EDUCATION & TRAINING FOUNDATION

T-LEVELS
THE NEXT LEVEL QUALIFICATION

Formative assessment materials for T Levels in Engineering and Manufacturing

et-foundation.co.uk

[Delivery Partner] is delivering this programme on behalf of the Education and Training Foundation.
This programme is funded by the Department for Education.

Introduction

This resource has been developed to support providers delivering T Levels in Engineering and Manufacturing. In particular, it relates to the core content and prepares learners for the core exams.

These materials are designed to support formative, not summative, assessment. Summative assessment is used to accredit learning, for example, by awarding a grade or qualification. Formative assessment is used to support learning and is also known as assessment for learning. Formative assessment should be designed to determine where learners are in their learning journey and whether they are progressing at the level expected at a particular milestone. If they are not, then formative assessment focuses on providing learners with feedback on what they have or have not achieved and provides guidance and activities to support further learning. Formative and summative assessments may use the same materials, but the response is different.

This resource has two sections:

1. Formative assessment questions

There are a range of questions covering the following core elements:

- Essential maths for engineering and manufacturing (core elements 4.1, 4.2).
- Essential science for engineering and manufacturing (core elements 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8).
- Materials and their properties (core elements 6.1, 6.2, 6.3, 6.4, 6.5, 6.6).
- Mechanical principles (core elements 7.1, 7.2).
- Electrical and electronic principles (core element 8.1).
- Mechatronics (core elements 9.1, 9.2, 9.3).

There are questions that address the following two assessment objectives:
AO2 – Apply knowledge and understanding of contexts, concepts, theories and principles to different situations and contexts.
AO3 – Analyse and evaluate information and issues related to contexts, concepts, theories and principles to make informed judgements.

Each question specifies:

- targeted content – the specification reference that the question is designed to assess
- the question itself
- indicative content – an indication of the content a learner may provide in response to the question. This section also includes a bullet point specific to the assessment objective:
    - **applied** – highlights key points that may be referred to in their application to the scenario
    - **issue** – relates to key points in the scenario that should be the focus of the response
- a model answer – an exemplar response that clearly demonstrates how it meets the targeted content and assessment objective.

When an awarding organisation produces summative assessment materials, it is essential they lead to valid and reliable outcomes. This means that learners are

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

assessed on what they should be assessed on (validity) and the evidence is marked in a standardised way (reliability). This is why awarding organisations produce mark schemes – so examiners can apply the marking in a consistent way and no learner is penalised because of who is marking their work.

Mark schemes are not appropriate for formative assessment in which learners do not benefit from being given a mark. Instead, they need narrative feedback and commentary. This may come from their tutor, peers or through self-reflection. Research shows that if learners are given a mark, they do not take note of the feedback. It is essential they take on board the feedback they receive through formative assessment. Therefore, these materials do not include a mark scheme as they are not designed to be used for summative assessment. The model answers are intended to be used to support formative assessment.

2. Developmental activities

Developmental activities provided here are linked to the following elements covered in the T Levels in Engineering and Manufacturing common core content for exam paper one:

1. Essential maths for engineering and manufacturing
2. Essential science for engineering and manufacturing
3. Materials and their properties
4. Mechanical principles
5. Electrical and electronic principles
6. Mechatronics

They are designed to help learners consolidate their learning by bridging any knowledge or skills gaps identified through their answers to the formative assessment questions.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Section one

Formative assessment questions

AO2 questions

AO2 Apply knowledge and understanding to different situations and contexts
This refers to the ability to use and apply knowledge and understanding of processes, procedures, generalisations, principles and theories to specified, concrete situations. AO2 is about being able to take the understanding of generalities (AO1b) and apply them to specific situations. It is more granular than the more extended synthesis/creation that may respond to an analysis (AO3a) of a complex holistic situation/brief.

Source: City & Guilds T Level Qualification in Engineering and Manufacturing specification, version 1.1.

Targeted content
4.1 Applied mathematical theory in engineering applications.

Question
A manufacturer is making a can to hold 250ml of energy drink. The production cost of the can is dependent on its radius, $x$cm. For practical reasons, the radius must be between 2·5cm and 4·5cm.

The production engineer has worked out a formula for calculating the cost:
$C = x^3 - 5x^2 + 3x + 16 \qquad 2{\cdot}5 \leq x \leq 4{\cdot}5.$

Justify the selection of the radius to achieve the minimum production cost.

Indicative content
- Differentiation rules for polynomial equations
- Maximum and minimum values
- Derivatives
- Boundary conditions
- Quadratic equations, quadratic formula
- Sketches (e.g. graphs) for problem-solving
- **Applied** – work out the minimum product cost.

Model answer
The points at which a function has its maximum or minimum values are points at which its derivative is equal to 0.

Take the derivative of the cost function and make it equal to 0.

$$C = x^3 - 5x^2 + 3x + 16$$

$$\frac{dC}{dx} = 3x^2 - 10x + 3 = 0$$

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Solve the quadratic equation using the quadratic formula.

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-(-10) \pm \sqrt{(-10)^2 - 4 \times 3 \times 3}}{2 \times 3}$$

Solution one: $x_1 = 0.33$ 0.33cm is not in the range of 2.5 and 4.5, so it is not a valid answer.

Solution two: $x_2 = 3$ 3cm is the valid answer.

Substitute 3 into the cost function.

$$C = 3^3 - 5 \times 3^2 + 3 \times 3 + 16 = 7$$

At the boundary conditions $x = 2.5$ and $x = 4.5$, the costs are calculated by substitution.

At $x = 2.5$, the cost is 7.875. And at $x = 4.5$, the cost is 19.375. Both of these give cost values greater than 7.

The can radius should be designed as 3cm to achieve the minimum production cost.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
4.1 Applied mathematical theory in engineering applications.

Question
Company A is developing a new product. The costs incurred during production include the fixed and variable costs.

Fixed costs are £150,000.

The variable cost per unit is £3.50.

The proposed selling price for the new product is £5 per unit.

The costing engineer has worked out the cost (C) equation as

$$C = 3.5x + 150{,}000$$

x is the number of products.

Work out the minimum number of products that must be produced for the company to make a profit.

Indicative content
- Linear equations for cost and revenue
- Solving simultaneous equations
- **Applied** – the breakeven point for the minimum number of products.

Model answer
When the revenue generated is equal to the cost, the breakeven point will be reached. The company will make a profit by passing the breakeven point.

Revenue (R) is the total amount of money generated by selling the product, which can be formulated as selling price x number of units sold.

In this question it is

$$R = 5x$$

Solving the following equations:

$$\begin{cases} C = 3.5x + 150{,}000 \\ R = 5x \end{cases}$$

$x = 100{,}000$

The minimum production volume is 100,000 for the company to start to make a profit.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
4.1 Applied mathematical theory in engineering applications.

Question
A manufacturer is designing a lifting solution for its factory shop floor.

There will be a crane to lift the load. This will be manoeuvred by a rod that extends from a cylinder. When the cylinder rod extends, the boom will start to lift.

This is shown in figure x.

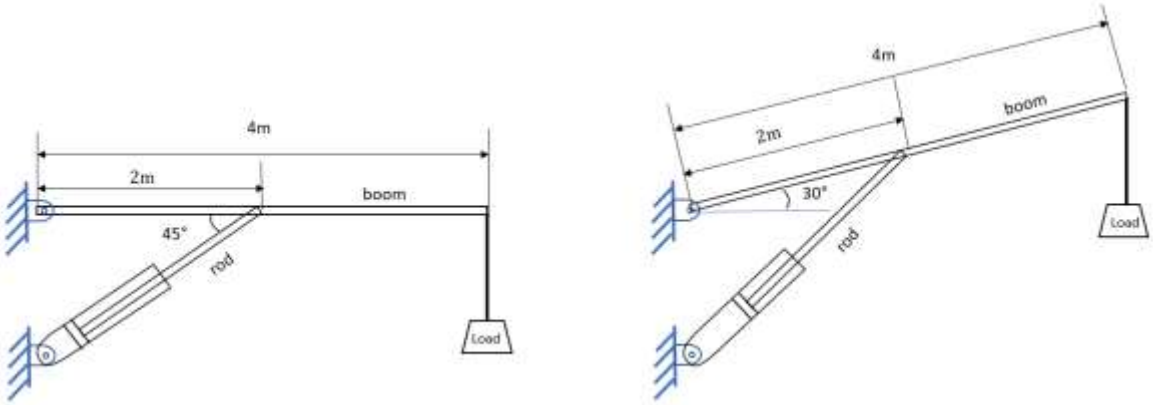


Figure x

The rod, when extended, must enable the boom to reach an inclined angle of 30° to the horizontal so the load can meet the minimum required clearance.

Work out the required extension of the rod.

Indicative content
- Different types of triangles formed
- Trigonometric ratios
- Sine/cosine rules
- Equations
- **Applied** – length of a rod to achieve a required angle to the horizontal.

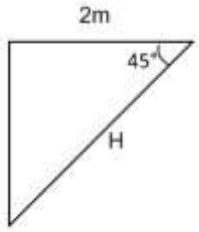
Model answer
The length of the cylinder rod at a 45° angle is calculated using trigonometric ratios (SOH/CAH/TOA) as it is a right-angled triangle. It is also an isosceles triangle.

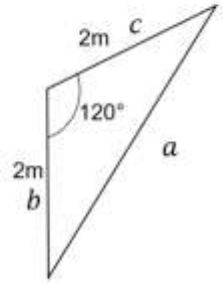
The ratio is CAH.
$\cos(45°) = \frac{2}{H}$

Rearrange the equation to calculate the length of cylinder rod $H = \frac{2}{\cos(45°)} = 2.828m$

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

If the boom is lifted to the 30° inclined angle, the triangle will become an obtuse-angled triangle but stay as an isosceles triangle, as shown below.





If the triangle is not right-angled, and there is not a matching side-angle pair, the cosine rule is needed.

$$a^2 = b^2 + c^2 - 2bc\cos A$$

$$a^2 = 2^2 + 2^2 - 2 \times 2 \times 2 \times \cos(120°)$$
$$a = \sqrt{12} = 3.464m$$

$$3.464 - 2.828 \; = \; 0.636m$$

Therefore, the rod must extend 0.636m for the boom to have a 30° inclined angle.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
4.2 Number systems used in engineering and manufacturing.

Question
An engineer is running diagnostics on a recently purchased machine. The machine console displays a binary error code 1001 1101. To find a remedy for this binary error code, the engineer must input the error code, or its equivalent, into a diagnostic tool. The diagnostic tool is quite old and only accepts hexadecimal codes.

Find the hexadecimal code the engineer should input in the diagnostic tool.

Indicative content
- Binary number
- Decimal number
- Hexadecimal number
- 4-bit
- 8-bit
- Convert
- Number weight
- **Applied** – codes to input in a diagnostic tool.

Model answer
The engineer would have to convert the error code from a binary number to a hexadecimal number. This conversion should happen in two stages.

Stage one will involve converting the binary number to a decimal number.
The 8-bit binary code will be split into two 4-bit binary numbers.

Converting 1001 to decimal requires multiplying each digit by its weight and adding the results.
$(1 \times 2^3) + (0 \times 2^2) + (0 \times 2^1) + (1 \times 2^0)$
$8 + 0 + 0 + 1 = 9$

Therefore, binary number 1001 is equivalent to decimal number 9.

Converting 1101 to decimal requires multiplying each digit by its weight and adding the results.
$(1 \times 2^3) + (1 \times 2^2) + (0 \times 2^1) + (1 \times 2^0)$
$8 + 4 + 0 + 1 = 13$

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Therefore, binary number 1101 is equivalent to decimal number 13.

Stage two will involve converting the decimal number to a hexadecimal number.

Any decimal number less than 16 can be directly converted to hexadecimal.

Decimal number 9 is equivalent to hexadecimal number 9.

Decimal number 13 is equivalent to hexadecimal number D.

Therefore, binary code, 1001 1101, is equivalent to hexadecimal number 9D.

This means the engineer would have to input 9D into the diagnostic tool.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
4.2 Number systems used in engineering and manufacturing.

Question
A customer has asked a printing factory to print off a batch of coloured packages. They have provided the hexadecimal colour code #DD12F0.

Hexadecimal colour codes start with a hashtag (#) and are followed by six letters or numbers. The first pair of letters/numbers is referring to red, while the second and third pairs are for green and blue respectively.

The factory system only uses codes based on the decimal number system.

Find the decimal number code that should be used for the printing machine.

Indicative content
- Hexadecimal number system
- Decimal number system
- **Applied** – convert hexadecimal numbers to decimal numbers for the colour printing machine.

Model answer
The first pair of digits are DD. These are converted to the decimal number system.

$(DD)_{16}$

$= 13 \times 16^1 + 13 \times 16^0$

$= 208 + 13$

$= (221)_{10}$

The second pair of digits are 12. These are converted to the decimal number system.

$(12)_{16}$

$= 1 \times 16^1 + 2 \times 16^0$

$= 16 + 2$

$= (18)_{10}$

The third pair of digits are F0. These are converted to the decimal number system.

$(F0)_{16}$

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

$= 15 \times 16^1 + 0 \times 16^0$

$= 240 + 0$

$= (240)_{10}$

Therefore, the decimal number code for the required colour is (221, 18, 240).

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.1 Units of measurement used in engineering.

Question
An aircraft engineer wants to buy sheet aluminium to cover 20m^2 of a recently designed aircraft wing surface. The engineer has found a supplier that sells the required aluminium sheets at £65.50 per ft^2. They have a budget of £14,000.

1m is equivalent to 3.281ft.

Work out if there is enough budget to pay for the aluminium.

Indicative content
- Conversion of m^2 to ft^2
- Conversion of ft^2 to m^2
- Conversion of m to ft
- Conversion of ft to m
- Surface area
- Price per ft^2
- Price per m^2
- **Applied** – cost of aluminium to cover the surface of an aircraft wing.

Model answer
The engineer is going to first convert the surface area that is m^2 to ft^2.
1m = 3.281ft
Therefore,
$1m^2 = (3.281^2)ft^2$
This means,
$20m^2 = 20 \times (3.281^2)ft^2$
$20m^2 = 215.3ft^2$

The engineer needs aluminium to cover $215.3ft^2$.
$1ft^2$ costs £65.50
This means,
$215.3ft^2$ will cost,
215.3 x £65.50 = £14,102.15

Therefore, the engineer with a budget of £14,000 would not have enough funds to buy the aluminium.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.2 Vector and co-ordinate measuring systems.

Question
An engineer testing the navigation system of a mobile robot places it at the centre of a testing arena laid out like a grid co-ordinate system, as shown in figure x.

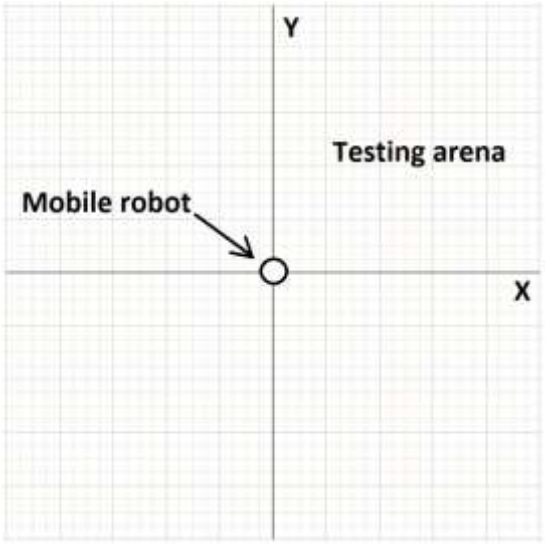


Figure x

The mobile robot's navigation is synchronised with the arena's co-ordinate system that uses a Cartesian co-ordinate system. The mobile robot's navigation instructions can only be accepted as polar co-ordinates.

Using the robot's control panel, the engineer programs the mobile robot to move to position (5, 65^o) and then stop. During the test, the engineer sees the mobile robot move to arena co-ordinates (2.1, 4.5) and then stop.

Work out whether the mobile robot can move to the position programmed into its navigation system.

Indicative content
- Cartesian co-ordinates
- Polar co-ordinates
- Converting between polar and Cartesian co-ordinates
- **Applied** – mobile robot navigating to a programmed position.

Model answer
The robot received the position information as polar co-ordinates (r, θ).
This needs to be converted to Cartesian co-ordinates (X, Y).

$X = 5 \cos 65^o = 2.11$
$Y = 5 \sin 65^o = 4.53$

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

This means the mobile robot was instructed to move to arena co-ordinates (2.11, 4.53).

The engineer saw the mobile robot move to arena co-ordinates (2.1, 4.5), which means the mobile robot is capable of navigating to programmed positions.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.3 Scientific methods and approaches to scientific inquiry and research.

Question
An engineer is testing a newly-designed electric motor to work out a suitable speed the motor can run at without overheating. The test involves running a loaded motor at different speeds while monitoring the internal temperature. The results are shown in table x.

Motor speed (rpm)	Temperature (°C)
100	50
200	50
300	200
400	220
500	240

Table x

The engineer concludes from the results that the recommended maximum speed of the loaded electric motor should be 200rpm.

Explain how the engineer could have come to this conclusion.

Indicative content
- Electric motor
- Revolutions per minute (rpm)
- Temperature
- Motor speed
- Heat dissipation
- Heat destruction
- Hazard
- Fires
- **Applied** – results of a loaded motor speed test.

Model answer
The results show that when the loaded motor is run at 100rpm and 200rpm, the internal temperature is steady at 50°C. However, when the loaded motor is run at 300rpm, the internal temperature rises to 200°C which is up to four times higher. The temperature rises even more when the loaded motor is run at 400rpm and further at 500rpm. At these temperatures, the internal components of the electric motor are at risk of heat destruction. These high temperatures could also cause a hazard to any operators of the motor if the heat were to transfer to the exterior of the motor. This would explain why the engineer recommended the loaded motor maximum speed of 200rpm.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.4 Measurement equipment, techniques and principles.

Question
An engineering company has received an order to manufacture 50,000 components. Based on the customer's specification, the length of the components has the dimension of 85.00 with a tolerance of ± 0.05, measured in mm.

Explain **one** type of measuring equipment that should be used during quality checks.

Indicative content
- Precision
- Accuracy
- Measurement devices: engineering rule, calliper, micrometer, dial test indicator (DTI), co-ordinate measuring machine (CMM), no/go gauges
- Measurement device characteristics and limitations
- Component dimensions
- Tolerances
- Number of components
- **Applied** – measurement of a large sample of components to a low level of tolerance.

Model answer
Based on the tolerance requirement of ±0.05mm, the device would need an accuracy of 0.05mm to meet the specification. A calliper or micrometer may meet the accuracy requirements. However, the device will also need to be able to measure the length of 85.00mm. A micrometer will not meet this need. Callipers are easy to use and take little time to calibrate and therefore provide an efficient way to perform measurement tasks in mass production.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.4 Measurement equipment, techniques and principles.

Question
An engineering company makes a metallic part. The drawing of the part is shown in figure x.

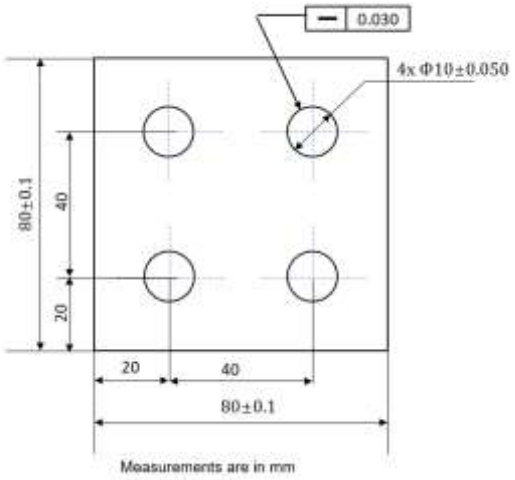


Figure x

The part needs to be fitted into a machine.

Explain why tolerances are provided in this drawing.

Indicative content
- Accuracy
- Precision
- Error
- Manufacturing process, fabrication techniques
- Accuracy limit
- Properties of materials
- Product specifications
- Specific tolerances from figure x
- Contract terms
- **Applied** – one part needs to fit into another.

Model answer
It is impossible to manufacture every product to an exact size. This has a low level of tolerance will ensure the part will fit into another part and the machine, into which it will fit, can perform as designed.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.8 Thermodynamics in engineering.

Question
A company supplies gas in two sizes of high-pressure cylinders. To meet demand in an emerging industry, a new size cylinder will be developed. The new cylinder will have a nominal volume of 5m^3 at 1 bar and 15°C.

Each cylinder will be filled with the gas at a pressure of 200 bar and at a temperature of 15°C.

Work out the internal volume of the new cylinder.

Indicative content
- Boyle's law
- Pressure (P), volume (V) and temperature (T) of gas
- Nominal and high-pressure conditions
- Unit conversion
- Temperature conversion
- **Applied** – the internal volume of a gas cylinder at a specific pressure and temperature.

Model answer
Given information is summarised below.

At the nominal condition:
P_1 = 1 bar = 100,000Pa
V_1 = 5m^3
T_1 = 15 + 273 = 288K

At the high-pressure condition
P_2 = 200 bar = 20,000,000Pa
V_2 = to be calculated
T_2 = 15 + 273 = 288K

Temperatures at both conditions are the same, therefore Boyle's law is used.

$$P_1V_1 = P_2V_2$$

Rearrange V_2 as the subject

$$V_2 = \frac{P_1V_1}{P_2}$$

Substitute

$$V_2 = \frac{100{,}000 \times 5}{20{,}000{,}000} = 0.025m^3 \ = 25L$$

The internal volume of the new cylinder will be 25L.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.8 Thermodynamics in engineering.

Question
A company needs a constant flow of hot water to meet its manufacturing requirements. Water at ambient temperature flows into a pipe inside a heat exchanger and is heated by the energy from burning gas.

After experiencing a significant drop in hot water temperature, a maintenance engineer is called and finds a limescale build-up in the water pipe.

Explain how the limescale in the water pipe affects the heat exchanger performance.

Indicative content
- Conduction
- Convection
- Conductivity
- Heat transfer efficiency
- Flow rate
- **Applied** – limescale reducing pipe size in heat exchanger.

Model answer
The heat exchanger mainly uses conduction and convection for heat transfer. The convection happens in the pipes. The limescale reduces the heat conductivity, leading to lower conduction. Limescale also reduces the size of the pipe, limiting the flow of water and therefore convection. Both of these affect the overall performance of the heat exchanger because of the limescale.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.1 Physical and mechanical properties of materials.

Question
A company that manufactures portable electric drills is in the process of selecting a material for the outer casing of its product.

Explain **two** properties the material for the outer casing should have to make sure the electric drill works well.

Indicative content
- Density
- Electrical conductivity
- Thermal conductivity
- Strength
- Fracture toughness
- Hardness
- **Applied** – portable electric drill casing properties.

Model answer
The electric drill should have low density. This is because an electric drill needs to be portable, and a low density will mean it has a lower weight and is therefore easier to move around.

The casing of the electric drill should have a low electrical conductivity. This is because a low value of electrical conductivity means the casing material does not readily conduct an electric current, offering a level of electrical insulation to anyone handling the drill, so it is safer to use.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.2 Types of material and their structures.

Question
A car manufacturing company is considering switching the material for the car body. The previous car body was made from low-carbon steel and now it is planning to use an aluminium alloy.

Explain how this change in material is likely to affect the performance of the car.

Indicative content
- Weight
- Density
- Fuel consumption
- Fuel efficiency
- **Applied** – material for a car body changed from low-carbon steel to aluminium alloy.

Model answer
Aluminium alloy is less dense than low-carbon steel and this will lead to a lighter car. The reduced weight of the car will allow it to use less fuel, allowing the car to travel further on a full tank of fuel. This reduced weight will also allow the car to reach a higher top speed as the car does not have the extra weight resisting its motion.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.3 The effects of processing techniques on materials.

Question
A steel metal working company used to supply I-beams for construction to a client, as shown in figure x.

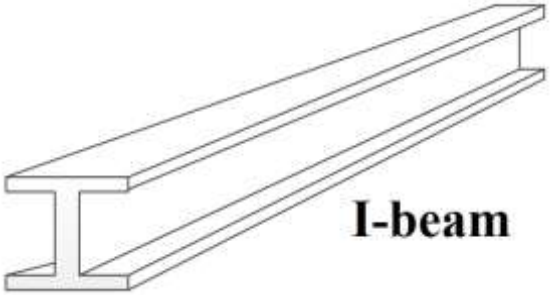


Figure x

During this period, the company used the hot rolling process on the steel products.

The company has recently won a new contract to supply steel components for a manufacturer of home appliances.

Explain **two** limitations of using hot rolling for this new contract.

Indicative content
- Malleable
- Strength
- Dimensional accuracy
- Surface finish
- Hardness
- Internal stresses
- Recrystallisation
- Hot rolling
- Cold rolling
- **Applied** – hot rolling for home appliances.

Model answer
Hot rolling is when steel is heated above the recrystallisation temperature and then passed through rollers to flatten it before it cools. This processing technique allows for the shaping of the I-beams while retaining the ductility of the steel. However, home appliances should not have ductile components and they should be rigid, so hot rolling would not be appropriate.

Hot rolling leads to the newly-shaped steel shrinking as it cools down, thereby altering the dimensional accuracy of the component. This would not be appropriate

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

in appliances as they need to fit and work together and the tolerances will be relatively small compared to I-beams.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.3 The effects of processing techniques on materials.

Question
An engineering company makes thermoplastic safety helmets using injection moulding. A pressure sensor monitors the injection pressure and mould pressure during the injection moulding process of the safety helmets. The pressure sensor is faulty.

Explain **two ways** the faulty pressure sensor could affect the properties of the safety helmets produced.

Indicative content

- Injection pressure
- Mould pressure
- Holding pressure
- Flush
- Strength
- Fracture toughness
- Purpose of safety helmets
- **Applied** – faulty pressure sensor involved in the manufacture of safety helmets.

Model answer
If the injection pressure were higher than the required value, the molten thermoplastic would spray out to the ends of the mould, immediately cooling and leading to a helmet with non-uniform mechanical characteristics. This would not provide uniform protection throughout the helmet, so it would not be fit for purpose.

A faulty pressure sensor could potentially create a situation where the operator sets the holding pressure too high. This could lead to a component that has internal stresses compromising the fracture toughness of the safety helmet. A low value of holding pressure would potentially lead to voids in the moulded safety helmet, compromising the strength of the safety helmet.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.3 The effects of processing techniques on materials.

Question
A company processes steel to make engine blocks.

Explain how using casting to process the steel makes it suitable for engine blocks.

Indicative content

- Casting process
- Grain structure
- Crystallisation
- Internal stresses
- Ductility
- Energy absorption
- **Applied** – casting for creating wires.

Model answer
Casting allows the metal to form gradually, without internal stresses. Metals are crystallised under heat, which means they form crystalline structures as they cool. So, the forces can be uniformly distributed in the metal and, as any force would be evenly distributed, it would not fracture easily.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.4 Heat treatments and surface treatments.

Question
An engineering company makes steel gears. The process involves heating steel and then forging it into the shape of the gear. When the hot forged gear is finally shaped, the steel component is immediately submerged in oil to rapidly cool it down.

Explain **one** effect of this rapid cooling process on the properties of the gear in service.

Indicative content
- Quenching
- Hardening
- Wear
- Forging
- Steel
- Grains
- Cooling
- **Applied** – fabrication of steel gears used in locomotive engines.

Model answer
This rapid cooling of the forged gear is known as quenching. It results in hardening the gear as smaller grains are formed in the steel metal. This hardening of the gear will enable it to withstand wear while in service, which will allow the gear to last longer.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.5 Causes of material failure and their prevention.

Question
A bicycle repair shop is presented with a metallic bicycle pedal that suddenly fractured recently. The only incident the bicycle owner can remember is one that happened six months ago when they collided with an uneven roadside kerb. At the time of the incident, the owner of the bicycle inspected the pedal and there was no visible damage.

Explain how the collision with an uneven roadside kerb could have led to the sudden fracture six months later.

Indicative content
- Fatigue
- Crack initiation
- Crack propagation
- Striations
- Fracture
- Stress concentrator
- **Applied** – failure of a metallic bicycle pedal following an earlier collision.

Model answer
The metallic bicycle pedal suffered fatigue failure. This is the failure of a metal because of repeated cyclic stresses.

When the cyclist collided with the uneven roadside kerb, a crack was initiated on the metallic pedal at the point of impact. As the cyclist kept on using the bicycle, the stresses applied on the pedal concentrated at the crack and led to crack propagation. This propagation continued as the months went by, causing internal striations. The propagation of the crack through the body of the metallic pedal weakened it over time.

After six months of use, the metallic pedal was weak to the point of fracturing when subjected to the same level of stresses as before. This is how a collision that happened six months ago could cause a sudden fracture of a metallic bicycle pedal.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
7.1 Principles of motion and mechanics in engineering and manufacturing systems.

Question
A company needs to drill three holes, A, B and C, in a metal component. The component is fixed by two screws onto a multi-head spindle drilling machine. Each drill head will exert a vertical force and a turning moment to the component at the same time, as shown in figure x.

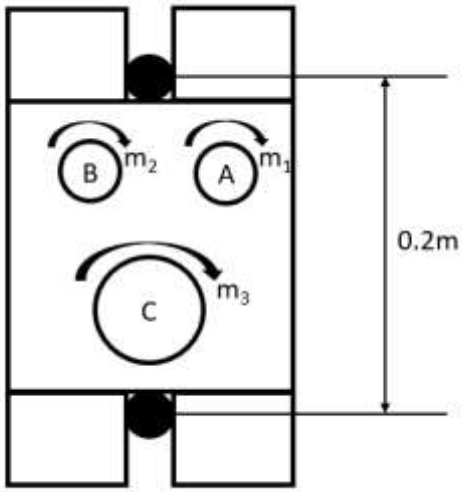


Figure x

It is given that moments for drilling holes, A and B, are $m_1 = m_2 = 12$Nm and for hole, C, is $m_3 = 20$Nm. The distance between the two fixing screws is 0.2m. Assume there is negligible friction between the component and the worktop.

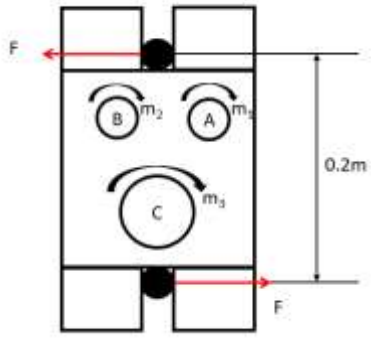
Work out the force acting on the two fixing screws.

Indicative content
- Principle of moments
- Clockwise/anti-clockwise
- Equilibrium
- Newton's third law
- Object
- Pivotal point
- Force
- **Applied** – force acting on screws given specific information.

Model answer
When the object is in equilibrium, the total moment is equal to zero, i.e. clockwise moment = anti-clockwise moment.

Take the component as the object and the position of bottom screw as the pivotal point.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.



The force exerted by the top screw is horizontal to the left, while the force exerted by the bottom screw is horizontal to the right. They are equal in magnitude.

Total clockwise moment = $m_1 + m_2 + m_3 = 12+12+20 = 44Nm$
Total anti-clockwise moment = F * L = F* 0.2 = 0.2F

44 = 0.2F
F = 220N

The forces exerted on the object by the screws are 220N. Therefore, the force exerted on each screw is 220N based on Newton's third law.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
7.2 Principles of forces and energy.

Question
An engineering team wants to improve the performance of an amateur racing car. Currently, the car can accelerate uniformly from 15m/s to 30m/s over 20s.

The engineering team has been provided with a new fuel to increase acceleration. With the new fuel it now takes 26s to travel a distance of 350m from rest at a constant acceleration.

Work out whether the new fuel has led to higher acceleration.

Indicative content
- Displacement (S)
- Velocity (U, V)
- Acceleration (A)
- Time (T)
- Equations
- **Applied** – effect of a new fuel on acceleration.

Model answer
To calculate the acceleration of the car with and without the new fuel, different equations are needed as different values are given.

Test one:

s=× u=15m/s v=30m/s a=? t=20s

$$v = u + at$$

$$a = \frac{v - u}{t} = \frac{30 - 15}{20} = 0.75m/s^2$$

Test two (with fuel):

s=350m u=0m/s v=× a=? t=26s

$$s = ut + \frac{1}{2}at^2$$

$$a = \frac{s - ut}{\frac{1}{2}t^2} = \frac{350 - 0}{\frac{1}{2}26^2} = 1.03m/s^2$$

The new fuel does lead to higher acceleration.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Question
An electrical engineer is designing a capacitor circuit for a camera flash. The engineer needs the charge across the capacitor, C1, to build up from 0 volts to 5 volts in less than 8 seconds. The draft design is shown in figure x.

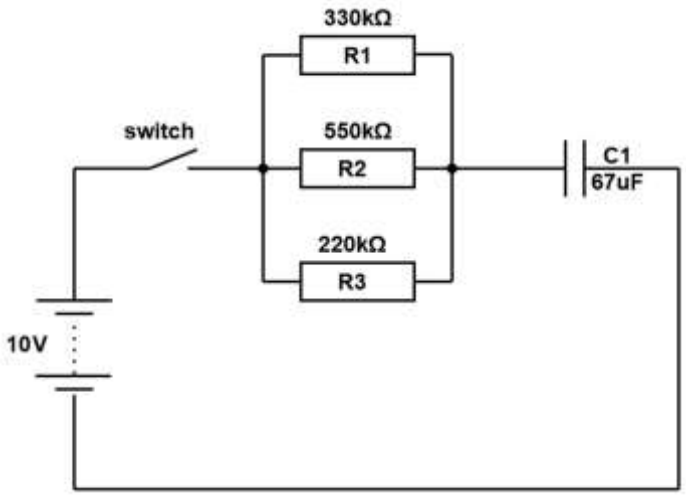


Figure x

Work out if this design would be suitable for the engineer's requirements.

Indicative content
- Total resistance
- Time constant
- Resistors in parallel
- Charging capacitor voltage
- **Applied** – creating a specific charge across a capacitor.

Model answer
The circuit analysis proceeds by first working out the total resistance present in the circuit. Resistors R1, R2 and R3 are connected in parallel and are therefore added as shown.

$$R = \left(\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right)^{-1} = \left(\frac{1}{330}+\frac{1}{550}+\frac{1}{220}\right)^{-1}$$

$$R = 106.45k\Omega$$

This means the total resistance in the circuit is 106.45kΩ.

The analysis moves on to work out the time constant of the circuit using the resistance determined previously and the capacitance shown in the diagram.

$$\tau = CR = (67 \times 10^{-6})\,(106.45 \times 10^{3}) = 7.13s$$

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

The time constant is now determined to be 7.13s.

The analysis moves on to work out the voltage across the capacitor after 8 seconds have elapsed.

$$V_c = V_0\left(1 - e^{-t/\tau}\right)$$

$$V_c = 10\left(1 - e^{-8/7.13}\right)$$

$$V_c = 6.7V$$

This means that after 8 seconds have elapsed, the voltage across the capacitor is 6.7V. Therefore, the circuit presented above is capable of charging to 5V in less than 8 seconds.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Question
A circuit repair technician is in the process of running diagnostics on a faulty electronic circuit for a printer. Under normal working conditions, charge is supposed to build across the capacitor from 0 volts to 9 volts in less than 15 seconds. Figure x shows the design of the circuit.

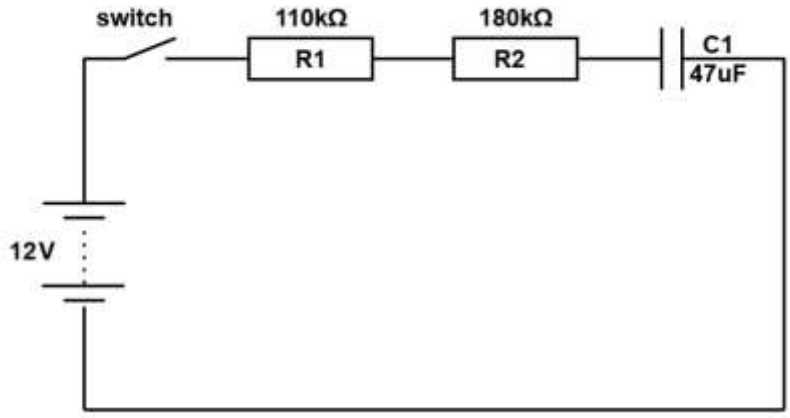


Figure x

Explain **two** characteristics of the circuit that could be changed to achieve the requirements.

Indicative content

- Switch
- DC power supply
- Resistors
- Resistors in series
- Charging capacitor voltage
- Capacitors
- **Applied** – characteristics of a faulty circuit.

Model answer
As the charge needs to be built up in 15 seconds, one of the problems with the circuit could be that it is taking longer. Charging time can be reduced by increasing the power supply voltage. The higher the voltage, the higher the current and the quicker the charge would build up. Increasing the voltage of the DC power supply would therefore achieve this.

Reducing the resistance in the circuit would allow the current to flow faster. This means the charge would be delivered in the 15 seconds needed.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.3 The basic principles of hydraulics and pneumatics.

Question
An engineering company needs a component sorting system for the fabricated bolts and nuts in its production process. The production process has a high safety risk as it involves welding, hot working and degreasing treatments. Changes in production sequences are a common occurrence.

Explain **two** benefits of introducing a pneumatic system for this situation.

Indicative content
- Use of air
- Effectiveness
- Reliability
- Simple design
- Safety
- Economical
- **Applied** –safety critical environment, changes in processes.

Model answer
Pneumatic systems can work in harsh environments, like ones with welding and hot-working processes that might generate high temperatures. This allows for the pneumatic system to be set up in any part of the production facility and still maintain its effectiveness as a sorting mechanism.

The pneumatic system is a simple design containing an air compressor, valves, cylinders and tubes. The simplistic design allows for easy disassembly and re-installation in another part of the production site in instances where changes are made to the production sequence. In case of breakdowns, the simplistic design of the pneumatic system allows for quick and easy repairs to be made, allowing the production process to restart with minimal time wasted.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

AO3 questions

AO3 Analyse and evaluate information and issues

Complex thinking that distinguishes patterns and relationships; breaking material into constituent parts; determining how constituent parts are related to one another and holistically; inferring underlying assumptions, conditions, relevance or causation.

The ability to analyse and evaluate the interrelated issues arising from a complex scenario to propose a best solution or predict impacts etc. For example, considering a response to a work-related problem or issue, like one related to income generation or performance management.

Source: City & Guilds T Level Qualification in Engineering and Manufacturing specification, version 1.1

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.1 Units of measurement used in engineering.

Question
An engineer wants to coat the outer walls of a water tank with paint. The tank is fixed to the ground and has an open top, as shown in figure x.

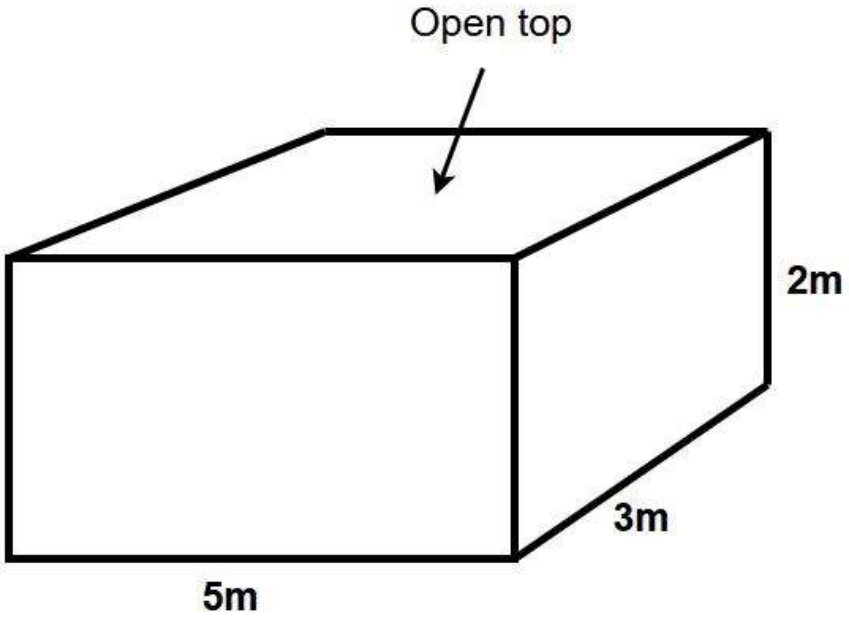


Figure x

The recommended paint spread, determined through years of experience, is 10ml per 15cm^2 of tank surface area. A paint supplier has agreed to provide paint at a cost of £46.50 for a 5L tin of paint. The engineer has requested £2,000 from the accounts department to buy the paint.

Justify the engineer's purchase order.

Indicative content
- Surface area
- Volume
- Converting ml to L
- Converting m^2 to cm^2
- **Issues** – problems related to conversion of units.

Model answer
The engineer would first work out the surface area of the tank to be covered by the paint.

Surface area = 2(height x width) + 2(height x length)
Surface area = 2(2 x 3) + 2(2 x 5)
Surface area = 32m^2

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

After finding the surface area in m^2, the engineer then converts that value to cm^2 because the paint coverage is known in cm^2.

1m is equal to 100cm
Therefore,
$1m^2$ is equal to 100^2cm^2
This means that,
$32m^2 = 32 \times 100^2cm^2$
Therefore, the surface area of the tank that needs to be covered by paint is $320{,}000cm^2$.

The paint spread is given as,
$15cm^2$ can be covered by 10ml of paint
This means that,
paint to cover $320{,}000cm^2 = (10 \times 320{,}000 \div 15)ml$
paint to cover $320{,}000cm^2 = 213{,}333.33ml$
Therefore, 213,333.33ml would be needed to coat the outer walls of the tank.

The millilitres are converted to litres.
$213{,}333.33ml = (213{,}333.33 \div 1{,}000)L$
$213{,}333.33ml = 213.333L$

The number of 5L tins of paint needed to produce 213.333L of paint is worked out next.

Number of paint tins $= 213.333 \div 5$
Number of paint tins = 42.67
This means the engineer would need 43 tins to produce the required paint.

The price for a single 5L tin of paint is £46.50
Therefore,
The price for 43 tins = 43 x 46.50 = £1,999.50

This means the engineer would need £1,999.50 to buy enough paint to fully coat the outer walls of the tank. The engineer's request for £2,000 would be justified as it would cover the calculated cost.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.2 Vector and co-ordinate measuring systems.

Question
A printed circuit board (PCB) that needs holes drilled into it has been presented to an automated drilling machine. The PCB is shown in figure x.

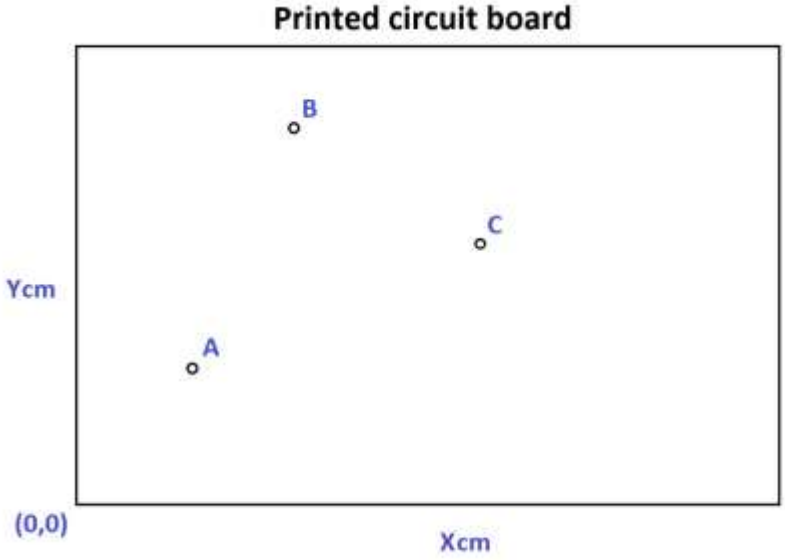


Figure x

An engineer has been tasked with programming the controller of the drilling machine with the path for the drill. The engineer needs to program a path to each point on the PCB. The co-ordinates for each of the points are shown in table x.

Points	Co-ordinates on PCB (x, y)
A	(2.0, 3.0)
B	(3.0, 8.0)
C	(6.4, 5.2)

Table x

Work out the paths the engineer must program into the controller of the robot.

Indicative content
- Distance
- Displacement
- Angle
- Bearing
- Cartesian co-ordinates
- Polar co-ordinates
- Waypoints
- **Issues** – path for a PCB drill converting Cartesian to polar.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Model answer

The engineer would have to program the drill to move from the origin (0, 0) to point A. Then program a path from point A to point B. Then finally a path from point B to point C.

The first path is from the origin, (0, 0), to point A, (2.0, 3.0).

Change in y = 3.0 – 0 = 3.0
Change in x = 2.0 – 0 = 2.0

Distance = $\sqrt{(}$ (change in y)^2 + (change in x)^2 $)$
Distance = $\sqrt{(}$ $3.0^2 + 2.0^2$ $)$ = 3.6cm

Angle = $\tan^{-1}$ (change in y ÷ change in x)
Angle = $\tan^{-1}$ (3.0 ÷ 2.0) = 56.3°

Therefore, the path for the drill to move from the origin to point A can be represented with the polar co-ordinates (3.6, 56.3°). The drill would have to move a distance of 3.6cm making an angle of 56.3° with the horizontal to reach point A.

The second path is from point A, (2.0, 3.0), to the point B, (3.0, 8.0).

Change in y = 8.0 – 3.0 = 5.0
Change in x = 3.0 – 2.0 = 1.0

Distance = $\sqrt{(}$ (change in y)^2 + (change in x)^2 $)$
Distance = $\sqrt{(}$ $5.0^2 + 1.0^2$ $)$ = 5.1cm

Angle = $\tan^{-1}$ (change in y ÷ change in x)
Angle = $\tan^{-1}$ (5.0 ÷ 1.0) = 78.7°

Therefore, the path for the drill to move from point A to point B can be represented with the polar co-ordinates (5.1, 78.7°). The drill would have to move a distance of 5.1cm making an angle of 78.7° with the horizontal to reach point B.

The third path is from point B, (3.0, 8.0), to the point C, (6.4, 5.2).

Change in y = 5.2 – 8.0 = -2.8
Change in x = 6.4 – 3.0 = 3.4

Distance = $\sqrt{(}$ (change in y)^2 + (change in x)^2 $)$
Distance = $\sqrt{(}$ $2.8^2 + 3.4^2$ $)$ = 4.4cm

Angle = $\tan^{-1}$ (change in y ÷ change in x)
Angle = $\tan^{-1}$ (-2.8 ÷ 3.4) = -39.5°

Therefore, the path for the drill to move from point B to point C can be represented with the polar co-ordinates (4.4, -39.5°). The drill would have to move a distance of 4.4cm making an angle of -39.5° with the horizontal to reach point C.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

This means the engineer would have to program the drill to move for 3.6cm at an angle of 56.3° to reach point A, then move for 5.1cm at an angle of 78.7° to reach point B, then finally move for 4.4cm at an angle of -39.5° to reach point C. This would ensure the drill could travel to all three points on the PCB.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.6 Forces and motion in engineering.

Question
A company has a slider-crank press, with the slider to be used to form metal components. The pressing force needs to reach a value of 3,150kN when $\alpha = 20°$ and $\beta = 4°$, as shown in figure x.

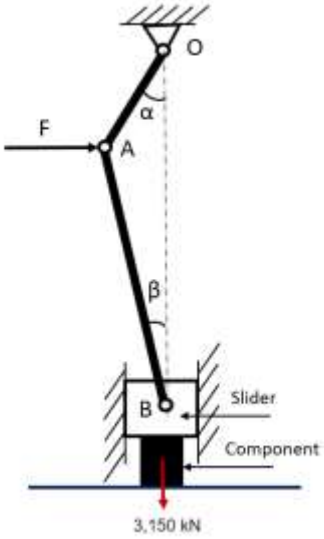


Figure x

Work out the force that should be applied at point A to achieve this requirement.

Indicative content
- Concurrent forces
- Force vector
- Resolving force
- Force equilibrium conditions
- Force polygon method
- Newton's third law
- Space diagram
- Equations
- **Issues** – the need to link two static equilibriums to calculate force.

Note: It is acknowledged that the term 'slider-crank press' may not be familiar to all learners. However, for AO3 questions, there is an expectation that learners can make inferences from the information provided. It is considered there is enough information for learners to make inferences and still answer the question.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

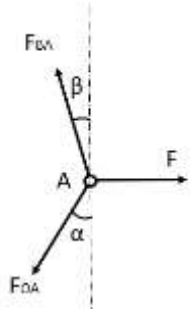
Model answer

When forces acting on the object reach the equilibrium, the following equations are satisfied: $\begin{cases}\sum F_x = 0\\ \sum F_y = 0\end{cases}$.

First, take A as the object.

Three forces acting on A achieved the equilibrium. Their directions are assumed as shown in the diagram, therefore:

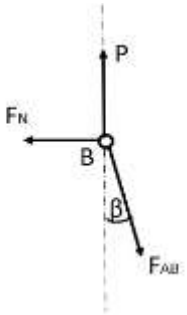
$$\begin{cases}\sum F - F_{OA}cos\alpha - F_{BA}cos\beta = 0 & \text{(Equation one)}\\ \sum F_{BA}sin\beta - F_{OA}sin\alpha = 0 & \text{(Equation two)}\end{cases}$$



Next, take B as the object.

Three forces acting on B achieved the equilibrium. Their directions are assumed as shown in the diagram, therefore:

$$\begin{cases}\sum P - F_{BA}cos\beta = 0 & \text{(Equation three)}\\ \sum F_{AB}sin\beta - F_N = 0 & \text{(Equation four)}\end{cases}$$



From Equation three,

$$F_{BA} = \frac{P}{cos\beta} = \frac{3150kN}{\cos(4°)} = 3157.69kN$$

Based on Newton's third law, F_{BA} and F_{AB} will be equal but opposite to each other.

$$F_{BA} = F_{AB} = 3157.69kN$$

From Equation two,

$$F_{OA} = \frac{F_{BA}sin\beta}{sin\alpha} = \frac{3157.69 \times \sin(4°)}{\sin(20°)} = 644.02kN$$

From Equation one,

$$F = F_{OA}cos\alpha + F_{BA}cos\beta = 644.02 \times \cos(20°) + 3157.69 \times \cos(4°) = 3755.18kN$$

Therefore, 3,755.18kN should be applied at point A to achieve a pressing force of 3,150kN at the slider.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.7 Fluid dynamics in engineering.

Question
Company A is measuring the volumetric flow rate of treated water. Water is flowing horizontally through the normal sized pipe (D_1 = 30cm), followed by a short section of contraction (D_2 = 5cm), then back to normal.

Pressure gauges provide pressure readings of P_1 = 140kPa and P_2 = 120kPa, as shown in figure x.

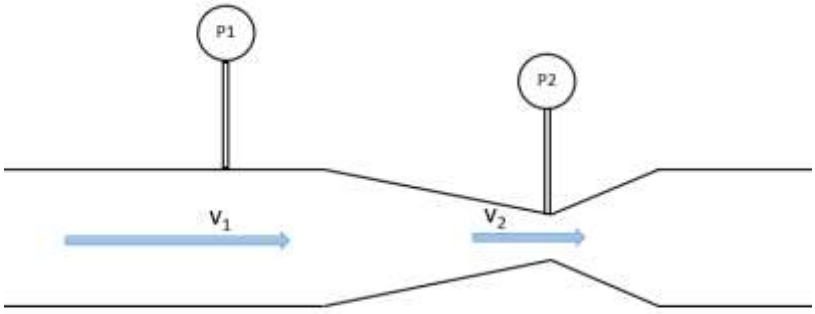


Figure x

The water density is 1000kg/m3.

The flow rate for this system should not exceed 180m^3 per hour.

Work out whether the flow rate meets requirements.

Indicative content
- Continuity equation
- Bernoulli equation
- Incompressible fluid
- Unit conversions
- Elevations in pipe flow
- Rearrange equations
- Volumetric flow rate
- **Issues** – flow rate meeting requirements.

Model answer
The water flow is steady and incompressible, so both continuity and Bernoulli equations are satisfied.

Continuity equation:

$$v_1 A_1 = v_2 A_2$$

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Bernoulli equation:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

There is no elevation in the pipe flow, $h_1 = h_2$

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

Rearrange the continuity equation by making v_2 the subject:

$$v_2 = \frac{A_1}{A_2} v_1$$

Substitute into a Bernoulli equation:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho \frac{{A_1}^2}{{A_2}^2} v_1^2$$

$$P_1 - P_2 = \frac{1}{2}\rho \frac{{A_1}^2}{{A_2}^2} v_1^2 - \frac{1}{2}\rho v_1^2$$

$$v_1^2 = \frac{P_1 - P_2}{\frac{1}{2}\rho \frac{{A_1}^2}{{A_2}^2} - \frac{1}{2}\rho}$$

$$v_1 = \sqrt{\frac{P_1 - P_2}{\frac{1}{2}\rho \frac{{A_1}^2}{{A_2}^2} - \frac{1}{2}\rho}} = \sqrt{\frac{140{,}000 - 120{,}000}{\frac{1}{2} \times 1000 \times (\frac{(\pi {D_1}^2)^2}{(\pi {D_2}^2)^2} - 1)}}$$ =0.176m/s

Volumetric flow rate = $v_1 A_1 = 0.176 \times \pi {D_1}^2 = 0.176 \times \pi \times 0.3^2 = 0.0497 m^3/s$

This is then converted $0.0497\ x\ 60\ x\ 60$ to 178.92m^3 per hour.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.5 Causes of material failure and their prevention.

Question
A maintenance engineer is working on board a ship currently out at sea. They have been asked to investigate a low-carbon steel pipe that has recently started leaking. The pipe is part of a plumbing system located at the rear of the ship.

The engineer sees that the surface of the pipe has flakes of brittle metal peeling off. They also see severe discoloration at multiple sites on the pipe, including the point where the pipe was leaking.

The engineer recommends the replacement pipe is made from stainless steel and coated with paint before installing it into the rest of the plumbing system on the ship.

Discuss the engineer's recommendations.

Indicative content
- Corrosion
- Galvanisation
- Pipe replacement
- Paint
- Coating
- Plastic
- Discoloration
- Flaking
- Cost-effective
- Access to materials
- Limitation because on board ship
- Salt and sea water
- **Issues** – leaking pipe on a ship.

Model answer
The flakes of metal peeling off the pipe, together with the discoloration, would suggest the pipe has suffered corrosion. This observation would be supported by the fact the pipe is on a ship. The salt air the ship is exposed to would be conducive to corrosion.

Stainless steel has corrosion resistance properties because of elements like chromium that are present in the metal. The engineer would therefore recommend the replacement pipe is made from stainless steel as it has the ability to resist corrosion.

Painting the stainless steel pipe would also help stop corrosion from happening again. This would allow the pipe to last longer in service and not require repair and replacement as often.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

One issue is whether the engineer has access to the materials while on the ship. This might need to be a longer-term change. They would need to order the materials to be available at the next port of call, which may mean the corrosion gets worse and the plumbing system is out of service for a period of time. The coating is more likely to be available on board a ship as it is used for many different purposes and this would be the priority to stop the corrosion getting much worse.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.6 Materials testing methods and interpretation of results.

Question
An engineering fabrication and construction company has been contracted to provide metal beams for a bridge building project. Two materials have been tested for suitability. The results from the test are shown in figure x.

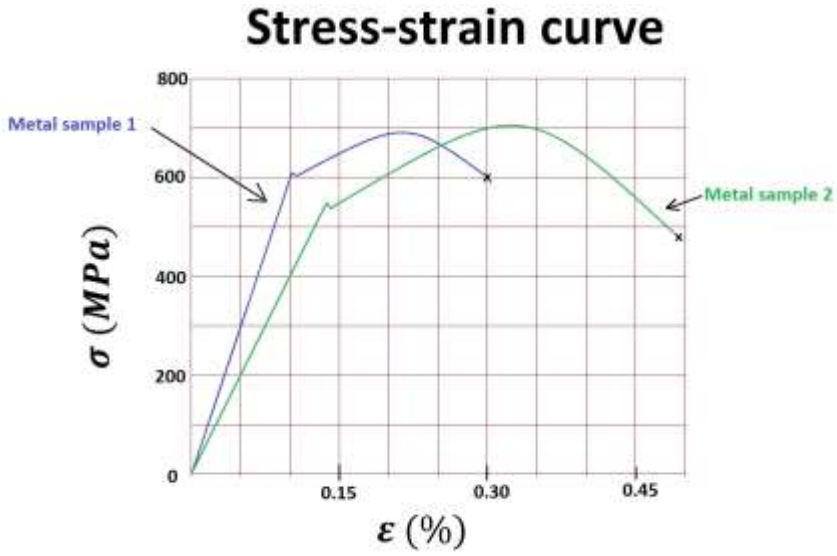


Figure x

Justify the selection of the material best suited for the beams on the planned bridge construction.

Indicative content

- Young's modulus
- Yield point
- Yield strength
- Elastic limits
- Ultimate tensile strength (UTS)
- Stiffness
- Deformation
- Strain at fracture
- Fracture toughness
- **Issues** – results from material tensile test used to inform material selection.

Model answer
Using the graph, Young's modulus for both metal samples can be found.

$$\text{Young's modulus (sample one)} = \frac{\text{change in stress}}{\text{change in strain}}$$

$$\text{Young's modulus (sample one)} = \frac{600 - 300}{0.0010 - 0.0005}$$

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

$$\text{Young's modulus (sample one)} = 600\text{GPa}$$

$$\text{Young's modulus (sample two)} = \frac{\text{change in stress}}{\text{change in strain}}$$

$$\text{Young's modulus (sample two)} = \frac{400 - 200}{0.0010 - 0.0005}$$

$$\text{Young's modulus (sample two)} = 400\text{GPa}$$

Using the graph, the yield point for both metal samples can be estimated.
Yield point (sample one) ≈ 610MPa
Yield point (sample two) ≈ 550MPa

Using the graph, the UTS for both metal samples can be estimated.
UTS (sample one) ≈ 690MPa
UTS (sample two) ≈ 710Mpa

Using the graph, the strain at fracture for both metal samples can be estimated.
Sample one fractures at strain of 0.3%
Sample two fractures at strain of 0.5%

Metal sample one has a higher Young's modulus value than metal sample two. This means metal sample one is stiffer than metal sample two, allowing it to have less elastic deformation when both metals are subjected to the same stress. Metal sample one also has a higher yield point than metal sample two. This means metal sample two starts to undergo plastic deformation earlier than metal sample one. This also means a stress that would plastically deform metal sample two would not necessarily plastically deform metal sample one. However, metal sample one could elastically deform, allowing it to revert to its original dimensions when the stress is removed. This means that so far metal sample one is stiffer and resists plastic deformation longer than metal sample two. As the load the materials might be subjected to is not permanent, it is important they can revert to original dimensions.

When it comes to the UTS of the metal samples, both samples have closely identical values, with metal sample two having a slightly higher value. This means although metal sample two can withstand higher value stresses than metal sample one, the difference is not significant and would not really influence the decision-making process. This UTS is the highest stress a material can withstand. Any stress value beyond that value would lead to fracture of the material.

The next property to consider is strain at fracture. This property indicates how much deformation a material allows for before fracturing. It also indicates how much energy the material can absorb before fracturing, which would allow a person to estimate the fracture toughness of the material. Metal sample two fractures at a higher strain value than metal sample one.

In conclusion, the data provided would lead to metal sample two being selected for the bridge construction project as it deforms earlier than metal sample one and it resists fracture for a longer period than metal sample one. Additionally, it has a

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

slightly higher UTS which, although not significant, is comparable to metal sample one. However, it is acknowledged there may be some weaknesses because of the weaker data related to elastic deformation linked to the lower value of yield point that was calculated. While important factors, the overriding factor for the bridge is the fracturing properties of the bridge and this is where metal sample two is clearly superior to metal sample one.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
7.1 Principles of motion and mechanics in engineering and manufacturing systems.

Question
Company A uses a simply supported beam to hold three loads, as shown in figure x.

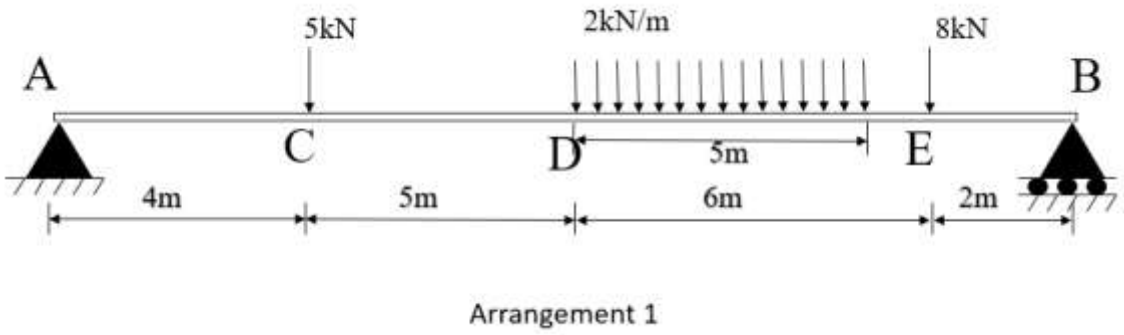


Figure x

As a result of limitations brought on by the roller strength, the reaction force at support B must be less than 15kN. To meet this requirement, an alternative arrangement has been proposed, as shown in figure y.

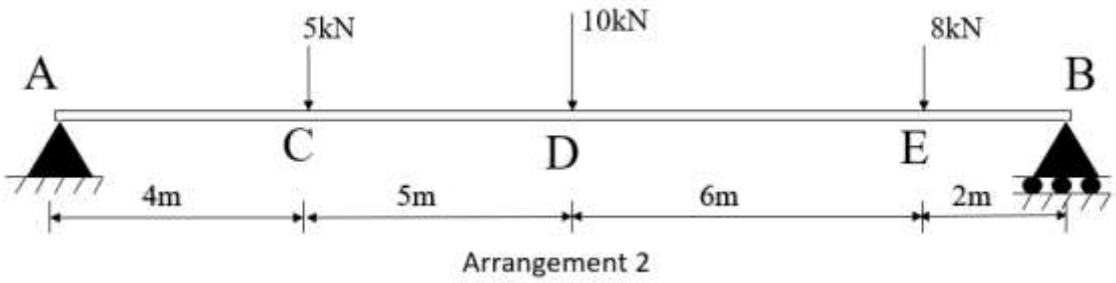


Figure y

Evaluate the impact of the **two** proposed load arrangements on the design limit.

Indicative content

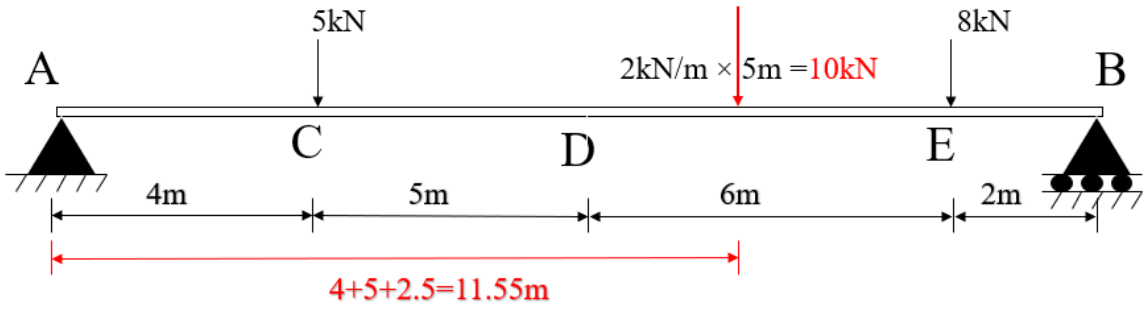
- Simply supported beam
- Pointed load
- Uniformly distributed load (UDL)
- Reaction force
- Static equilibrium conditions
- Pivot point
- Design limit
- **Issues** – simply supported beams with pointed load and UDL.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Model answer

Apply static equilibrium conditions to both load arrangements, using A as the pivot point.

Original arrangement:



Equivalent force for UDL is $\boldsymbol{UDL = 2\frac{kN}{m} \times 5m = 10kN}$, position is in the middle of the span, 11.55m to the pivot point A.

clockwise moment = anti-clockwise moment

$$5kN \times 4m + 10kN \times 11.55m + 8kN \times (4+5+6)m = R_B \times (4+5+6+2)m$$

$$R_B = \frac{20 + 115.5 + 120}{17} = 15.03kN$$

Therefore, in this arrangement, the reaction force for support B exceeds the design limit by 0.03kN.

New arrangement**:**

clockwise moment = anti-clockwise moment

$$5kN \times 4m + 10kN \times (4+5)m + 8kN \times (4+5+6)m = R_B \times (4+5+6+2)m$$

$$R_B = \frac{20 + 90 + 120}{17} = 13.53kN$$

Therefore, in this arrangement, the reaction force for support B does not exceed the design limit. The force is 1.47kN below the design limit.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
7.2 Principles of forces and energy.

Question
Company A is using a gravity drop hammer, similar to the one shown in figure x, to perform forging operations. A ram with a mass of 500kg is falling from a height of 2m to strike a component into the required shape. The combined mass of the work piece and its support is 5,000kg.

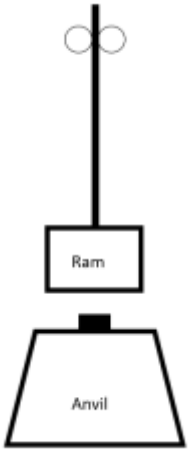


Figure x

The kinetic energy lost in the operation is being used to deform the work piece. Assume there is no friction and no rebound during the process.

Recommend **one** approach to improve the performance of the hammer. Justify your answer.

Indicative content
- Potential energy
- Kinetic energy
- Principle of momentum
- **Issues** – gravity drop hammer.

Note: It is acknowledged that the term 'ram' may not be familiar to all learners. However, for AO3 questions, there is an expectation that learners can make inferences from the information provided. It is considered there is enough information for learners to make inferences and still answer the question.

Model answer
Given m_1= 500kg, m_2 = 5,000kg, h = 2m

Phase one – free fall of ram.
Assume the velocity of the ram before hitting the component is v_1. During this process, potential energy is converted to kinetic energy while the total energy is conserved.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

$$m_1 gh = \frac{1}{2} m_1 v_1^2 = 9810J$$

Rearrange the equation:

$$v_1 = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 2} = 6.26m/s$$

Phase two – objects collide.

After the collision, the ram and the component with its support will have the same velocity of v_2. During this process, the total momentum before and after collision remains constant.

$$m_1 v_1 = (m_1 + m_2) v_2$$

Rearrange the equation:

$$v_2 = \frac{m_1}{m_1 + m_2} v_1 = \frac{500}{500+5000} \times 6.26 = 0.57m/s \qquad \text{(Equation one)}$$

However, in this process, the total energy is not conserved. The kinetic energy lost is calculated as:

$$KE_{lost} = \frac{1}{2} m_1 v_1^2 - \frac{1}{2}(m_1 + m_2) v_2^2 = 8916.525J \qquad \text{(Equation two)}$$

Therefore $\frac{8916.525}{9810} = 90.89\%$ of the energy is used to do the work.

Substitute equation one into equation two and simplify:

$$KE_{lost} = \frac{1}{2} m_1 v_1^2 - \frac{1}{2}(m_1 + m_2) v_2^2 = \frac{1}{2} m_1 v_1^2 - \frac{1}{2}(m_1 + m_2)\left(\frac{m_1}{m_1 + m_2} v_1\right)^2$$

$$KE_{lost} = \frac{1}{2} m_1 v_1^2 - \frac{1}{2}(m_1 + m_2) \frac{m_1^2}{(m_1 + m_2)^2} v_1^2$$

$$KE_{lost} = \frac{1}{2} m_1 v_1^2 - \frac{1}{2} \frac{m_1^2}{m_1 + m_2} v_1^2 \qquad \text{(Equation three)}$$

Equation three indicates that increasing the mass m_2 of the work piece support will increase KE_{lost}.

The recommendation is that increasing the mass of the support will best improve the performance of the hammer. This is because the lost energy does the work, and so it is the mass of the support that increases the lost energy.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Question
An electric engineer designing a generator is considering using a ferromagnetic material that displays the characteristics shown in figure x.

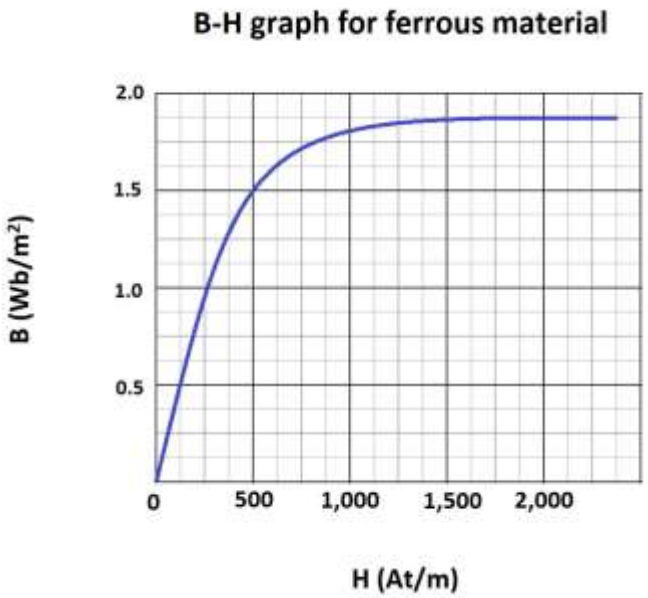


Figure x

The engineer has found that during normal generator operation, the magnetic field applied to the pole of the stator in the generator will amount to 500At/m.

The engineer has built a prototype to investigate the suitability of this material as a stator in the generator. The prototype has a 10cm conductor moved in the uniform field generated by the material when magnetised with 500At/m.

The design of the generator has been represented by the diagram in figure y.

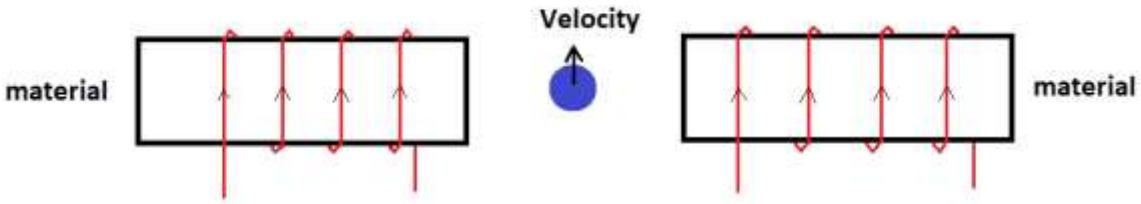


Figure y

The engineer aims to induce a voltage of no less than 6 volts at maximum velocity of the coil movement. Given the mechanical limitations of generator construction, the maximum velocity the coil can attain in the system is found to be 45m/s.

Work out the suitability of this material for the construction of the pole of the generator stator. Justify your answer.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Indicative content

- Relationship between flux density and field strength
- Magnetic field strength (H)
- Magnetic flux density from B-H curve
- Electromotive force (EMF) induction
- Weber per square metre (Wb/m2)
- Amp turns per metre (At/m)
- **Issue** – based on all available data, is the material suitable for a generator stator?

Model answer

From the B-H graph of the material, it is found that when the material is magnetised with a field strength of 500At/m, a flux density of 1.5Wb/m^2 is produced by the material. A high flux density value for this material would potentially lead to greater EMF induction.

This means that in the generator prototype, the material will be emanating a uniform field with flux density of 1.5Wb/m^2. A uniform field emanating from the material would ensure uniform EMF induction in the generator.

To work out the suitability of the material for the generator component, the velocity required to induce 6 volts in the conductor is determined. The movement of the conductor is necessary for the conditions of EMF induction. The velocity of the conductor, flux density, length of the conductor and induced EMF are related by the following expression:

$$Induced\ voltage, E = BLV$$

From this expression, the velocity required to achieve the required induced EMF can be determined by making velocity the subject of the expression:

$$V = \frac{E}{BL} = \frac{6}{1.5 \times 0.1} = 40m/s$$

This means a velocity of 40m/s is required to induce a voltage of 6 volts in the conductor.

From this expression:

Induced voltage, E = BLV

It would mean that a higher velocity, with all other factors remaining constant, would lead to a greater induced EMF.

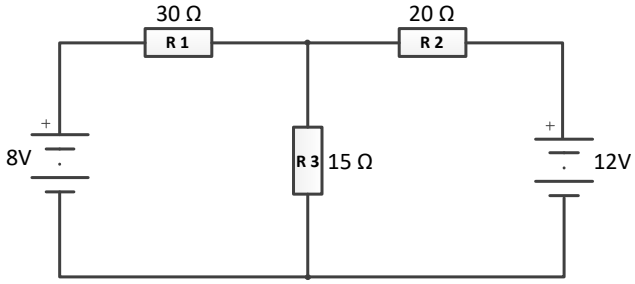
With the conductor predicted to reach a maximum velocity of 45m/s, it is reasonable to predict the voltage induced in the conductor using the material would be more than 6 volts. This would satisfy the requirement of the engineer and justify the reason for using this material for the generator stator.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Question
An electrical engineering designer is developing an electrical heating system for a medium-sized workshop. He is currently investigating two separate circuit configurations, as shown in figure x.

Configuration one:



Configuration two:

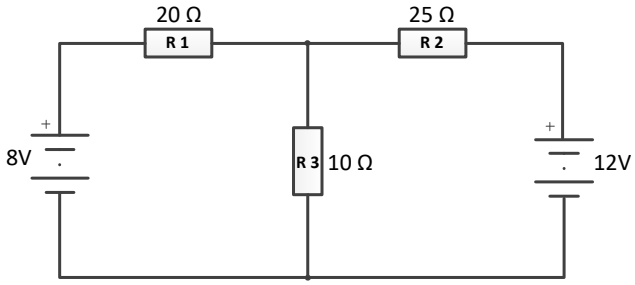


Figure x

Each of these configurations allow the heating device, R3, to generate the same amount of heat.

Justify the circuit that should be used for the system.

Indicative content

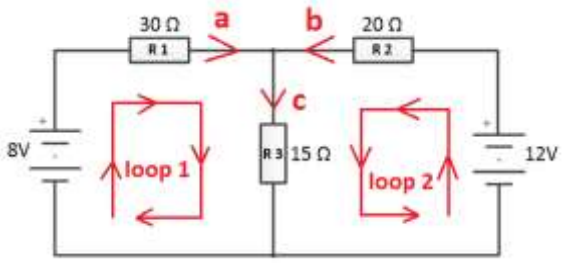
- Kirchhoff's current and voltage laws
- Ohm's current and voltage laws
- Resistors in a DC circuit network
- Power calculations
- Solving simultaneous equations
- **Issues** – comparison of power consumed by device in two different circuit configurations.

Model answer
Content in red is the unknown variable so that it stands out.

The power consumed by the resistor, R3, is determined for both circuit configurations. To work out the power, the current flowing through resistor, R3, is determined first. This is done using Kirchhoff's voltage and current laws.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

For circuit configuration one, the direction of current flowing through each branch is assumed. These currents are labelled as a, b and c.



Loop 1 generates the following equation using Kirchhoff's voltage law, which states the algebraic sum of voltages around a loop equate to zero:
$8 – 30a – 15c = 0$

Loop 2 generates the following equation using Kirchhoff's voltage law:
$12 – 20b – 15c = 0$

Kirchhoff's current law generates the following equation in relation to the currents at the node:
$a + b = c$

The three equations above are simultaneous equations with unknown variables a, b and c. Solving the simultaneous equations allows for current, c, to be found.

Making, a, the subject:
$a = c – b$

Substituting for a in the loop 1 equation:
$8 – 30(c – b) – 15c = 0$
$8 – 30c + 30b – 15c = 0$
$8 + 30b – 45c = 0$

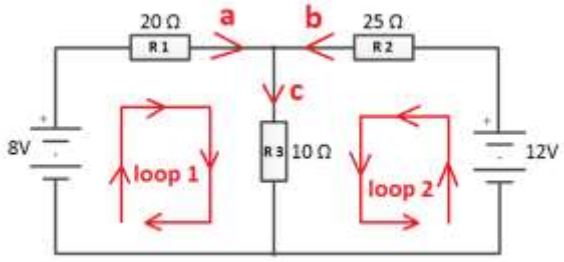
Loop 1 and loop 2 equations now only have variables, b and c:
$8 + 30b – 45c = 0$ x2 $16 + 60b – 90c = 0$
$12 – 20b – 15c = 0$ x3 $36 – 60b – 45c = 0$ +

$52 – 135c = 0$
$c = 52 \div 135 = 0.385A$

For configuration one, the current flowing through the device, R3, is 0.385A
The power consumed by the device, R3, is calculated as follows:
$P = I^2R = (0.385)^2 \times (15) = 2.22W$

For circuit configuration two, the direction of current flowing through each branch is assumed. These currents are labelled as a, b and c.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.



Loop 1 generates the following equation using Kirchhoff's voltage law, which states the algebraic sum of voltages around a loop equate to zero:
$8 – 20a – 10c = 0$

Loop 2 generates the following equation using Kirchhoff's voltage law:
$12 – 25b – 10c = 0$

Kirchhoff's current law generates the following equation in relation to the currents at the node:
$a + b = c$

The three equations above are simultaneous equations with unknown variables a, b and c. Solving the simultaneous equations allows for current, c, to be determined.

Making, a, the subject:
$a = c – b$

Substituting for a in the loop 1 equation:
$8 – 20(c – b) – 10c = 0$
$8 – 20c + 20b – 10c = 0$
$8 + 20b – 30c = 0$

Loop 1 and loop 2 equations now only have variables, b and c:
$8 + 20b – 30c = 0$ x5 $40 + 100b – 150c = 0$
$12 – 25b – 10c = 0$ x4 $48 – 100b – 40c = 0$ +

$88 – 190c = 0$
$c = 88 \div 190 = 0.463A$

For configuration two, the current flowing through the device, R3, is 0.463A.
The power consumed by the device, R3, is calculated as follows:
$P = I^2R = (0.463)^2 \times (10) = 2.14W$

In configuration one, the device, R3, consumes 2.22W
In configuration two, the device, R3, consumes 2.14W

To conserve electrical power usage, the configuration that has the device consuming the least amount of power is suitable. This means configuration two is suitable for the purposes of the application as it allows the company to save on power usage.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.1 The key components of a mechatronics system.

Question
A confectionery production company, that produces more than 500 boxes of chocolate per day, needs sensors to measure the temperature of part of the chocolate production process.

The production process requires temperatures be monitored and kept within a strict range of 5°C to 10°C, with a permissible deviation of ±0.2°C. The company needs 100 sensors to fully cover the production process.

The company is presented with the specifications of two types of temperature sensors with similar physical dimensions.

Table x contains the specifications for two sensors.

Sensor one	**Sensor two**
Operating range: -30°C to +100°C	Operating range: -20°C to +170°C
Accuracy: ±0.1°C	Accuracy: ±0.5°C
Resolution: 0.05°C	Resolution: 0.05°C
Supply voltage: 3.0V-5.5V	Supply voltage: 2.2V-3.6V
Price: £10 per pack of 20	Price: £5 per pack of 20

Table x

Justify the sensor selection that would suit the company from the description presented.

Indicative content
- Sensor accuracy
- Sensor resolution
- Sensor range
- Electrical power supply
- Cost efficiency
- **Issues** – balance operating temperature with power consumption and accuracy.

Model answer
The temperature sensors presented both have an operating range that covers the required sensing range of 5°C to 10°C, with sensor two having a larger span of 190°C compared to sensor one which is 130°C. Both sensors have the same resolution of 0.05°C which means that in this specific property they are comparable. Sensor one requires a higher voltage of 3.0-5.5 volts compared to sensor two which needs 2.2-3.6 volts. As the company needs to buy 100 sensors, this factor adds up to sensor one drawing more electrical power than sensor two. When it comes to the

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

price of the sensors, sensor one is twice as expensive as sensor two and this is also a factor against its selection, as the production company would want to maximise profits and minimise expenses.

When looking at the accuracy of the sensors, sensor one has a higher accuracy than sensor two. The accuracy of sensor one, which is ±0.1°C, would allow the sensor to detect when the temperature was approaching the permissible deviation and allow for the control system to adjust the conditions to prevent the temperature from getting out of the allowed range. The accuracy of sensor two, which is ±0.5°C, would stop it from sensing when the temperature was about to cross the permissible border. This means the control system would always have to take this into account and provide a larger boundary for the control of the temperature so it does not go beyond the range allowed.

This means the company would be justified in selecting sensor one as its accuracy would allow for finer control of the temperature conditions in the chocolate production process. With sensor one, the company would have to withstand the higher power requirement and price to obtain finer monitoring and control of the chocolate production process. The extra expense of buying 100 of sensor one could be covered by the profits generated from improvements in production quality as a result of their purchase and installation.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.1 The key components of a mechatronics system.

Question
A company that assembles cars wants to buy a stepper motor to use in its robotic arm end effector. The motor is needed to move an arm to pick up a component and then move that component to the frame of the car. The robot then needs to hold the position for 10 seconds as the component gets attached onto the frame of the car. This activity would require a holding torque of 15Ncm and an accuracy greater than ±0.05° always.

On a few occasions, the motor may be needed to provide a holding torque of 40Ncm for less than 10 seconds. This situation arises because of the nature of the operation and it has been recorded to average out as 20 minutes in a 14-hour work shift. During this intensive work, the motor would typically draw up to 50 per cent higher than its rated current from the power supply. The company circuit breakers are set to trip when the current drawn exceeds 20A.

Table x shows the characteristics of two stepper motors.

Stepper motor one	**Stepper motor two**
Holding torque: 20Ncm	Holding torque: 30Ncm
Rated voltage: 12V	Rated voltage: 24V
Rated current: 15A	Rated current: 10A
Step angle: 1.8◦	Step angle: 1.8◦
Angle accuracy: 5%	Angle accuracy: 2%

Table x

Justify the motor selection for the application described.

Indicative content
- Holding torque
- Rated voltage
- Rated current
- Step angle
- Accuracy
- Circuit breaker
- **Issues** – selecting a motor for a robotic arm end effector.

Model answer
Step accuracy of stepper motor one = 5% x 1.8° = 0.09°
Step accuracy of stepper motor two = 2% x 1.8° = 0.036°

Stepper motor one and stepper motor two both have holding torque values that are greater than the minimum required for the application described. This means that for

this quality, both motors are reasonable candidates for selection. Stepper motors one and two have step sizes of 1.8° which makes them equal in this regard.

However, stepper motor two has an accuracy of 2 per cent while stepper motor one has an accuracy of 5 per cent. This means that stepper motor one has a step accuracy of ±0.09°, while stepper motor two would have an accuracy of ±0.036°. This characteristic of the stepper motor shows that stepper motor two would allow the company to meet its specification of requiring the accuracy of the stepper motor to be greater than ±0.05° always. However, this does not mean that stepper motor two does not have any drawbacks.

Stepper motor two has a higher rated voltage and this means the company would have to take this into account and weigh it against the need to maintain its production quality. Stepper motor one has a rated current of 15A, while stepper motor two has a rated current of 10A.

In cases when the stepper motor is required to provide a holding torque higher than the rated torque, stepper motor one would end up drawing 22.5A from the power supply leading to the circuit breakers tripping. This could halt the production process and cause disruptions to the company’s production and manufacturing processes. However, with stepper motor two rated current of 10A, when the motor is needed to operate beyond its rated torque, as described in the question, the motor would end up drawing 15A which would not trip the circuit breakers like stepper motor one. So, this means that stepper motor two would be a reasonable selection for the accuracy and low rated current, as explained above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.1 The key components of a mechatronics system.

Question
A parcel sorting facility receives parcels in batches throughout the day. The parcels are brought into the loading part of the facility in a vehicle, usually a van.

On arrival, an operator takes the parcels from the van and loads them onto a conveyor.

When parcels have been loaded onto a conveyor, an operator turns on the conveyor that moves the parcels to the inside of the facility.

Once inside the facility, an operator – with a start and stop control panel – stops the conveyor motor, unloads the parcels from the conveyor and places them in the right containers after examining the labels.

Discuss how mechatronics could be used to improve the system.

Indicative content
- Weight detection
- Obstacle detection
- Motor control
- Automatic start
- Automatic stop
- Microcontroller
- **Issues** – inefficient system – too many operatives.

Model answer
The current set of components includes: conveyor motor, start and stop buttons. With a mechatronic system, the components would include: conveyor motor, pressure sensor, limit switches, microcontroller, start and stop buttons.

Pressure sensors are devices that produce an electrical signal proportional to the pressure exerted on the device. In this instance, they would be placed underneath the conveyor and used for weight detection. The pressure sensors are connected to the microcontroller.

Limit switches are switches operated by a moving part or the presence of an obstacle. They are placed at the end of the conveyor and used to detect when a parcel has reached the end of the conveyor. The limit switches are connected to the microcontroller.

The start and stop buttons are connected to the microcontroller.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

In the new integrated system, pressure sensors detect when a parcel has been placed onto the conveyor. The signal from the pressure sensor is sent to the microcontroller. The microcontroller is programmed to start moving the conveyor when a parcel is detected on the conveyor. To move the conveyor, the microcontroller sends a signal to the conveyor motor commanding it to start moving. This allows the system to automatically start the conveyor motor, without needing an operator to perform that function. This allows the parcels to travel on the conveyor.

Limit switches are placed at the end of the conveyor. The function of the limit switches is to detect when the parcels have reached the end of the conveyor. When the parcels reach the end of the conveyor, they activate the limit switches. The limit switches send signals to the microcontroller allowing it to detect the presence of parcels at the end of the conveyor. The microcontroller then sends a signal to the conveyor motor commanding it to stop. When the parcels at the end of the conveyor are removed by the operator and placed in their designated containers, the microcontroller detects if there are parcels on the conveyor using the pressure sensor. If there are parcels, then the microcontroller sends a signal to the conveyor motor commanding it to automatically restart.

With the introduction of a mechatronic system, two operators would not be required. The system would start operating as soon as the parcel was put on the belt. This means it could work efficiently as the van driver would not need to wait for an operator to start the system. However, it would mean the driver having to put the parcel onto the belt, which they don’t do at the moment, and this might mean a change in their terms and conditions. Drivers are used to picking up parcels to put in the van, so they shouldn’t need a lot of training.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.2 The operation, function and applications of programmable logic controllers (PLC) in mechatronic systems.

Question
An engineering workshop has four Computer Numerical Control (CNC) machines.

Each of the CNC machines is enclosed in a safety cage. The safety cage has a gate that uses a micro switch to detect when the gate is open or closed. There is a light on the operator's console that is supposed to show when the gate is open.

Around each machine, inside the cage, is a safety mat. There is a light on the operator's console that indicates when pressure is applied to the mat.

Each machine has a safety guard that uses a micro switch to detect when the safety guard is engaged or disengaged. There is a light on the operator's console that shows when the safety gate is engaged.

The safety regulations require that during normal operation of the CNC machine, power should be cut off to the motors in less than 200ms of the safety guard being disengaged.

The company wants to install a single PLC in the workshop to replace the four operators. This will hopefully reduce staff costs but maintain the same level of safety.

An engineer is presented with three options for PLCs, shown in table x.

PLC options	**Read time per channel (ms)**	**Write time per channel (ms)**	**Program execution time (ms)**	**Price including installation (£)**
Option A	1.5	1.0	10	15,000
Option B	4.5	4.0	13	7,000
Option C	10.0	9.0	15	5,000

Table x

The engineer selects option B for the engineering workshop.

Justify the engineer's choice.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Indicative content

- Scan time
- Scan cycle
- PLC inputs
- PLC outputs
- PLC program execution
- Input read time
- Output write time
- Safety
- Staffing
- **Issues** – reduce staffing costs, maintain safety.

Model answer

The engineer starts by establishing a few facts:

- There are four cage gates and four lights to show when the gates are open.
- There are four safety mats and four lights to show when pressure is applied to the mats.
- There are four safety gates and four lights to show when the safety gates are engaged.
- There are four machines that are each going to be controlled by the PLC through a relay. Each machine, like the other components, is also going to have a light on the operator's console to show when it is running.

The inputs to the PLC will be as follows:

- Four channels connected to the cage gate micro switches.
- Four channels connected to the safety mat pressure sensors.
- Four channels connected to the safety gate micro switches.

The outputs of the PLC will be as follows:

- Four channels connected to the lights showing the state of the cage gates.
- Four channels connected to the lights showing the state of the safety mats.
- Four channels connected to the lights showing the state of the machine safety gates.
- Four channels connected to the lights showing the state of the machine operation.
- Four channels connected to the relays of the machines.

This makes a total of 12 channels for the inputs and 20 channels for the outputs.

The PLC operates by scanning each input channel, then moving on to scan the PLC program, after which it moves on to update each of the outputs based on the state of the inputs and the programmed logic. This constitutes a scan cycle that is repeated for the lifetime of the PLC operation. The time for the scan cycle determines the responsiveness of the system. This is important because there is a requirement that the safety gate invokes a response in less than 100ms.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Since the scan time for each channel is known and scan time for the program is also known, the time to complete a scan cycle can be calculated.

Option A
Time to read all input channels = number of inputs x time to read an input
Time to read all input channels = 12 x 1.5 = 18ms

Time to execute PLC program = 10ms

Time to write to all output channels = number of outputs x time to write to an output
Time to write to all output channels = 20 x 1.0 = 20ms

Scan cycle time = read time + execution time + write time
Scan cycle time = 18 + 10 + 20 = 48ms

Option B
Time to read all input channels = number of inputs x time to read an input
Time to read all input channels = 12 x 4.5 = 54ms

Time to execute PLC program = 13ms

Time to write to all output channels = number of outputs x time to write to an output
Time to write to all output channels = 20 x 4.0 = 80ms

Scan cycle time = read time + execution time + write time
Scan cycle time = 54 + 13 + 80 = 147ms

Option C
Time to read all input channels = number of inputs x time to read an input
Time to read all input channels = 12 x 10.0 = 120ms

Time to execute PLC program = 15ms

Time to write to all output channels = number of outputs x time to write to an output
Time to write to all output channels = 20 x 9.0 = 180ms

Scan cycle time = read time + execution time + write time
Scan cycle time = 120 + 15 + 180 = 315ms

The calculations show that option A would allow the system to respond to the safety gate in less than 50ms as the scan cycle time was 48ms. This would allow the system to comply with the safety requirements of less than 200ms responsiveness. However, this installation is expensive when compared to the other options.

The calculations also show that option B would allow the system to respond to the safety gate in less than 150ms as the scan cycle time was 147ms. This option is less

than half the price of option A and allows the system to comply with the safety requirements of a response time of less than 200ms.

The option C scan cycle time was calculated as 315ms. This scan cycle would not allow the system to comply with the safety requirement of having a response time of less than 200ms. This option is the cheapest but cannot be adopted as it would not meet the safety requirements.

This shows the engineer would be justified in choosing option B as it provides the cheapest choice that is still able to meet the safety requirements of the system.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.2 The operation, function and applications of programmable logic controllers (PLC) in mechatronic systems.

Question
A paint manufacturing company produces various types of paint. The company is financially sound. Over the last two years, the quality manager has identified issues with the final paint quality, although there is no consistent pattern. The company employs several engineers and some have a few years of moderate programming experience.

Discuss how installing a PLC to automate the paint mixing process would affect the company.

Indicative content
- PLC
- Reliability
- Versatility
- Ease of use
- Safety
- Cost-effective
- Programming
- Automation
- Profits
- Product quality
- Manual labour
- Funding
- Expertise of staff
- **Issues** – inconsistent paint quality, sound finances, engineers with moderate programming experience.

Model answer
The PLC is an industrial, solid-state computer that monitors inputs and outputs and then makes logic-based decisions that allow for the automation of the paint mixing process.

The PLC is reliable and would enable the company to see a marked improvement in the quality of paint produced. This reliability would ensure the paint quality is maintained, which is important because the results are currently inconsistent.

The PLC is versatile, allowing the company to make changes to the paint mixing process without having to reinstall the system. This is especially important as the company produces various paint types.

The PLC is easy to program, so the engineers who would be required to program the system would not need extensive programming knowledge. The company would not

need to hire specialists to program the PLCs because it already employs engineers with some programming experience.

The PLC would allow the company to save on manual labour costs as the automated process does not need as many operators. Also, staff already have the expertise or can easily be upskilled to work on the new system, so that will not incur additional costs. The company is financially sound, and this will help it become even more financially efficient with reduced costs. However, the cost of introducing the system needs to be considered. Although the company is financially sound, this does not mean it will have the money needed to invest. But if it is looking for funding, that should not be a problem as it currently has good finances.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Section two

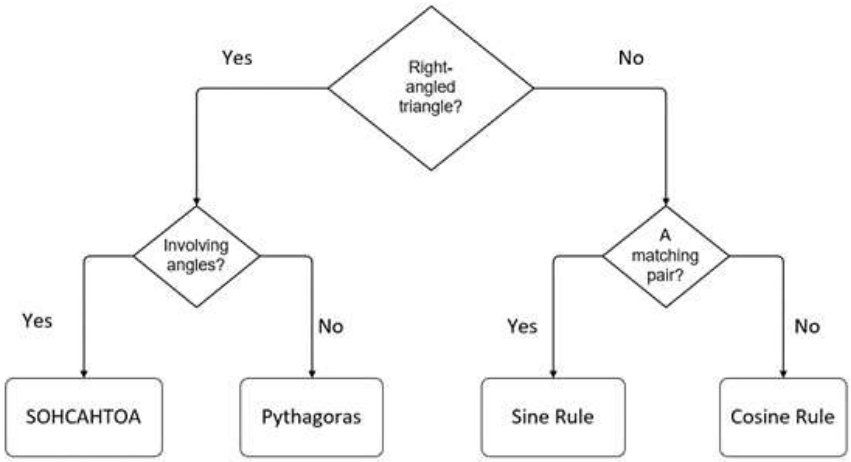
Developmental activities

Targeted content
4.1 Applied mathematical theory to engineering applications.

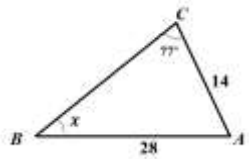
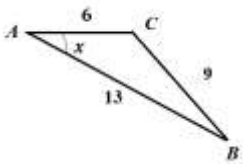
Developmental activity
This activity will enable learners to develop their understanding of sine and cosine rules. It starts with a refresher activity that allows learners to consolidate their prior knowledge before they are presented with a table to complete.

The following instructions should be followed by the learner.

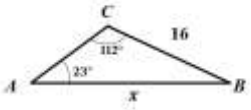
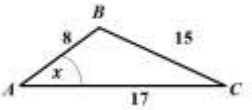
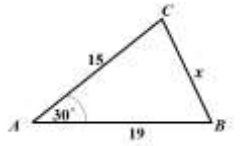
Step one: Familiarise yourself with the flowchart for choosing the correct rule to solve the problem.



Step two: Complete the following table.

Question	Which rule to use? (tick)		Answers with your working
	Sine	Cosine	
			
			

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Step three: Self-reflection

If you have made mistakes, here is a checklist for common misconceptions:

1. Using the Pythagoras theorem instead of trigonometry equations.
2. Incorrect labelling of the vertices and sides.
3. Sine function instead of cosine function.
4. Incorrectly using the cosine rule as $a^2 = b^2 + c^2 + 2bcCos(A)$ or $a^2 = b^2 - c^2 - 2bcCos(A)$.
5. Incorrectly rearranging the equations.
6. Substituting errors (e.g. value for a substituted into b).
7. Incorrectly applying BIDMAS for calculating the final answer using cosine rules.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
4.1 Applied mathematical theory in engineering applications.

Developmental activity
This activity will allow learners to develop their differentiation skills. Learners visit an online platform that contains questions they can attempt individually or in selected groups.

The following instructions should be followed by the learner.

Use the website below to improve your differentiation skills. It has practice problems for differentiation with step-by-step solutions.
Paul's Online Notes: Differentiation Formulas - practice problem

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
4.2 Number systems used in engineering and manufacturing.

Developmental activity
This activity will enable learners to practice number conversions. It comprises three tables that learners need to complete. The first table allows learners to practice their ability to convert binary numbers to decimal numbers. The second table allows learners to practice their ability to convert decimal numbers to hexadecimal numbers. The third table allows learners to develop their ability to apply the number conversions to a specific application.

For learners to complete:

Convert the following binary numbers to decimal numbers.	
1011	
0110	
1010	

Convert the following decimal numbers to hexadecimal numbers.	
213	
109	

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

166	
If binary number 0000 is equivalent to 0 volts and binary number 1111 is equivalent to 5 volts, work out the voltage values equivalent to the following binary numbers.	
1011	
0110	
1010	
0011	
0101	
0111	
1110	

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content

5.1 Units of measurement used in engineering.

Developmental activity

This activity will enable learners to practice unit conversions. The developmental activity comprises two tables. The first table allows learners to practice converting between m^2 and ft^2. The second table allows learners to apply conversion knowledge to a specific application.

For learners to complete:

Convert the following areas from m^2 to ft^2.	
$33m^2$	
$15m^2$	
$47m^2$	

If $1ft^2$ costs £20.50, work out how much the following would cost.	
$360ft^2$	
$190ft^2$	

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

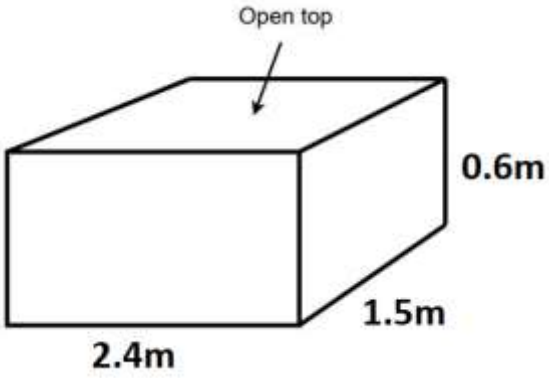
$240ft^2$	

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.1 Units of measurement used in engineering.

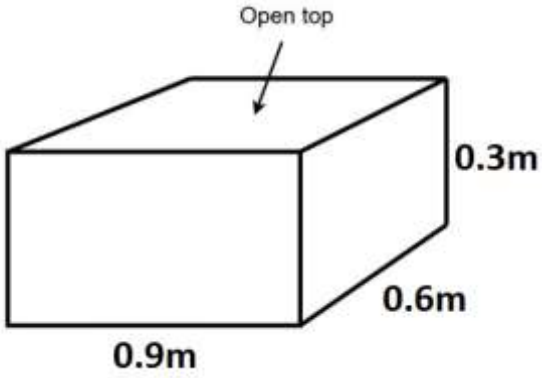
Developmental activity
This activity will allow learners to practice unit conversions in the context of calculating the surface area of an open tank. For each of the questions, learners must present their working and answer below the figure of the tank.

a) Work out the surface area in cm^2 of the outer walls of the open tank.



Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

b) Work out the surface area in cm^2 of the outer walls of the open tank.



Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.2 Vector and co-ordinate measuring systems.

Developmental activity
This activity will allow learners to practice converting between Cartesian and polar co-ordinates. It comprises two tables that learners need to complete. The first table requires learners to convert polar co-ordinates to Cartesian co-ordinates. The second table requires learners to convert Cartesian co-ordinates to polar co-ordinates.

Convert the following polar co-ordinates to Cartesian co-ordinates.	
(7, 30°)	
(15, 50°)	
(6, 20°)	

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

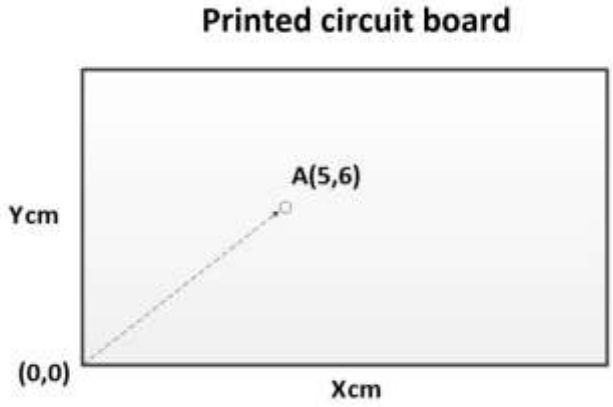
Convert the following Cartesian co-ordinates to polar co-ordinates.	
(8, 13)	
(11, 19)	
(25, 15)	

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.2 Vector and co-ordinate measuring systems.

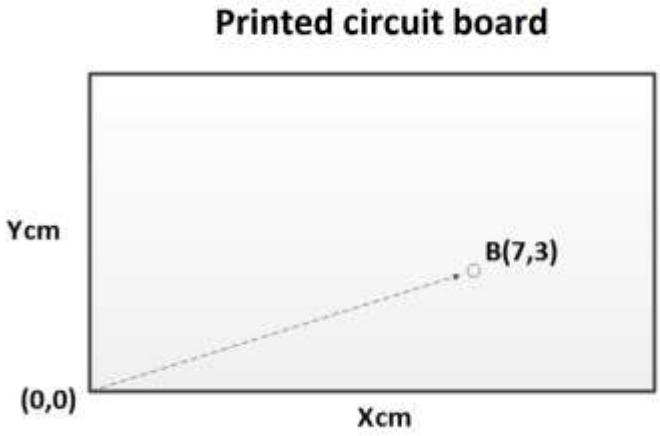
Developmental activity
This activity will allow learners to practice applying conversion between co-ordinate systems. The question requires the learners to correctly identify they are converting the position presented to them from a Cartesian co-ordinate to a polar co-ordinate.

a) Calculate the path required to move from the origin to point A.



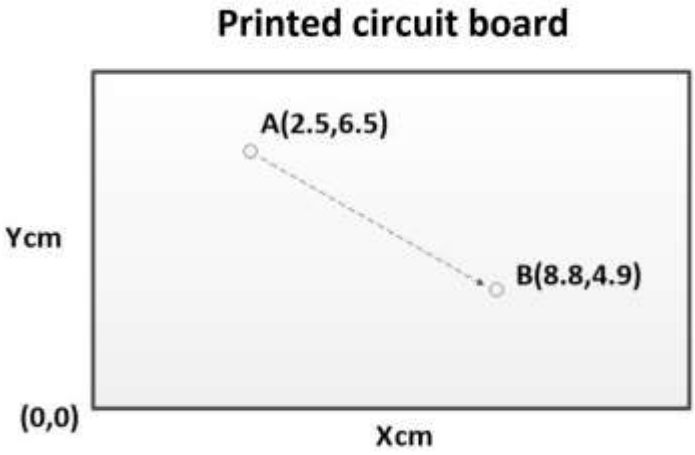
Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

b) Calculate the path required to move from the origin to point B.



Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

c) Calculate the path required to move from point A to point B.



Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.4 Measurement equipment, techniques and principles.

Developmental activity
This table is designed to guide learners to summarise the characteristics and limitations of each type of measuring equipment.

Through research, complete the following table*.

Name of the equipment	Image	Accuracy limit	List two advantages	List two limitations
Engineering rule				
Vernier calliper				
Micrometer				
Dial test indicator (DTI)				
Co-ordinate measuring machine (CMM)				

*If further reading is necessary to complete the table, the following document provides more information: Good practice guide no. 40, National Physical Laboratory

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

To consolidate your learning, please identify the measuring device that should be used in the following scenarios and explain why.

Scenarios	Measuring device	Why?
Measuring the dimension of a classroom		
Screw and bolt		
Measuring the outside diameter of a pipe to an accuracy of 0.02mm		
Large gears		
High precision component used in aeroplanes		

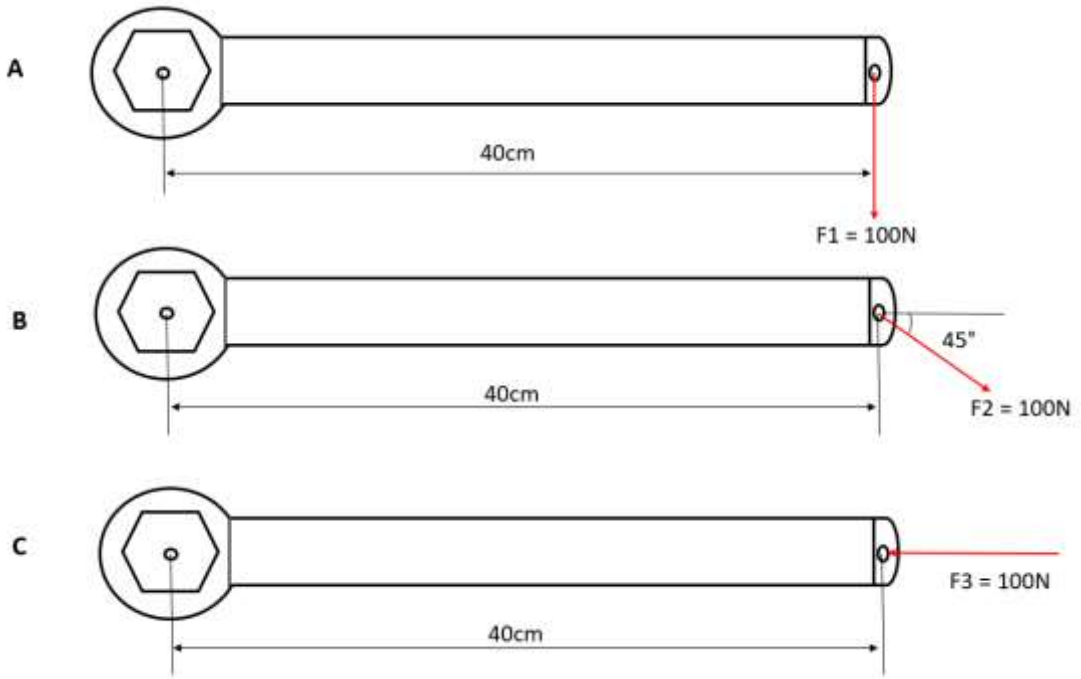
Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.6 Forces and motion in engineering.

Developmental activity
This activity will allow learners to develop their understanding of force moments and static equilibrium. It comprises three questions that learners must complete independently.

Complete the following questions (show your working):

1. A spanner is used to turn a nut, as shown below. Three forces with the same magnitude are applied at the same position on the spanner, but in three different directions.

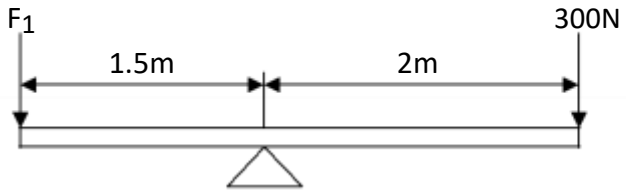


a) Calculate the moments for scenarios A, B and C.

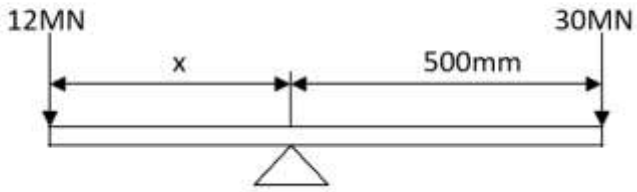
b) Compare the calculated moments for all three scenarios.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

2. For the beam shown in the diagram below, work out the force that must be acting at position F_1 if the beam is balanced. Show your working and write your answer below.



3. For the beam shown in the diagram below, work out the distance (x) if the beam is balanced. Show your working and write your answer below.



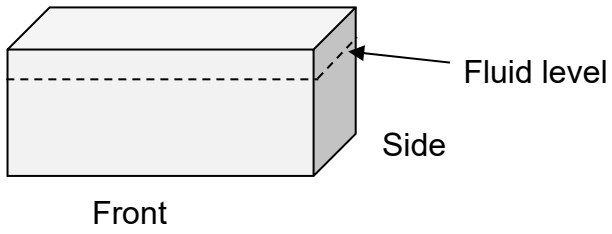
Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.7 Fluid dynamics in engineering.

Developmental activity
This activity will allow learners to develop their understanding of hydrostatic pressure and continuity equation. It comprises two questions that learners must complete.

Complete the following questions:

1. A fuel storage tank with vertical sides is 3m wide and has a fuel with a density of 780kg/m^3. The tank contains fuel to a depth of 1.8m.

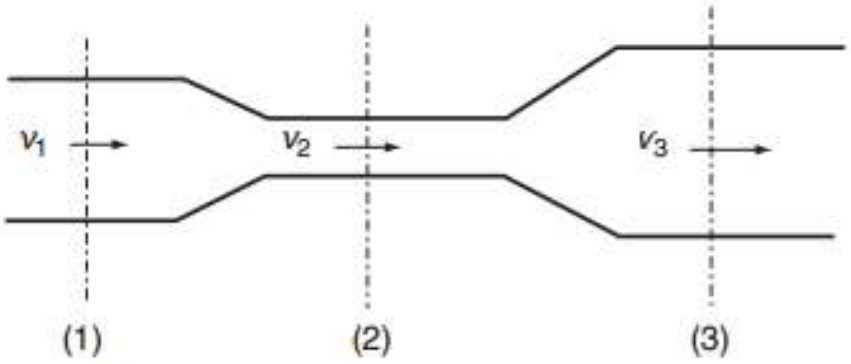


a) Calculate the hydrostatic thrust that acts on the side of the tank and its position (height in the tank).

b) Work out the overturning moments.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

2. The pipe in the diagram conveys oil with a density of 875kg/m³. The diameters are as follows: section 1 = 100mm, section 2 = 50mm, section 3 = 150mm.



If the flow velocity is 8m/s at section 2, work out:

a) the volume flow rate and mass flow rate at section 1

b) the velocity at section 1

c) the velocity at section 3.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
5.8 Thermodynamics in engineering.

Developmental activity
This activity will allow learners to develop their understanding of thermal expansion. It comprises two questions. The first question shows learners how to approach the task. The second question requires learners to use knowledge from the previous question to correctly answer it.

Follow the example by completing the steps:

1. A copper tube on a central heating system is 1.8m long at 18°C. If the coefficient of linear expansion for the copper is 17×10^{-6} /°C, calculate the length of the tube when it is heated to 65°C.

Step one: Identify the original length of the tube.
$L =$

Step two: Identify the change in temperature.
$\Delta t =$

Step three: Identify the coefficient of linear expansion.
$\alpha =$

Step four: Use the thermal expansion expression to work out the length of the tube when heated.
$\Delta L = L \, \alpha \, \Delta t$

$\Delta L = ?$

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Complete the following question on your own:

2. A block of aluminium is heated from room temperature (20°C) to 500°C. The block was 2m long at room temperature. What is its final length when heated, given that the coefficient of thermal expansion for the block is 24×10^{-6} /°C?

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.1 Physical and mechanical properties of materials.

Developmental activity
This activity will allow learners to develop their understanding of the different physical and mechanical properties of materials. Learners must define the properties of different materials and then provide applications for some of those defined material properties.

Define the following material properties.	
Property	Definition
Density	
Electrical conductivity	
Thermal conductivity	
Tensile strength	
Fracture toughness	

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

a) Describe **two** engineering applications of material density.

b) Describe **two** engineering applications of material electrical conductivity.

c) Describe **two** engineering applications of material thermal conductivity.

d) Describe **two** engineering applications of material tensile strength.

e) Describe **two** engineering applications of material fracture toughness.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.2 Types of material and their structures.

Developmental activity
This activity will enable learners to develop their understanding of different material types and their common applications. It is designed to allow learners to gain a better understanding of how the material applications can be correlated to their properties that are heavily dependent on the structure of the material.

Carry out the following tasks:
List the common properties of aluminium.
List **five** engineering applications of aluminium.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Carry out the following tasks:
List the common properties of low-carbon steel.
List **five** engineering applications of low-carbon steel.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.2 Types of material and their structures.

Developmental activity
Learners should complete the question below on their own and then exchange answers with other learners so they can peer assess each other. After peer assessment, ask learners to decide which answer they think is closest to the correct one. Learners can then look at the model answer to gauge how close their answer was to it. Learners who struggled to get the correct answer can be allowed to attempt the development activity after this one.

Question
An engineering bottling company, that makes containers for an energy drink, is considering changing the material for its containers. The previous material for the containers was aluminium alloy. The company is now considering changing to a thermoplastic polymer material.

Explain how this change in material will affect the energy drink container in service.

Model answer
Thermoplastic polymers are less dense than aluminium alloys, which means the energy drink container is going to be lighter, allowing for easier portability than before.

Thermoplastic polymers have lower operating temperatures than aluminium alloys, which means the user would have to be careful not to expose the product to high temperatures as these could lead to deformation of the energy drink container or, in extreme cases, creep then fracture.

Thermoplastic polymers have higher fracture toughness values, so the energy drink container would be capable of absorbing more energy before fracture compared to aluminium alloy. This would enable the user to drop the product from medium heights and still expect the bottle not to fracture. It would deform but not fracture, ensuring the contents of the container do not spill.

Thermoplastic polymers are more readily resistant to chemical attack compared to aluminium alloy and this would allow the bottle and contents to remain intact if exposed to corrosive chemicals.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.2 Types of material and their structures.

Developmental activity
This activity follows on from the previous one. It can be completed by learners who struggled to complete the previous activity and will develop learners' understanding of the materials mentioned in the previous activity. It comprises two tables.

Carry out the following tasks:
List the common properties of thermoplastic polymers.
List **five** engineering applications of thermoplastic polymers.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Carry out the following tasks:
List the common properties of aluminium alloys.
List **five** engineering applications of aluminium alloys.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.3 The effects of processing techniques on materials.

Developmental activity
Learners should attempt the following questions to develop their understanding of material processing techniques.

a) Describe the hot rolling process.

b) What are the effects of the hot rolling process on the properties of steel?

c) List **three** applications of hot rolled steel.

d) Describe the cold rolling process.

e) What are the effects of the cold rolling process on the properties of steel?

f) List **three** applications of cold rolled steel.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.3 The effects of processing techniques on materials.

Developmental activity

This activity will allow learners to develop their understanding of the effects of processing techniques on the properties of materials. It comprises a table containing questions about injection moulding of a thermoplastic. Learners must answer the questions in the table.

Briefly describe the injection moulding process of thermoplastics.
Briefly explain the importance of injection pressure.
Briefly explain the importance of mould pressure.
List **three** applications of thermoplastic injection moulding.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.3 The effects of processing techniques on materials.

Developmental activity

This activity will allow learners to develop their understanding of the effects of processing techniques on the properties of materials. It comprises a table containing questions about casting and its effects on metals. Learners must answer the questions in the table.

Perform the following tasks:
Explain the casting process.
List the effects of casting on metals.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.3 The effects of processing techniques on materials.

Developmental activity

This activity will allow learners to develop their understanding of the effects of processing techniques on the properties of materials. It comprises a table containing questions about hot rolling and its effects on metals. Learners must answer the questions in the table.

Perform the following tasks:
Explain the hot rolling process.
List the effects of hot rolling on metals.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.4 Heat treatments and surface treatments.

Developmental activity
This activity will allow learners to develop their understanding of the quench hardening heat treatment process and its applications. It comprises a table containing questions about quench hardening. Learners must answer the questions in the table.

Briefly explain the quench hardening process.
List **three** types of mediums used in quench hardening.
List the effects of quench hardening on the properties of steel.
List **three** applications of quench hardening.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.5 Causes of material failure and their prevention.

Developmental activity
Learners should attempt the following questions to develop their understanding of fatigue failure and its causes.

a) What are the common causes of fatigue failure in metals?

b) What are the characteristics exhibited by a fracture surface of a metallic component that has failed because of fatigue?

c) What are some of the ways that fatigue failure can be prevented in metallic components?

d) Explain the difference between high-cycle fatigue and low-cycle fatigue.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.5 Causes of material failure and their prevention.

Developmental activity
This activity will allow learners to develop their understanding of corrosion resistance. It comprises three questions that learners must answer.

a) List **three** methods of preventing corrosion in metals.

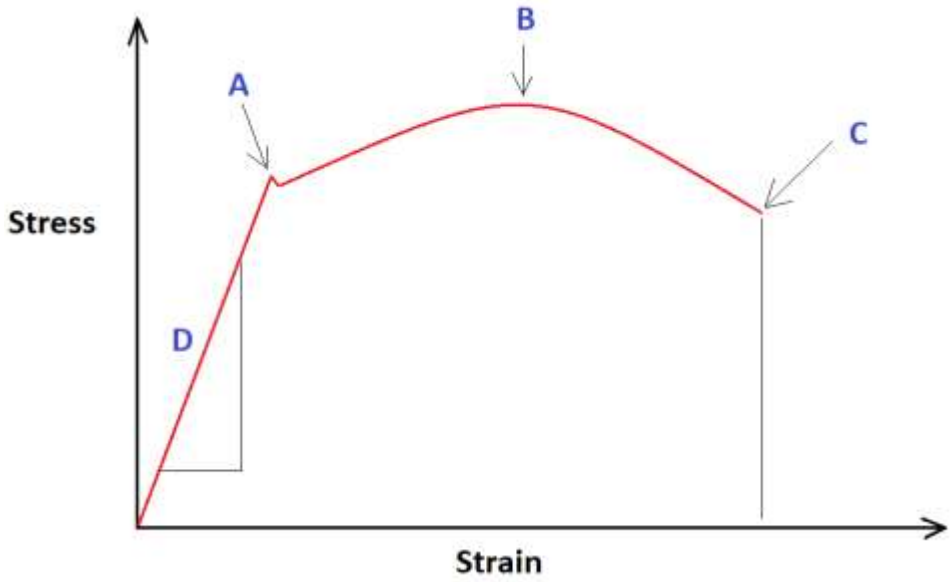
b) List **three** elements that are present in stainless steel.

c) List **three** applications of stainless steel.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
6.6 Materials testing methods and interpretation of results.

Developmental activity
This activity will enable learners to develop their understanding of the stress-strain graph. It comprises two tables that learners must complete. The first table allows learners to develop their ability to correctly identify the important points on a stress-strain graph. The second table allows learners to develop their understanding of the importance of the properties identified from a stress-strain graph.

Here is a stress-strain graph of a metal sample. 
Give the name of point A.
Give the name of point B.
Give the name of point C.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Give the name of the gradient of line D.
Give **one** engineering application of a material's Young's modulus.
Give **one** engineering application of a material's elastic limit.
Give **one** engineering application of a material's ultimate tensile strength (UTS).
Give **one** engineering application of a material's maximum strain.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

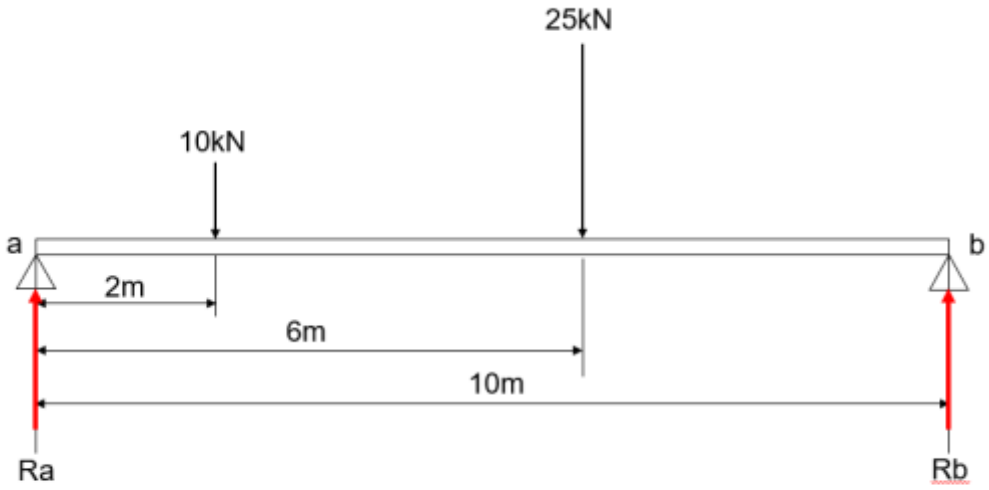
Target content
7.1 Principles of motion and mechanics in engineering and manufacturing systems.

Developmental activity
This activity will allow learners to develop their understanding of simply supported beams. It comprises two questions that learners must complete while showing their working.

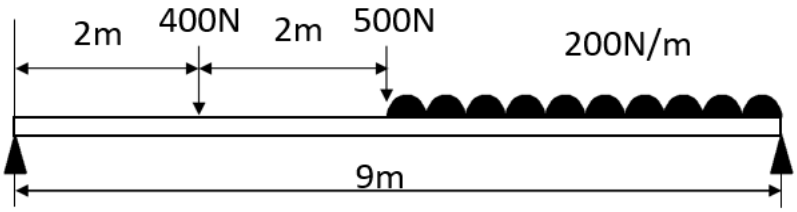
For learners:

Complete the following questions and show your working.

a) A beam is loaded, as shown below. Calculate the reaction forces at both supports.



b) For the beam shown below, label the diagram and calculate the reaction forces at both supports.



Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
7.2 Principles of forces and energy.

Developmental activity
This activity will allow learners to develop their understanding of the application of equations of motion. Learners must follow the instructions to complete the table.

How to use this practice worksheet:

1. Identify the variables given one by one. Complete the cell with the value and its unit.
2. Identify which variable you need to calculate. Put a question mark (?**)** next to the variable.
3. Identify the variable which is neither given nor required to calculate. Put a cross ☒ in the cell next to the variable.
4. Ignore the equations with the variable marked with ☒. The remaining equation is the one that should be used in the calculation.

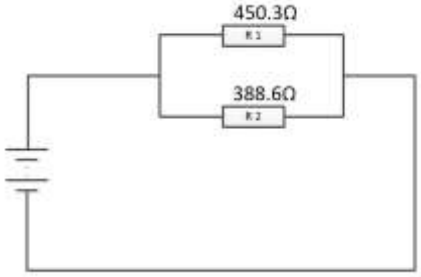
$v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{1}{2}(u + v)t$	Example: A car accelerates uniformly from 5m/s to 15m/s, taking 7.5 seconds. How far did it travel during this period?	A runner starts from rest and runs for 30 seconds at a uniform acceleration of 2m/s$^{2.}$ How fast are they travelling at the end?	A luxury car takes 10.0 seconds to travel 0.4 km from rest. Find its acceleration.	A F1 car's final velocity in a quarter mile is 152mph. Calculate its time. 1mph = 0.117m/s
S	**?**			
U	5m/s			
V	15m/s			
A	☒			
T	7.5s			
The remaining equation	$s = \frac{1}{2}(u + v)t$ This is the only equation without '*A*'			
Working out and answer	$s = \frac{1}{2}(u + v)t$ $S = \frac{1}{2}(5 + 15) \times 7.5$ $= 75m$			

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

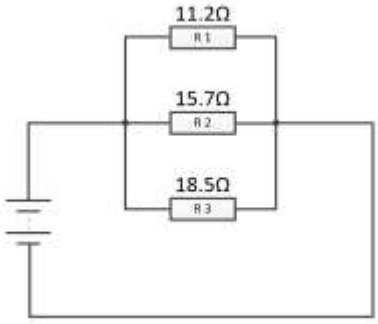
Developmental activity
This activity will enable learners to develop their understanding of resistances in DC circuits and time constants in capacitor circuits. It comprises four questions. The first two questions will allow learners to practice their ability to calculate total resistance in a DC circuit. The last two questions will allow learners to practice their ability to calculate time constants of DC capacitor-resistor circuits.

1.Circuit



Find the total resistance of the circuit shown above.

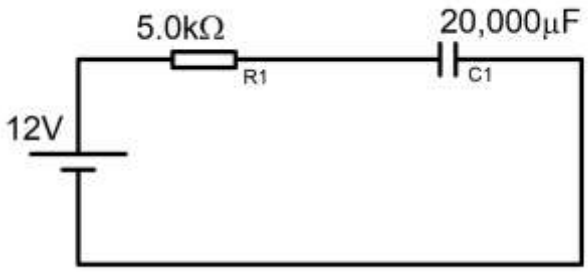
2.Circuit



Find the total resistance of the circuit shown above.

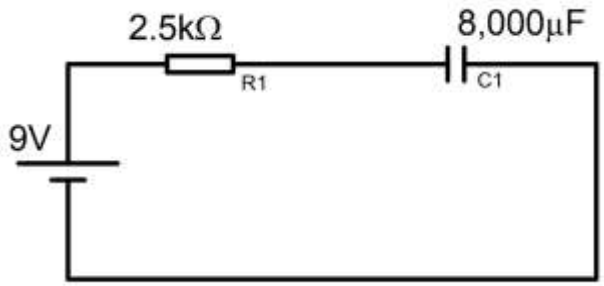
Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

3.Circuit



Calculate the time constant of the circuit shown above.

4.Circuit



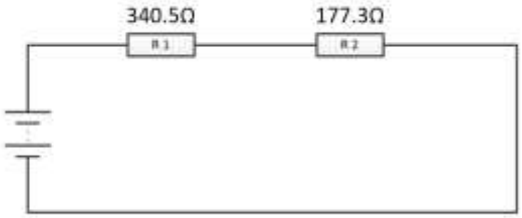
Calculate the time constant of the circuit shown above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

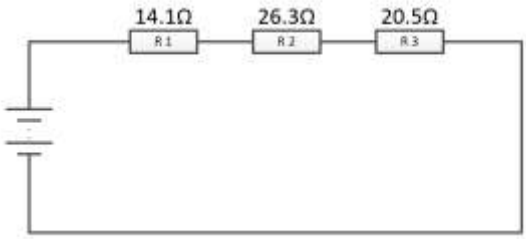
Developmental activity
This activity follows on from the previous one. It is designed to allow learners to further develop their ability to calculate the total resistance and time constant. It should be attempted by learners who struggled to complete the questions in the previous developmental activity. Learners who managed to correctly complete the previous activity can be allowed to skip this one.

1.Circuit



Find the total resistance of the circuit shown above.

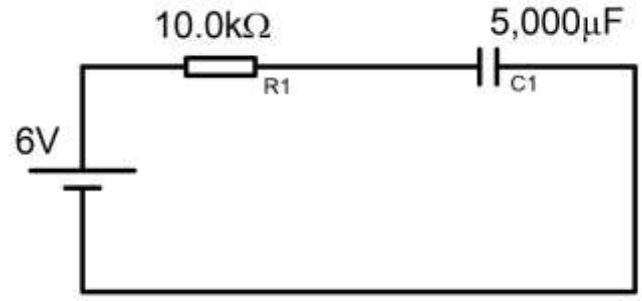
2.Circuit



Find the total resistance of the circuit shown above.

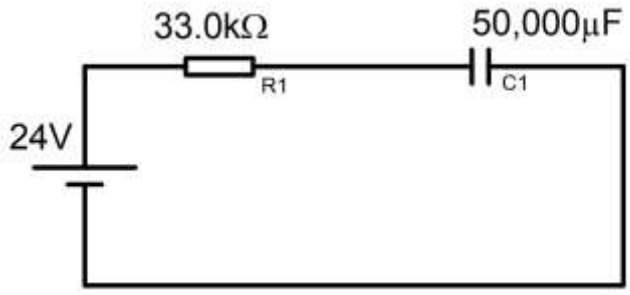
Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

3.Circuit



Calculate the time constant of the circuit shown above.

4.Circuit



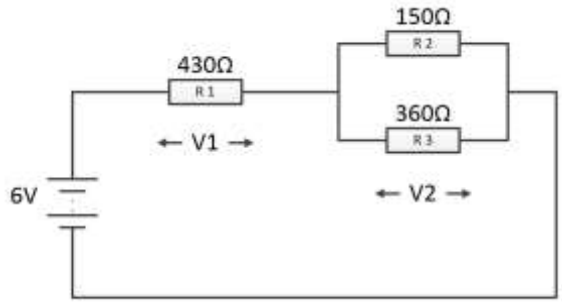
Calculate the time constant of the circuit shown above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Developmental activity
This activity will allow learners to develop their ability to analyse DC resistor circuits. It comprises two questions. These questions require learners to perform calculations to find the resistance, current and voltage around the circuit.

1.Circuit



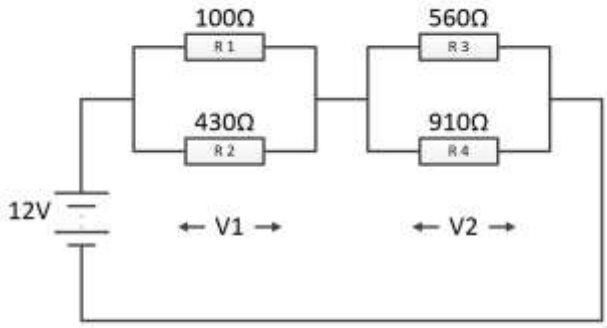
a) Find the total resistance ($\mathbf{R}_T$) of the circuit above.

b) Work out the total current ($\mathbf{I}_T$) in the circuit above.

c) Calculate the voltages ($\mathbf{V}_1$, $\mathbf{V}_2$) across the resistors in the circuit above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

2.Circuit



a) Find the total resistance ($\mathbf{R}_T$) of the circuit above.

b) Work out the total current ($\mathbf{I}_T$) in the circuit above.

c) Calculate the voltages ($\mathbf{V}_1$, $\mathbf{V}_2$) across the resistors in the circuit above.

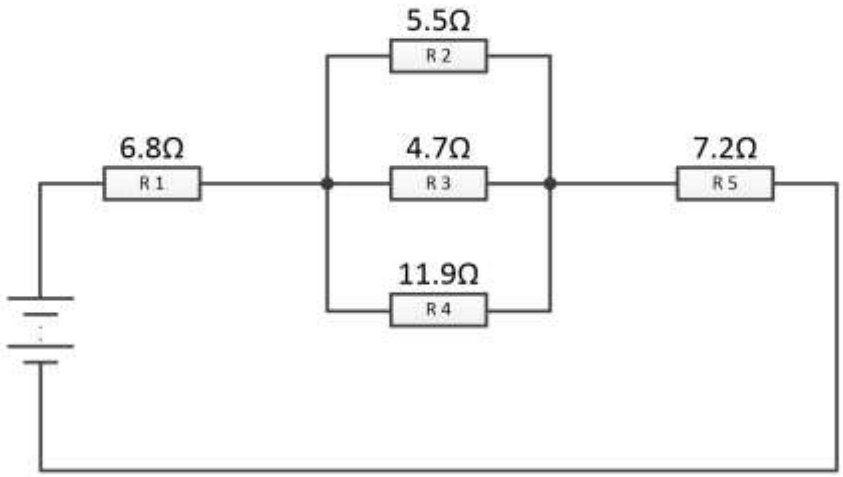
Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Developmental activity
Learners should complete the question below on their own and then exchange answers with other learners so they can peer assess each other. After peer assessment, ask learners to reflect on their results. They can then be shown the model answer and those who didn't get the correct answer can try to work out how and where they went wrong. Learners who struggled to get the correct answer can be allowed to attempt the developmental activity after this one.

Question
An electrical engineer is in the process of designing an electrical circuit that controls the production of aluminium cans. As part of this process, the engineer is investigating the production circuitry of the workshop and needs to revisit the power distribution of the system so the electrical device, represented by resistor R3, receives 0.22A of current.

Analyse the circuit below to work out the voltage the power supply should be set to so the electrical device, R3, receives 0.22A flowing through it.



Model answer
The first stage of the analysis is to work out the voltage across resistor, R3, when a current of 0.22A flows through it.

$R_3 = 4.7\Omega$

$I_3 = 0.22A$

$V_3 = I_3 \times R_3 = 0.22 \times 4.7 = 1.034V$

$V_3 = V_{234} = 1.034V$

This voltage, 1.034V, would be the same voltage across all three resistors: R2, R3 and R4.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

The next stage of the analysis is to find the total resistance of the three resistors and then use that resistance with the determined voltage to work out the total current flowing through the circuit.

$$R_{234} = \left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right)^{-1} = \left(\frac{1}{5.5} + \frac{1}{4.7} + \frac{1}{11.9}\right)^{-1} = 2.09\Omega$$

$$I_{234} = I_T = \frac{V_{234}}{R_{234}} = \frac{1.034}{2.09} = 0.49A$$

With the total current determined, the total resistance is calculated and used to work out the total voltage in the system.

$$R_T = R_1 + \left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right)^{-1} + R_5$$

$$R_T = 6.8 + \left(\frac{1}{5.5} + \frac{1}{4.7} + \frac{1}{11.9}\right)^{-1} + 7.2 = 16.09\Omega$$

$$V_T = I_T \times R_T = 0.49 \times 16.09 = 7.9V$$

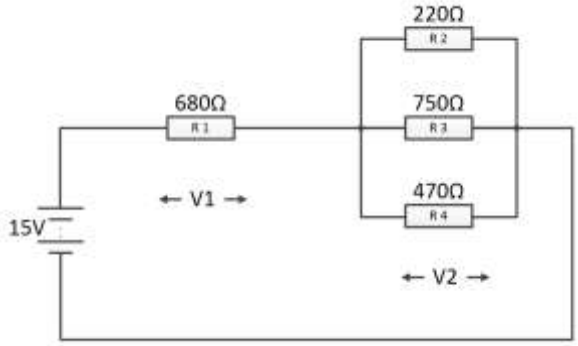
This total voltage is the voltage of the power supply that would ensure a current of 0.22A flows through resistor R3.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Developmental activity
This developmental activity follows on from the previous activity and can be completed by learners who struggled to complete the previous one. It is designed to help learners correctly analyse resistor DC circuits. The activity comprises two circuits that learners must analyse on their own. Learners who managed to correctly complete the previous activity can be allowed to skip this one.

1.Circuit



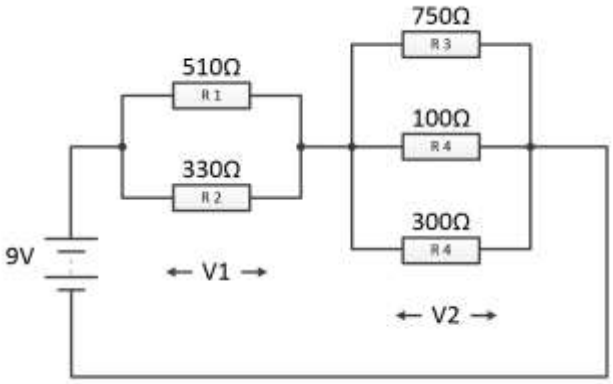
a) Find the total resistance ($\mathbf{R}_T$) of the circuit above.

b) Work out the total current ($\mathbf{I}_T$) in the circuit above.

c) Calculate the voltages ($\mathbf{V}_1$, $\mathbf{V}_2$) across the resistors in the circuit above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

2.Circuit



a) Find the total resistance ($\mathbf{R}_T$) of the circuit above.

b) Work out the total current ($\mathbf{I}_T$) in the circuit above.

c) Calculate the voltages ($\mathbf{V}_1$, $\mathbf{V}_2$) across the resistors in the circuit above.

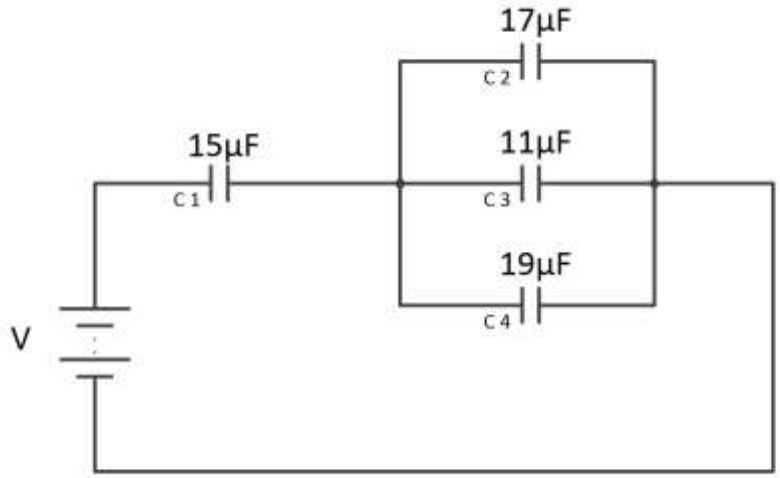
Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Developmental activity
Learners should complete the question below on their own and then exchange answers with other learners so they can peer assess each other. After peer assessment, ask learners to reflect on their results. They can then be shown the model answer and those who didn't get the correct answer can try to work out how and where they went wrong. Learners who struggled to find the correct answer can be allowed to attempt the developmental activity after this one.

Question
A test technician is tasked with ensuring all capacitors on a circuit board are charging to the right amount. This is so the technician can pass the circuit board to the next stage of production where it will be developed further. The circuit shown below is a section of the board that is powered by a DC supply.

Analyse the circuit to work out the voltage of the power supply that would enable a charge of 50µC to build across capacitor C3.



Model answer

The capacitor under consideration is C3.

$C_3 = 11\mu F$

The charge needed across this capacitor is 50uF.

$Q_3 = 50\mu C$

Using this information, the voltage across the capacitor under these conditions is determined as shown.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

$$V_3 = V_{234} = \frac{Q_3}{C_3} = \frac{50 \times 10^{-6}}{11 \times 10^{-6}} = 4.55V$$

After working out the voltage across the capacitor, the total capacitance of the three capacitors is determined and used to calculate the total charge in the circuit.

$$C_{234} = C_2 + C_3 + C_4 = 17 + 11 + 19 = 47\mu F$$

$$Q_{234} = Q_T = C_{234} \times V_{234}$$

$$Q_T = (47 \times 10^{-6}) \times (4.55) = 213.64\mu C$$

With the total charge of the circuit determined, the total capacitance of the circuit is calculated and then those two values are used to work out the total voltage in the system.

$$C_T = \left(\frac{1}{C_1} + \frac{1}{C_{234}}\right)^{-1} = \left(\frac{1}{15} + \frac{1}{47}\right)^{-1} = 11.37\mu F$$

$$V_T = \frac{Q_T}{C_T} = \frac{213.64 \times 10^{-6}}{11.37 \times 10^{-6}} = 18.8V$$

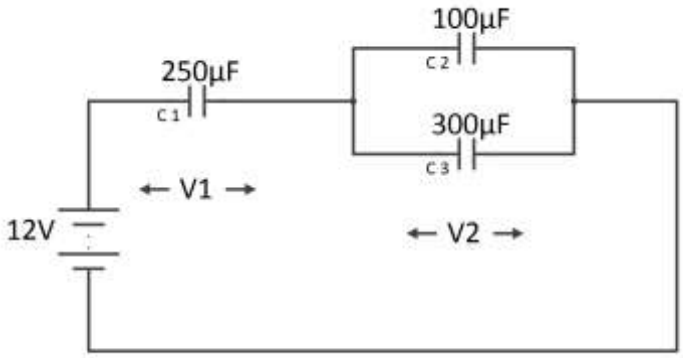
The total voltage calculated is the voltage the power supply should be set to ensure a charge of 50µC builds across capacitor C3.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Developmental activity
This developmental activity follows on from the previous activity and can be completed by learners who struggled to complete the previous one. It is designed to help learners correctly analyse a capacitor DC circuit. Learners who managed to correctly complete the previous activity can be allowed to skip this one.

1.Circuit



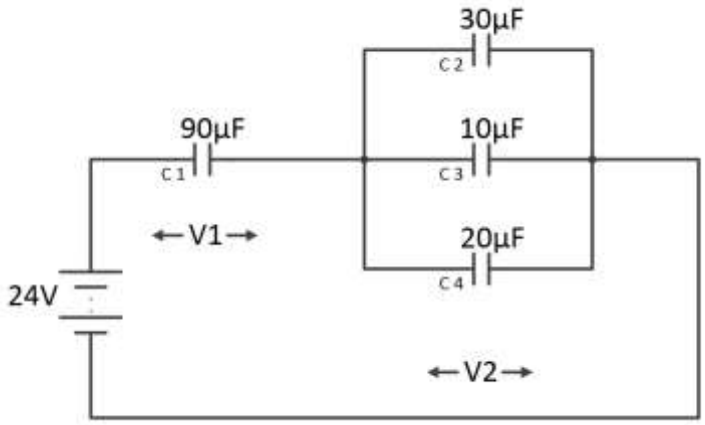
a) Calculate the total capacitance, $\mathbf{C_T}$, in the circuit above.

b) Calculate the total charge, $\mathbf{Q_T}$, in the circuit above.

c) Calculate the voltages, $\mathbf{V_1}$ and $\mathbf{V_2}$, across the capacitors in the circuit above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

2.Circuit



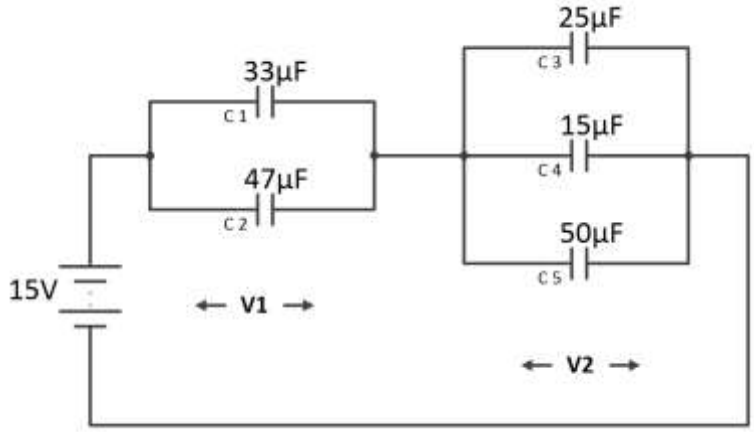
a) Calculate the total capacitance, $\mathbf{C_T}$, in the circuit above.

b) Calculate the total charge, $\mathbf{Q_T}$, in the circuit above.

c) Calculate the voltages, $\mathbf{V_1}$ and $\mathbf{V_2}$, across the capacitors in the circuit above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

3.Circuit



a) Calculate the total capacitance, $\mathbf{C_T}$, in the circuit above.

b) Calculate the total charge, $\mathbf{Q_T}$, in the circuit above.

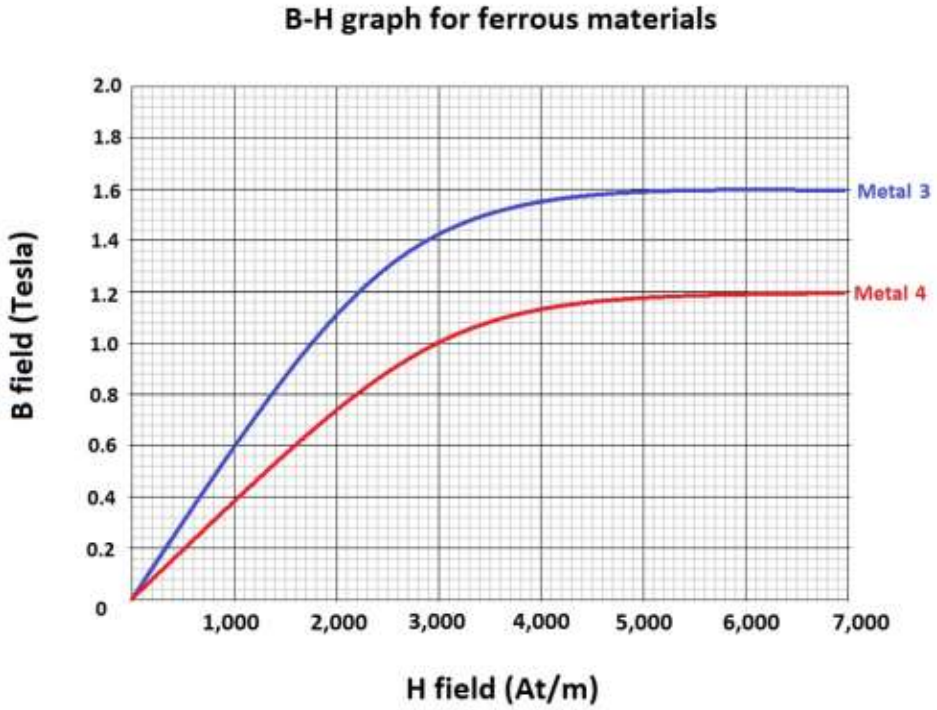
c) Calculate the voltages, $\mathbf{V_1}$ and $\mathbf{V_2}$, across the capacitors in the circuit above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Developmental activity
This activity will enable learners to develop their understanding of the principles of electromagnetism. It comprises six questions. The first four questions allow learners to develop their understanding of the relationship between magnetic flux density (B) and magnetic field strength (H). The last two questions allow learners to develop their understanding of electromagnetic induction by making calculations to work out induced voltage.

1.The image below shows the B-H graphs for electromagnets with cores made from ferrous materials:

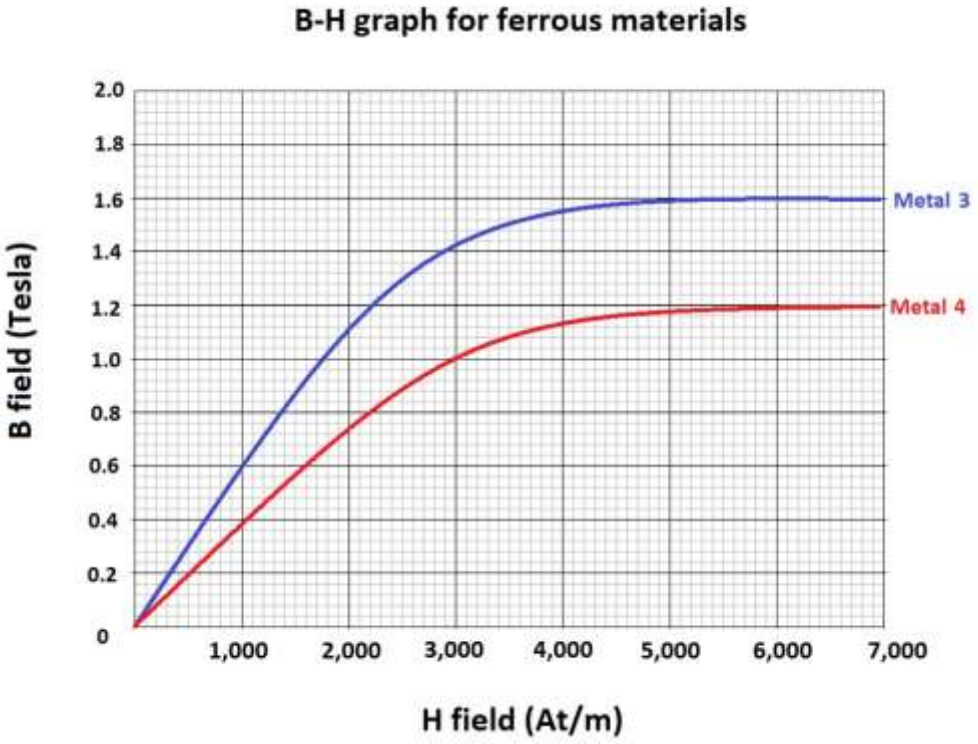


a) What magnetic field strength, **H**, will produce a **flux density, B**, of 0.6T in **metal 3**?

b) Calculate the magnetic permeability of **metal 3** under these conditions.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

2.The image below shows the B-H graphs for electromagnets with cores made from ferrous materials:

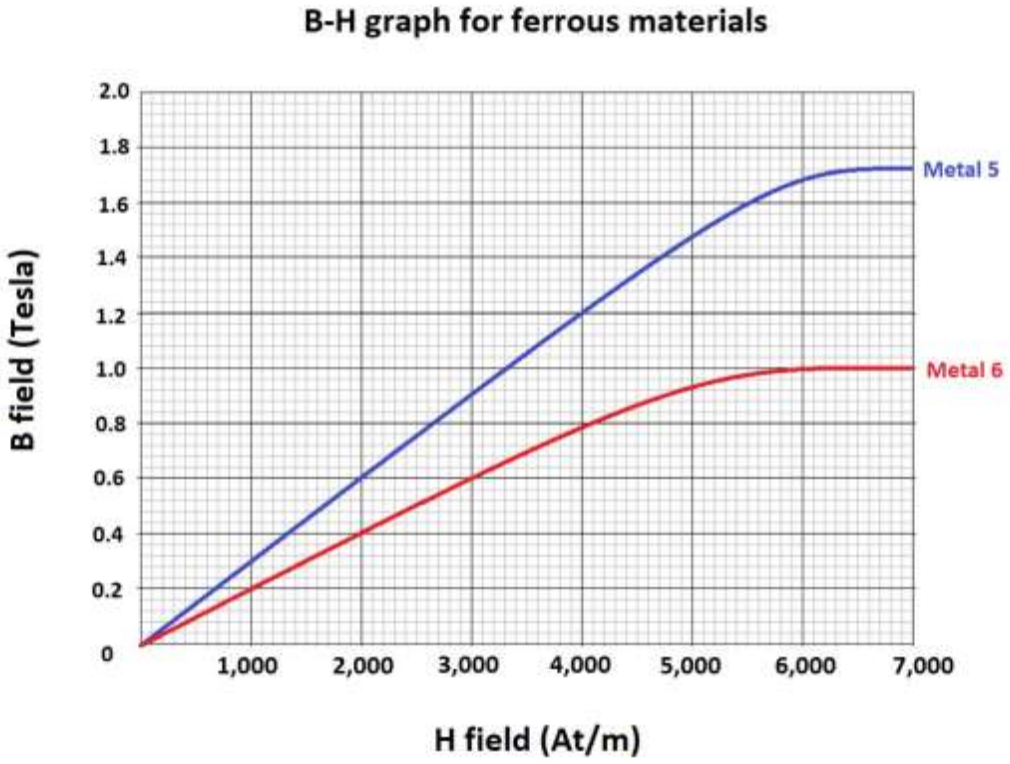


a) What magnetic field strength, **H**, will produce a **flux density, B**, of 1.0T in **metal 4**?

b) Calculate the magnetic permeability of **metal 4** under these conditions.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

3.The image below shows the B-H graphs for electromagnets with cores made from ferrous materials:

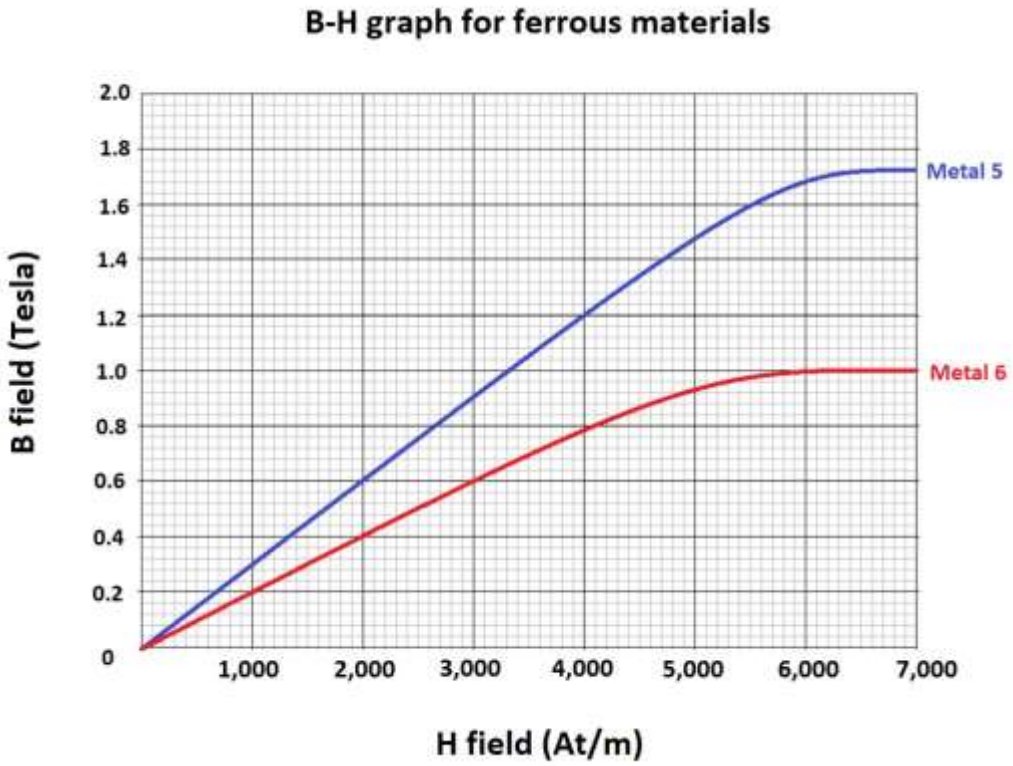


a) How much flux density, **B**, would **metal 5** produce when subjected to a magnetic **field strength, H**, of 4,000At/m?

b) Calculate the magnetic permeability of **metal 5** under these conditions.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

4.The image below shows the B-H graphs for electromagnets with cores made from ferrous materials:

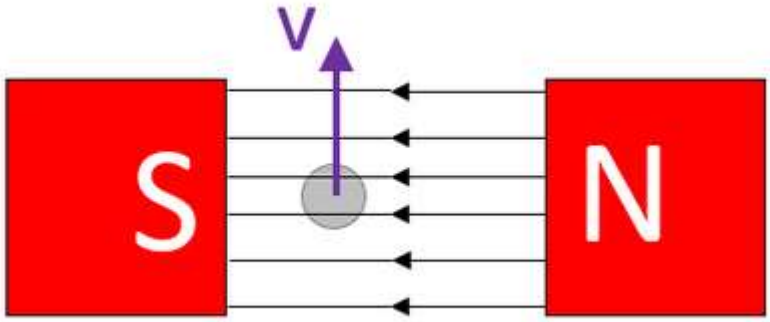


a) How much flux density, **B**, would **metal 6** produce when subjected to a magnetic **field strength, H**, of 3,000At/m?

b) Calculate the magnetic permeability of **metal 6** under these conditions.

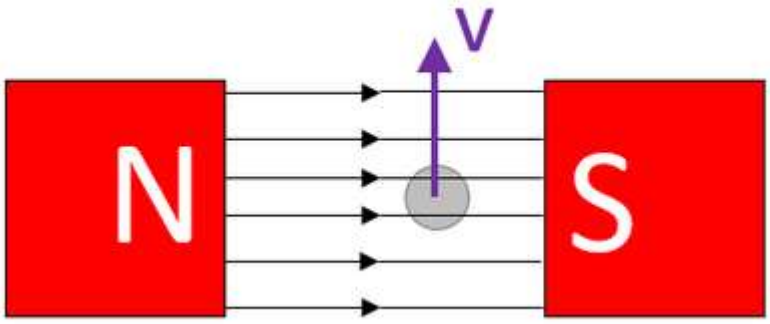
Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

5. A conductor which is **50cm** long is passing through a magnetic flux density of **0.77T**.



If the conductor travels at a velocity of **20.0m/s**, calculate how much EMF would be induced in the conductor.

6. A conductor which is **100cm** long is passing through a magnetic flux density of **1.50T**.



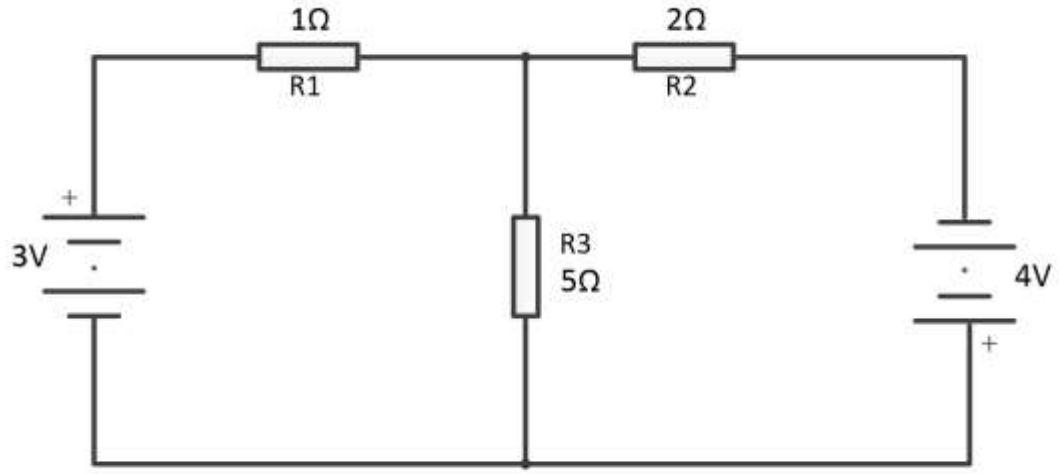
If the conductor travels at a velocity of **15.2m/s**, calculate how much EMF would be induced in the conductor.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Developmental activity
The activity will allow learners to develop their understanding of Kirchhoff's current and voltage laws. It comprises two circuits that learners must analyse by calculating the current flowing through each of the branches.

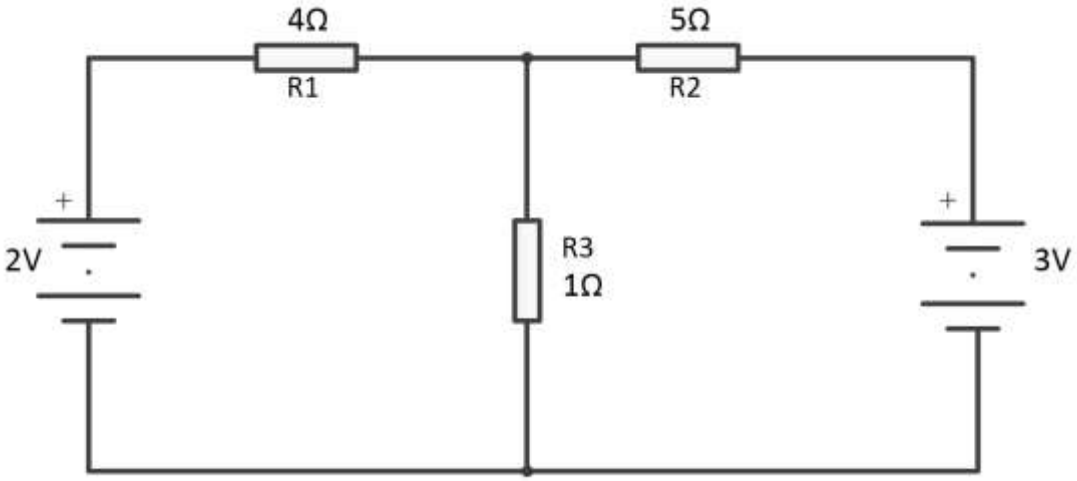
1.Circuit



Using Kirchhoff's laws, calculate the currents flowing through each of the branches in the circuit above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

2.Circuit



Using Kirchhoff's laws, calculate the currents flowing through each of the branches in the circuit above.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
8.1 Principles of electrical and electronic systems.

Developmental activity
This activity will allow learners to develop their understanding of differential protection systems. It comprises a table that contains questions that learners must answer. Learners can be asked to answer the questions individually or in groups.

Briefly explain the differential protection scheme.
Briefly explain **one** cause of ground faults in transformers.
Briefly explain **one** cause of short circuits in transformers.
List **two** types of overcurrent protection devices.
Briefly explain how an overcurrent protection device operates.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.1 The key components of a mechatronics system.

Developmental activity
This activity will allow learners to develop their understanding of the common terms used with sensors and measurements. It comprises a table of terms and definitions.

1. Match the following terms associated with sensors to their definitions.

Note the following definition:
Measurand – The physical quantity that is to be measured by the sensor and that causes a representative response in the sensor output.

Terms	**Definitions**
Accuracy	An undesired change in a sensor output over time.
Resolution	The specified deviation that can be expected in consecutive measurements under the same conditions and using the same measuring instrument.
Error	A ratio of the amount of change in output signal resulting from an amount of change in the input measurand.
Range	The degree to which a measurement agrees with the standard or desired amount.
Sensitivity	The difference between a sensor output and the output of an ideal sensor under the same conditions.
Repeatability	The smallest change in the measurand that the sensor can detect.
Drift	The extent of values over which the measurand is intended to measure, bounded by zero and full scale.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.1 The key components of a mechatronics system.

Developmental activity
This activity will allow learners to develop their understanding of sensors used in mechatronic systems. It comprises a table of tasks that learners must complete. Learners can use an online resource to do the first task in the table, while the rest of the tasks can be completed without using an online resource. The first two tasks focus on the temperature sensor and the final task allows learners to explore other types of sensors.

Carry out the following tasks:
Find an image of a temperature sensor from any online source and put it in the space below.
List **six** applications of temperature sensors in engineering manufacturing.
List **five** other types of sensors used in engineering production and manufacture.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.1 The key components of a mechatronics system.

Developmental activity
This activity will allow learners to develop their understanding of DC motors used in mechatronic systems. It comprises a table of tasks that learners must complete. Learners can use an online resource to do the first task in the table, while the rest of the tasks can be completed without using an online resource. The first two tasks focus on the stepper motor and the final task allows learners to explore other types of DC motors.

Carry out the following tasks:
Find an image of a stepper motor from any online source and put it in the space below.
List **four** applications of stepper motors in engineering manufacturing.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

List **five** other types of DC motors used in engineering production and manufacture.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.1 The key components of a mechatronics system.

Developmental activity
This activity will allow learners to develop their understanding of the key components of a mechatronic system. It comprises four tasks (a, b, c and d) that learners must complete.

a) List **four** applications of microcontrollers in engineering manufacturing.

b) Apart from weight detection, list **three** other applications of pressure sensors in engineering.

c) Apart from the limit switch, list **three** other devices that can be used to detect the presence of obstacles.

d) State whether the following devices are input devices or output devices:

Device	**Input or output**
Limit switch	
Push button	
Pressure sensor	
Motor	

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.2 The operation, function and applications of programmable logic controllers (PLCs) in mechatronic systems.

Developmental activity
This activity will allow learners to develop their understanding of the operation and function of PLCs in mechatronic systems. It comprises three tasks (a, b and c) that learners must complete.

a) An engineering workshop has two switches and a motor relay connected to a PLC. The time to read is 15ms per channel, the time to write per channel is 12ms and the time to execute is 15ms. Work out the scan cycle time for the system.

b) An engineering workshop has three push buttons and two motor relays connected to a PLC. The time to read is 11ms per channel, the time to write per channel is 10ms and the time to execute is 20ms. Work out the scan cycle time for the system.

c) An engineering workshop has a microswitch, two pressure sensors and two motor relays connected to a PLC. The time to read is 18ms per channel, the time to write per channel is 15ms and the time to execute is 10ms. Work out the scan cycle time for the system.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.2 The operation, function and applications of programmable logic controllers (PLCs) in mechatronic systems.

Developmental activity
This activity will allow learners to develop their understanding of the functions and applications of PLCs in mechatronic systems. It comprises four tasks (a, b, c and d) that learners must complete.

a) List **two** types of PLCs.

b) List **three** advantages of PLCs.

c) List **three** disadvantages of PLCs.

d) List **three** applications of PLCs.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

Targeted content
9.3 The basic principles of hydraulics and pneumatics.

Developmental activity
This activity will allow learners to develop their understanding of the basic principles and applications of pneumatic systems. It comprises four tasks (a, b, c and d) that learners must complete. Learners can attempt the tasks individually, then exchange work with their peers for assessment. After the peer assessment, learners can reflect on their results.

a) Briefly explain how a pneumatic system operates.

b) List **four** components found in a typical pneumatic system.

c) List **four** benefits of using a pneumatic system in engineering manufacturing.

d) List **four** applications of pneumatic systems in both the engineering and commercial fields.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.

With thanks to:
Ross Hawkins, Weston College (peer reviewer)

Producers
Wenling Zhang
Anthony Ntaki
Loughborough College

PRODUCED BY

Loughborough College is working in partnership with the Education and Training Foundation to deliver this resource.

FUNDED BY

This resource is funded by the Department for Education.

Association of Colleges is delivering this resource on behalf of the Education and Training Foundation. It is funded by the Department for Education.