \quad \checkmark$$

$$R235 = R25 + R3 = 130.15 + 220 = 350.15\Omega \quad \checkmark$$

$$R1235 = \frac{R235 \times R1}{R235 + R1} = \frac{350.15 \times 6800}{350.15 + 6800} = 333\Omega \quad \checkmark$$

$$R46 = \frac{R4 \times R6}{R4 + R6} = \frac{330 \times 560}{330 + 560} = 207.64\Omega \quad \checkmark$$

$$RT = R1235 + R46 = 333 + 207.64 = 540.64\Omega \quad \checkmark$$

Total Resistance = 540.64Ω

Supply Current/ current in each resistor

$$I = \frac{V}{RT} = \frac{10}{540.64} = 18.5mA \quad \checkmark$$

Supply current = 18.5mA $\checkmark$

$$V4 = I \times R46 = (18.5 \times 10^{-3}) \times 207.64 = 3.84V \quad \checkmark$$

$$I4 = \frac{V4}{R4} = \frac{3.84}{330} = 11.64mA \quad \checkmark$$

$$I6 = \frac{V4}{R6} = \frac{3.84}{560} = 6.86mA \quad \checkmark$$

$$V1 = V - V4 = 10 - 3.84 = 6.16V \quad \checkmark$$

$$I1 = \frac{V1}{R1} = \frac{6.16}{6800} = 0.91mA \quad \checkmark$$

$$I = I1 + I3, \quad I3 = I - I1 = 18.5 - 0.91 = 17.59mA \quad \checkmark$$

$$V3 = I3 \times R3 = (17.59 \times 10^{-3}) \times 220 = 3.89V$$

$$V_2 = V_1 - V_3 = 6.16 - 3.89 = 2.27V$$

$$I_2 = \frac{V_2}{R_2} = \frac{2.27}{470} = 4.83mA$$

$$I_5 = \frac{V_2}{R_5} = \frac{2.27}{180} = 12.61mA$$

Current in each resistor

$$I_1 = 0.91mA$$

$$I_2 = 4.83mA$$

$$I_3 = 17.59mA$$

$$I_4 = 11.64mA$$

$$I_5 = 12.61mA$$

$$I_6 = 6.86mA$$

Calculated voltages

$$V_1 = 6.16V$$

$$V_2 = 2.27V$$

$$V_3 = 3.89V$$

$$V_4 = 3.84V$$

$$V_2 = V_5 = 2.29V$$

$$V_4 = V_6 = 3.84V$$

Power value across each resistor

$$P = I^2 \times R$$

$$P_1 = I_1^2 \times R_1 = (0.906 \times 10^{-3})^2 \times 6800 = 5.58mW$$

$$P_2 = I_2^2 \times R_2 = (4.83 \times 10^{-3})^2 \times 470 = 10.96mW$$

$$P_3 = I_3^2 \times R_3 = (17.59 \times 10^{-3})^2 \times 220 = 68.07mW$$

$$P_4 = I_4^2 \times R_4 = (11.64 \times 10^{-3})^2 \times 330 = 44.71mW$$

$$P_5 = I_5^2 \times R_5 = (12.61 \times 10^{-3})^2 \times 180 = 28.62mW$$

$$P_6 = I_6^2 \times R_6 = (6.86 \times 10^{-3})^2 \times 560 = 26.35\text{mW}$$

$$\underline{P_1 = 5.65\text{mW}}$$

$$\underline{P_2 = 10.96\text{mW}}$$

$$\underline{P_3 = 68.07\text{mW}}$$

$$\underline{P_4 = 44.71\text{mW}}$$

$$\underline{P_5 = 28.62\text{mW}}$$

$$\underline{P_6 = 26.35\text{mW}}$$

Well done, an excellent set of calculations.

4. Assessment of practical and calculated results, variations and relevant theories. Comment on the practical and calculation results, discussing any variations when comparing these results, making reference to relative theories such as Kirchhoff's laws and how it applies to the results.

Calculated and practical results in this task varied, there will always be differences and 100% accuracy cannot be guaranteed due to a variety of factors. Voltages varied between 0.01 and 0.1V, the total resistance by over 8 ohms and the currents typically between 0.1 and 0.2 mA. The resistors used in the practical application of this circuit had gold bands, indicating a tolerance of $\pm 5\%$. (Ref: eepower.com/resistor-guide).

As is shown in *table 1, page 5* the measured values of the resistors here have some variance from the stated values of those resistors. For example, R1 which should have been 6800Ω read 6700Ω when measured with a multi-meter. This can have a knock-on effect when calculating total resistance within the circuit, supply current, currents across each resistor and the p.d values calculated here. This is in line with the tolerance of $\pm 5\%$, as $6800/100 \times 5 = \pm 340\Omega$.

Multi-meters can have accuracy differences, related to their calibration and variance in internal resistance (typically internal resistances are close to $10\text{M}\Omega$). Additional resistance can be inducted into the circuit via the probe leads. This is especially true if these leads are contaminated, effecting the quality of the contact between the probe and the part of the circuit being measured. (Ref: fluke.com/en-gb/learn/blog).

The way the probe is held to a resistor leg can also have an effect on the values recorded.

Rounding in formulas to one or two decimal places can have an effect on calculated results, creating a variance from the measured results. This can happen when several calculations are required, such as, determining individual current calculations across each resistor- leading to power calculations using the rounded figures from the current calculations.

Readings taken in order to record voltages in this circuit, where the multi-meter is connected in parallel, will reduce resistance in the circuit. This is what is known as the loading effect of multi-meters. When recording Current values with the multi-meter connected in series, this will increase the resistance. Resulting in a small effect on the measurement of the current. One must come to the realization that results will never be 100% accurate to calculated values, there will always be slight variations due to the factors mentioned.

Ohms Law: *'This law states, that the current through a resistor varies in direct proportion to the voltage applied across the resistor provided the temperature remains constant'* (EITB, 1985) This law is represented by the formulas, $I=V/R$, $V=IR$, $R=V/I$. Given that the temperature has remained constant for this task, with the use of a resistive dc circuit, ohms law has been used in the calculations to determine current and voltage values. Such as can be seen in the supply current calculation,

$$I = \frac{V}{RT} = \frac{10}{540.64} = 18.5mA$$

However, the following also applies in this instance:

'A single equivalent resistance can be found when two or more resistors are connected together in either series, parallel or combinations of both, and that these circuits obey Ohm's law. However, sometimes in more complex circuits we cannot simply use Ohm's law alone to find the voltages or currents circulating within the

circuit. For these types of calculations, we need certain rules which allow us to obtain the circuit equations and for this we can use Kirchhoff's laws.' (Bird, 2017.)

Kirchoff's laws state:

'Current Law. At any junction in an electric circuit the total current flowing towards that junction is equal to the total current flowing away from the Junction.' (Bird, 2017.) ✓

This law can be applied to the combination circuit used here. For example, the supply current can be calculated by adding the sum of the currents flowing into particular junctions of the circuit, where resistors can be found in parallel, as these formulas show: ✓

$$I = I_1 + I_3 = 0.91 + 17.59 = 18.5 \text{ Ma}$$

$$I = I_4 + I_6 = 11.64 + 6.86 = 18.5 \text{ Ma}$$

'Voltage Law. The algebraic sum of the products of current and resistance forming a closed path in a network is equal to the algebraic sum of the electromotive forces (emf) in the path' (Tooley, 2019) ✓

Essentially, individual voltage drops across resistances in series should equal the supply voltage. Given that the supply voltage in this circuit= 10V, applying Kirchhoff's Second law proves the calculated and recorded results:

$$V = V_1 + V_4 = 6.16 + 3.84 = 10V$$

When resistors are connected in series and in parallel, as is the combination circuit here, the total current through a parallel group should equal that which flows through the series resistor. This can be seen in the following formula: ✓

$$I_3 = I_2 + I_5 = 4.83 + 12.61 = 17.44 \text{ Ma}$$

You need to be very careful with your units — mA.

Task 2 – Capacitors

Task 2.1

Explain the construction of the capacitor, include methods that could be used to alter the value of the capacitor.

A capacitor consists of two- terminals, two plates of a conductor with a dielectric insulator between them. The materials of the conductive plates can consist of brass, copper or aluminium. The space between the plates consists of a non-conductive material and is known as the dielectric region. This region can be made from insulating materials such as waxed paper, ceramic or mica. Capacitors store electric charge similar to a battery, one terminal will store a positive charge, the other a negative charge when a voltage is applied. A capacitor will perform functions such as charging and discharging within a circuit. (Shukla, V. and*,N. 2018) ✓

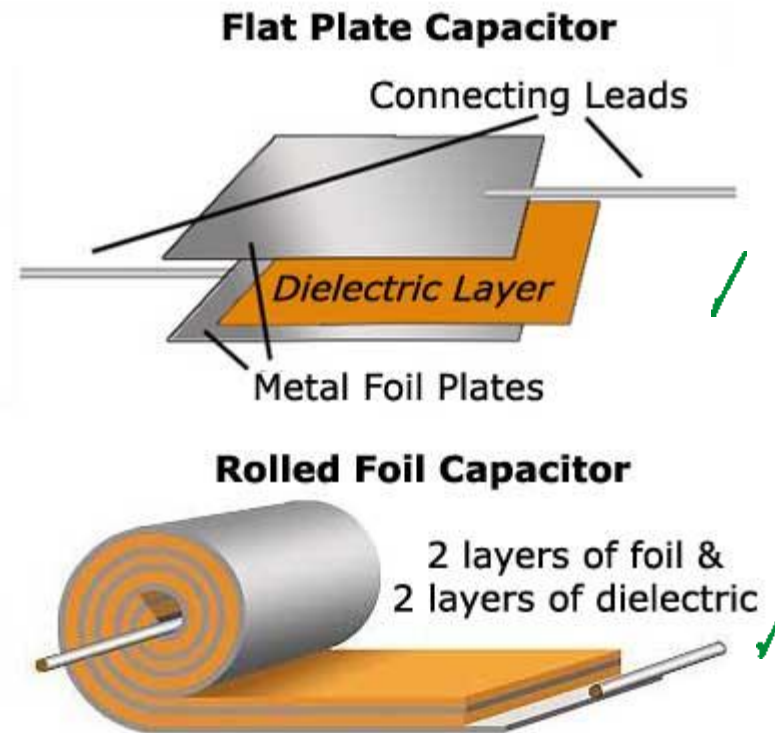


Figure 4, (Coates, E. 2020)

Figure 4 shows the construction of fixed value capacitors. Ideally, the build of the capacitor should meet the following criteria:

- Be as thin as possible, as capacitance is inversely proportional to distance between materials ✓
- High permittivity, as this directly effects the efficiency of the dielectric ✓
- Dielectric strength be strong enough for voltage rating ✓

'When a capacitor is fully charged there is a potential difference, (p.d) between its plates, and the larger the area of the plates and/ or the smaller the distance between them (known as separation) the greater will be the charge that the capacitor can hold and the greater will be its capacitance.' (Ref: Storr. W, 2022) ✓

Another way to change the value of a capacitor would be via inserting a solid medium between the conductive plates, which would have to have a dielectric constant greater than that of air. (Tooley M. 2019) A capacitors ability to store electric charge (coulombs) is proportional to the applied voltage, hence the following formula used to calculate charge: $Q = C \times V$ ✓

As capacitance represents the capacitors' ability to store charge, one Farad can be defined as *"the capacitance of a capacitor which requires a charge of one coulomb to establish a potential difference of one volt between its plates"* (Ref, Michael Faraday). ✓ Therefore the formula for capacitance can be represented as:

Capacitor with an Air dielectric:

$$C = \frac{Q}{V} = \epsilon \frac{A}{d} \quad \checkmark$$

Capacitor with a solid as a dielectric:

$$C = \frac{Q}{V} = \epsilon_0 \epsilon_r \frac{A}{d} \quad \checkmark$$

In the formula above, A is the area of the plates in m², therefore, the larger the area, the more potential charge the capacitor can hold. The separation between plates is represented by d. The smaller the distance, the higher the ability of the plates to store charge. This is due to 'the -ve charge on the -Q plate having a greater effect on the +Q charged plate, resulting in more electrons being repelled off of the +Q charged plate, thus increasing the overall charge.' (Storr, W. 2022)
Hence why capacitors come in many different shapes and sizes according to their capacitance value. ✓ Very good work.

Task 2.2

Figure 4 shows a circuit containing capacitors in series/parallel to a d.c. voltage source.

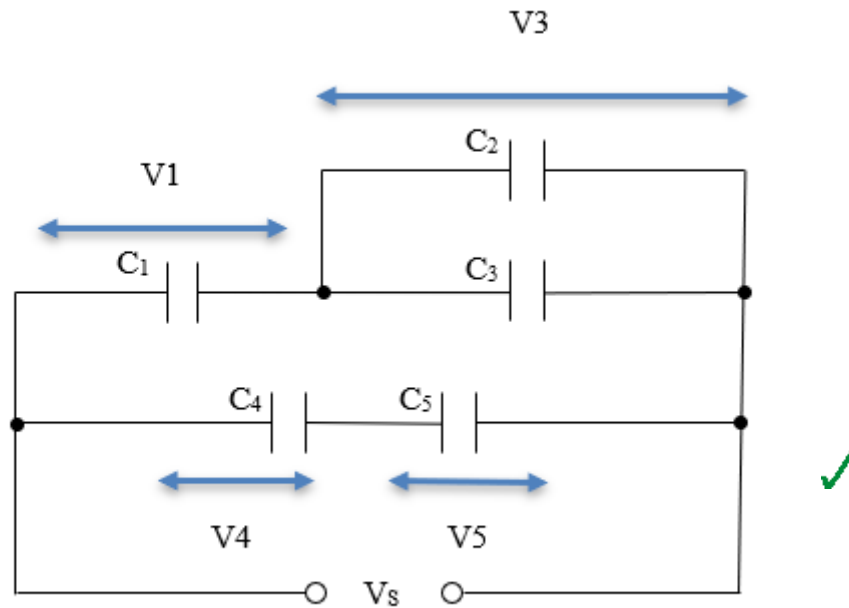


Figure 5, capacitor circuit

Using the values stated in Table 2, determine:

- the equivalent circuit capacitance
- the total charge
- the charge in each capacitor
- the energy stored in each capacitor
- the total energy stored in the circuit.

Table 2 – values for Task 2

Student Number	C_1 (μF)	C_2 (μF)	C_3 (μF)	C_4 (μF)	C_5 (μF)	V_s (V)
10	18	12	39	27	33	25

General notes

- I (current) has no effect on calculations, therefore is not labelled in figure 4.
- Q stands for charge.

- $V_2 = V_3$
- The charge in each capacitor is equivalent to the total charge, Q_t .
- Rough workings can be seen in Appendix B

(a) The equivalent circuit capacitance

$$C_{23} = C_2 + C_3 = 12 + 39 = 51\mu F$$

$$C_{123} = \frac{C_1 \times C_{23}}{C_1 + C_{23}} = \frac{18 \times 51}{18 + 51} = 13.30\mu F$$

$$C_{45} = \frac{C_4 \times C_5}{C_4 + C_5} = \frac{27 \times 33}{27 + 33} = 14.85\mu F$$

$$C_t = C_{123} + C_{45} = 13.3 + 14.85 = 28.15\mu F$$

Circuit capacitance= 28.15 μ F

(b) The total charge

$$Q_t = C_t \times V = 28.15 \times 25 = 703.75\mu C$$

Total charge= 703.75 μ C

(c) The charge in each capacitor

$$Q_4 = Q_5 = C_{45} \times V = 14.85 \times 25 = 371.25\mu C$$

$$Q_1 = Q_t - Q_{45} = 703.75 - 371.25 = 332.5\mu C$$

$$Q_1 = C_{123} \times V = 13.30 \times 25 = 332.5\mu C$$

$$V_1 = \frac{Q_1}{C_1} = \frac{332.5}{18} = 18.47V$$

$$V_2 = V_3 = V - V_1 = 25 - 18.47 = 6.53V$$

$$Q_2 = C_2 \times V_3 = 12 \times 6.53 = 78.36\mu C$$

$$Q_3 = C_3 \times V_3 = 39 \times 6.53 = 254.67\mu C$$

$$V_4 = \frac{Q_4}{C_4} = \frac{371.25}{27} = 13.75V$$

$$V_5 = \frac{Q_5}{C_5} = \frac{371.25}{33} = 11.25V$$

The charge in each capacitor is equivalent to the total charge, Q_t .

(d) The energy stored in each capacitor

$$W = \frac{1}{2} \times C \times V^2$$

$$W1 = \frac{1}{2} \times C1 \times V1^2 = \frac{1}{2} \times 18 \times 18.47^2 = 3070.27 \mu J \quad \checkmark \quad = 3.07 \text{ mJ}$$

$$W2 = \frac{1}{2} \times C3 \times V3^2 = \frac{1}{2} \times 39 \times 6.53^2 = 255.85 \mu J \quad \checkmark$$

$$W3 = \frac{1}{2} \times C2 \times V3^2 = \frac{1}{2} \times 12 \times 6.53^2 = 831.50 \mu J \quad \checkmark$$

$$W4 = \frac{1}{2} \times C4 \times V4^2 = \frac{1}{2} \times 27 \times 13.75^2 = 2552.34 \mu J \quad \checkmark$$

$$W5 = \frac{1}{2} \times C5 \times V5^2 = \frac{1}{2} \times 33 \times 11.25^2 = 2088.28 \mu J \quad \checkmark$$

(e) Total energy stored within the circuit

$$Wt = \frac{1}{2} \times Ct \times V^2 \quad \checkmark$$

Very well done.

$$Wt = \frac{1}{2} \times 28.15 \times 25^2 = 8796.88 \mu J \quad \checkmark$$

Total energy in circuit= 8796.88 μJ

Task 3 – Magnetism

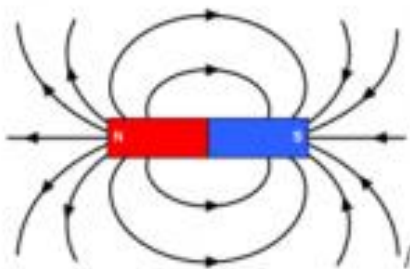
1. Explain the principles of permanent magnets including the distribution of magnetic fields.

'The field produced by a straight line of current is directly proportional to the current magnitude and inversely proportional to the perpendicular (radial) distance from the line of current. It is also related to a property defined as the permeability

of the medium in which the field exists, usually surrounding the line of current.’
(Nippes, 2014) → does not relate to permanent magnetism

Permanent magnets are manufactured from ferrous metals, typically iron or steel. These magnetics ‘retain significant magnetization after the magnetizing current is removed’ (Bahrdt, J.,2011). Paraphrasing Fernow, R. Chapter 9, p211, where space is confined, permanent magnets can provide stronger fields than electro-magnets, do not require cooling and a power source to work. Strength of the magnetic field produced is not determined by the physical size of the magnet. Magnetic fields always form a completely closed loop. Magnetic fields are elastic, when distorted they try to return to their original shape. Observe figures 6 and 7 for examples of magnetic field distributions created by bar magnets. ✓

Single bar magnet:



Between magnets:

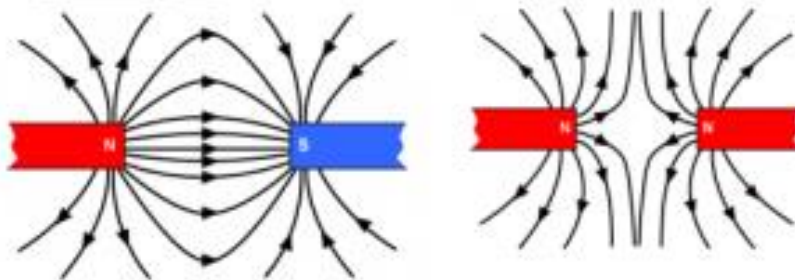


Figure 6, magnetic field distributions created by permanent magnets, (Hydr0Gen, 2019)

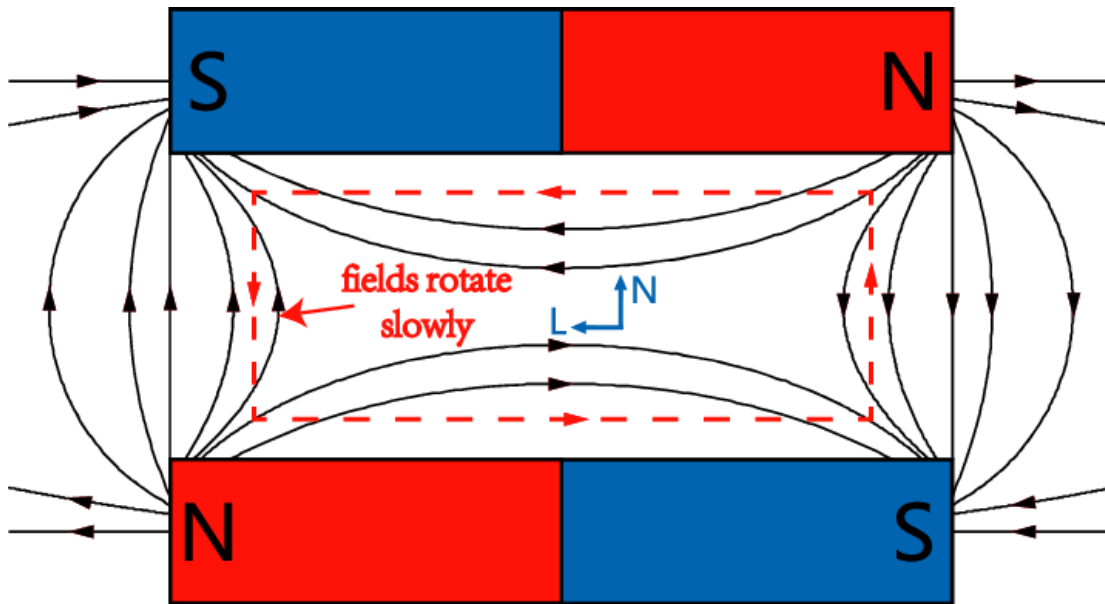


Figure 7, 'Magnetic field distribution between two antipolarity permanent magnets in a nonconducting context, such as in a vacuum. The red dashed box indicates an arbitrarily chosen plane to test Ampère's law.' (Xu, 2015)

The magnetic flux produced by the magnets in these examples are represented by lines. As can be seen in the diagrams above, the direction of magnetic flux produced by a permanent magnet always travels from N-pole to S-pole. Currents in the same direction have attractive forces, whilst currents in opposite directions will have repulsive forces. Flux density is affected by the distance of the return path from the one North Pole end to the South pole end, so the magnetism will be weaker the greater the distance between the poles of the magnet/ magnets being used to generate a magnetic field. ✓

2. Solve the following problems:

- a) The maximum working flux density of a lifting electromagnet is 1.6T and the effective area of a pole face is circular in cross-section. If the total magnetic flux produced is 550mWb determine the radius of the pole face.

See Appendix C for rough workings.

Flux density= $B = 1.6\text{T}$ Magnetic flux= $\phi = 550\text{mWb}$

$$B = \frac{\phi}{A} \Rightarrow A = \frac{\phi}{B} = \frac{0.55}{1.6} = 0.344\text{m}^2$$

$$A = \pi r^2 \Rightarrow r^2 = \frac{A}{\pi} \Rightarrow r = \sqrt{\frac{0.344}{\pi}} = 0.331\text{m}$$

Radius= 0.3308m

- b) An iron toroid having a mean radius of 0.1m and cross-sectional area of 3.49cm^2 is wound with a 1200 turn coil. The coil current results in a flux of 0.2mWb in the toroid. Using the following data, determine (i) the coil current and (ii) the relative permeability of the toroid under these conditions.

H(At/m)	80	85	90	95	100
B(T)	0.5	0.55	0.58	0.59	0.6

See page 12, figure 8, for the graph for the above data. See Appendix C for rough workings.

(b)(i) $A = 3.49\text{cm}^2$ $A = 3.49 \times 10^{-4}\text{m}^2$ $\phi = 0.2\text{ mWb}$

$$B = \frac{\phi}{A} = \frac{0.2 \times 10^{-3}}{3.49 \times 10^{-4}} = 0.573\text{T}$$

So when $T = 0.573\text{T}$, $H (\text{A/m}) = 89\text{A/m}$ approx. Referencing figure 8, graph.

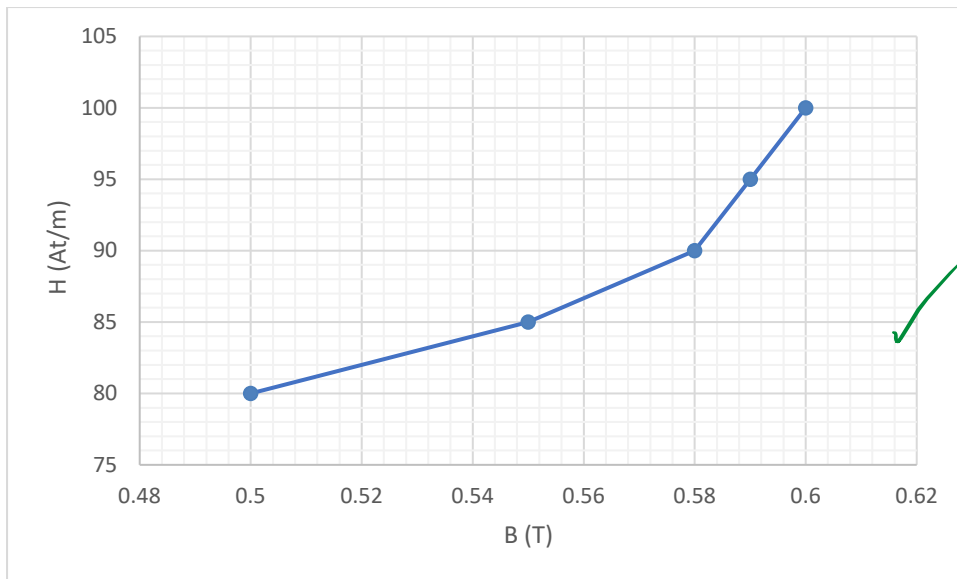


Figure 8, graph

(b)(i) continued;

$$H = \frac{N \times I}{L} \gg L = 2\pi r L = 2 \times \pi \times 0.1 L = 0.628m$$

$$I = \frac{L \times H}{N} = \frac{0.628 \times 89}{1200} = 46.58Ma \quad \text{At}$$

Coil current= 46.58Ma

(b)(ii)

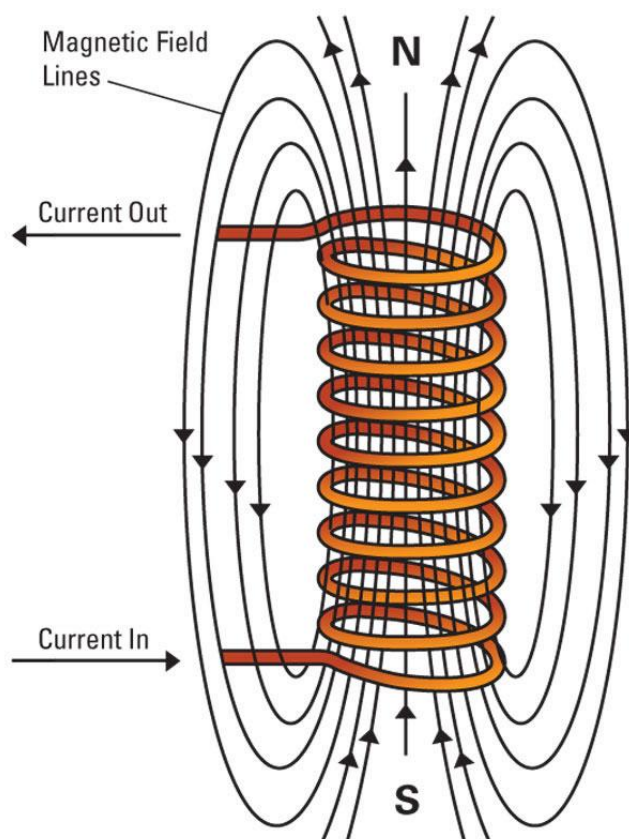
$$M_o \times M_r = \frac{B}{H}$$

$$\mu_r = \frac{B}{\mu_o \times H} = \frac{0.573}{4\pi \times 10^{-7} \times 89} = 5123.36$$

Relative permeability= 5123.36

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

An electromagnet is essentially a magnet that is powered by an electric current. Its construction consists of a magnetic core encircled by a coil. An electric current is induced in order to magnetise the core. Magnetism of the electromagnet is lost when the current flow is interrupted. (ANUM, 2022) ✓

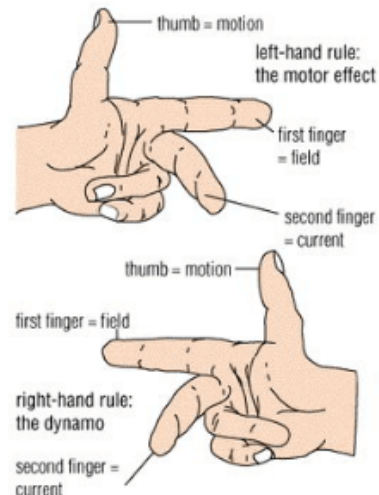
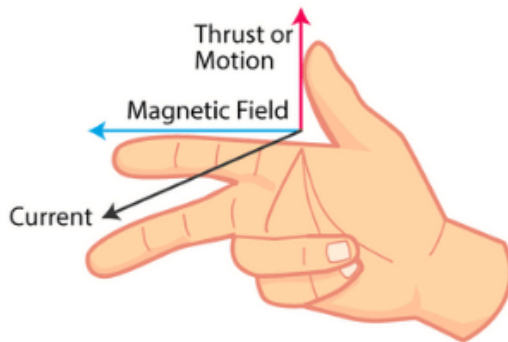


A simple electromagnet can be created by wrapping a coil of insulated copper wire around an iron core. Once a current is passed through the electromagnet, magnetic field lines will be created as per figure 9. 'North and south poles can be identified by facing each end of the coil in turn. A north pole is produced at the end where conventional current appears to take an anti-clockwise path through the coil, and a south pole is produced at the end where the path of the current appears to be in clockwise direction' EITB. (1985) ✓

Figure 9, electromagnetic fields generated by an electromagnet, Available at: <https://ece.northeastern.edu/fac-ece/nian/mom/electromagnets.html>

Fleming's hand rules can be seen in figure 10, page 18. With the left-hand rule, 'Whenever a current carrying conductor comes under a magnetic field, there will be a force acting on the conductor. The direction of this force can be found using Fleming's Left Hand Rule' Carter. R.G. (2010) Fleming's left-hand rule is mainly applied to electric motors, the right-hand rule is related to electric generators that use electromagnets in their construction. ✓

What is Fleming's Hand Rule?



Electrical 4 U

Figure 10, Fleming's Hand rules, (Electrical4U, 2021)

A soft iron core will generally have a higher permeability than non-magnetic materials, hence will intensify a magnetic field as compared to other materials when used in an electromagnet. Bird, J. (2017). If the coil is in a vacuum, then the absolute permeability of free space is expressed as,

$$\mu_0 = \frac{\text{flux density produced}}{\text{Magnetising force}}$$

Therefore, the relative permeability of a magnetic material, assuming a constant magnetic force, is calculated using the following relationship: EITB. (1985);

$$\mu_r = \frac{\text{Flux density produced when the material forms the core of the coil}}{\text{Flux density produced when a vacuum forms the core of the coil}}$$

There are several ways to increase the strength of an electromagnet, including increasing the current running through it, increasing the number of windings in the coil as well as lowering the ambient temperature and or replacing a non-magnetic core with a ferro- magnetic material. Deziel, C. (2019). With reference to the current supply for an electromagnet, 'according to Amperes law, the magnetic field around a current-carrying wire is directly proportional to the strength of the current' Tooley, M. (2019).

4. A transformer is a device that uses some of the principles associated with magnetism. Explain the operation and construction of a transformer, include diagrams and equations to show how voltage, current and turn ratios are related. Discuss how transformers are an essential part of the National Grid System.

The basic principle of a transformer is as follows,

'If a second coil is wound over an inductor and an alternating current passed through the inductor, an alternating voltage will appear on the second coil... the ratio of the applied voltage and the induced voltage is the same as the ratio of the turns on each coil. In this way, power can be transferred from one coil to the other by means of a varying magnetic field' Carter. R.G. (2010) ✓

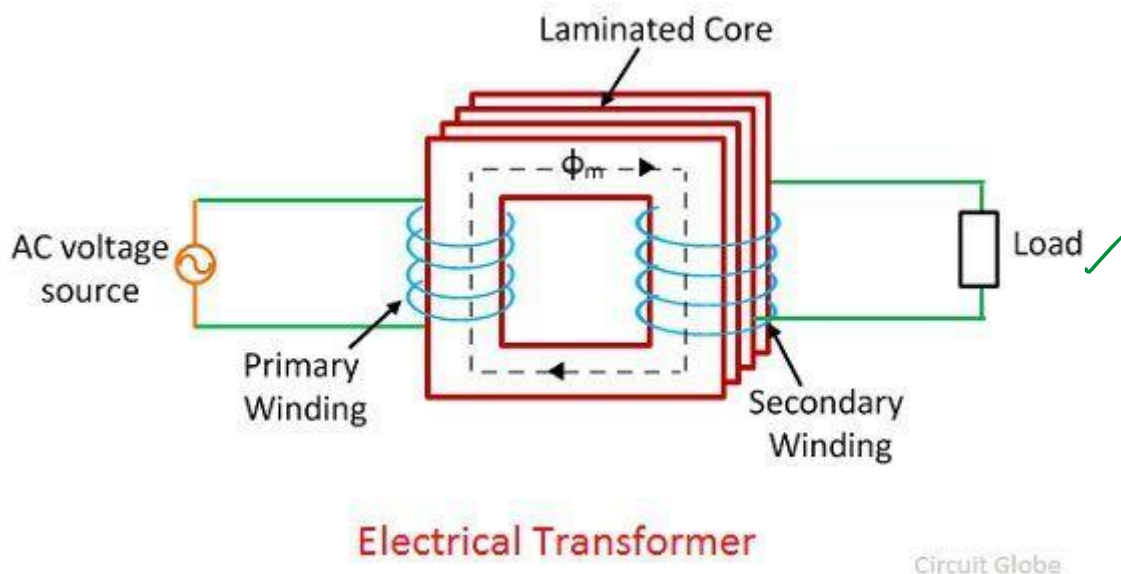


Figure 11, illustration of the workings of a transformer, 23, A.D.N.A. et al. (2017)

As per figure 11, transformers can be used to 'step up' or 'step down' voltages, insulate a circuit from a distribution system, match impedances when connecting circuits, filter signals at particular frequencies, as well as, shape wave forms and invert signals (such as phase shifting with AC voltage sources). Voltages or currents are adjusted via increasing or decreasing the number of turns on the secondary winding. If both coils have an equal number of turns, the voltage out will be equal to the voltage in, and there will be a phase shift of 180° . EITB. (1985) ✓

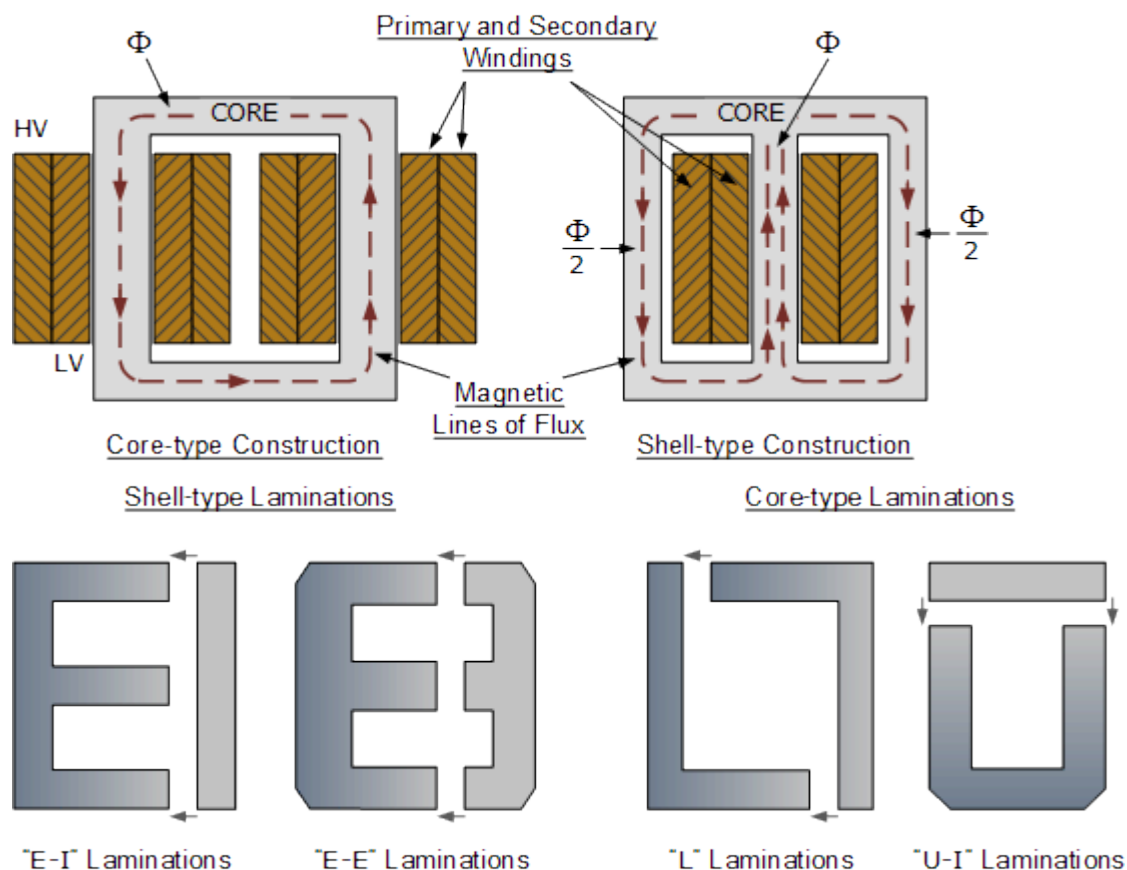


Figure 12, <https://www.electronics-tutorials.ws/transformer/transformer-construction.html>

As per figure 12, providing a path for magnetic flux improves efficiency, however the eddy currents induced in the iron core oppose the induced voltage and produce heat. This problem can be reduced by laminating the core of the transformer. Insulation between laminations can be achieved by wither paint, varnish, paper sheet or metal oxide between each section of lamination. Vodovozov, V. (2019)

'Transformer core laminations are usually stacked alternately to each other to produce an overlapping joint with more lamination pairs being added to make up the correct core thickness. This alternate stacking of the laminations also gives the transformer the advantage of reduced flux leakage and iron losses. E-I core laminated transformer construction is mostly used in isolation transformer's, step-up and step-down transformer's as well as the auto transformer.' Storr, W. (2022) ✓

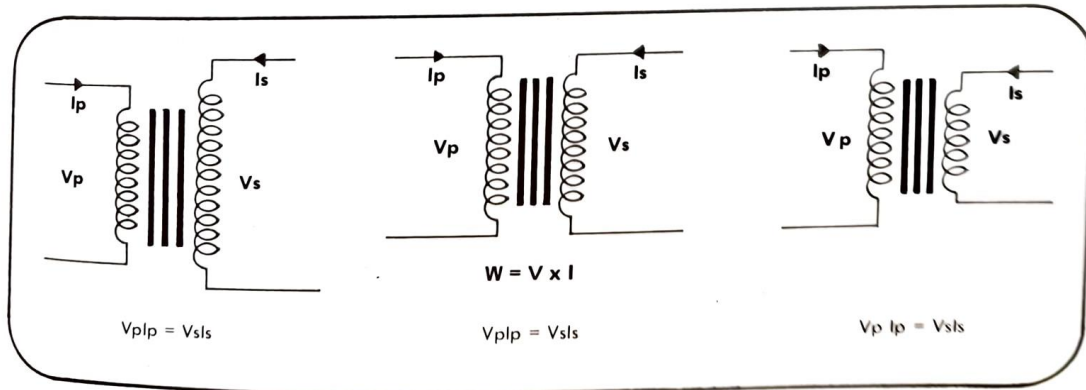


Figure 13, Ratios of voltages, EITB (1985)

Various formulas for calculating transformer values are given in figure 13. If no losses of energy are assumed, the following formula can be used to calculate the effect the number of turns on the windings has on the emf applied and induced in the transformer. This is derived from faradays law of inductance: ✓

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \quad \checkmark$$

Where V_p = emf applied to primary winding

V_s = emf induced in secondary winding

N_p = number of turns in primary winding

N_s = number of turns in secondary winding ✓

Due to resistive and magnetic losses, it can be assumed that in practice the secondary voltage of a loaded transformer is less than a theoretical value. Robertson, C.R. (2010). Faradays law of induction states that *'the magnitude of the emf induced in a circuit is proportional to the rate of change with time t of the magnetic flux ϕ that cuts across the circuit'*: Britannica, (2022). ✓

$$emf = \frac{d\phi}{dt} \quad \checkmark$$

In 1831 Faraday discovered that when a magnetic field about an electromagnet is made to grow and collapse by opening and closing the electric circuit of which it was a part, an electrical current could be detected in a separate conductor nearby.

'When a changing voltage is applied to the primary coil, the back emf generated by the primary is given by Faradays law:' ✓

$$V_p = \text{Emf} = -N_p A \frac{\Delta B}{\Delta t}$$
 ✓

'The induced voltage in the secondary coil is also given by Faradays law. Where the rate of change of flux is essentially the same as that in the primary coil- so the number of turns determines Vs:' Carter. R.G. (2010)

$$V_s = -N_s A \frac{\Delta B}{\Delta t}$$
 ✓

The national grid makes extensive use of step-up and step-down transformers. For a given power increasing voltage reduces the current required and thus reduces the energy losses in the cables, as per formula, $P=IV$. Reducing losses is important within the national grid as electrical energy has to be transported over long distances via cables to domestic and industrial applications. Using low current, high voltages across electrical power line transmissions reduces heat loss and power loss. ✓

At the power station end of the grid, step-up transformers are used to increase the output voltage from the station (generally around 25kV) to 400 kV for effective power line transmission. This step up is to reduce losses in energy due to the resistance of the cables. A step-down transformer will decrease the p.d. at local substations for the safe use of electricity in homes, domestic and industrial appliances. These values will typically be within the range of 230 to 11,000 volts, dependant upon application. Brown, P. (2022) /

Shows a very good understanding

5. Solve the following problems:

- a) An iron ring of cross-sectional area 8.4cm^2 and mean diameter 25cm , contains an air gap 3mm wide. It is required to produce a flux of 1.4mWb in the air gap. Calculate the mmf required, given that the relative permeability of the iron is 1200 under these operating conditions.

See Appendix C for rough workings.

5(a)

$$A = 8.4\text{cm}^2 = 8.4 \times 10^{-4}\text{m}^2 \quad d = 25\text{cm} = 0.25\text{m} \quad \text{air gap} = 3\text{mm} = 3 \times 10^{-3}$$

$$\phi = 1.4\text{mWb} \quad \mu_r = 1200 \quad l_{\text{iron}} = \pi d$$

For Iron,

$$S_i = \frac{l_{\text{iron}}}{\mu_0 \times \mu_r \times A} = \frac{0.25 \times \pi}{(4\pi \times 10^{-7}) \times 1200 \times (8.4 \times 10^{-4})}$$

$$= 0.620 \times 10^6 \text{ A/Wb}$$

For air,

$$S_a = \frac{l_a}{\mu_0 \times \mu_r \times A} = \frac{3 \times 10^{-3}}{(4\pi \times 10^{-7}) \times 1 \times (8.4 \times 10^{-4})}$$

$$= 2.84 \times 10^6 \text{ A/Wb}$$

Total S=

$$I_s = \frac{\text{mmf}}{\phi} = \text{mmf} = S \times \phi = (3.46 \times 10^6) \times (1.4 \times 10^{-3}) = 4844 \text{ At}$$

Mmf required $I_s = 4844 \text{ At}$

Well done.

- 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 80 turns and rotates at 1200rev/min . (i) Calculate the maximum generated e.m.f. (ii) If the coil generates 100V , at what speed will the coil rotate?

5 (b)(i)

$$\text{EMF } E = 2 \times B \times l \times V \times N$$

Therefore,

$$V = \omega r = \frac{nr}{60(t)} \times \frac{(2\pi \times 6 \times 10^{-2})}{2} = \frac{1200}{60} \times \frac{(2\pi \times 6 \times 10^{-2})}{2} = 3.770$$

$$\underline{V = \omega r = 3.770 \text{ m/s}}$$

$$E = 2 \times 1.2 \times (10 \times 10^{-4}) \times 3.77 \times 80 = 72.382 \text{ V}$$

$$\underline{V = 72.382 \text{ V}}$$

5 (b)(ii)

$$E = 100 \text{ V}$$

$$\omega = \frac{V}{r} = \frac{5.208}{\frac{6 \times 10^{-2}}{2}} = 173.6 \text{ radians per second}$$

$$\text{Speed} = \frac{173.6 \times 60}{2\pi} = 173.6 \times \frac{60}{2\pi} = 1657.76 \text{ rpm}$$

$$\underline{\text{Coil speed} = 1657.76 \text{ rpm}}$$

Good Work.

Task 4 – AC Circuits

1. Using the oscilloscope measurements for a sine wave stated in table 3 perform the following calculations

- Peak voltage
- Frequency
- Average voltage
- Root mean square (rms) voltage.

Student Number	Oscilloscope Settings		Grid Spacing	
	Volts/Div	Timebase (ms/Div)	Vertical (peak to peak)	Horizontal (1 cycle)
10	2	5	5.5	4.4

$$V_{pp} = 2 \times 5.5 = 11V \quad \checkmark$$

$$T = 5 \times 4.4 = 22ms \quad \checkmark$$

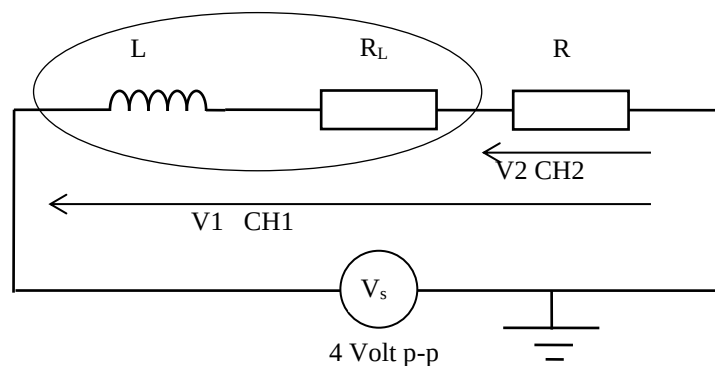
$$A. \text{ Peak Voltage} = V_p = V_m = \frac{V_{pp}}{2} = \frac{11}{2} = 5.5V \quad \checkmark$$

$$B. \text{ Frequency} = \frac{1}{BT} = \frac{1}{22 \times 10^{-3}} = f = 45.45Hz \quad H_c \quad \checkmark$$

$$C. \text{ Average Voltage} = V_{av} (\text{average}) = 0.637 \times V_m = 0.637 \times 5.5 = 3.5035V \quad \checkmark$$

$$D. \text{ Root mean square (rms) voltage} = V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{5.5}{\sqrt{2}} = 3.889V \quad \checkmark$$

2. Below is a RL circuit:



$$\underline{L = 2.2mH, R = 27\Omega, R_L = 4.18 \Omega \text{ (measured value)}}$$

3. Measure and record the value of each of the component.

$L = 2.19\text{mH}$ $R = 26.8\ \Omega$ $R_L = 4.18\ \Omega$ ✓

4. Produce a table of measurements as shown below:

Fre- quency (f) (kHz)	CH1 (V) <i>pk to pk</i> Voltage	CH2 (V) <i>pk to pk</i> Voltage	Time Differ- ence (be- tween peaks) (μS)	Phase Angle ($^\circ$)
1	1.7	1.36	60	21.60
2	2	1.3	69	49.68
3	2.36	1.24	52	56.16
4	2.68	1.16	45	64.80
5	2.94	1.08	37	66.60
6	3.14	1	32.4	69.98
7	3.26	0.92	30	75.60
8	3.44	0.84	26	74.88
9	3.54 ✓	0.78 ✓	23.6 ✓	76.46 ✓

5. Produce a table of calculations as shown below:

Fre- quency (f - kHz)	$X_L\ (\Omega)$	R_T	$Z\ (\Omega)$	Current (A)	Phase An- gle ($^\circ$)
1	13.76	30.98	33.90	0.1180	23.95
2	27.52	30.98	41.44	0.0965	41.62
3	41.28	30.98	51.61	0.0775	53.11
4	55.04	30.98	63.15	0.0633	60.63
5	68.80	30.98	75.45	0.0530	65.76
6	82.56	30.98	88.18	0.0454	69.43
7	96.32	30.98	101.18	0.0395	72.17
8	110.08	30.98	114.36 ✓	0.0350 ✓	74.28
9	123.84 ✓	30.98	127.66 ✓	0.0313 ✓	75.96 ✓

Show clearly one full example of your method for calculating for X_L (Ω), Z (Ω), Current (A) and Phase Angle ($^\circ$) for a chosen frequency.

Frequency= 4 kHz $R_t = 30.98\Omega$ $L = 2.19\text{mH}$

$$X_L = 2\pi FL \quad \checkmark$$

$$X_L = 2\pi \times 4 \times (2.19 \times 10^{-3}) = 0.055 = 55.04\Omega \quad \checkmark$$

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{30.98^2 + 55.04^2} = 63.16\Omega \quad \checkmark$$

*Have not shown
the calculation of R_T*

$$V = I \times Z \quad I = \frac{V}{Z} = \frac{4}{63.16} = 0.0633\text{A} \quad \checkmark$$

$$\phi = \tan^{-1} \frac{X_L}{R} = \tan^{-1} \frac{55.04}{30.98} = 60.63^\circ \quad \checkmark$$

$X_L = 55.04\Omega$

$Z = 61.22\Omega$

Current (A)= 0.0653A

Phase Angle= 64.04°

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

The accuracy of results can vary due to a variety of factors. Resistor tolerances, for example, are not sold with 8 significant digits of precision, as exactly 100.000000 Ω . Realistically, you'd expect to see $100 \pm 5\% \Omega$. Under this specification, both a 25 Ω and a 35 Ω resistor would be acceptable. Robbins. (2021). Tolerances are related to cost, higher precision resistors do exist but one would have to assess how important that degree of accuracy would be to the circuit values in question. If calculated results use a 26 ohm resistor for example, a variance of $\pm 5\%$ would affect calculated vs measured results. This is due to many calculations using resistance as an element in equations, such as ohms law, $V = I \times R$. Even phase angle calculations use a resistor value, as can be seen in the formula, $\tan^{-1} \frac{X_L}{R} = \phi$. Tooley, M. (2019). ✓

Equipment such as multi-meters and oscilloscope can have their own internal resistances that can affect the measured value, explaining how calculated results can vary from measured ones. *'Since the multimeter is part of the circuit in which measurements are made, its internal resistance will affect the current flow through the circuit being measured. If the digital multimeter has a very high resistance, this resistance will cause a small change in the current circuit. If the internal resistance of the multimeter is low, the circuit being tested may cause significant changes.'* (Brown et al., 2022)

The multimeter was not part of the circuit.

Human errors can affect the accuracy of measured results, for example, not getting good contact with the probes of a meter on the circuit may affect the measured value. When using an oscilloscope, how the cursor alignment is managed can cause an inaccurate measurement of phase angles and peak to peak values of wave forms. The pixelization of the oscilloscope screen can also cause accuracy issues, as pictured in figure 14.

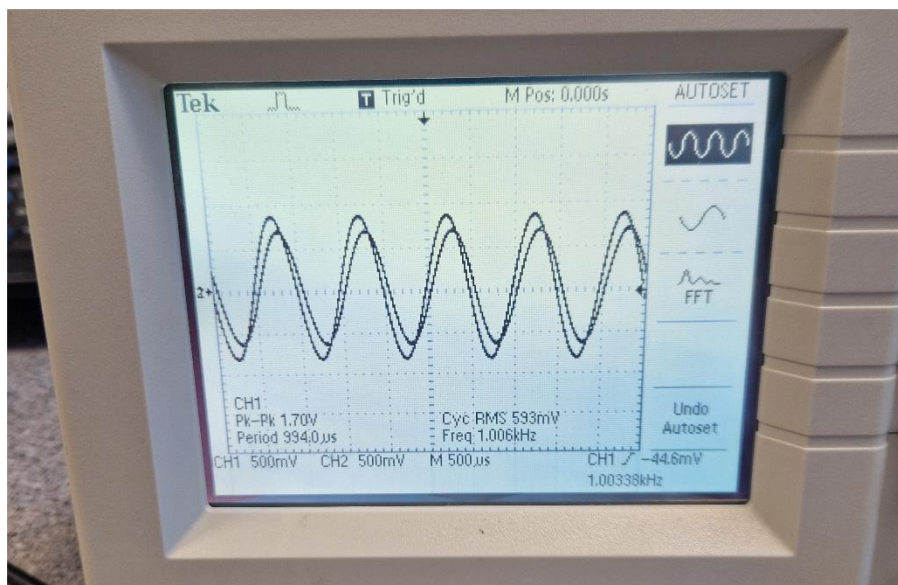


Figure 14, oscilloscope reading, pixelization and cursor alignment

Measured phase angle results for a 4kHz signal were as follows, with the calculated results to the side as a comparison,

Measured Phase Angle= 64.8° Calculated Phase Angle= 60.63°

Rounding within formulas can affect the results when comparing measurements vs calculations. Where the phase angle is measured from on the oscilloscope can impact the accuracy on the measurement in comparison to the calculated result. ✓

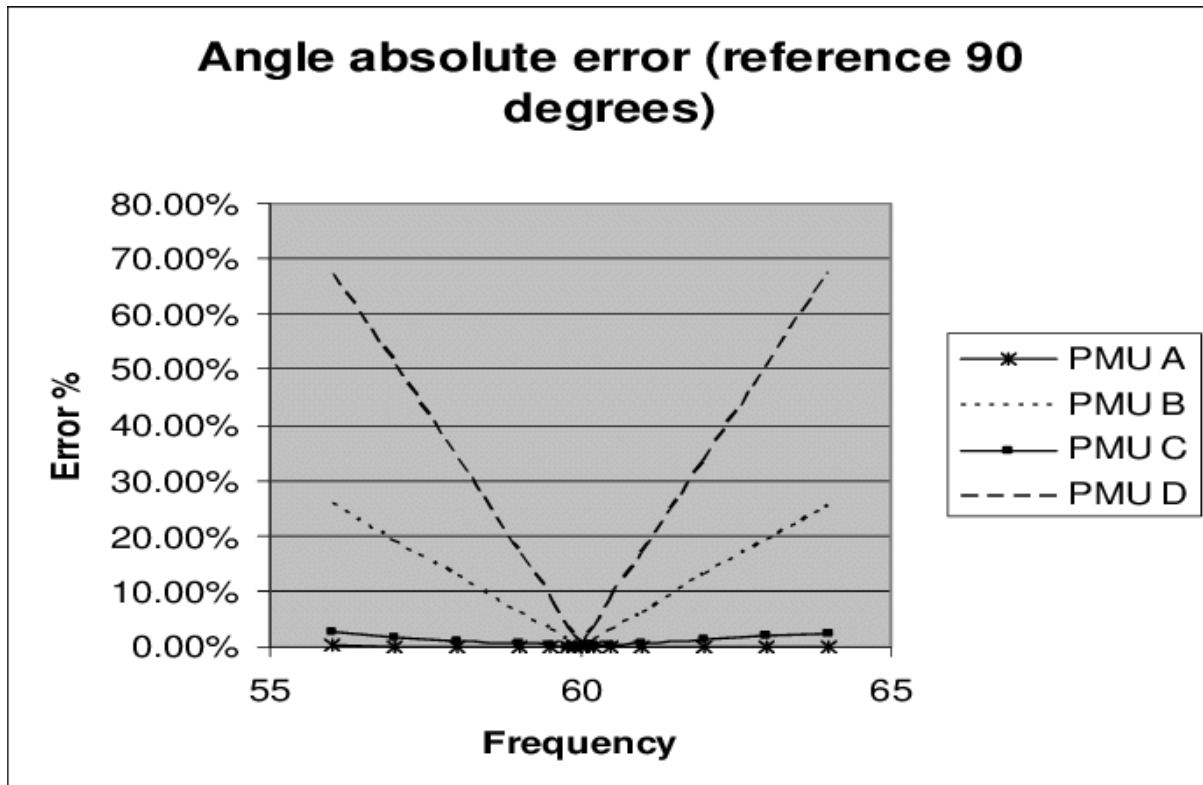


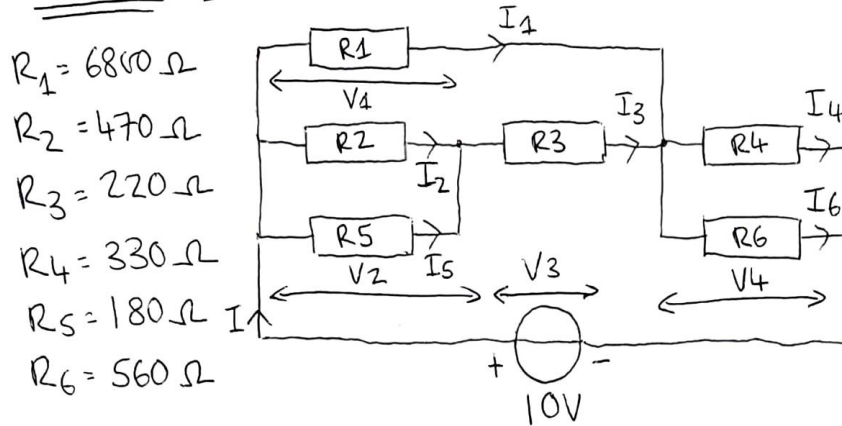
Figure 15

‘Figure 15 shows the percentage deviation from 90 degrees of the phase angles measured by the tested PMU units at off-nominal frequencies within 55 and 65 Hz. From Figure 15 it can be concluded that the PMU A phase angle measurement is stable and very close to 90 degrees within the testing frequency range. Conversely, the phase angle measurements from the remaining three PMUS have errors which depend upon the frequency. The above results reveal that even the units with proper magnitude correction algorithms yield different phase measurements at off-nominal frequencies.’ (Depablos, J. & Centeno 2004)

The above extract is an example of how an accurate phase angle measurement can be difficult to obtain, as the accuracy of the measurement is subject to errors that can be induced by certain frequencies. Circuit impedance values, slight variances in time differences peak to peak do occur, hence one would expect to see a difference between measured and calculated results. ✓

Appendix A

Task 1 - DC Circuits



Total Resistance

$$R_{25} = \frac{R_2 \times R_5}{R_2 + R_5} = \frac{470 \times 180}{470 + 180} = \underline{\underline{130.15 \Omega}}$$

$$R_{235} = R_{25} + R_3 = 130.15 + 220 = \underline{\underline{350.15 \Omega}}$$

$$R_{1235} = \frac{R_{235} \times R_1}{R_{235} + R_1} = \frac{350.15 \times 6800}{350.15 + 6800} = \underline{\underline{333 \Omega}}$$

$$R_{46} = \frac{R_4 \times R_6}{R_4 + R_6} = \frac{330 \times 560}{330 + 560} = \underline{\underline{207.64 \Omega}}$$

$$R_T = R_{1235} + R_{46} = 333 + 207.64 = \underline{\underline{540.64 \Omega}}$$

Supply Current

$$I = \frac{V}{R_T} = \frac{10}{540.64} = \underline{\underline{18.50 \text{ mA}}}$$

$$V_4 = I \times R_{46} = 18.5 \times 10^{-3} \times 207.64 = \underline{\underline{3.84 \text{ V}}}$$

$$I_4 = \frac{V_4}{R_4} = \frac{3.84}{330} = \underline{\underline{11.64 \text{ mA}}}$$

$$I_6 = \frac{V_4}{R_6} = \frac{3.84}{560} = \underline{\underline{6.86 \text{ mA}}}$$

$$V_1 = V - V_4 = 10 - 3.84 = \underline{\underline{6.16V}}$$

$$I_1 = \frac{V_1}{R_1} = \frac{6.16}{6800} = \underline{\underline{0.91mA}}$$

$$I = I_1 + I_3 \quad I_3 = I - I_1 = 18.5 - 0.91 = \underline{\underline{17.59mA}}$$

$$V_3 = I_3 \times R_3 = 17.59 \times 10^{-3} \times 220 = \underline{\underline{3.89V}}$$

$$V_2 = V_1 - V_3 = 6.16 - 3.89 = \underline{\underline{2.27V}}$$

$$I_2 = \frac{V_2}{R_2} = \frac{2.27}{470} = \underline{\underline{4.83mA}}$$

$$I_5 = \frac{V_2}{R_5} = \frac{2.27}{180} = \underline{\underline{12.61mA}}$$

P.D. value across each resistor

$$P = I^2 \times R$$

$$P_1 = I_1^2 \times R_1 = (0.91 \times 10^{-3})^2 \times 6800 = \underline{\underline{5.63mW}}$$

$$P_2 = I_2^2 \times R_2 = (4.83 \times 10^{-3})^2 \times 470 = \underline{\underline{10.96mW}}$$

$$P_3 = I_3^2 \times R_3 = (17.59 \times 10^{-3})^2 \times 220 = \underline{\underline{68.07mW}}$$

$$P_4 = I_4^2 \times R_4 = (11.64 \times 10^{-3})^2 \times 330 = \underline{\underline{44.71mW}}$$

$$P_5 = I_5^2 \times R_5 = (12.61 \times 10^{-3})^2 \times 180 = \underline{\underline{28.62mW}}$$

$$P_6 = I_6^2 \times R_6 = (6.86 \times 10^{-3})^2 \times 560 = \underline{\underline{26.35mW}}$$

Appendix B

Task 2.2

10/11/22

$$C_1 = 18 \mu\text{F}$$

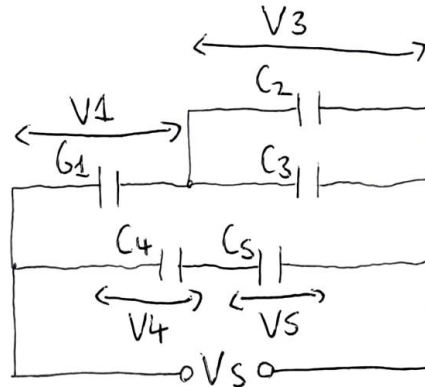
$$C_2 = 12 \mu\text{F}$$

$$C_3 = 39 \mu\text{F}$$

$$C_4 = 27 \mu\text{F}$$

$$C_5 = 33 \mu\text{F}$$

$$V_S = 2.5\text{V}$$



$$V_2 = V_3$$

Since all capacitors are in μF , $\times 10^{-6}$, no conversion is required.

$$(a) C_{23} = C_2 + C_3 = 12 + 39 = \underline{\underline{51 \mu\text{F}}}$$

$$C_{123} = \frac{C_1 \times C_{23}}{C_1 + C_{23}} = \frac{18 \times 51}{18 + 51} = \underline{\underline{13.30 \mu\text{F}}}$$

$$C_{45} = \frac{C_4 \times C_5}{C_4 + C_5} = \frac{27 \times 33}{27 + 33} = \underline{\underline{14.85 \mu\text{F}}}$$

$$C_T = C_{123} + C_{45} = 13.3 + 14.85 = \underline{\underline{28.15 \mu\text{F}}}$$

$$(b) Q_T = C_T \times V = (28.15 \times 10^{-6}) \times 2.5 = \underline{\underline{703.75 \mu\text{C}}}$$

$$(c) Q_4 = Q_5 = C_{45} \times V = 14.85 \times 2.5 = \underline{\underline{371.25 \mu\text{C}}}$$

$$Q_1 = Q_T - Q_{45} = 703.75 - 371.25 = \underline{\underline{332.5 \mu\text{C}}}$$

$$Q_1 = C_{123} \times V = 13.30 \times 2.5 = \underline{\underline{332.5 \mu\text{C}}}$$

$$V_1 = \frac{Q_1}{C_1} = \frac{332.5}{18} = \underline{\underline{18.47 \text{V}}} \quad (V = Q/C)$$

$$V_2 = V_3 = V - V_1 = 2.5 - 18.47 = \underline{\underline{6.53 \text{V}}}$$

$$Q_2 = C_2 \times V_3 = 12 \times 6.53 = \underline{78.36 \mu C}$$

$$Q_3 = C_3 \times V_3 = 39 \times 6.53 = \underline{254.67 \mu C}$$

$$d) (W = \frac{1}{2} \times C \times V^2)$$

$$W_1 = \frac{1}{2} C_1 \times V_4^2 = \frac{1}{2} \times 18 \times 18.47^2 = \underline{3070.27 \mu J}$$

$$W_2 = \frac{1}{2} C_2 \times V_3^2 = \frac{1}{2} \times 12 \times 6.53^2 = \underline{831.50 \mu J}$$

$$W_3 = \frac{1}{2} C_3 \times V_3^2 = \frac{1}{2} \times 39 \times 6.53^2 = \underline{255.85 \mu J}$$

$$V_4 = \frac{Q_4}{C_4} = \frac{371.25}{27} = \underline{13.75 V}$$

$$V_5 = V - V_4 = 25 - 13.75 = \underline{11.25 V}$$

$$W_4 = \frac{1}{2} \times C_4 \times V_4^2 = \frac{1}{2} \times 27 \times 13.75^2 = \underline{2552.34 \mu J}$$

$$W_5 = \frac{1}{2} \times C_5 \times V_5^2 = \frac{1}{2} \times 33 \times 11.25^2 = \underline{2088.28 \mu J}$$

$$e) W_T = \frac{1}{2} \times C_T \times V^2$$

$$= \frac{1}{2} \times 28.15 \times 25^2$$

$$= \underline{8796.88 \mu J}$$

Appendix C

2(a) flux density $B = 1.6 \text{ T}$ Magnetic flux $\Phi = 550 \text{ mWb}$

$$B = \Phi / A \Rightarrow A = \Phi / B = \frac{0.55}{1.6} = 0.344 \text{ m}^2$$

$$A = \pi r^2 \quad A = \pi (0.344)^2 \Rightarrow r^2 = A / \pi \Rightarrow r = \sqrt{A / \pi}$$

$$\cancel{A = 0.372} \quad \cancel{r = \sqrt{\frac{0.372}{\pi}}} \quad r = \sqrt{\frac{0.344}{\pi}} = 0.331$$

$$\underline{r = 0.331 \text{ m} = 33.09 \text{ cm}}$$

(b)(i)

$$A = 3.49 \text{ cm}^2 \quad A = 3.49 \times 10^{-4} \text{ m}^2 \quad 0.2 \text{ mWb} = \Phi$$

$$B = \frac{\Phi}{A} = \frac{0.2 \times 10^{-3}}{3.49 \times 10^{-4}} = \underline{0.573 \text{ T}}$$

So when $T = 0.573$, $H (\text{A/m}) = 89 \text{ A/m}$ approx
referencing the graph.

and,

$$H = \frac{N \times I}{l} \Rightarrow l = 2\pi r \quad l = 2 \times \pi \times 0.1$$
$$l = 0.628 \text{ m}$$

$$I = \frac{l \times H}{N} = \frac{0.628 \times 89}{1200} = \underline{46.58 \text{ mA coil current}}$$

$$(b)(ii) \mu_0 \times \mu_r = B / H$$

$$\mu_r = \frac{B}{\mu_0 \times H} = \frac{0.573}{4\pi \times 10^{-7} \times 89} = \underline{5123.36} \text{ relative permeability}$$

5.(a) $A = 84 \text{ cm}^2 = 84 \times 10^{-4} \text{ m}^2$ $d = 25 \text{ cm} = 0.25 \text{ m}$
 air gap = $3 \text{ mm} = 0.003 \text{ m} = 3 \times 10^{-3}$ $\Phi = 1.4 \text{ mWb}$
 $\mu_r = 1200$

$$\boxed{\ell_{\text{im}} = \pi d}$$

For iron,

$$S_i = \frac{\ell_{\text{im}}}{\mu_0 \times \mu_r \times A} = \frac{0.25 \times \pi}{(4\pi \times 10^{-7}) \times 1200 \times (8.4 \times 10^{-4})}$$

$$= 0.620 \times 10^6 \text{ A/Wb}$$

For air,

$$S_a = \frac{\ell_a}{\mu_0 \times \mu_r \times A} = \frac{3 \times 10^{-3}}{(4\pi \times 10^{-7}) \times 1 \times (8.4 \times 10^{-4})}$$

$$= 2.84 \times 10^6 \text{ A/Wb}$$

$$\text{Total } S = S_i + S_a = (0.620 \times 10^6) + (2.84 \times 10^6) = 3.46 \times 10^6 \text{ A/Wb}$$

$$I_s = \frac{\text{mmf}}{\Phi} \Rightarrow \text{mmf} = S \times \Phi = (3.46 \times 10^6) \times (1.4 \times 10^{-3})$$

$$\underline{I_s = 4844 \text{ At}} \quad \text{mmf required}$$

5.(b)(i) EMF, $E = Z \times B \times \ell \times V \times N$

and, $V = W_r = \frac{n_r}{60(\text{t})} \times \frac{(2\pi \times 6 \times 10^{-2})}{2} = \frac{1200}{60} \times \frac{(2\pi \times 6 \times 10^{-2})}{2}$

$$V = 3.77 \text{ m/s}$$

$$E = 2 \times 1.2 \times (10 \times 10^{-4}) \times 3.77 \times 80$$

$$= \underline{\underline{72.38 \text{ V}}}$$

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