Fundamental and derived SI units

The Système International d’Unités (SI) was the culmination of more than a century of international effort to develop a universally acceptable system of units of measurement. It was developed and subsequently adopted by the Conférence Générale des Poids et Mesures (CGPM) in 1954 to harmonize the increasing expansion of world trade and exchange of scientific information. The Thirtieth World Health Assembly endorsed the use in medicine of SI units in May 1977.1

The SI comprises three types of unit: fundamental, derived and supplementary units. There are two supplementary units: the unit of plane angle, the radian (symbol: rad), and the unit of solid angle, the steradian (symbol: sr). They can be used to form derived units; however, these are not relevant to general medical practice and will not be discussed further in this review.

Fundamental units

Seven units have been selected as the basic or fundamental units on which the system is based (Table 1). These units are defined very precisely and over time require further precision with the progress of science. Their definitions are given in Appendix 1.1

Derived units

SI derived units are formed by multiplying the base unit by itself, or combining two or more base units by simple multiplication or division. There are a large number of units within this group; some examples are given in Table 2.

A number of derived units have been allocated special names, the purpose of which is to abbreviate potentially inconvenient unit symbols. An example of this is the unit of force. This is defined as the force that gives a mass of 1 kg an acceleration of 1 m s⁻² (the speed of the mass increases each second by 1 m s⁻¹). The derivation of this unit is therefore kg·m·s⁻²; it is otherwise named newton (symbol: N).

A further example of particular relevance is the unit of pressure. Pressure is the action of force on an area or newton per square metre and has been given the special name pascal (symbol: Pa). However, the derivation of this unit is force (kg·m·s⁻²) divided by area (m²), or kg·m·s⁻²·m⁻², which reduces to kg·m⁻¹·s⁻². Eighteen SI derived units have been given special names. Those of relevance to anaesthesia are shown in Table 3. From the two examples and Table 3, it becomes apparent that, despite the development of a diverse collection of derived units and symbols, all are a function of the seven fundamental units.

SI prefixes

Often it is inappropriate to use the SI unit in its standard format as this is inconveniently too large or too small; for example, the use of metre to describe large distances. To overcome this difficulty, a series of SI prefixes (Table 4) are used to form decimal multiples and submultiples of the SI unit. However, the prefixed units formed should not be called SI units. The exception is the unit of mass where kilogram is the SI unit (not gram).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Fundamental SI units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>Name of unit</td>
</tr>
<tr>
<td>Length</td>
<td>Metre</td>
</tr>
<tr>
<td>Mass</td>
<td>Kilogram</td>
</tr>
<tr>
<td>Time</td>
<td>Second</td>
</tr>
<tr>
<td>Electric current</td>
<td>Ampere</td>
</tr>
<tr>
<td>Thermodynamic temperature</td>
<td>Kelvin</td>
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<tr>
<td>Luminous intensity</td>
<td>Candela</td>
</tr>
<tr>
<td>Amount of substance</td>
<td>Mole</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Examples of derived units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>Name of derived unit</td>
</tr>
<tr>
<td>Area</td>
<td>Square metre</td>
</tr>
<tr>
<td>Volume</td>
<td>Cubic metre</td>
</tr>
<tr>
<td>Speed</td>
<td>Metre per second</td>
</tr>
<tr>
<td>Acceleration</td>
<td>Metre per second square</td>
</tr>
</tbody>
</table>

Key points

- SI units were adopted in medicine in 1977 to harmonize the exchange of scientific information.
- Seven base units are used to form a large number of derived units, some with special names.
- Prefixed units are not SI units (except kg).
- Work, force and power have precise definitions.
- Cardiac and respiratory work may be calculated from pressure/volume graphs.
Non-SI units

A few non-SI units have also been adopted as they are so widely used. Of relevance to medical practice is the unit of volume, for which the 'cubic decimetre' has been given the 'special name' of litre, and time, for which the SI unit of second is replaced by minute, hour and day.\(^1\)

Simple mechanics

The SI derived units of force, work and power are familiar and commonly used everyday terms. Within the scientific community however, these terms require precise usage and have limited meanings. Within anaesthesia and intensive care, they are often applied to the cardiovascular and respiratory systems where the terms cardiac work and work of breathing are often referred to. The precise meaning of these derived units in this situation is illustrated below.

The unit of force is defined above.

\[
\text{Force} = m \times a
\]

\[= N\]

The unit of work is defined as the product of the force exerted and distance (d) moved in the direction of the force and is named joule (J).

\[
\text{Force} = f \times d
\]

\[= J\]

The unit of power is defined as the work done per unit time (s) and is named watt (W).

\[
\text{Power} = J \times s^{-1} \]

\[= W\]

Cardiac work

The change in volume and pressure of the ventricle can be used to calculate cardiac work for a single cardiac cycle. Figure 1 illustrates these changes in the left ventricle and, as work = change in pressure (\(\Delta P\)) \times change in volume (\(\Delta V\)), the area contained within the \(P - V\) loop represents the external work necessary to expel the stroke volume, that is, stroke work.\(^2\) The area below this loop during diastolic filling represents the work performed by the right ventricle and left atrium to fill the left ventricle (internal work).

Any increase in mean arterial pressure, with cardiac output maintained, will therefore result in additional energy requirements and oxygen demand. Similarly, a high cardiac output resulting from, for example, thyrotoxicosis and anaemia will...
also increase cardiac work. Prolonged myocardial exposure to these conditions may subsequently lead to heart failure.

Cardiac work done:

\[
\text{Work} = \Delta P \times \Delta V
\]
\[
= (14.6 \times 10^3) \text{Pa} \times (70 \times 10^{-6}) \text{m}^3
\]
\[
= 1022 \times 10^{-3} \text{ J}
\]

(note the conversion of mm Hg to Pascal, an SI unit).

Work of breathing

During inspiration, movement of gas (the work of breathing) is usually achieved by diaphragmatic and intercostal muscle contraction. This overcomes lung and chest wall compliance (elastic forces), the viscous resistance of movement of gases down airways, together with the inertia created by both gases and tissues, which is usually very small. During inspiration, muscle contraction generates a reduction in pressure within intrapleural space, which is transferred to the alveolus, and gas movement takes place. This is demonstrated in the pressure/volume loop in Fig. 2. The work expended in overcoming airway resistance and compliance during the inspiratory phase is given by the areas AFCBA and ABCDA, respectively. An increase in airway resistance would cause a greater bowing of the line AFC, while a reduced compliance reduces the slope of line ABC.

During expiration, the area ABCEA is the work required to overcome airway resistance and is usually contained within the area ABCDA. Therefore, expiration is passive using the stored elastic energy within the lung and chest tissues. The difference between areas ABCEA and ABCDA is the energy dissipated as heat.

Conclusion

SI units and simple mechanics are defined precisely despite being terms often used loosely in everyday language. Appreciation of these definitions and derivations is important in medical practice, particularly in describing work, as this improves understanding of how oxygen demand changes under different physiological conditions.

Appendix 1: Definition of SI units

Metre

The metre is the basic unit of length. It is the distance light travels, in a vacuum, in \(\frac{1}{299792458}\)th of a second.

Kilogram

The kilogram is the basic unit of mass. It is the mass of an international prototype in the form of a platinum-iridium cylinder kept at Sevres in France. It is now the only basic unit still defined in terms of a material object, and also the only one with a prefix[kilo] already in place.

Second

The second is the basic unit of time. It is the length of time taken for \(9192631770\) periods of vibration of the caesium-133 atom to occur.

Ampere

The ampere is the basic unit of electric current. It is that current which produces a specified force between two parallel wires which are 1 metre apart in a vacuum. It is named after the French physicist Andre Ampere (1775–1836).

Kelvin

The kelvin is the basic unit of temperature. It is \(\frac{1}{273.16}\)th of the thermodynamic temperature of the triple point of water. It is named after the Scottish mathematician and physicist William Thomson 1st Lord Kelvin (1824-1907).

Mole

The mole is the basic unit of substance. It is the amount of substance that contains as many elementary units as there are atoms in 0.012 kg of carbon-12.

Candela

The candela is the basic unit of luminous intensity. It is the intensity of a source of light of a specified frequency, which gives a specified amount of power in a given direction.
Key References


Please see multiple choice questions 12–15.