# Unit 57: Electrical and Electronic Principles

## Delivery guidance

The aim of this unit is to provide learners with opportunities to develop skills and knowledge that demonstrate how mathematical and scientific principles have been combined through theory and experimentation into useful electrical and electronic principles. Key areas of study include:

- the use of algebraic, trigonometric and statistical mathematical methods to solve engineering problems
- solving engineering problems involving static and direct current electricity and circuits
- understanding the importance of magnetism and electromagnetic induction in engineering
- solving engineering problems involving single-phase alternating current.

### Approaching the unit

It is essential that you allow learners to investigate the unit content in as hands-on way as practical to link the theoretical concepts with practical experience.

The history of electrical and electronic principles and the characters involved form important factors in learners' understanding how theories have developed and are proven. It can provide points of interest and context for learners interested in 'why' rather than just 'what'. You should provide learners with opportunities to carry out practical investigations so that they can explore the principles developed by a range of key scientists and engineers.

At the same time, learners need to develop skills in selecting and applying appropriate mathematical techniques to analyse and solve problems. You can make the need for this clearer through application of these skills to real situations related to the unit content.

### Learning aim A

The mathematical content which is included in learning aim A is to support learners when analysing electrical problems. It is important that it is not seen as an end-in-itself, but rather an invaluable aid to developing skills that make it possible to solve electrical and electronic engineering problems. It is highly likely that the majority of learners will have studied these topics prior to this course. Several will likely already be quite capable mathematically but may not have experience in applying their knowledge and skills in practical situations.

Use a diagnostic set of questions to identify learner strengths and areas for further development in the different sections of the learning aim at the start of the unit. This could concentrate the areas needed for initial attention and identify any areas for remedial action, e.g. you could direct your learners to a range of online resources to guide learners towards improving their skills using mathematical and scientific revision sites.

Refer to the skills in context as you cover the unit content, e.g. you could highlight the use of transposition and simplification when solving equations such as Coulomb's Law or Kirchhoff's Laws, logarithms and exponentials for capacitor charging/discharging. Ensure that each time you solve a problem as a sample/demonstration that you include a full range of progression steps to indicate what will be expected in the set assignment.


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Topic A3 Statistical Methods could be delivered holistically – include a practical exercise, e.g. give learners 20 resistors of the same nominal value, a resistor colour chart, and a multimeter. Learners should identify the nominal resistor value and measure the actual resistance of each using the Ohm setting on the multimeter. (It helps if the resistors are 5% tolerance or worse to ensure some variation). Talk to individuals about their diagnostic test as they carry out the practical. They could use the data to draw charts and calculate values listed in topic A3 specification content.

## Learning aim B

Learning aim B covers a wide range of topics which form the foundations of electrical and electronic principles. It is important that learners understand the concept of charge, current as charge flow and voltage as energy causing the movement (potential difference). A way to link together the content would be to trace the development of ideas through the people credited with generating the underlying theory.

You could gain attention and interest by demonstrating the effects of charge through simple learner experiments on attraction/repulsion. Use a Van de Graaf generator, linking the observations to a simple atomic model and introduce the concept of:

- force on a conductor – definition of charge, unit and Coulomb's Law (a chance to investigate who was Charles Augustin de Coulomb). An opportunity to review conventions for SI units e.g. C for abbreviation but lower-case coulomb when writing the full name
- electric field
- electric field strength – get learners to estimate the charge on the Van de Graaf generator from the length of spark
- current as movement of charge.

Direct your learners to investigate online resources related to them (see Resources list).

A Wimshurst machine would be a good introduction to the idea of a Leyden jar (capacitor) and the concept of charge storage. When investigating the factors affecting capacitance you could use two large sheets of aluminium (or foil) and a multimeter with a capacitance scale. Use different spacing materials would introduce the concept of permittivity.

You could follow a historical trail to Ohm, and the concept of current flow, field strength and resistance, introducing the relevant equations and solve problems using the skills introduced in Learning Aim A as each concept is met.

DC circuit theory offers you many opportunities to use practical investigations to explore key principles e.g. Ohm's Law, combinations of resistors in series and parallel, Kirchhoff's voltage and current laws, charge/discharge experiment for a capacitor-resistor circuit using standard equipment. Give different groups different aspects of practical tasks to feed back to the main group, e.g. some pairs may have series and others parallel circuits, groups can have different component values for the charge/discharge experiment, etc.

It may be appropriate to introduce elements of learning aim D, e.g. characteristics of sinusoidal waveforms and use of an oscilloscope for learners to carry out a practical investigation of rectification and voltage regulation when studying diodes. Alternatively, you could leave the stabilised power supply until after learners have investigated single-phase alternating current.

## Learning aim C

Learning aim C provides further opportunities for learners to carry out practical investigations into the world of magnetism and electromagnetic induction.

Learners carry out practical investigations of magnetic fields around permanent magnets to recall possible prior learning on the concepts of magnetic fields and define flux density. Extend the investigation into the factors affecting electromagnets and link the relevant equations to the algebra content in learning aim A. You could direct your learners to investigate magnetic materials and introduce factors such as permeability, magnetic hysteresis, coercive force and reluctance.

Demonstrate the effect of a moving conductor in a magnetic field (or vice-versa). A solid piece of aluminium and one with a comb edge set up as a pendulum in a strong magnetic field gives a good demonstration of eddy current effects. There are many videos available on the internet (see Resources section).There are further opportunities for small groups to investigate particular effects and to feed back their observations to the main group, enhancing their communication skills.

You could get learners to try to make a simple motor using a 1.5V AA cell a piece of wire, a screw and a small neodymium disk magnet. Use video resources to support this activity (see resources section). In order to Formalise Lenz’s Law and Fleming Right Hand Rule (generator), link this to applications, e.g. wind-up torch (Trevor Baylis wind-up radio), etc. Compare with Fleming’s Left-Hand Rule for motors. (Refer to the skills from learning aim A when solving typical problems relating to magnetic fields). Include a couple of slot-racing cars as examples of DC motors and hold a race competition to generate interest and consolidate understanding.

You could complete the investigation into generators and motors by looking at real-life examples of each to see how the basic concepts are applied practically. Continue the historical theme by including the contribution of individuals such as Faraday, Sturgeon, Edison, etc.

A demountable transformer kit would be a good resource to investigate the effect of the number of turns, permeability, transformer principle, step-up/down voltage ratios and efficiency.


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## Learning aim D

To deliver learning aim D, you need a minimum of a function generator and a twin-beam oscilloscope to demonstrate waveform characteristics. The function generator should provide sinusoidal, square and triangular waveforms to allow learners to investigate each of the parameters listed in the unit content D1. (You may have introduced sinusoidal waveforms with learning aim B but it is important to reiterate how to set up the equipment safely).

Introduce the concept of phasors through reference to circular measure in learning aim A and use of a 'phasor wheel' to demonstrate the equivalence. This ties in with the unit content in A2. Converting between Polar and Rectangular (Cartesian) notation for a sinusoidal waveform provides learners with good practice in the use of Pythagoras' Theorem and trigonometric ratios. You could demonstrate phase difference in RL and RC circuits by displaying waveforms on an oscilloscope, but you must take care in the selection of reference points.

It is important that you stress the need for learners to use radian measure when carrying out phasor calculations. Show them how to set up their calculator to work in radian mode. Review trigonometric methods and vector addition from learning aim A.

When learners set up function generator to give a sinusoidal waveform of given frequency and amplitude, they should connect the oscilloscope to check the waveform meets the given specification. They should record the waveform, noting the parameters listed in learning aim D, then use a digital multimeter to measure the rms voltage. They should repeat the measurements with the function generator set to triangular waveform and/or square waveform.

When comparing waveform measurements consider how the meter reading relates to the waveform. Review learners' knowledge with questioning such as: How does the time period relate to the frequency? How do the results differ from the sinusoidal waveform? Then, introduce the concept of form factor to them to underpin understanding.

When comparing waveforms for RC and RL circuits note the dependence on frequency of capacitive and inductive reactance. Complete sample calculations of $X_C$ and $X_L$. (You could use simulation software for comparison). Explain the need to use phasor diagrams to calculate the impedance of RC and RL circuits because of the phase difference between the waveforms.


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## Assessment model (in internally assessed units)

| Learning aim | Key content areas | Recommended assessment approach |
|---|---|---|
| **A** Examine how algebraic, trigonometric and statistical mathematical methods can be used to solve engineering problems | **A1** Algebraic methods<br>**A2** Trigonometric methods<br>**A3** Statistical methods | This unit will be assessed through a Pearson Set Assignment.<br>Learners will be required to interpret and use data and information relating to engineering scenarios.<br>Learners' work will be submitted in the form of a completed assignment, which will be assessed by centre staff using the assessment criteria in this unit. |
| **B** Examine engineering problems involving static and direct current electricity and circuits | **B1** Static and direct current electricity principles<br>**B2** Direct current circuit theory<br>**B3** Direct current networks | |
| **C** Examine magnetism and electromagnetic induction in engineering | **C1** Magnetism<br>**C2** Electromagnetic Induction | |
| **D** Examine engineering problems involving alternating current electricity and circuits | **D1** Alternating current waveforms<br>**D2** Single-phase alternating current principles | |


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## Assessment guidance

This unit is assessed using a Pearson Set Assignment Brief as stated in 'Section 2 Structure' of the Qualification Specification. This assessment is set by Pearson and must be taken under controlled conditions before it is marked by teachers as stated in the Unit Specification 'Assessment Controls', i.e.

- **Time:** the assignment must be completed in the stated time for the assignment.
- **Invigilation:** learners should be invigilated and on centre premises when completing the assignment.
- **Resources:** resources and learners' work should be kept securely in the centre between assessment periods.
- **Research:** learners may need to research their local environment to collect data to support their response. If this is the case, they are permitted to take notes and bring them back to the centre. Research time will be accounted for in the time requirement for the assignment.

Set assignment units are subject to the external standards verification processes common to all BTEC units. By setting an assignment for some units, Pearson can ensure that all learners take the same assessment for a specific unit.

Set assignments are available from September each year and are valid for one year only. It is advisable for you to check the Pearson BTEC resources for sample assignments to prepare your learners for assessment.

Learners may resit a set assignment to obtain a higher grade. If retaking, a learner must take a different authorised Pearson Set Assignment to that previously taken. If a learner has more than one attempt, then the best result will be used for qualification grading, up to the permitted maximum. It is unlikely that learners will need to, or benefit from, taking all assessments twice so you are advised to plan appropriately.

For information on preparing for assessment you should see Section 5 'Assessment structure' of the Qualification Specification.

## Getting started

This provides you with a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

### Unit 57: Electrical and Electronic Principles

**Introduction**

You could start by asking learners to list areas of everyday life that depend upon electrical and electronic products and discuss their findings. (The outcomes should indicate that all aspects of our lives are so dependent upon electrical and electronic devices). They are important elements in all engineering disciplines, therefore it is important that all engineers have a working knowledge of electrical and electronic principles.

Introduce the idea that the historical development of principles provides an understanding of how theories arise from observation and development of theories, and how they can be encapsulated in mathematical terms to analyse problems.

### Learning aim A: Examine how algebraic, trigonometric and statistical mathematical methods can be used to solve engineering problems

Use a diagnostic set of graded questions to identify learner strengths and areas for further development. Explain that this is not a pass/fail test but one to identify where to focus efforts to ensure everyone can carry out the functions necessary to take advantage of the unit. The questions could be organised in three sections:

- Algebraic
- Trigonometric
- Statistical

You could use the collected data to identify topics which the group would benefit from studying together, e.g. sample worked problems, questions for learners to test and therefore evaluate their skills and knowledge acquisition.

You should ensure that topics are covered in an engineering context. Learners are likely to have covered the topics previously in a purely mathematical sense. Placing the content in an engineering context can help learners understand and apply techniques, e.g. if you are working on transposition you could use Ohm's Law type questions, V=IR, I=V/R, R=V/I, and show how the pattern is the same for mass, density and volume M=VD, D=M/V, V=M/D.

Use a variety of strategies to ensure that all learners engage with the content. Get learners to suggest methods, carry out steps. Can they devise a method for remembering how to solve similar problems, e.g. they could use a triangle to ensure that they carry out the 'Ohm's Law type' transposition correctly.

You could find that the majority of learners are competent in a particular area, but individuals have gaps in knowledge. In that case, direct them to further support resources. There are banks of learning materials available but take care to ensure that they are at an appropriate level (see Resources).

Note: Algebraic and Trigonometric methods appear in context in the remaining learning aims, so can be treated holistically with the unit content, further reinforcing learners' ability to select and apply appropriate analytical methods. There is less direct connection to statistical methods to the remaining unit content, so it may be worth carrying out a practical statistical exercise, e.g. measure


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the value of 50 resistors and represent the data in statistical diagrams, calculation of statistical averages, etc. to cover the Unit content A3 Statistical methods.

Provide learners with a plan for covering learning aim A content. A lot of this may well be covered holistically as it links to the unit content, so it is important that they are confident that they will cover all the unit content.

**Note:** It would aid learners to have access to summary notes for each topic in the unit specification, with spaces for them to complete to confirm understanding and ability to complete problems in the required manner. An example of how this was done in one centre was for the teacher to complete notes on a smart board during the teaching session and to upload the pages on a virtual learning environment (VLE) for learners to access.

**Learning aim B: Examine engineering problems involving static and direct currents, electricity and circuits**

**B1 Static and direct current electricity principles**

Introduce the concept of electrical charge through reflection on early learner experiences e.g. combing hair, rubbing a balloon, etc. Ask learners to demonstrate simple experiments. Give a demonstration of effects using a Van de Graaf Generator (or similar). Get learners to explain their observations and the limitations of such generators.

You could then formalise the findings, e.g.:

- the concept of charge, types of charge and units (a chance to look at the history of Coulomb)
- the concept of current as moving charge
  $i = \frac{q}{t}$
- the concept of field strength
  $E = \frac{F}{q} = \frac{V}{d}$

It might surprise learners if they estimate the voltage on the Van de Graaf generator from the length of spark (electrical breakdown of air 3kv/mm approx.). Discuss the difference between charge, current and voltage, and the definition of voltage as energy per unit charge (J/C).

Note: when carrying out sample calculations it is important that you include all progressive steps to prepare learners for assessment.

Take the idea of force on a charge and introduce Coulomb's Law and carry out typical calculations.

$$F = \frac{q_1 q_2}{r^2}$$

Take the opportunity to link to transposition in LAA. (Refer back to the transposition later when studying magnetism. This could lead to a discussion of how the equation sfor field have similar styles.)

A Wimshurst machine would give a good introduction to the concept of charge storage using a capacitor (Leyden jar). (Use online videos if the hardware is not available). This could lead into examining the factors affecting capacitance and the concept of permittivity

$$C = \frac{\varepsilon A}{d}$$

Then, introduce the definition of capacitance, units and energy stored,

$$Q = CV \qquad E = \frac{1}{2}QV = \frac{1}{2}CV^2$$

and get learners to carry out typical calculations using the equations. You could ask learners to investigate types of capacitor and their uses. Note that care must be taken in terms of handling materials – a Risk Assessment should be carried out.

Learners carry out a practical exercise to measure the charge and discharge of a capacitor. Values must be selected to allow for readings at, for example, 5 second intervals up to about 50 seconds, e.g. C=100▪F, R=100k▪. Learners could also carry out the experiment with capacitors in series and/or parallel to confirm the combination rules for capacitors. The analysis of these results link with A1 Algebraic methods, indices, logarithms, exponential growth and decay. Give the groups different pairs of resistor and capacitor that give a time constant of approximately 10s so that they can compare outcomes and determine patterns. Using this type of strategy provides learners with a wider range of outcomes that they have time to obtain individually. You could tabulate the results and make them available, e.g. a member from each pair could place their results on a table on a smart board. The page could be shared and uploaded to a virtual learning environment. This could be used to summarise all the practical exercises.

Learners carry out practical exercises measuring voltage and current for a given fixed resistor and different lengths of resistance wire (e.g. nichrome). Use the opportunity to draw graphs and reinforce the concept of proportionality and transposition of equations to analyse data. Identify factors affecting resistance value. Calculate power and efficiency.

$V = IRV = IR$

$R = \frac{\rho l}{A}$

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

$\eta = \frac{P_{out}}{P_{in}}$

Learners carry out measurements on series and parallel resistor combinations (with five resistors) to confirm rules of combination and Kirchhoff's Voltage and Current Laws (KVL and KCL).

Complete studying resistor circuits with learners carrying out a practical exercise using two power sources and resistors to practice applying KVL and KCL (B3 Direct current networks).

Reinforce the theory and use of equations via set problems to underpin knowledge.

Learners measure and plot forward and reverse characteristics of a pn junction diode before explanation of construction and operation. Learners can be tasked to carry out an investigation into rectification and voltage regulation at this point, but you may decide to leave it until having covered single-phase AC circuits.

**Learning aim C: Examine magnetism and electromagnetic induction in engineering**

Introduce the topic by getting learners to examine magnetic fields around permanent magnets, e.g. field around a bar magnet, between like and unlike poles, using a plotting compass or iron filings. You could use the results to define flux density and magnetic field strength. Direct learners to investigate magnetic materials, recent developments and applications, e.g. neodymium magnets.

Extend the practical investigation of magnetic fields into the field around a current carrying conductor, noting the effect of multiple turns, current and core material to introduce the concept of magnetic permeability and magnetomotive force (mmf).

$F = NI = BIl \quad H = \frac{NI}{l} \quad \mu = \mu_0 \mu_r \quad \mu_0 = 4\pi \times 10^{-7}\ H/m$

You could bring the ideas together in a plenary session, covering the non-routine methods identified in C1 Magnetism, presenting B-H curves for different materials. (This could be returned to when discussing the requirements for a transformer core).

Introduce the concept of induction by getting learners to investigate moving a magnet in a coil connected to a galvanometer (or coil round a magnet) to note what happens. Can learners determine what the key factors are? You can formalise the results into the bullet points in C2 Electromagnetic induction and applying the accompanying formulae, e.g. Lenz's Law, Fleming Right Hand Rule.

$$e \propto -\frac{d\phi}{dt} \qquad e = Blv$$

Challenge learners to make a simple motor using only a 1.5V AA cell, a piece of wire, a screw and a small neodymium disk magnet. You could provide learners with simple motors to investigate. One way to generate interest would be for learners to examine slot-racing cars and get them to work. Then, formalise the construction and introduce the concept of inductance and energy stored in the coil.

Use a demountable transformer kit to demonstrate transformer operation. This need not be more complex than coils of different turns wound on C-cores, but care must be taken to only use with a low voltage ac supply. It may be worth making a set of transformers in ABS boxes with suitable safe connectors to give an output of 12V rms (approx.) for safe investigation of single-phase alternating current topics if commercial supplies are not available.

**Learning aim D: Examine engineering problems involving alternating current electricity and circuits**

Review circular measure from A2 Trigonometric methods and use the concept of a rotating vector (phasor) as a sinusoidal waveform. (There are a lot of animations and explanations available online). Use a circle of card marked in radian with 0 at the 3 o'clock position increasing counter-clockwise with a pointer free to rotate about the centre (use a paper split-pin to secure) to demonstrate a phasor. This could also be used to demonstrate adding a second phasor, etc.

Review triangular measurement, A2 Trigonometric methods, to apply rules for adding vectors to phasor sum of alternating currents. Write the resultant phasor in sinusoidal form.

$$v = V_{max} sin(\omega t \pm \phi)$$

You could demonstrate the phase difference for an inductor and a capacitor and introduce the concept of reactance and impedance.

$$X_L = \omega L = 2\pi f L \qquad X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

Use phasor diagrams to calculate impedance for RC, RL and RLC circuits. You could get learners to solve problems using graphical and analytical methods and discuss the merits of both methods. Can learners predict what might happen when $X_L = X_C$?

Demonstrate the use of the function generator and oscilloscope to consolidate the waveform characteristics covered in D1 Alternating waveforms.

Learners carry out practical investigations into half-wave and full-wave rectification (using discrete diodes). The practical exercise could be extended by having pre-built circuits with test-points to investigate a rectifier circuit with simple voltage regulation using a Zener diode. Use the low voltage ac sources as above. You could use sample questions to consolidate learning.

| Assignment Preparation |
|---|
| It is important to use the Pearson BTEC sample assignment material to prepare learners for the assessment. Use similar questions at each stage of teaching the unit, so that learners are accustomed to the structure and language. Allow time for structured revision and preparation. Check any requirements for learners to research material for the Pearson set assessment and give them time to prepare it. |

## Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

This unit links to:
- Unit 1: Mechanical Principles
- Unit 2: Delivery of Engineering Processes Safety as a Team
- Unit 3: Product Design and Manufacture in Engineering
- Unit 4: Applied Commercial and Quality Principles in Engineering

## Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/endorsed-resources) for more information as titles achieve endorsement.

### Textbooks

Buckenham A, Thomson G et al.: *BTEC National Engineering Student Book: For the 2016 specifications (BTEC Nationals Engineering 2016),* Pearson Education, ISBN-10: 129214100X, ISBN-13: 978-1292141008
A useful introduction to key topics.

Greer A, Taylor GW, Fuller A: *BTEC National Mathematics for Technicians, 3rd edition*, OUP Oxford; 4 edition (16 Aug. 2004), ISBN-10: 0748779493, ISBN-13: 978-0748779499
Presents topics in an approachable manner, with worked examples, exercises and solutions.

Robertson C.R, *Fundamental Electrical and Electronic Principles,* Newnes; Textbook edition (16 May 2008, ISBN-10: 0750687371, ISBN-13: 978-0750687379
Covers the essential principles that form the foundations for electrical and electronic engineering courses.

### Websites

There are numerous websites covering the topics in the unit content. Selection is down to your personal delivery preference. However, you need to take care that the level is appropriate, as many resources are aimed at Higher Level courses.

### Videos

For a useful range of video resources, visit YouTube and search for the following:
- 'Using the Van de Graaff generator' – demonstrates experiments using a Van de Graaff generator (applicable to learning aim B)
- 'MIT Physics Demo – The Wimshurst Machine' – explains how the Wimshurst machine works (applicable to learning aim B)
- 'DIY: How To Make a Simple Homopolar Motor' – examples of simple dc motor using neodymium magnet (applicable to learning aim C)
- 'Eddy Currents and Magnetic Braking of a Pendulum' demonstration of eddy currents
- 'Sine and cosine from rotating vector' – phasor as a sinusoidal wave (first part) (applicable to learning aim D)
- 'AC2 Addition of Phasors Graphically' adding phasors graphically (applicable to learning aim D)

*Pearson is not responsible for the content of any external internet sites. It is essential for tutors to preview each website before using it in class so as to ensure that the URL is still accurate, relevant and appropriate. We suggest that tutors bookmark useful websites and consider enabling students to access them through the school/college intranet.*