Unit 6: Vehicle Electrical and Electronic Principles

NQF Level 3: **BTEC National**

Guided learning hours: 60

Unit abstract

This unit will give any aspiring automotive engineer an understanding of the underlying principles governing the operation of electrical and electronic devices and circuits used within a modern vehicle. The unit aims to build on prior knowledge and provide learners with a firm foundation for further study of vehicle electrics and/or electronics.

Learners will gain an understanding of electrical and electronic principles through the analysis of direct current (DC) motor vehicle electrical circuits. Learners will also be introduced to the principles and properties of magnetism as applied to motor vehicle circuit devices.

Learners will then examine the concepts of digital electronic principles and microprocessor applications in motor vehicles. Finally, learners will be introduced to single-phase alternating current (AC) theory as applied to vehicle alternators. They will consider waveform characteristics and determine the values (using phasor and algebraic representation and actual waveform measurements using an oscilloscope) of alternating quantities.

The unit has been designed to encourage learners to take an investigative approach through practical construction, measurement and testing of circuits and, where applicable, the use of computer-based circuit analysis and simulation.

Learning outcomes

On completion of this unit a learner should:

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) motor vehicle circuits

2 Understand the principles, properties and motor vehicle applications of magnetism

3 Understand the concepts of digital principles and applications of microprocessors in motor vehicles

4 Be able to use single-phase alternating current (AC) theory to determine vehicle alternator performance.

Unit content

---

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) motor vehicle circuits

DC circuit theory: voltage eg potential difference, electromotive force (emf); resistance eg conductors and insulators, resistivity, temperature coefficient, internal resistance of a DC source; circuit components (power source eg battery, stabilised power supply; resistors eg function, types, values, colour coding; diodes eg types, characteristics, forward and reverse bias modes); circuit layout (DC power source, resistors in series, resistors in parallel, series and parallel combinations); Ohm's law, power and energy formulae eg V = IR, P = IV, W = Pt, application of Kirchoff's voltage and current laws

DC motor vehicle circuits: circuits to include a DC power source, four components including circuit protection and switching arrangement; vehicle applications eg lighting circuits (side and rear lamp, main and dip headlamp, front and rear fog lamps, stop lamp, reverse lamp, indicator and hazard warning system), auxiliary circuits (horn, window winding, central locking, interior heater, rear screen heater), vehicle security systems, air-conditioning, use of relays, circuit protection devices (DC power source circuit protection fuse and resistors (series/parallel)) operating component(s) such as motor assembly; diode resistor circuit with DC power source, series resistors and diodes eg bulb failure circuit, low oil pressure circuits, alternator rectifier

Measurements in DC motor vehicle circuits: safe use of a multimeter eg setting, handling, health and safety; measurements (circuit current, voltage, resistance, internal resistance of a DC power source; testing a diode's forward and reverse bias)

2 Understand the principles, properties and motor vehicle applications of magnetism

Characteristics of magnetic field: field patterns eg flux, flux density (B), magnetomotive force (mmf) and field strength (H), permeability, B/H curves and loops; ferromagnetic materials; reluctance; magnetic screening; hysteresis

Electromagnetic induction: principles eg induced emf, eddy currents, self and mutual inductance; motor vehicle applications (electric motor/generator eg series and shunt motor/generator, transformer eg primary and secondary current and voltage ratios); motor vehicle applications of Faraday and Lenz's laws eg electrical induction in an alternator, electromagnetic coil

3 Understand the concepts of digital principles and applications of microprocessors in motor vehicles

Digital principles: binary system eg binary notation and algebra, bits and bytes, input/output (I/O) voltage levels; logic system eg AND, OR, NOT NAND and NOR gates; truth tables, memory circuits, sequential and clocked circuits, flip flops, read only memory (ROM)/random access memory (RAM) structures and organisation; timers; digital to analogue (D/A) and analogue to digital (A/D) converters; types of integrated circuits eg classification, operation, performance characteristics and identification; vehicle applications eg fault diagnosis, code readers, data logging, visual/audio output, speed sensor processing, engine timing control, satellite navigation

Microprocessors: microprocessor system eg programmes, language, I/O interface, memory; construction of microprocessor eg control section, arithmetic and logic sections, register section, memory, I/O section buses, fetch and execute cycle, control by clock pulses; motor vehicle application of microprocessors eg engine management, antilock braking systems (ABS), climate control, suspension settings, transmission modes

4 Be able to use single-phase alternating current (AC) theory to determine vehicle alternator performance

Single-phase AC circuit theory: waveform characteristics eg sinusoidal and non-sinusoidal waveforms, amplitude, period time, frequency, instantaneous, peak/peak-to-peak, root mean square (rms), average values, form factor; determination of values using phasor and algebraic representation of alternating quantities eg graphical and phasor addition of two sinusoidal voltages, reactance and impedance of pure resistor (R), inductor (L) and capacitor (C) components

Alternator performance: safe use of an oscilloscope eg setting, handling, health and safety; measurements (periodic time, frequency, amplitude, peak/peak-to-peak, rms and average values)

Grading grid

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all of the learning outcomes for the unit. The criteria for a pass grade describes the level of achievement required to pass this unit.

Grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 use DC circuit theory to calculate current, voltage and resistance in three motor vehicle circuits P2 use a multimeter to carry out circuit measurements in DC motor vehicle circuits P3 compare the forward and reverse characteristics of two different types of semi-conductor diode P4 describe the characteristics of a magnetic field and explain the relationship between flux density (B) and field strength (H) P5 explain how the principles of electromagnetic induction apply to a given motor vehicle application	M1 use Kirchoff's laws to determine voltage and current in a motor vehicle circuit that has at least five nodes and the power dissipated in a load resistor containing two voltage sources M2 compare the function and principles of operation of two different vehicle applications of microprocessors M3 compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram.	D1 analyse the operation and the effects of varying component parameters of a motor vehicle power supply circuit that includes at least a transformer, diode and resistor D2 evaluate the performance of a motor and a generator used within a motor vehicle system by reference to electrical and electronic theory.

Grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P6 describe two different vehicle system applications of digital principles P7 describe the function and operation of two vehicle system integrated circuits P8 describe the function and principles of operation of a vehicle system microprocessor P9 use single-phase AC circuit theory to explain and determine the characteristics of a sinusoidal AC waveform P10 use an oscilloscope to measure and determine the performance of a vehicle alternator.		

Essential guidance for tutors

Delivery

It is important that learners receive the appropriate induction, development and support whilst working on this unit. They may also need a certain level of computer skills in order to use computer-based software for circuit simulation.

The four learning outcomes of this unit are linked and the delivery strategy should ensure that these links are maintained.

Learning outcome 1 is the most likely starting point for delivery, as it will establish much of the underpinning knowledge and skills required for the remaining learning outcomes. The unit could be delivered through a combination of theory lessons and demonstrations, reinforced through practical work in a vehicle laboratory or workshop. It is important that learners have a thorough understanding of circuit theory if they are to be able to recognise, understand and apply their knowledge to the relevant components.

Initially, delivery could use paper-based or computer-based exercises (eg calculating the required value of a second resistance in a series circuit to give a current flow of 2A with a 12V DC power source). However, even at this stage it may be beneficial to introduce learners to real circuit components. A task that requires learners to practise the theoretical calculations and then check a vehicle circuit in a practical environment would stimulate the learning process, aid development and reinforce relevance.

The ability of learners to lay out circuits is an important part of learning outcome 1 and will support the other learning outcomes. Most tutors might start with paper-based methods of drawing simple circuits (eg power source and series/parallel combination of resistors such as voltage and current divider circuits). It is likely that they will move on to computer simulation and the use of real circuits/components, using either bread boarding techniques or soldered circuits. It would be appropriate at this time to use vehicle wiring diagrams.

Learners should be given the opportunity to practise using the formulae identified in the unit content, although they are not required to memorise them. However, they should be expected to select the most appropriate formulae to determine the required circuit values of current, voltage or resistance. In addition, learners should have the confidence to transpose equations to meet their needs (eg use Ohm's law $V = IR$ and the power equation $P = IV$ to arrive at $P = I^2R$, use $R = R_1+R_2$ to arrive at $R_1 = R - R_2$). Because the ability to transpose formulae is a mathematical skill tutors will need to ensure that appropriate support is provided during both the delivery of this learning outcome and the unit as a whole. Centres should carefully consider how best to integrate the learning that takes place in this and other mathematical/science based units.

During the delivery of this unit, learners should be given the opportunity to experience as wide a range of measurement and computer-based simulation software as possible. However, it would not be appropriate to use computer-based simulation packages without any actual practical use or development of vehicle electrical and electronic circuits and components. Tutors are therefore encouraged to relate theory to real vehicle engineering applications wherever possible. Industrial visits or work experience could be used to support learning and give learners an appreciation of the industrial applications of electrical and electronic principles.

Note that the use of ‘eg’ in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an ‘eg’ needs to be taught or assessed.

Assessment

Much of the evidence for the pass criteria could be generated through practical experimentation and investigation with real components and circuits and computer-based software packages.

It is likely that at least four assessment instruments will be needed for this unit. If practical work and tests are also used then the total number of pieces of assessed work could be more. This should be carefully considered so as to not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final product that can be handed in for assessment at the end of the session without further need for report writing. Alternatively, practical work could be observed by the tutor/witness and a record of observation used for assessment evidence. Both of these methods will help in ensuring authenticity of evidence and also keep the assessment activities short, sharp and relevant.

Evidence of the use DC circuit theory to calculate current, voltage and resistance in three motor vehicle circuits (P1) could be produced by using paper- or computer-based methods. Between them, the three motor vehicle circuits need to be chosen to cover the required aspects of the unit content. However, it is essential that any simulation (paper- or computer-based) is combined with practical hands-on experience of real circuits and components. Prototyping circuits using simulation software to establish theoretical circuit values, followed by learners building the circuit and physically checking theory against actual results by measurement, could achieve this. Whichever method is used, tutors need to ensure that there is sufficient product evidence of the circuit being used/developed and the formulae selected to determine the required current, voltage or resistance values. This is particularly important where computer software is used that does not have a facility to print results or where printouts do not show sufficient detail to meet the criterion.

The ability to use a multimeter to carry out circuit measurements in DC motor vehicle circuits (P2) will require process evidence (ie it will need to be observed by the tutor or assessor during relevant practical activities on motor vehicle applications). This could be the end product measurement of circuits being assessed for P1. Tutors could capture this evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery.

The comparison of the forward and reverse characteristics of two different types of semiconductor diode (P3) will require the use of a multimeter, power supply, ammeter with shunt, and a switch resistor box. This could be a progression from P1/P2 and could be set up on a vehicle for learners to build, test and compare against data and detail provided.

The characteristics of magnetic fields (P4) could be demonstrated on an OHP by using magnets and iron filings. Learners could sketch or be provided with a handout of the results and then make appropriate comparisons with expected theoretical results. The relationship between flux density (B) and field strength (H), may be set within the context and use of different materials such as silicon iron and mild steel in vehicle examples such as coil, relay and starter operation.

Evidence for P5 will be descriptive and learners will need to consider the movement of a conductor within a magnetic field in vehicle examples such as alternators, starters and solenoids.

For P6, learners need to describe two different vehicle system applications of digital principles. It is expected that one of these will involve the application of a binary system and the other a logic system including D/A and A/D converters, as appropriate to the particular vehicle application. There is a strong link between P6 and P7, which could be used to good effect if the vehicle system applications of digital principles (P6) includes and enables learners to describe the function and operation of two vehicle system integrated circuits (P7).

For P8, a practical investigation of a microprocessor application for a selected vehicle system, combined with a descriptive task, could be used. The investigation and report needs to focus on the microprocessor system being applied and its construction. Typical motor vehicle applications of microprocessors could be engine management, anti-lock braking systems, climate control, suspension settings or transmission modes.

P9 requires learners to use single phase AC circuit theory to explain and determine the characteristics of a sinusoidal AC waveform. This should include waveform characteristics and the determination of values using phasor and algebraic representation of alternating quantities. There is a useful link here with P10 and an assignment could be structured to provide a relevant link between the theory and application of AC to a vehicle.

All the merit and distinction criteria have close links with the pass criteria and tutors should try to design their assignments around these links.

M1 relates to the use of Kirchoff's laws and naturally follows on from learners' use of DC circuit theory to calculate current, voltage and resistance in P1. To achieve M1, learners need to be able use Kirchoff's laws to determine voltage and current in a motor vehicle circuit that has at least five nodes, and the power dissipated in a load resistor containing two voltage sources. Learners should be encouraged to use computer-based simulation to check their calculations.

M2 links to P8 and is designed to encourage learners to taker a wider and deeper look at the application of microprocessors in motor vehicles. It is important to keep in mind that the comparison should be based on the original findings for P8 (ie the microprocessor system being applied and its construction).

M3 is an extension of P9 and P10, for which learners will have demonstrated an ability to work with a single sinusoidal AC waveform. To achieve M3 learners need to compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram. There are possible links outside of this unit, for example to *Unit 5: Applications of Vehicle Science and Mathematics*.

For D1, learners must analyse the operation and the effects of varying component parameters of a motor vehicle power supply circuit that includes at least a transformer, diode and a resistor. To achieve this, a basic power supply could be simulated to allow all the respective properties to be investigated without the hazards of damaging a vehicle's system. This could be achieved using a function generator, alternating voltage or variable power source, along with a small isolating transformer, diode rectifiers (half wave and bridge) and load resistors in circuits such as, alternator applications, bulb failure warning systems or data input devices.

D2 requires learners to evaluate the performance of a motor and a generator used within a motor vehicle system by reference to electrical and electronic theory. This can be achieved practically using appropriate experimental rigs that allow learners to compare their results with known characteristics for specific machines eg alternator output, motor applications such as door or window operating systems.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit also covers some of the knowledge and understanding associated with the Level 3 Automotive Skills National Occupational Standards in Vehicle Maintenance and Repair, particularly:

- Unit AE 4: Diagnose Rectify Engine Electrical Faults
- Unit AE 6: Diagnose Rectify Auxiliary Equipment Electrical Faults
- Unit MR 7: Diagnose Rectify Vehicle engine and Component Faults.

This unit relates strongly to *Unit 5: Applications of Vehicle Science and Mathematics* and it would be useful to study these units concurrently. Data from experiments within this unit can be manipulated mathematically and so provide evidence for both units.

Essential resources

It is essential that learners have access to a vehicle workshop equipped with test rigs, vehicles and up-to-date electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components, as identified in the unit content together with the means to physically construct circuits. With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software for computer-based circuit simulation and analysis.

Indicative reading for learners

Bird J O — *Electrical and Electronic Principles and Technology, Second Edition* (Newnes, 2004) ISBN 0750665505

Bird J O — *Electrical Circuit Theory and Technology* (Newnes, 2004) ISBN 0750657847

Denton T — *Automobile Electrical and Electronic Systems* (Butterworth-Heinemann, 2004) ISBN 0750662190

Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skill evidence are given here. Tutors should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

Application of number Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• solving vehicle electrical and electronic problems and interpreting results using conventional methods and/or computer-based software approaches.	N3.1 Plan an activity and get relevant information from relevant sources. N3.2 Use this information to carry out multi-stage calculations to do with: a amounts or sizes b scales or proportion c handling statistics d using formulae. N3.3 Interpret the results of your calculations, present your findings and justify your methods.

Information and communication technology Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• researching and using a variety of different sources for vehicle electrical and electronic products and component information • developing and presenting information on electrical and electronic principles to meet the unit criteria/content, eg magnetic field.	ICT3.1 Search for information, using different sources, and multiple search criteria in at least one case. ICT3.2 Enter and develop the information and derive new information. ICT3.3 Present combined information such as text with image, text with number, image with number.

Problem solving Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• solving problems in DC and AC circuits using conventional methods and computer-based software simulation and analysis packages.	PS3.1 Explore a problem and identify different ways of tackling it. PS3.2 Plan and implement at least one way of solving the problem. PS3.3 Check if the problem has been solved and review your approach to problem solving.