2 Applied science and mathematics in engineering

2.1 Application of SI units of measurement

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SI units are standard units of measurement defined by the International System of Units. This is a metric system used worldwide for the standardisation of measurements.

SI unit A standard unit of measurement defined by the International System of Units

2.1.1 SI units of measurement

Table 2.1 SI units of measurement

	Unit of measurement	SI symbol	Levels of measurement
Current	Ampere	A	+ Microamp – the unit of current equal to one-millionth of an ampere + Milliamp – this is one-thousandth of an ampere + Amperes (amps) – the SI base unit of electric current + Kiloamp – equal to 1000 amperes
Luminous intensity – measure of visible radiated light that is emitted	Candela	cd	+ Microcandela – a unit or measurement of the luminous intensity equal to one-millionth of a candela + Millicandela – a standard unit for measuring the intensity of the light source, equal to one-thousandth of a candela + Candela – the SI unit of luminous intensity
Thermodynamic temperature	Kelvin	K	+ Kelvin – SI base unit of thermodynamic temperature; the absolute measure of temperature or the average internal energy of an object + Degrees Celsius – a unit of temperature on the Celsius scale
Mass	Kilogram	Milligram (mg) Gram (g) Kilogram (kg)	+ Milligram – one-thousandth of a gram + Gram – a unit of mass + Kilogram – equal to 1000 grams; the quantity of mass is measured in kilograms
Length	Metre	Millimetre (mm) Centimetre (cm) Metre (m) Kilometre (km)	+ Micrometre – equals one-millionth of a metre; often used to measure the size of fibre + Millimetre (mm) – one-thousandth of a metre + Centimetre (cm) – a metric unit of measurement equal to one-hundredth of a metre + Metre (m) – the SI base unit of length (100 cm or 1000 mm) + Kilometre (km) – a metric unit of measurement equal to 1000 metres
Amount of substance	Mole	mol	+ Nanomole – the amount of substance in a mole, equivalent to 0.001 of a micromole + Micromole – this means one-millionth of a mole + Millimole – an SI unit equivalent to one-thousandth of a mole + Mole – the given amount of substance/quantity (n) measured in moles
Time	Second	s	+ Millisecond – this is one-thousandth of a second + Microsecond – this is one-millionth of a second + Second – the SI unit of measurement (s) for time; there are 60 seconds in 1 minute + Minute – a measurement of time equal to 60 seconds + Hour – a measurement of time that contains 60 minutes or 3600 seconds

Exam tip

You should be able to identify the SI unit of measurement for each of the terms listed in Table 2.1, and what it means. Keep reading through the items in the table to reinforce your learning.

Typical mistake

When students are asked to name the SI units for measurements that are commonly used in engineering standards, the answer 'metric' or 'imperial' is not required.

Exam tip

Ensure that you understand and revise the difference between nano, micro and milli. Remember that a milli is equivalent to one-thousandth (1/1000th), a micro is equivalent to one-millionth (1/1,000,000th) and a nano is 0.001 of a micro.

Now test yourself TESTED

1. What is the difference between a microamp and a milliamp?
2. What is the unit of time measured in?
3. Explain what thermodynamic temperature is.
4. What is the SI symbol for kiloamp?
5. What is the quantity of mass measured in?

Revision activity

Create a series of flash cards that contain either SI unit abbreviations or descriptions of the SI units. Check your knowledge of the SI units by matching the abbreviations to the correct descriptions.

2.1.2 Application of base SI units

You will need to understand how equations of SI units are derived from base units and how the unknown factor can be found.

The unknown factor is found by using numbers that are multiplied together to find a missing number. For example:

- When working with hydraulics, gears and pulleys, SI units could be used to calculate the force or power required, for example the weight of an object to be lifted.
- In power stations SI units could be used to calculate the power to be generated.
- In household appliances, SI units could be used to calculate the efficiency of an appliance.
- In integrated circuits, SI units could be used to calculate the current flowing through the circuit.
- When working with aircraft, space vehicles and missiles, SI units would enable distances and weights of the objects to be calculated, and could inform the engineer of changes that may need to be made to a product's design.
- Telephone, radio and fibre-optic communications are all used to transmit data, whether from a voice or the internet, from one specific point to another. SI unit s enables measurement of the time taken to transmit the data.
- In the case of pharmaceuticals, fossil fuels, cosmetics, and food and drinks, SI units kg, g and mg are used to measure the weight of items.
- For buildings, roads, bridges and railways, SI units kg, g and mg are used to measure the weight to be carried.
- SI units kg, g and mg are used to measure the weight of individual transportation methods, such as cars, trucks, motorcycles and trains.
- Prosthetics, medical devices and radiotherapy use SI units mm or cm to calculate the size of parts.
- In applications, systems and computer programming, SI unit A is used to measure current.

2.2 Equations used to calculate energy, force, motion, electrical and geometric shapes

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You will need to understand how mathematical and scientific equations are used in engineering disciplines to calculate energy, force, motion, electrical power and geometric shapes.

2.2.1 Equations for properties

Energy

Energy is the ability to do work.

Energy The ability to do work

Force Pushing or pulling an object to create movement

Pressure A measure of force per unit of area

Table 2.2 Equations for energy

Property	Equation	
Efficiency (%)	(useful energy out ÷ total energy in) × 100	
Power	P = E ÷ t	power = energy ÷ time
Work done	W = F × d	work done = force × distance

Example

Calculate the efficiency of a light bulb where energy out is 40 watt hours and energy in is 200 watt hours:

Useful energy out — 40; Total energy in — 200

40 ÷ 200 = 0.2

0.2 × 100 = 20 — Efficiency

In this example, therefore, the bulb is 20% efficient.

Force and motion

Force is simply pushing or pulling an object to create movement. The movement is the motion of the object.

An example would be when looking at how a car travels along a motorway to identify how fast it is travelling.

Table 2.3 Equations for force and motion

Property	Equation	
Speed	s = d ÷ t	speed = distance ÷ time
Acceleration	a = (v − u) ÷ t	acceleration = change in velocity ÷ time
Force	F = m × a	force = mass × acceleration
Moment of force	m = F × d	moment = force × perpendicular distance from pivot
Momentum	p = m × v	momentum = mass × velocity
Pressure	p = F ÷ A	pressure = force ÷ area

Example

A car travels 5 miles in 5 minutes. Calculate the speed at which the car is travelling.

Using the calculation speed = distance ÷ time:

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5 miles ÷ 5 minutes = 1 mile per minute
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The speed, therefore, equates to 60 miles per hour.

Mass

Mass is the amount of matter present in a body. It is important as it allows you to calculate the amount of force needed to move an object.

Table 2.4 Equations for mass

Property	Equation	
Weight	w = m × g	weight = mass × gravity
Density	d = m ÷ v	density = mass ÷ volume
Mass	M = v × d	mass = volume × density

Mass The amount of matter present in a body

Weight A measure of how much gravity is pulling on an object

Density A measure of mass per unit of volume

Power The amount of energy being transferred in a period of time

Example

A ship is being designed. When designing the ship to float its weight must be lighter than the water, otherwise it will sink.

The ship is weighed in a dock to confirm the level of water it displaces. It displaces 7 m^3 of water. The density of the water is 997 kg/m^3 at a temperature of 25 °C. Calculate the mass of the ship using the formula mass = volume × density:

Volume — Density — Mass

7 m^3 × 997 kg/m^3 = 6979 kg

Electrical power

This is used to confirm the amount of energy being transferred through a circuit.

This is important, especially when all of us use electrical items on a daily basis, such as laptops and mobile phones. We expect to be able to use these items safely and without the risk of injury, such as electrocution. Therefore, the electrical **power** needed for any device must be calculated correctly.

Table 2.5 Equations for electrical power

Property	Equation	
Power	P = V × I	power = voltage × current
Voltage	V = I × R	voltage = current × resistance
Current	I = P ÷ V	current = power ÷ voltage
Resistance	R = V ÷ I	resistance = voltage ÷ current

Typical mistake

Many students struggle to answer questions regarding the mass of products, especially those with cylindrical shapes. Remember to calculate the overall volume of each shape, then deduct the mass of any hole from the original shape. Follow a step-by-step process.

Example

An electric kettle is connected to the 240 V mains supply and draws a current of 5 amps (A). Calculate the power of the kettle. Remember: power (P) = voltage (V) × current (I).

Voltage (V) — Current (I)

P = 240 × 5 = 1200 W

1200 W = 1.2 kW, so P = 1.2 kW

Power (P)

Geometric shapes

Shapes often need to be calculated, especially when measuring a product that contains multiple parts that all connect together. If the sizes are not measured correctly, the component parts will not fit.

Table 2.6 Equations for geometric shapes

Property	Equation
Area – square	length of side^2
Area – rectangle	length of side 1 × length of side 2
Area – triangle	(length of base × height of triangle) ÷ 2
Area – circle	π × radius^2
Volume – cube	length of side^3
Volume – pyramid	(1/3) × (base area) × height of pyramid
Volume – cylinder	π × radius^2 × height of cylinder

Example

The radius of a wheel is 0.2 m. Calculate the area of the wheel.

Area of a circle = π × radius^2

= π × 0.2^2 = 0.13 m^2

2.2.2 Application of equations

You will need to understand how equations can be used to evaluate the unknown factor for different properties:

- Hydraulics, gears and pulleys – to calculate the power needed in a hydraulic water pump, or for the gear ratio when pulling a heavy object or to identify the number of pulleys needed to lift a heavy weight easily.
- Power stations, household appliances and integrated circuits – to calculate the amount of power needed to supply a local housing estate, or to ensure that home electrical items do not overheat and that circuits operate together without failure.
- Aircraft, space vehicles and missiles – to calculate the weight and speed of aircraft in flight and in space, and how to guide missiles to their exact destination.
- Telephone, radio and fibre-optic communications – calculations can be produced to identify the frequency of transfer, the speed of data and the quality.
- Pharmaceuticals, fossil fuels, food and drinks, and cosmetics – specific calculations relating to the testing of medicines and cosmetics, to prolong the life of food items, the sugar levels in drinks or for locating new sources of fossil fuels.
- Buildings, roads, bridges and railways – to calculate the strength of a bridge, the materials that could be used, or the life expectancy of a design.
- Cars, trucks, motorcycles and trains – to calculate how materials perform, weights of products or energy consumption.
- Prosthetics, medical devices and radiotherapy – to calculate sizes of medical parts, materials and strength, applications, or to predict how treatments could perform.
- Applications, systems and computer programming – to calculate power requirements for a product system or programme requirements, for example on a robotic production line.

Exam tip

When calculating mathematical formulae and equations to produce a final answer, show all working out as you could gain marks for these stages even if your final answer is incorrect.

Typical mistake

If a question asks you to produce an answer to a stated number of decimal places, you must ensure that your final answer meets the requirements of the question.

Now test yourself

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1 What is the equation used to calculate weight?
2 Explain how you would calculate the volume of a pyramid.
3 What is meant by energy efficiency?
4 What is the difference between speed and acceleration?
5 Explain the difference between volume and area.

Revision activity

You will need to revise the different equations used to calculate electrical power, voltage, current and resistance. Read through the calculations provided and use these in a range of scenarios. An example has been provided below.

Scenario A

Calculate the power required to operate a handheld 230 V electric saw drawing a current of 10 amps for a period of 10 minutes.

Exam checklist

In this content area you learned about:

- How SI units of measurement are used in engineered products and projects
- SI units of measurement:
  - current – ampere
  - luminous intensity – candela
  - thermodynamic temperature – kelvin
  - mass – kilogram
  - length – metre
  - amount of substance – mole
  - time – second
- How equations of SI units are derived from base units and how the unknown factor can be found
- How mathematical and scientific equations are used in engineering disciplines to calculate energy, force, motion, electrical power and geometric shapes
- How equations for properties can be used to evaluate the unknown factor

Exam practice questions

1 Identify which unit would be used to measure luminous intensity. [1]
  a Minutes
  b Candela
  c Kelvin
  d Kilogram

2 Identify which unit would be used to measure current. [1]
  a Ampere
  b Seconds
  c Candela
  d Kilometre

3 Identify which SI unit of measurement would be best to use on a technical drawing of a shelf bracket. [1]
  a Millimetre (mm)
  b Kilometre (km)
  c Centimetre (cm)
  d Metre (m)

4 Identify which unit of measurement would be best to use to measure the amount of a substance. [1]
  a Candela
  b Mole
  c Amp
  d Micrometre

5 A designer has produced an engineering component at a scale of 1:10. The length of the component on the drawing measures 40 mm. Calculate the actual length of the component part. Show all working out. [2]

6 A hairdryer is a household appliance that is used to heat air. Air is forced through a nozzle using a fan mechanism. The power supply to the hair dryer is 240V (mains). The heating element inside the hairdryer is 1200 watts (1.2 kW) Calculate the current going through the hairdryer. Show all working out. [3]

7 A helicopter flight from London to Paris takes 2 hours and covers a distance of 465 km. Calculate the speed that the helicopter must be travelling at. Give your answers in kilometres per hour (km/h). Show all working out. [3]

8 The total power input to a substation is 600 MW. The useful power output is 480 MW. Calculate the efficiency of the substation. Show all working out and round up to the nearest whole unit. [3]

9 You are an engineer at a car body supplier. Your manager has asked you to confirm the efficiency of the production line. Calculate the efficiency of the production line using the following data. Show all working out. [4]
  - Total energy consumption is 40 watt hours.
  - Useful energy out is 32 watt hours.

10 You are a sheet metal worker and have been asked to manufacture a circular component out of 2 mm aluminium with a radius of 8 cm. Calculate the surface area of the component part. Give your answer to one decimal place (1 dp). Show all working out. [4]