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• cover all the Subject Outcomes of the subject
• contain appropriate weighting of topics
• provide clearly defined key concepts
• provide comprehensive, current and easy-to-follow content, at the appropriate language level, in a logical sequence and at a suitable pace
• present students with a wide variety of learning and assessment activities.
Electrical Principles & Practice

NQF Level 2

Student’s Book

Jowaheer Consulting and Technologies
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Topic 1
SI units of measurement
Module 1

SI units of measurement

Overview

In this topic, you are going to study more closely the International System of Units, the most widely used system of measurement today.

Why and how do we measure things? We measure things so that we are accurate in what we say and do. As an engineering student, you will need to take measurements and perform calculations. The results will be meaningless unless they are numerically and dimensionally correct and accurate. For example, we can say that the length of the classroom is 10. Ten what? Units of measurement provide a common way of understanding the quantity we are describing. In this module, you will gain an understanding of the SI units used in engineering.

By the end of this module, you will be able to:
• identify base units of measurement used in engineering
• define the physical quantities that are measured by the SI units
• describe the rules when writing SI units of measurements
• convert scientific notation to decimal notation and vice versa (convert answer to 3 decimal digits)
• list common prefixes used in engineering
• derive new units from the relationships between SI units (i.e. the quantities they measure) Range: speed, velocity, acceleration, force, weight, work, energy, torque, resistance, density, pressure and power
• explain the theory and measure plane and solid angles.
Units in this module
Unit 1.1 SI base units of measurement
Unit 1.2 Converting SI units
Unit 1.3 SI derived units of measurement

Unit 1.1 SI base units of measurement

By the end of this unit, you will be able to:
• identify base units of measurement used in engineering
• define the physical quantities that are measured by SI units
• describe the rules when writing SI units of measurement.

Different measurement systems

Until 1968, South Africa used the imperial system of measurement. South Africa gradually introduced the metric system of measurement using SI units over a number of years. Finally, in 1973, the use of imperial measurements was prohibited.

The imperial system of measurement was the system used throughout the British Empire. Its base units were length expressed in feet, mass expressed in pounds and time expressed in seconds. A big disadvantage of this system, as you will see later, is that it is not based on the decimal system.

The United States of America (USA) uses the United States customary system or American system. Although this system is similar in many respects to the British imperial system, there are a number of important numerical differences.

The International System of Units (SI)

The International System of Units is abbreviated SI from its French name, Système International d’Unités. Almost all countries in the world use this system in science and commerce. The main exceptions are the USA, Liberia and Myanmar (Burma).

The SI is a system of units of measurement. There are seven base units and numerous derived units. It is also a metric, or decimalised, system based on the number ten. The base units and their physical quantities are:
• metre for length
• kilogram for mass
• second for time
• ampere for electric current
• kelvin for temperature
• candela for luminous intensity
• mole for the amount of a substance.
All the other SI units are derived from these seven base units.

In a decimalised system, all units are related by powers of 10 and are identified by prefixes. This makes the conversion of units easier. For example, it is easy to convert metres to millimetres by simply moving the decimal point – 1,456 metres is 1,456 millimetres. You will learn more about this in Unit 1.2.

**Defining a unit of measurement and physical quantity**

A **unit of measurement** is a defined, physical quantity in terms of which other quantities of the same kind may be expressed as simple multiples of the unit of measurement. For example, length is a physical quantity. The SI unit of measurement for length is the metre. The International System of Units defines the metre as follows:

A **metre** is the length of the path travelled by light in a vacuum during a time interval of $\frac{1}{299,792,458}$ of a second.

**Example 1**

FIFA specifies the field dimensions of a soccer field as follows:

- Length: min 90 m max 120 m
- Width: min 45 m max 90 m

Here, FIFA is expressing other quantities of the metre in terms of simple multiples of the metre. So, the length of a soccer field must be a minimum of 90 metres and a maximum of 120 metres.

**Physical quantity** is a physical property of a phenomenon, body or substance that can be quantified by measurement. A more formal definition is given in the *International Vocabulary of Metrology, 3rd edition* (VIM3), which defines quantity as:

the property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference.

**SI base units**

As you have learnt, there are different types of SI units of measurement. There are seven SI base units and many derived units. The base units are combined to form derived units. Table 1.1 shows the seven SI base units.
Table 1.1 The seven SI base units

For a measurement to be of value, a unit of a physical quantity must have the same magnitude regardless of where you take the actual measurement. By convention, the units of measurement of the seven base quantities have been defined as explained below.

**Metre (m)**

The metre (m) is the base unit of length (l). The metre is defined as follows:

**A metre** is the length of the path travelled by light in a vacuum during a time interval of \( \frac{1}{299,792,458} \) of a second.

Table 1.2 shows SI multiples for the metre (m).

<table>
<thead>
<tr>
<th>Physical quantity</th>
<th>Physical quantity symbol</th>
<th>SI base unit</th>
<th>SI base unit symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>l</td>
<td>metre</td>
<td>m</td>
</tr>
<tr>
<td>mass</td>
<td>m</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>time</td>
<td>t</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>electric current</td>
<td>I</td>
<td>ampere</td>
<td>A</td>
</tr>
<tr>
<td>temperature</td>
<td>T</td>
<td>kelvin</td>
<td>K</td>
</tr>
<tr>
<td>luminous intensity</td>
<td>( I_v )</td>
<td>candela</td>
<td>cd</td>
</tr>
<tr>
<td>amount of a substance</td>
<td>( n )</td>
<td>mole</td>
<td>mol</td>
</tr>
</tbody>
</table>

**Table 1.2 SI multiples for the metre (m)**

<table>
<thead>
<tr>
<th>Submultiples</th>
<th>Value</th>
<th>Symbol</th>
<th>Name</th>
<th>Value</th>
<th>Symbol</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( 10^{-1} ) m</td>
<td>dm</td>
<td>decimetre</td>
<td>( 10^{1} ) m</td>
<td>dam</td>
<td>decametre</td>
</tr>
<tr>
<td></td>
<td>( 10^{-2} ) m</td>
<td>cm</td>
<td>centimetre</td>
<td>( 10^{2} ) m</td>
<td>hm</td>
<td>hectometre</td>
</tr>
<tr>
<td></td>
<td>( 10^{-3} ) m</td>
<td>mm</td>
<td>millimetre</td>
<td>( 10^{3} ) m</td>
<td>km</td>
<td>kilometre</td>
</tr>
<tr>
<td></td>
<td>( 10^{-6} ) m</td>
<td>( \mu ) m</td>
<td>micrometre</td>
<td>( 10^{6} ) m</td>
<td>Mm</td>
<td>megametre</td>
</tr>
<tr>
<td></td>
<td>( 10^{-9} ) m</td>
<td>nm</td>
<td>nanometre</td>
<td>( 10^{9} ) m</td>
<td>Gm</td>
<td>gigametre</td>
</tr>
<tr>
<td></td>
<td>( 10^{-12} ) m</td>
<td>pm</td>
<td>picometre</td>
<td>( 10^{12} ) m</td>
<td>Tm</td>
<td>terametre</td>
</tr>
</tbody>
</table>

**Note**

1. Although people often use the term ‘micron’, it is preferable to use the term ‘micrometre’.
2. The standard spelling is metre for the metric unit of length in all English-speaking countries. The exception is the USA where it is spelt meter. All countries spell measuring devices (such as parking meter and speedometer) as ‘meter’, for example speedometer, thermometer and voltmeter.
Kilogram (kg)
The kilogram (kg) is the base unit of mass (m). The kilogram is defined as follows:

A kilogram is equal to the mass of the international prototype kilogram (IPK).

The IPK is the mass of the platinum-iridium cylinder stored at the International Bureau of Weights and Measures at Sevres, near Paris, France.

Second (s)
The second (s) is the base unit of time (t). The second is defined as follows:

A second is the length of time taken for 9 192 631 770 periods of vibration of the caesium-133 atom to occur.

Common multiples of the second are:
- $10^{-3}$ s or ms or millisecond
- $10^{-6}$ s or µs or microsecond
- $10^{-9}$ s or ns or nanosecond.

Ampere (A)
The ampere (A) is the base unit of electric current (I). The ampere is defined as follows:

An ampere is the constant current that produces an attractive force of $2 \times 10^{-7}$ newtons per metre of length between two straight, parallel conductors of infinite length and negligible circular cross section placed one metre apart in a vacuum.

Kelvin (K)
The kelvin (K) is the base unit of temperature (T). The Kelvin scale is an absolute, thermodynamic temperature scale that uses absolute zero as its null point. Absolute zero is the temperature at which all thermal motion ceases. The reference point that defines the Kelvin scale is the triple point of water at 273.16 K (0.01 °C; 32.02 °F). The triple point of a substance is the temperature and pressure at which three phases, namely gas, liquid and solid, of that substance coexist in thermodynamic equilibrium. The kelvin is defined as follows:

A kelvin is 1/273.16 of the difference between absolute zero and the triple point of water.

Note
When referring to kelvin as the base unit of temperature, it is spelt with a lower case ‘k’. However, when referring to the Kelvin scale, we use a capital letter ‘K’.

Did you know?
Other interesting facts about the kilogram are that it is the only SI base unit with an SI prefix as part of its name. It is also the only SI unit that is still defined by an artefact. All other SI units have been redefined using a fundamental physical property that can be reproduced in a laboratory. A kilogram is almost exactly equal to the mass of one litre of water.
Candela (cd)

The candela (cd) is the base unit of luminous intensity ($I_v$). The candela is defined as follows:

A candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency $540 \times 10^{12}$ hertz and that has a radiant intensity in that direction of $\frac{1}{683}$ watt per steradian.

Mole (mol)

The mole (mol) is the base unit of a substance ($n$). A mole is defined as follows:

A mole is the amount of a substance that contains as many particles as there are atoms in 0,012 kg (12 g) of the isotope carbon-12.

Thus, by definition, one mole of pure $^{12}$C has a mass of exactly 12 g.

Aspirin is a remarkable analgesic (pain killer) that also prevents certain heart conditions. Aspirin has the following formula: $C_9H_8O_4$. Therefore, 1 mol of aspirin contains:

- 9 mol of carbon atoms
- 8 mol of hydrogen atoms
- 4 mol of oxygen atoms.

**Example 2**

Aspirin is a remarkable analgesic (pain killer) that also prevents certain heart conditions. Aspirin has the following formula: $C_9H_8O_4$. Therefore, 1 mol of aspirin contains:

- 9 mol of carbon atoms
- 8 mol of hydrogen atoms
- 4 mol of oxygen atoms.

**Figure 1.4 An aspirin tablet**

**Did you know?**

The average surface temperature on earth is 288 K.

A standard candle emits a luminous intensity of 1 cd.

**Words & terms**

**candela**: the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency $540 \times 10^{12}$ hertz and that has a radiant intensity in that direction of $\frac{1}{683}$ watt per steradian

**mole**: the amount of substance that contains as many particles as there are atoms in 0,012 kg (12 g) of the isotope carbon-12

**Rules about writing SI units of measurement**

**Physical quantities**

- Symbols for physical quantities are written in italics, for example $m$ for mass and $l$ for length.
- Write the value of a quantity as a number followed by a space and then the unit symbol, for example 5 m or 288 K. This rule also includes the degree symbols for temperature, for example 1 °C and 32 °F. The exception to this rule is the symbols for plane angular degrees, minutes and seconds, °, ′, and ″. Place these symbols immediately after the number with no intervening space, for example 10° 15′ 35″.
- Spaces are used to separate thousands, for example 1 000.
- In South Africa, we use the decimal comma rather than the decimal point, for example 1,5 m rather than 1.5 m.
Unit symbols

- Unit symbols are written in upright roman type, for example m for metres and s for seconds.
- Unit symbols are written in lower case, for example s for second and m for metre. The exception to this rule is where symbols are derived from the name of a person. For example, the unit of current is named after André-Marie Ampère. Its symbol is written as upper case A, but the unit itself is written ampere.
- Unit symbols are not written in plural. For example, m means metre or metres, while ms means milliseconds.
- When derived units are formed by multiplication, join unit symbols with a centre dot · or a non-break space, for example N·m or N m.
- When derived units are formed by division, join symbols with a solidus/ or write them as a negative exponent. For example, write metre per second as m/s, m s⁻¹ or m·s⁻¹.

Unit names

- Names of units start with a lower case letter, for example metre, ampere and kelvin, even when the symbol for the unit is a capital letter. This also applies to degrees Celsius because degree is the unit.
- Names of units are written in plural using the normal rules of English grammar, for example newtons is the plural of newton and henries is the plural of henry. The exceptions to this rule are the units lux, hertz and siemens that remain the same in singular and plural form. Note that this rule applies only to the full names of units, not to their symbols.

Prefixes

- A prefix is part of the unit symbol. Its symbol is added to the unit symbol without a separator, for example c in cm and m in mA.
- Compound prefixes are not allowed. For example, there is no such thing as centimillimetre.
- All symbols of prefixes larger than 10³ (kilo) are upper case, for example MW for megawatt and GM for gigametre.

Work in groups of five.
1. Copy and complete the table below with the correct quantity symbols.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Quantity symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) length</td>
<td></td>
</tr>
<tr>
<td>b) time</td>
<td></td>
</tr>
<tr>
<td>c) mass</td>
<td></td>
</tr>
<tr>
<td>d) luminous intensity</td>
<td></td>
</tr>
<tr>
<td>e) temperature</td>
<td></td>
</tr>
<tr>
<td>f) amount of a substance</td>
<td></td>
</tr>
</tbody>
</table>
2. Correct the mistakes in the following unit symbols.
   a) 0,25 w
   b) Km
   c) 20 °K
   d) m.p.s
   e) 250 kgs

3. Complete the following sentences with the missing words or unit symbols.
   a) The _____ of the mechanical workshop is 20 m.
   b) Jabu takes 30 _____ to unlock his locker.
   c) The _____ of an orange is 140 g.
   d) The sun radiates light energy which has an estimated luminous intensity of \(10^{18}_____\).
   e) The triple point of water is defined as 273,16 _____.

Unit 1.2 Converting SI units

By the end of this unit, you will be able to:
• convert scientific notation to decimal notation and vice versa (convert answer to 3 decimal digits).

Scientific notation

Scientific notation is also known as exponential notation. It is a way of easily writing very large or very small numbers. In scientific notation, all numbers are written as follows:

\[ a \times 10^b \]

We read this as: \(a\) times ten to the power of \(b\), where the exponent \(b\) is an integer and the coefficient \(a\) is a real number that must be greater than or equal to one and less than 10.

Example 3

The Earth’s mass is about 597360000 000 000 000 000 kg. In scientific notation, we write this as \(5,973 \times 10^{24}\) kg.

Figure 1.5 The Earth has a mass of \(5,973 \times 10^{24}\) kg
The number 0,15 × 10³ is not correctly written in scientific notation since the coefficient is not between 1 and 10. Move the decimal point to the right until the coefficient is between 1 and 10. For each place you move the decimal comma to the right, the exponent will be lowered by 1 power of ten. Therefore, 0,15 × 10³ = 1,5 × 10² in scientific notation.

Example 5

Table 1.3 provides some examples of conversions between decimal and scientific notation.

<table>
<thead>
<tr>
<th>Decimal notation</th>
<th>Scientific notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>3 × 10²</td>
</tr>
<tr>
<td>4 000</td>
<td>4 × 10³</td>
</tr>
<tr>
<td>7 000 000</td>
<td>7 × 10⁶</td>
</tr>
<tr>
<td>0,25</td>
<td>2,5 × 10⁻¹</td>
</tr>
<tr>
<td>17,583</td>
<td>1,758 3 × 10⁴</td>
</tr>
</tbody>
</table>

Table 1.3 Conversions between decimal and scientific notation

Converting decimal notation to scientific notation

To convert from decimal notation to scientific notation, move the decimal comma separator (,) the desired number of places to the left or right. If you move the comma \(n\) places to the left, then multiply by \(10^n\).  

Example 6

Convert 2 120 000 to scientific notation.

Start with 2 120 000. Move the decimal comma six places to the left = 2,12 and multiply by 10⁶. This gives the result 2,12 × 10⁶.

If you move the comma \(n\) places to the right, then multiply by \(10^{-n}\).
Example 7

Convert 0,001 23 to scientific notation.

Start with 0,001 23. Move the comma three places to the right = 1,23 and multiply by $10^{-3}$. This gives the result $1,23 \times 10^{-3}$.

Converting scientific notation to decimal notation

To convert from scientific notation to decimal notation, take the number and move the comma separator by the number of places indicated by the exponent. Move the comma separator left if the exponent is negative or right if the exponent is positive.

Example 8

Convert $2,5 \times 10^4$ to decimal notation.

Start with $2,5 \times 10^4$. Move the comma four places to the right to give the result 25 000.

Rules for scientific notation when multiplying and dividing

When you multiply two numbers, add the exponents, if the bases are the same.

Example 9

$(2,5 \times 10^2) \times (2 \times 10^8) = 5 \times 10^{10}$

$(2,5 \times 10^{-2}) \times (2 \times 10^8) = 5 \times 10^6$

When you divide two numbers, subtract the exponent of 10 in the denominator from the exponent of 10 in the numerator.

Example 10

$\frac{2,5 \times 10^2}{2 \times 10^8} = 1,25 \times 10^{-6}$

$\frac{2,5 \times 10^{-2}}{2 \times 10^8} = 1,25 \times 10^6$
Rounding off to 3 decimal places

Let's say, for example, that you arrive at an answer of 2,288.7. Rounding off this answer to 3 decimal places will give you 2,289. If the fourth digit is 5 or greater than 5, we make the previous digit one greater. If, however, the fourth digit is less than 5, the previous digit stays the same. If the answer was 2,222.35, then rounding it off would give you 2,222.

Example 11

Convert 8,245.9 to three decimal places.
The answer is 8,246.

Assessment activity 1.2

Work in pairs.
1. Copy and complete the table below. We have done the first one as an example.

<table>
<thead>
<tr>
<th>Decimal notation</th>
<th>Scientific notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) 200</td>
<td>$2 \times 10^2$</td>
</tr>
<tr>
<td>b)</td>
<td>$2 \times 10^3$</td>
</tr>
<tr>
<td>c) 0.075</td>
<td></td>
</tr>
<tr>
<td>d) 1 000 000</td>
<td></td>
</tr>
<tr>
<td>e) 0.000 025</td>
<td></td>
</tr>
</tbody>
</table>

2. Convert 7,120.9 to 3 decimal places.

Common prefixes

One of the advantages of the metric system is that it is easy to convert SI units of measurement that have the same base but a different prefix by using multiplication or division. You can make SI units larger or smaller by using prefixes which denote multiplication or division by a particular amount. The most common prefixes with their meanings are listed in Table 1.4.

<table>
<thead>
<tr>
<th>Prefix symbol</th>
<th>Prefix name</th>
<th>Multiply or divide from the base unit</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>tera</td>
<td>multiply by $1 \times 10^{12}$</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>G</td>
<td>giga</td>
<td>multiply by $1 \times 10^9$</td>
<td>$10^9$</td>
</tr>
<tr>
<td>M</td>
<td>mega</td>
<td>multiply by $1 \times 10^6$</td>
<td>$10^6$</td>
</tr>
<tr>
<td>k</td>
<td>kilo</td>
<td>multiply by $1 \times 10^3$</td>
<td>$10^3$</td>
</tr>
<tr>
<td>h</td>
<td>hecto</td>
<td>multiply by $1 \times 10^{2}$</td>
<td>$10^{2}$</td>
</tr>
<tr>
<td>d</td>
<td>deci (a tenth)</td>
<td>divide by $10$  (or multiply by $0,1$)</td>
<td>$10^{-1}$</td>
</tr>
<tr>
<td>c</td>
<td>centi (a hundredth)</td>
<td>divide by $100$ (or multiply by $0,01$)</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>m</td>
<td>milli (a thousandth)</td>
<td>divide by $1000$ (or multiply by $0,001$)</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>μ</td>
<td>micro (a millionth)</td>
<td>divide by $10000$</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>n</td>
<td>nano</td>
<td>divide by $1000000$</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>p</td>
<td>pico</td>
<td>divide by $1000000000$</td>
<td>$10^{-12}$</td>
</tr>
</tbody>
</table>

Table 1.4 Common prefixes and their meanings
Table 1.5 shows some common conversions with which you should be familiar.

<table>
<thead>
<tr>
<th>Length</th>
<th>Area</th>
<th>Volume</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm = 1 cm</td>
<td>100 mm² = 1 cm²</td>
<td>1 000 mm³ = 1 cm³</td>
<td>1 h = 60 min</td>
</tr>
<tr>
<td>100 cm = 1 m</td>
<td>10 000 cm² = 1 m²</td>
<td>1 000 000 cm³ = 1 m³</td>
<td>1 min = 60 s</td>
</tr>
<tr>
<td>1 000 m = 1 km</td>
<td>1 000 000 m² = 1 km²</td>
<td>1 000 cm³ = 1 litre</td>
<td>1 day = 24 h</td>
</tr>
</tbody>
</table>

Table 1.5 Some common metric conversions

Let's now study some examples of how to convert SI units. Remember the following rules:
- When you convert from small units to large units, divide.
- When you convert from large units to small units, multiply.

**Example 12**
Convert 2 km to metres.
Kilometres are larger units than metres. Multiply by the number of metres in 1 km, which is 1 000:
\[
2 \text{ km} = 2 \times 1000 \text{ m}
\]
\[
= 2000 \text{ m}
\]

**Example 13**
Convert 250 mm to cm.
Millimetres are smaller units than centimetres. Divide by the number of millimetres in a centimetre, which is 10:
\[
250 \text{ mm} = \frac{250 \text{ cm}}{10}
\]
\[
= 25 \text{ cm}
\]

Figure 1.6 will help you to convert from mm to km and vice versa.

**Example 14**
Convert 3 hours to seconds.
There are 60 min in an hour so multiply by 60 to get minutes:
\[
= 3 \times 60
\]
\[
= 180 \text{ min}
\]

There are 60 s in a minute so multiply by 60 to get seconds:
\[
= 180 \times 60
\]
\[
= 1080 \text{ s}
\]

**Did you know?**
Minutes and hours are not SI units, but are accepted for use with the SI.
Sometimes you will need to compare measurements. First, change all the measurements to the same units. You can only compare units with like units.

**Example 15**

Which is heavier, 1 kg of rice or 2 000 g of pap?

Use the same unit for both:
- Rice = 1 kg = 1 000 g
- Pap = 2 000 g

Therefore, 2 000 g of pap is heavier than 1 kg of rice.

**Example 16**

Convert 100 mm² to m².

\[
100 \text{ mm}^2 = 100 \text{ mm}^2 \times \frac{1 \text{ m}^2}{1 000 000 \text{ mm}^2} = 1 \times 10^{-4} \text{ m}^2
\]

**Example 17**

Convert 200 cm³ to m³.

\[
200 \text{ cm}^3 = 200 \text{ cm}^3 \times \frac{1 \text{ m}^3}{1 000 000 \text{ cm}^3} = 2 \times 10^{-4} \text{ m}^3
\]

**Example 18**

Convert 125 mm³ to m³.

\[
125 \text{ mm}^3 = 125 \text{ mm}^3 \times \frac{1 \text{ m}^3}{1 000 000 000 \text{ mm}^3} = 1.25 \times 10^{-7} \text{ m}^3
\]

**Think about it**

When South Africa converted from the British imperial system of measurement to the SI and metric systems people had to know how to convert imperial units to metric units. They were expected to memorise the conversion table. Tables 1.6, 1.7 and 1.8 show some of the conversions.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Imperial</th>
<th>Imperial</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm</td>
<td>0,03937 in</td>
<td>1 in</td>
<td>2,54 cm</td>
</tr>
<tr>
<td>1 cm</td>
<td>0,3937 in</td>
<td>1 ft</td>
<td>12 in</td>
</tr>
<tr>
<td>1 m</td>
<td>1,0936 yd</td>
<td>1 yd</td>
<td>3 ft</td>
</tr>
<tr>
<td>1 km</td>
<td>0,6214 mile</td>
<td>1 mile</td>
<td>1 760 yd</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 naut. mile</td>
<td>2 025,4 yd</td>
</tr>
</tbody>
</table>

*Table 1.6 Converting length*
**Module 1 SI Units of measurement**

**Temperature conversion**

Temperature is the degree of heat in a substance or body. The kelvin is the primary SI unit of measurement for temperature. In practice, however, in science and engineering, it is often used in conjunction with the degree Celsius, which has the same magnitude. Absolute zero at 0 K is −273,15 °C. (Remember the definition of the kelvin: The kelvin is 1/273,16 of the difference between absolute zero and the triple point of water.)

Fahrenheit is the temperature scale proposed by the German physicist, Daniel Gabriel Fahrenheit (1686–1736). Today, the Celsius scale has replaced the Fahrenheit scale in most countries, with the exception of the USA, Belize and Canada. It is still important that you know how to convert Fahrenheit temperatures in case you have to deal with equipment manufactured in the USA.

On both the Fahrenheit and Celsius scales, the unit of temperature is called a degree and the degree symbol is followed by a capital letter representing the scale, measured as °C or °F. On the Kelvin scale, we simply use the capital letter K.

On the Kelvin scale, water freezes at 273 K and boils at 373 K. On the Celsius scale, water freezes at 0 °C and boils at 100 °C. On the Fahrenheit scale, water freezes at 32 °F and boils at 212 °F.
Did you know?

A costly conversion

On 23 July 1983, Air Canada Flight 143, a 767-200, ran out of fuel while in flight and had to glide with both engines out almost 80 km to an emergency landing. Fuel loading was miscalculated through misunderstanding of the recently adopted metric system which replaced the imperial system.

For the trip, the pilot calculated a fuel requirement of 22 300 kg (49 000 lb). A check indicated that there were 7 682 litres already in the tanks. To calculate how much more fuel had to be added, the crew needed to convert the quantity in the tanks to a weight, subtract that figure from 22 300 and convert the result back into a volume.

A litre of jet fuel weighs 0.803 kg so the correct calculation was:

\[ 7682 \text{ litres} \times 0.803 = 6169 \text{ kg} \]
\[ 22300 \text{ kg} - 6169 \text{ kg} = 16131 \text{ kg} \]
\[ 16131 \text{ kg} ÷ 0.803 = 20088 \text{ litres of fuel to be transferred}. \]

Between the ground crew and flight crew, however, they arrived at an incorrect conversion factor of 1.77, the weight of a litre of fuel in pounds. Their calculation produced:

\[ 7682 \text{ litres} \times 1.77 = 13597 \text{ kg} \]
\[ 22300 \text{ kg} - 13597 \text{ kg} = 8703 \text{ kg} \]
\[ 8703 \text{ kg} ÷ 1.77 = 4916 \text{ litres of fuel to be transferred}. \]

Instead of 22 300 kg of fuel, they had 22 300 pounds on board. This was only a little over 10 000 kg or less than half the amount required to reach their destination.


Assessment activity 1.3

Work in groups of five.

1. Copy and complete the following table. We have done the first one for you as an example.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>6 m</td>
</tr>
<tr>
<td>b)</td>
<td>20 mm</td>
</tr>
<tr>
<td>c)</td>
<td>2 km</td>
</tr>
<tr>
<td>d)</td>
<td>1 m</td>
</tr>
<tr>
<td>e)</td>
<td>8 000 ml</td>
</tr>
<tr>
<td>f)</td>
<td>180 minutes</td>
</tr>
<tr>
<td>g)</td>
<td>1 MΩ</td>
</tr>
<tr>
<td>h)</td>
<td>105 mm³</td>
</tr>
<tr>
<td>i)</td>
<td>373.15 K</td>
</tr>
<tr>
<td>j)</td>
<td>150 mm²</td>
</tr>
<tr>
<td>k)</td>
<td>115 °F</td>
</tr>
</tbody>
</table>
Unit 1.3 SI derived units of measurement

By the end of this unit, you will be able to:
• derive new units from the relationships between the SI units (i.e. the quantities they measure)
• explain the theory and measure plane and solid angles.

SI derived units

As you learnt in the previous units, the International System of Units (SI) specifies a set of seven base units from which all other units of measurement are derived. These other units are called SI derived units.

Derived units are units that may be expressed in terms of base units by means of the mathematical symbols of multiplication and division. Certain derived units have been given special names and symbols, for example the ohm (Ω) for electrical resistance.

Speed

Speed is the rate of change in position of an object. Stated differently, speed is the distance travelled by an object divided by the time taken to cover the distance. (Speed is a scalar quantity – it requires only magnitude to define it, unlike velocity. See below.) The unit used is m/s.

\[
\text{Speed} = \frac{\text{distance}}{\text{time}}
\]

\[
v = \frac{d}{t}
\]

\[
v = \text{m/s} = \text{m·s}^{-1}
\]

Example 20

A car travels 6 km in 10 min. What is the average speed?

\[
v = \frac{d}{t} = \frac{6 \times 1000}{10 \times 60} = 10 \text{ m/s}
\]

Velocity

Velocity is the rate of displacement of an object. Displacement is the distance travelled in a given direction. Velocity is thus a vector physical quantity – it requires magnitude and direction. The unit of velocity is also m/s, but it is given with the direction in which the displacement took place.

Average velocity = displacement / elapsed time

\[
\bar{v} = \frac{\Delta s}{\Delta t}
\]

\[
\bar{v} = \text{m/s or m·s}^{-1}
\]

Note

• To convert from m/s to km/h, multiply by 3.6.
• To convert from km/h to m/s, divide by 3.6.
18 

**Example 21**

A car travels 1.2 km north in 1 min. What is its velocity?

\[ v = \frac{\Delta s}{\Delta t} \]
\[ = \frac{1200 \text{ m}}{60 \text{ s}} \]
\[ = 20 \text{ m/s north} \]

**Acceleration**

**Acceleration** is the rate of change in velocity per unit time.

Average acceleration = change in velocity / elapsed time

\[ a = \frac{\Delta v}{\Delta t} \]
\[ = \text{m/s}^2 \text{ or m/s}^2 \]

**Example 22**

An object takes 10 s from rest to reach a velocity of 25 m/s. Calculate its acceleration.

\[ a = \frac{\Delta v}{\Delta t} \]

Initial velocity = 0 m/s
Final velocity = 25 m/s
Change in velocity = final velocity – initial velocity
= (25 – 0) m/s
= 25 m/s
Change in time = 10 s

\[ \therefore \text{Acceleration} = \frac{25 \text{ m/s}}{10 \text{ s}} \]
\[ = 2.5 \text{ m/s}^2 \]

**Force**

In physics, a **force** is an influence that changes the motion of a body or produces motion or stress in a free body. The **newton** (N) is the SI unit of force. One newton is the amount of force that imparts an acceleration of 1 m/s² to a mass of 1 kg.

Force = mass \times acceleration

\[ F = m \times a \]

1 N = 1 kg \times m/s² = 1 kg\cdot m/s²

![Figure 1.10 A force of 1 N imparts an acceleration of 1 m/s² to a body with a mass of 1 kg](image-url)
Example 23

Determine the force required to accelerate a body with a mass of 500 g at 3 m/s².

\[ F = m \times a \]
\[ = 0.5 \text{ kg} \times 3 \text{ m/s}^2 \]
\[ = 1.5 \text{ kg·m·s}^{-2} \]
\[ = 1.5 \text{ N} \]

Weight

The force equation \( F = m \times a \) applies to all forces including the pull of gravity. In this case, the force equation may be written as follows:

\[ W = m \times g \]

where

\( m \) = mass of object
\( g \) = 9.81 m/s²
\( W \) = weight of object

In other words, the weight of an object is the force with which the Earth attracts the object. It is measured in newtons.

Example 24

Calculate the weight of a steel rod with a mass of 1.5 kg.

\[ W = m \times g \]
\[ = 1.5 \text{ kg} \times 9.81 \text{ m/s}^2 \]
\[ = 14.715 \text{ N} \]

Note

Mass is the amount of matter contained in an object and may be found by using ordinary scales. Mass is measured in kilograms (kg).
Work and energy

Work is done whenever a force moves along with or acts all the time on an object to displace it. There must be resistance of some kind to the object’s motion otherwise the force would not be necessary. The distance used in calculating work done must be the object’s displacement in the direction of the force.

The SI unit of work is the joule. The joule is defined as the work done when a force of 1 N acts through a distance of 1 m in the direction of the force.

\[ W = F \times s \]

\[ 1 \text{ J} = 1 \text{ N} \times 1 \text{ m} \]

![Figure 1.13 A force of 1 N moves an object a distance of 1 m](Image)

Energy is sometimes defined as the capacity for doing work. Whenever work is done by a source of energy, for example a fuel, some of the energy in the source is transferred into another form of energy or to another place. Work done in any way is simply the amount of energy transferred from the source. Work and energy transferred must therefore be measured in the same unit, namely the joule.

Example 25

A car requires a force of 200 N to pull a trailer 10 m on a horizontal surface. Calculate the work done.

\[ W = F \times s \]

\[ = 200 \text{ N} \times 10 \text{ m} \]

\[ = 2000 \text{ J} \]

\[ = 2 \text{ kJ} \]

Torque

Torque is a turning moment produced by a force. In other words, it is the product of the force tending to rotate an object and the perpendicular radius arm through which the force acts.

\[ \tau = F \times r \]

\[ \tau = \text{N} \cdot \text{m} \]
In Figure 1.14, a force of 60 N is applied at point A, which produces a turning moment or torque of 15 N·m at point B. Calculate the distance $x$ from point A to point B.

\[
\Gamma = F \times r
\]

\[
\therefore r = \frac{\Gamma}{F} = \frac{15}{60} = 0.25 \text{ m or 250 cm}
\]

**Example 26**

**Resistance**

The resistance of an electrical element is a measure of its opposition to an electric current. The ohm is the SI unit of electrical resistance. Its symbol is the capital Greek letter omega (\(\Omega\)). The ohm can be defined as follows: A conductor has a resistance of one ohm if it passes a current of one ampere when a potential difference of one volt is maintained between its ends.

Resistance = potential difference / current

\[
R = \frac{V}{I} \\
\Omega = \frac{V}{A}
\]

**Example 27**

Calculate the resistance of a lamp if a current of 2 A flows through it and the applied voltage is 12 V.

\[
R = \frac{V}{I} = \frac{12}{2} = 6 \Omega
\]

**Did you know?**

George Simon Ohm (1787–1854) was a physics teacher who did much of his research on electricity in the school laboratory. We owe the unit of resistance to him.

Count Alessandro Volta (1745–1827) was an Italian physicist whose research in electricity led him to the invention in 1800 of the voltaic pile. The unit of voltage is named after him.
Density

The density of an object is defined as its mass per unit volume:

\[ \text{Density} = \frac{\text{mass}}{\text{volume}} \]

\[ \rho = \frac{m}{V} = \frac{\text{kg}}{\text{m}^3} \]

**Example 28**

Calculate the density of a material if it has a mass of 0.1 kg and occupies a volume of 0.5 m³.

\[ \rho = \frac{m}{V} = \frac{0.1}{0.5} = 0.2 \text{ kg/m}^3 \]

Pressure

Pressure is the force per unit area applied in a direction perpendicular to the surface of an object. The pascal (Pa) is the SI unit of pressure. One pascal is the pressure generated by a force of one newton acting on an area of one square metre.

\[ \text{Pressure} = \frac{\text{force}}{\text{area}} \]

\[ P = \frac{F}{A} \]

\[ \text{Pa} = \frac{\text{N}}{\text{m}^2} \]

**Example 29**

What is the pressure exerted by an object with a mass of 20 kg? The total contact surface area is \(1 \times 10^{-4} \text{m}^2\).

\[ F = m \times a = 20 \text{ kg} \times 9.81 \text{ m/s}^2 = 196.2 \text{ N} \]

\[ P = \frac{F}{A} = \frac{196.2 \text{ N}}{1 \times 10^{-4} \text{ m}^2} = 1.96 \times 10^6 \text{ Pa} = 1.96 \text{ MPa} \]

Power

Power is the rate of energy transfer. Both formulae below express the same quantity, namely how much energy is taken from the source and stored in the job every second. It follows from the formulae below that one unit of power equals one joule of work or energy per second. The **watt** (W) is the special name given to the joule per second (J/s).

\[ \text{Power} = \text{rate of energy transfer} \]

\[ P = \frac{W}{t} = \frac{\text{J}}{\text{s}} \]

**Note**

At 4 °C, pure water has a density of 1 000 kg/m³. Therefore, 1 000 kg of pure water will occupy a volume of 1 m³ and will be equal to 1 000 litres.
If 500 J of work are used in 5 s, what is the rate at which the work is done?

\[ P = \frac{w}{t} = \frac{500}{5} = 100 \text{ W} \]

Table 1.9 provides a summary of derived SI units and their symbols covered in this unit.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Quantity symbol</th>
<th>Unit</th>
<th>Unit symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed</td>
<td>( v )</td>
<td>metres per second</td>
<td>m/s or m·s(^{-1} )</td>
</tr>
<tr>
<td>velocity</td>
<td>( v )</td>
<td>metres per second</td>
<td>m/s or m·s(^{-1} )</td>
</tr>
<tr>
<td>acceleration</td>
<td>( a )</td>
<td>metres per second squared</td>
<td>m/s(^2) or m·s(^{-2} )</td>
</tr>
<tr>
<td>force</td>
<td>( F )</td>
<td>newton</td>
<td>N</td>
</tr>
<tr>
<td>weight</td>
<td>( W )</td>
<td>newton</td>
<td>N</td>
</tr>
<tr>
<td>work</td>
<td>( \omega )</td>
<td>joule</td>
<td>J</td>
</tr>
<tr>
<td>torque</td>
<td>( \Gamma )</td>
<td>newton metre</td>
<td>N·m</td>
</tr>
<tr>
<td>resistance</td>
<td>( R )</td>
<td>ohm</td>
<td>( \Omega )</td>
</tr>
<tr>
<td>potential difference</td>
<td>( V )</td>
<td>volt</td>
<td>V</td>
</tr>
<tr>
<td>density</td>
<td>( \rho )</td>
<td>kilogram per metre cubed</td>
<td>kg/m(^3)</td>
</tr>
<tr>
<td>pressure</td>
<td>( P )</td>
<td>pascal</td>
<td>Pa</td>
</tr>
<tr>
<td>power</td>
<td>( P )</td>
<td>watt</td>
<td>W</td>
</tr>
</tbody>
</table>

Table 1.9 Summary of derived SI units and their symbols
Measuring plane and solid angles

There are two units that we use to measure plane and solid angles:

- Plane angle: radian with symbol rad
- Solid angle: steradian with symbol sr

Radian (rad)

The radian is defined as the plane angle between the two radii of a circle that are cut off on the circumference of an arc of length equal to the radius of that circle. The formula is:

\[ \frac{l}{r} \text{ radian} \]

where:
- \( l \) = arc length
- \( r \) = radius of the circle.

Steradian (sr)

The steradian is defined as the solid angle subtended at the centre of a sphere by an area of its surface equal to the square of the radius of the sphere. The formula is:

\[ \frac{s}{r^2} \]

where:
- \( s \) = surface area
- \( r \) = radius of the sphere.

Table 1.10 gives examples of other SI derived units that are expressed in terms of SI base units and SI supplementary units.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>SI unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Symbol</td>
</tr>
<tr>
<td>angular acceleration</td>
<td>radian per second squared</td>
</tr>
<tr>
<td>angular momentum</td>
<td>kilogram metre squared per second</td>
</tr>
<tr>
<td>angular velocity</td>
<td>radian per second</td>
</tr>
<tr>
<td>area</td>
<td>square metre</td>
</tr>
<tr>
<td>luminance</td>
<td>candela per square metre</td>
</tr>
<tr>
<td>magnetic field strength</td>
<td>ampere per metre</td>
</tr>
<tr>
<td>mass flow rate</td>
<td>kilogram per second</td>
</tr>
<tr>
<td>mass per unit area</td>
<td>kilogram per square metre</td>
</tr>
<tr>
<td>mass per unit length</td>
<td>kilogram per metre</td>
</tr>
<tr>
<td>momentum</td>
<td>kilogram metre per second</td>
</tr>
<tr>
<td>rotational frequency</td>
<td>1 per second</td>
</tr>
<tr>
<td>specific volume</td>
<td>cubic metre per kilogram</td>
</tr>
<tr>
<td>volume</td>
<td>cubic metre</td>
</tr>
</tbody>
</table>

Table 1.10 Examples of other derived SI units

Note

\[ \pi \text{ radians} = 180° \]

1 radian \( \approx 57,3° \)
Work on your own.
1. Differentiate between speed and velocity.
2. If density is defined as mass per unit volume, derive the unit symbol for density.
3. Calculate the weight of a body with a mass of 20 kg. Take gravitational acceleration as 9.81 m/s².
4. A body of mass 500 g is raised to a height of 25 cm above the ground. Determine the work done against the force of gravity.
5. Calculate the torque exerted on a spanner if a force of 20 N is applied to the spanner end. The spanner is 30 cm long.

Summary
• There are different measurement systems, including the imperial and metric systems.
• The International System of Units (SI) has seven base units and numerous derived units.
• A unit of measurement is a defined, physical quantity in terms of which other quantities of the same kind may be expressed as simple multiples of the unit of measurement.
• Physical quantity is a physical property of a phenomenon, body or substance that can be quantified by measurement.
• The seven SI base units are length, mass, time, electric current, temperature, luminous intensity and amount of a substance.
• Scientific notation is also known as exponential notation. It is a way of easily writing very large or very small numbers.
• One of the advantages of the metric system is that it is easy to convert SI units of measurement that have the same base but a different prefix by using multiplication or division.
• Temperature is the degree of heat in a substance or body. The kelvin is the primary SI unit of measurement for temperature. In practice, however, it is often used in conjunction with the degree Celsius, which has the same magnitude.
• Derived units are units that may be expressed in terms of base units by means of the mathematical symbols of multiplication and division. Certain derived units have been given special names and symbols.
1. List the seven SI base units of measurement.

2. Copy and complete the table below.

<table>
<thead>
<tr>
<th>Without SI prefix</th>
<th>With SI prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) 2 000 W</td>
<td></td>
</tr>
<tr>
<td>b) 5 500 g</td>
<td></td>
</tr>
<tr>
<td>c) 15 000 Pa</td>
<td></td>
</tr>
<tr>
<td>d) 1 000 000 J</td>
<td></td>
</tr>
<tr>
<td>e) 2 500 V</td>
<td></td>
</tr>
</tbody>
</table>

3. State the SI units of each of the following quantities:
   a) area
   b) volume

4. State whether the following are true or false:
   a) The prefix M stands for milli.
   b) The prefix k means multiply by 100.
   c) To convert mm to cm, you must multiply by 10.
   d) To convert km to m, divide by 1 000.
   e) When you convert 100 cm³ to m³, the answer is 1 × 10⁻² m³.

5. Define the following terms:
   a) density
   b) electrical potential
   c) power

6. The Rathete family are going on holiday to Cape Town. The family consists of Mr and Mrs Rathete and their two children, Prince and Miriam. Mr Rathete calculated the distance from his house in Houghton, Gauteng to Manenberg, Cape Town as 1 800 km.
   a) What is this distance in metres?
   b) Mrs Rathete packs 2 l of mango juice for the long trip. How many millilitres is 2 l?
   c) Prince estimates the total weight of the entire luggage as 50 kg. Convert the weight into grams.
   d) Miriam pours 500 ml of oil into the engine. How many litres did Miriam pour into the engine?

7. A force of 20 N is applied at the end of a handle 500 mm in length. The handle is rotated five complete revolutions. Calculate how much work is done.

8. Maria has a body temperature of 101 °F. What is the temperature equivalent on the Celsius scale?

9. Calculate the force required to accelerate a body with a mass of 750 g at 10 m/s.

10. A torque wrench is used as shown in Figure 1.17. Calculate the force F required to produce 25 N·m of torque.

   ![Figure 1.17 Using a torque wrench](image-url)