GCE AS

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WJEC Eduqas GCE AS in

ELECTRONICS

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GUIDANCE FOR TEACHING

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SUMMARY OF AMENDMENTS

Version	Description	Page number
2	Changes required due to submission of NEA switching to electronic upload: Section ‘Component 2’ replaced and marked exemplar removed as exemplars are now available on Portal.	18-20

Contents

Introduction

The WJEC Eduqas AS in Electronics provides a broad, coherent, satisfying and worthwhile course of study. It encourages learners to develop confidence in, and a positive attitude towards, electronics and to recognise its importance in their own lives and in today's technological society.

The WJEC Eduqas AS in Electronics will ensure that learners have the electronic and mathematical knowledge and electronic engineering skills to solve problems. This should enable learners to appreciate how many problems in society can be tackled by the application of the scientific ideas in the field of electronics using engineering processes. The scope and nature of the learner's study should be coherent and practical. The practical work enables learners to see the theoretical knowledge contained in the specification in action and to gain greater understanding of the knowledge in a practical context.

Studying WJEC Eduqas AS in Electronics enables learners to:

- develop essential scientific knowledge and conceptual understanding of the behaviour of electrical/electronic circuits
- develop and demonstrate a deep understanding of the nature, processes and methods of electronics as an engineering discipline
- develop competence and confidence in a variety of practical, mathematical and problem solving skills
- develop and learn how to apply observational, practical and problem-solving skills in the identification of needs in the world around them and the testing of proposed electronic solutions
- develop and learn how to apply creative and evaluative skills in the development and assessment of electronic systems to solve problems
- develop their interest in electronics, including developing an interest in further study and careers associated with electronics.

Learners should be prepared to apply the knowledge, understanding and skills specified in a range of theoretical, practical, industrial and environmental contexts. Learners' understanding of the connections between the different elements of the subject and their holistic understanding of the subject is a requirement of this specification. In practice, this means that learners will be required to draw together different areas of knowledge, skills and understanding from across the full course of study.

Practical work is an intrinsic part of this specification. It is vitally important in developing a conceptual understanding of many topics and it enhances the experience and enjoyment of electronics. The practical skills developed are also fundamentally important to learners going on to further study in electronics, engineering and related subjects, and are transferable to many careers.

Additional ways that WJEC Eduqas can offer support:

- specimen assessment materials and mark schemes
- face-to-face CPD events
- examiners' reports on each question paper
- free access to past question papers and mark schemes via the secure website
- free access to question bank
- direct access to the subject officer
- free eBook resources
- free online resources
- exam results analysis
- online examination review.

Aims of the Guidance for Teaching

The principal aim of the Guidance for Teaching is to support teachers in the delivery of the new **WJEC Eduqas AS in Electronics** specification and to offer guidance on the requirements of the qualification and the assessment process.

The guide is **not intended as a comprehensive reference**, but as support for professional teachers to develop stimulating and exciting courses tailored to the needs and skills of their own learners in their particular institutions. In addition, it must not be used instead of the specification, but must be used to support the delivery of it.

Possible Delivery Model

Component 1 should be taught alongside practical work and Component 2 (NEA). Practical work should be taught as an integral part of the theory. The first four sections can be taught when required in the other sections of Component 1.

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<tr><td rowspan="4">12</td><td colspan="7">Component 1</td></tr>
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Assessment Objectives

	Objective
AO1	Demonstrate knowledge and understanding of the: (1a) ideas of electronics (1b) techniques and procedures of electronics.
AO2	Apply knowledge and understanding of the: (1a) ideas of electronics (1b) techniques and procedures of electronics.
AO3	Analyse problems and design: (1a) design electronic systems to address identified needs (1b) build electronic systems to address identified needs (only assessed in NEA) (1c) test electronic systems to address identified needs (only assessed in NEA) (1d) evaluate electronic systems to address identified needs.

The following questions in the sample assessment materials exemplify the WJEC interpretation of each of the assessment objectives:

AO1: demonstrate knowledge and understanding of the ideas, techniques and procedures of electronics.

Component 1 Q1(a) asks learners to define capacitance. This question is based upon statement 1.2(f) define capacitance … of the specification. Since the question requires learners to demonstrate their knowledge of capacitance in a familiar context, it is classed as AO1 strand 1a. This is also classed as knowledge in isolation.

Component 1 Q3(a) asks learners to give simplify expressions. This question is based on the statement 1.6(d) simplify logic systems using Boolean algebra… and statement 1.6(f) use de Morgan's theorem to simplify a logic system of the specification. Since the question requires learners to demonstrate their knowledge of the algebra simplification techniques, this is classed as AO1 strand 1b.

AO2: apply knowledge and understanding of the ideas, techniques and procedures of electronics.

Component 1 Q6(c) asks learners to explain what happens to the output voltage when a light beam is broken to the input of a sub-system. This question is based on the statement 1.2(a) use standard circuit symbols to interpret… circuit diagrams; statement 1.3(a) describe the use of photosensitive devices… in a voltage divider circuit to provide analogue signals; statement 1.3(b) … interpret and use characteristic curves for the above devices and statement 1.7(d) recall how the output state of a comparator depends upon the relative values of the two input states and design comparator switching circuits. This requires the application of ideas in unfamiliar context, it is classed as AO2 strand 1a and it also requires the application of procedures to determine the action of the comparator and is hence AO2 strand 1b.

AO3: analyse problems and design, build, test and evaluate electronic systems to address identified needs. Only stands 1a and 1d can be assessed on written papers (all strands will be assessed in the NEA).

Component 1 Q9(a) requires learners to design a circuit for a non-inverting amplifier based on an op-amp with some set details. AO3 1a requires learners to analyse problems and design electronic systems to address identified needs. This is therefore classed as AO3 strand 1a.

Component 1 Q7(a) requires learners to evaluate why feedback is used in voltage amplifiers built from op-amps used in audio an amplifier system. AO3 1d requires learners to analyse problems and evaluate electronic systems to address identified needs. This requires the learners to evaluate the electronic systems and hence classed as AO3 strand 1d.

Component 1

1. SYSTEM SYNTHESIS

Spec Statement		Comment
(a)	recognise that electronic systems consist of inputs, processes and outputs and may include feedback	
(b)	represent complex systems in terms of sub-systems	
(c)	analyse and design system diagrams	Design, analyse or modify a block diagram of a system.

2. DC ELECTRICAL CIRCUITS

Spec Statement		Comment
(a)	use standard circuit symbols to interpret and draw circuit diagrams	
(b)	define resistance R, as $R=\frac{V}{I}$, describe the effects of resistors in circuits and be able to use the equation $V = IR$	
(c)	use the equations to calculate the effective resistance of combinations of resistors connected in series and/or parallel $R = R_1 + R_2 + \ldots$ resistors in series $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$ resistors in parallel $R = \frac{R_1 R_2}{R_1 + R_2}$ two resistors in parallel	
(d)	analyse circuits (based on a single power supply) using Kirchhoff's laws and Thevenin's theorem	Use Thevenin's theorem to draw equivalent circuits for a voltage divider consisting of two resistors or a sensing circuit and hence predict the effect of loading.
(e)	select appropriate values of resistor from the E24 series	
(f)	define capacitance, C as $C = \frac{Q}{V}$	
(g)	explain how capacitors can be used to form the basis of timing circuits and use the equations to calculate the effective capacitance of capacitors in series and parallel $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$ capacitors in series $C = \frac{C_1 C_2}{C_1 + C_2}$ two capacitors in series $C = C_1 + C_2 + \ldots$ capacitors in parallel	

3. INPUT AND OUTPUT SUB-SYSTEMS

Spec Statement		Comment
(a)	describe the use of photosensitive devices, ntc thermistors and switches in a voltage divider circuit to provide analogue signals	"Photosensitive devices" include the LDR and the phototransistor. Appreciate that the current through a voltage divider should be at least ten times that drawn from the output.
(b)	determine experimentally, interpret and use characteristic curves for the above devices	
(c)	use the equation to calculate output voltages for a voltage divider $V_{OUT} = \frac{R_2}{R_1 + R_2} V_{IN}$	Recall that this equation assumes that no current is drawn from the output of the voltage divider.
(d)	explain how a Schmitt inverter can be used to provide signal conditioning	Describe the benefits of fast rise time for a signal.
(e)	design and construct sensing circuits with photosensitive devices, ntc thermistors and switches	The treatment will be limited to voltage divider circuits.
(f)	describe the use of a buzzer, a loudspeaker, a motor, a solenoid, a relay; a mechanical actuator (servo) and a seven-segment display in a system	

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4. ENERGY AND POWER

Spec Statement		Comment
(a)	recall that power is defined as the rate of doing work and use the relationship between energy, power and time $E = Pt$	
(b)	select and apply the rms voltage and current equations, $V_{rms} = \frac{V_0}{\sqrt{2}}$ and $I_{rms} = \frac{I_0}{\sqrt{2}}$, including power calculations in a sinusoidal AC circuit	
(c)	use the power relationships $P = VI = I^2R = \frac{V^2}{R}$ for AC and DC circuits	AC power calculations will not involve power factor.

5. SEMICONDUCTOR COMPONENTS

Spec Statement		Comment
(a)	describe the use of light-emitting diodes, silicon diodes and zener diodes in electronic systems	Realise that the forward voltage for a silicon diode is approximately 0.7 V when the diode is conducting. Indicate the zener voltage V_Z and holding current $I_{Z(MIN)}$ on the characteristic graphs.
(b)	carry out relevant calculations on circuits containing these devices using data, including interpreting and sketching characteristic graphs including calculating series resistor values for LED circuits and selecting appropriate zener diodes	Select zener diodes, given data on zener voltage and power rating.
(c)	describe the use of n-channel enhancement mode MOSFETs and npn bipolar transistors in switching circuits, using data to select suitable components for circuits	Describe the switching action of a npn transistor by making reference to its voltage transfer characteristic. Know that V_{BE} depends on I_B and is approximately 0.7 V when the transistor is conducting. Recognise that MOSFETs have a very high input resistance. Understand that r_{DS} decreases from a very high value to a very low value as V_{GS} is increased and is at a minimum value, called r_{DSon}, at saturation. Compare the performance of MOSFET and transistor switches. State the need for diode protection for transistors and MOSFETs.
(d)	define g_M as the gradient of an I_D-V_{GS} graph	
(e)	select and apply the equations $I_C = h_{FE} I_B$ bipolar transistor $I_D = g_M (V_{GS} - 3)$ MOSFET $P = I_D^2 r_{DSon}$ power dissipated in a MOSFET	Recall conditions necessary for these equations to be valid. Understand that an enhancement mode MOSFET does not conduct until the gate threshold voltage (V_{GSth}) is reached. In calculations V_{GSth} is assumed to be 3 V.

6. LOGIC SYSTEMS

	Spec Statement	Comment
(a)	identify and use NOT; 2 and 3-input AND, NAND, OR, NOR, XNOR and XOR logic gates	The 3-input XOR gate is treated as two 2-input XOR gates cascaded together, i.e. the first two signals are fed into a 2-input XOR gate, with its output fed into a second 2-input XOR gate together with the third signal. The resulting truth table is that of a 74LVC1G386 logic gate. The 3-input XNOR is considered as the inverse of this 3-input XOR gate. Draw and interpret graphs of the output signal from a logic gate given the input signals.
(b)	construct, recognise and use truth tables for these gates and simple combinations of them	Recall use of mechanical switches with resistors and pulse generators to provide inputs for logic systems. Recall use of an LED and resistor to indicate the output state of a logic system.
(c)	use combinations of one or more types of gate to perform other logic functions including NAND-gate simplification	Show how the following logic gates can be made up from NAND gates: NOT, 2 input AND, OR and NOR gates. Implement a logic system using only NAND gates and identify redundant gates in such a system.
(d)	simplify logic systems using Boolean algebra, Karnaugh maps and multiplexers	Draw a Karnaugh map for a logic system with up to four inputs and use it to minimise the number of gates required. Design and analyse a system with up to four inputs using a multiplexer as a programmable logic system.
(e)	design and construct circuits containing logic gates, with consideration to sourcing, sinking, pull-up and pull-down resistors	Translate a design specification into a truth table. Design and test a system, with up to four inputs from a specification. Generate the Boolean expression for a system [with up to four inputs] from a logic diagram or a truth table.
(f)	use de Morgan's theorem to simplify a logic system $\overline{A+B}=\overline{A}.\overline{B}$ $\overline{A.B}=\overline{A}+\overline{B}$	Apply de Morgan's theorem to simplify a logic system having up to three inputs.
(g)	use the Boolean identities $A.1=A,\ A.0=0,\ A.A=A,$ $A.\overline{A}=0,\ A+1=1,\ A+0=A,$ $A+A=A,\ A+\overline{A}=1$	
(h)	select and apply the Boolean identities $A+\overline{A}.B=A+B$ $A.B+A=A.(B+1)=A$	

7. OPERATIONAL AMPLIFIERS

	Spec Statement	Comment
(a)	recall the characteristics of an ideal op-amp and be aware that these may be different for a typical op-amp	Recall the following characteristics of an ideal op-amp: • infinite open loop gain • infinite input impedance • zero output impedance • infinite slew-rate • infinite common-mode rejection ratio.
(b)	recognise that the voltage difference between the two inputs of an op-amp with negative feedback is virtually zero (resulting in a virtual earth if one of the inputs is at 0 V) provided the output is not saturated	
(c)	explain the use of an op-amp in a comparator circuit	
(d)	recall how the output state of a comparator depends upon the relative values of the two input states and design comparator switching circuits	
(e)	recall and apply the conditions for the balance of a bridge circuit	A comparator circuit often receives input signals from the centres of two voltage dividers, making up a bridge circuit.
(f)	define the voltage gain, G, of an amplifier as $G = \frac{V_{OUT}}{V_{IN}}$ and be able to select and apply the equation	
(g)	draw, recognise and recall the characteristics of the following op-amp circuits, • non-inverting amplifier • inverting amplifier • summing amplifier • comparator • voltage follower circuit	Draw and interpret response graphs of inverting and non-inverting amplifiers for AC and DC input signals.
(h)	select and apply the following equations for op-amp circuits: non-inverting amplifier $G = 1 + \frac{R_F}{R_1}$ inverting amplifier $G = -\frac{R_F}{R_{IN}}$ summing amplifier $V_{OUT} = -R_F\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + ...\right)$	

(i)	select and apply the following equations for op-amp circuits: comparator $V_{OUT} = V_S$ for $V_+ > V_-$ $V_{OUT} = -V_S$ for $V_+ < V_-$ voltage follower circuit $V_{OUT} = V_{IN}$	
(j)	relate the input impedance of an op-amp to its configuration	Recall that the input impedance of a non-inverting amplifier is equal to that of the op-amp it uses. Recall that the input impedance of an inverting amplifier is approximately equal to that of its input resistor.
(k)	recall that the bandwidth is the frequency range over which the voltage gain is greater than $\frac{1}{\sqrt{2}}$ of its maximum value and estimate this bandwidth from a frequency response curve and use the gain-bandwidth product (unity gain bandwidth) to estimate bandwidth	
(l)	design single stage amplifiers based on inverting and non-inverting voltage amplifiers to achieve a specified voltage gain or bandwidth	Applications could include using calibrated sensors to provide a dc input to a non-inverting amplifier.
(m)	explain how clipping and slew-rate can lead to distortion	Recognise clipping distortion, and describe how it can be reduced by increasing the supply voltage, reducing the gain or reducing input amplitude. Recognise slew rate distortion for a step input and a high frequency sinusoidal input.
(n)	select and apply the equations $\text{slew rate} = \frac{\Delta V_{OUT}}{\Delta t}$ definition of slew rate $\text{slew rate} = 2\pi f V_P$ minimum slew-rate for distortion of free sinusoidal signal	

8. TIMING CIRCUITS

Spec Statement		Comment
(a)	use the equation for the time constant (T) for an RC circuit: $T = RC$	
(b)	select and apply the exponential charging and discharging equations: $V_C = V_0\left(1 - e^{-\frac{t}{RC}}\right)$ for a charging capacitor $V_C = V_0 e^{-\frac{t}{RC}}$ for a discharging capacitor and use 0.69 RC as the half time and 5 RC as an approximation to estimate effective charging and discharging times	Sketch capacitor charge and discharge curves for voltage and current.
(c)	select and apply the equations $t = -RC\ln\left(1 - \frac{V_C}{V_0}\right)$ charging capacitor $t = -RC\ln\left(\frac{V_C}{V_0}\right)$ discharging capacitor	
(d)	calculate values of T, R and C for a charging / discharging capacitor by using a graph (including log graphs)	
(e)	use a RC circuit in debouncing switches	
(f)	recall the properties of monostable circuits	Recall that a monostable circuit has one stable and one unstable state.
(g)	explain the use of a monostable circuit in conjunction with a RC network in a time-delay circuit	State the advantage of adding a buffer to the output of the RC network.
(h)	recall the properties of an astable circuit and its use as a pulse generator	Recall that an astable circuit has two unstable states.

(i)	explain the operation, draw and design the circuit of an astable circuit based upon a Schmitt trigger and select and apply the approximation $f \approx \frac{1}{RC}$, where f is the operating frequency	
(j)	draw and analyse circuits for monostable and astable circuits based upon a 555 timer IC, and select and apply the following equations to calculate their characteristics including pulse duration, frequency, mark-space ratio $f = \frac{1}{T}$ frequency, period relationship $T = 1.1RC$ 555 monostable $t_H = 0.7(R_1 + R_2)C$ mark time of a 555 astable circuit $t_L = 0.7R_2C$ space time of a 555 astable circuit $f = \frac{1.44}{(R_1 + 2R_2)C}$ frequency of a 555 astable circuit $\frac{T_{ON}}{T_{OFF}} = \frac{R_1 + R_2}{R_2}$ mark/space ratio of an astable	Draw and interpret output graphs for monostable and astable circuits. T is the time period.

9. SEQUENTIAL LOGIC SYSTEMS

Spec Statement		Comment
(a)	design and describe the action of a Set-Reset ($\overline{SR}$) latch based on NAND gates	Use a truth table sequence to describe the action of the bistable.
(b)	describe the significance of propagation delays in sequential systems	
(c)	construct and use timing diagrams to explain the operation of sequential logic circuits	
(d)	recall the characteristics and uses of the inputs and outputs of D-type flip-flops for: • transition gates • frequency divider circuits • asynchronous counters	Draw a timing diagram to illustrate how a transition gate can be used to produce edge-triggering. Design a transition gate to a given specification. Design up and down counters based on D-type flip-flops. (up to 4-bit) Design 4-bit modulo-n counters and binary coded decimal (BCD) counters and draw the resulting timing diagrams.
(e)	design systems that use a dedicated 4-bit counter and combinational logic to produce a sequence of events	
(f)	design and analyse a 2 digit decimal counting system	Describe the use of decoders and seven-segment displays. Decoders are available integrated with BCD counters in a single IC or separately.
(g)	convert between binary, decimal, hexadecimal and binary-coded decimal (BCD) number systems	

10. MICROCONTROLLERS

Spec Statement		Comment
(a)	analyse and design flowchart programs to program microcontrollers	Questions are limited to designing a flowchart to meet a given specification, analysing a given flowchart, modifying a given flowchart or completing a template for a flowchart. Use the following operations in flowcharts: input/output, counting, branching, testing, time delay and arithmetic operations.

11. MAINS POWER SUPPLY SYSTEMS

Spec Statement		Comment
(a)	recall the use of diodes for half-wave and full wave rectification	Draw and explain the use of diodes in half-wave and full-wave bridge rectifiers. Calculate the peak value of the output voltage of half-wave and full-wave rectifiers, given the rms input voltage.
(b)	describe the effect of capacitors and loads on the output of a simple power supply	Draw graphs to show the effect of a capacitor and the effect of load resistance on ripple voltage for a simple power supply.
(c)	select and apply the ripple voltage equation $V_r = \frac{I}{f_r C}$	
(d)	design zener-regulated power supplies and draw graphs to show the effect of loading	Design a simple power supply consisting of a zener diode and current-limiting resistor connected as a voltage divider. Calculate suitable values for the current-limiting resistor and the maximum value of output current available.

Component 2

Extended system design and realisation tasks (NEA)

See sections 2.2 and 3.2 of the specification (AS/A Level Electronics) and e-Submission for information on how to upload work for moderation.

NEA task forms (available on AS/A Level Electronics under NEA) must be completed for each learner and submitted with reports. The task form gives the assessment criteria for the Component. It is also used to record learner details, details of the project and marks awarded. The task form includes a declaration that **must be signed by both the learner and the teacher**. Note that declarations must be signed by **all** learners – not just those selected for moderation.

Further guidance for the NEA is given below:

General Guidance

Learners must select their **own problem** on which their project will be based. This should result in a wide range of different projects being produced by each centre.

Projects should be neither under nor over ambitious. The teacher must agree and sign off the problem on learners' tasks sheets, ensuring that it is appropriate for the ability and interests of the learner.

Circuits may be constructed on prototype board, strip board or printed circuit board. The layout and mounting of components and wiring should be neat, logical and allow testing and fault finding of the system.

Learners should progress through the following 4 stages and produce reports in 4 sections corresponding to these (see later section on Project Reports).

System Planning

When a problem has been chosen, learners should produce a design specification in both qualitative and quantitative terms (typically at least 3 of each), and including 3 or more detailed realistic **measurable** parameters (2 or more for Task 3). These could include parameters such as temperature ranges, pressure etc. needed for their chosen application.

Specifications should contain realistic and **justified** numerical parameters, against which the performance of the final circuit can be judged. Parameters should be based on the required operation of the system. Parameters such as maximum current, supply voltage or component properties would **not** be valid, without justification.

System Development
The system should be developed as a number of sub-systems, individually tested and evaluated before being incorporated into the complete system. All test results should be recorded as tables and/or graphs, where appropriate. Photographs of test equipment showing measurement or simulations can also be included as an effective way of showing evidence of testing.

For Task 1 and 2 projects that include microcontrollers programmed using flowcharts, a subroutine / procedure can be considered as **one** sub-system as long as a specification is provided for it and it can be tested and evaluated in a similar fashion to a component based sub-system.

System Realisation
The complete system should be fully tested and test results recorded. When necessary, learners should attempt to make any modifications needed for their circuit to meet the specification and produce a final set of performance parameters for the completed system.

A photograph of the finished circuit must be included in this section. No other form of evidence (e.g. videos) should be included.

Evaluation
Learners should, by referring to their test results, evaluate the final system against the design specification and suggest further developments. Further developments should relate to improving the operation of the system rather than superficial changes to circuits.

Project reports
Reports should be presented in the 4 sections described above: System planning, System Development, System Realisation and Evaluation.

Learners should aim to ensure that evidence for each of the assessment criteria (given on the task form) is presented in the appropriate section of each report.

Assessment
The NEA is internally marked by teachers using the assessment criteria given on the task form. The criteria descriptor which best matches the candidate's work should be identified and awarded. Criteria partially achieved can be taken into account when determining the mark awarded.

The **criteria achieved, partially achieved** and **not achieved** and **marks awarded** for each section of each task, **must be clearly recorded on the candidates' task form** – see exemplars with completed task forms on Portal.

Marks can only be awarded when there is supporting evidence. **Learners' reports must be annotated to show where each of the criteria have been achieved and awarded** – see exemplars on Portal. It is helpful if teachers comment on the extent to which the circuit worked and met the specification.

Marks can only be awarded for learners' own work. Any assistance that goes beyond the guidance given in the specification must be recorded on the task form and taken into account when marking. The centre is responsible for carrying out internal standardisation where two or more teachers have been involved in the marking of the work submitted.

Submission of moderation samples

Once all learners' work has been marked, the marks must be entered into the online IAMIS system and sent electronically to WJEC. The online system will then select and return the candidates identified for the moderation sample.

The moderation samples must be in electronic form (scanned if necessary) and uploaded to the IAMIS system. Each sample must be uploaded as a single pdf document with the candidate number included as part of the filename. Guidance can be found on e-Submission.

Each sample must include:

- a completed task form (signed by both the candidate and teacher, showing which criteria have been achieved, the marks awarded for each section and the total marks)
- the 3 task reports, each in 4 sections (see above), clearly identified and annotated by teachers to show where the assessment criteria awarded, have been achieved
- photographic evidence of the completed physical systems.

Further specific guidance

Task 3

This task required learners to produce a program using flowchart programming and to run and test the program on a microcontroller IC. Programming in assembly language (or any other programming language) is not required for AS.

Suitable systems to use for this task include Circuit Wizard and PICAXE.

Programs can be developed and initial testing carried out using a development board such as Arduino **but the final program must be run by a microcontroller IC**, mounted on a circuit board.

The report must include the program flowchart, a description of how the program works, details of testing of the program and a photograph of the final circuit with microcontroller IC mounted.