AS | Physics - 9702 - 1.2 Deriving SI Units

INTRODUCTION

Physical quantities are a characteristic or properties of an object that can be measured or calculated from other measurements. Scientists often make measurements. These need to be stated with the units of the quantity being measured, and the accuracy of the measurements. In the last unit we explored the different physical quantities and their SI units. In this unit we explore how these SI units are derived.

LEARNING OBJECTIVES

By the end of this unit you should be able to:

1. Express derived units as products or quotients of the SI base units and use the derived units for quantities.
2. Use SI base units to check the homogeneity of physical equations.
3. Recall and use prefixes and their symbols to indicate decimal submultiples or multiples of both base and derived units.

Deriving SI Units

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Introduction

In this section we look at how SI units are derived.

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TERMS AND DEFINITIONS

Prefix - A specifier that is prepended to units of measurement to indicate multiples or fractions of the units.

Standard form - A system in which numbers are written as a number greater than 1 and less than 10 multiplied by a power of 10 which may be positive or negative.

Derived Units - Units that are formed from a combination of one or more S.I. base units.

Homogenous equation - An equation which when expressed in base units has the same units throughout, as separated by +, - and = signs.

1. Derived Units

All other units that are not S.I. units can be expressed as a combination of one or more **base units**.

For example, velocity is defined as the rate of change of displacement = $\Delta s/\Delta t$. Therefore, the unit of velocity is the unit of displacement divided by the unit for time = m/s.

Another derived quantity is Force, whose derived unit is the Newton.

F = mass x acceleration

N = kg x ms^{-2}

N = $kg\ m\ s^{-2}$

1.1 Pascals in S.I. base units

Pressure can be calculated by the following equation:

$P = F/A$

pressure = Force / Area or

- Force = mass x acceleration, so the base units for force is kg m s^{-2}.
- The base unit for area is m^2.
- So, pressure has base units kg m s^{-2} / m^2.
- Simplified, this is **kg m^{-1} s^{-2}**.

1.2 Density

Density can be calculated by the following equation:

density = mass / volume

- The base unit for mass is kg.

- The base unit for volume is m^3.
- So, density has base units kg / m^3 or **kg m^{-3}**.

Check your understanding

Express the Joule in S.I. base units.

Type your answer here

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2. Homogeneous Equations

When each term in an equation, as separated by +, - or = has the **same base units**, the equation is said to be homogeneous.

To check the homogeneity of physical equations, you can follow these steps:

1. Check the units on both sides of the equation.
2. Determine if they are similar.
3. If they do not match, the equation is inhomogeneous or heterogenous.

To further understand the concept of homogeneity, please follow this ▶ link ◀ to a short video.

NOTE : Digit coefficients are unitless and do not contribute to the units of measurement.

3. Prefixes

You will come across very small and very large numbers throughout your Physics journey. This can be pretty confusing and problematic. Numbers are written using the powers of 10 to make them less awkward. This is known as **scientific notation** or ***standard form***. For example:

3 700 000 000 000 m = 3.7×10^{12} m or

0.0000037 s = 3.7×10^{-6} s

Each SI unit has **multiples** and **submultiples** to avoid using very high or low numbers. We use ***prefixes*** as an abbreviation for some of the powers of 10. For example, the height of a mountain is 6200 m, but it may be written as 6.2×10^{3} m or 6.2 km. The prefix comes before the unit (e.g. kilometre, milligrams, etc.). For example:

$3\,700\,000\,000\,000$ m = 3.7×10^{12} m = 3.7 terametres = 3.7 Tm

0.0000037 s = 3.7×10^{-6} s = 3.7 microseconds = 3.7 μ s

The table below shows the most often used prefixes:

Prefix	Symbol	Value
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

EXAM - STYLE QUESTIONS

Consider the EXAM-STYLE QUESTION below. After reflecting on this question, click the FEEDBACK and EXPLANATION tabs to reveal the suggested answer.

QUESTION	FEEDBACK	EXPLANATION

1. The drag force F_D acting on a car moving with speed v along a straight horizontal road is given by

$$F_D = v^2Ak$$

where k is a constant and A is the cross-sectional area of the car.

Determine the SI base units of k. [2]

2. A unit may be stated with a prefix that represents a power-of-ten multiple or submultiple. Complete Table 1.1 to show the name and symbol of each prefix and the corresponding power-of-ten multiple or submultiple.

Table 1.1

prefix	power-of-ten multiple or submultiple
kilo (k)	10^3
tera (T)	
( )	10^{-12}

[2]

QUESTION	FEEDBACK	EXPLANATION

1. kg m^{-3}

2. 10^{12} , Pico

QUESTION	FEEDBACK	EXPLANATION

1. $F_D = v^2Ak$

   $N = (m\ s^{-1})^2 \times m^2 \times k$

   $kg\ m\ s^{-2} = m^2\ s^{-2} \times m^2 \times k$

   $kg\ m\ s^{-2} = m^4\ s^{-2}\ k$

   In order to make the equation homogenous, we assign kg m^{-3} to k.

2. Assumed knowledge from memory.

You must be careful when using prefixes, especially when it comes to *squaring* or *cubing* prefixes.

For example:

- 1 mm = 10^{-3} m, so 1 mm^2 = $(10^{-3}\ m)^2$ which equals $\mathbf{10^{-6}\ m^2}$.
- Similarly, 1 mm^3 = $(10^{-3}\ m)^3$ which equals $\mathbf{10^{-9}\ m^3}$.

Example:

The density of water is approx. 1.0 g cm^{-3}. Calculate this value in kg m^{-3}.

Firstly, you have to find the conversions for the units:

Then, you use these in the value for the density of water:

$1\ g = 1 \times 10^{-3}\ kg$
$1\ cm^3 = 1 \times 10^{-6}\ m^3$

$1.0\ g\ cm^{-3} = 1.0 \times 1 \times 10^{-3} / 1 \times 10^{-6}$
$= 1.0 \times 10^3\ kg\ m^{-3}$

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KEY TAKEAWAYS

- All other units, aside from S.I. units can be derived from the **base units**.
- When each term in an equation as separated by +, - or = has the **same base units**, the equation is said to be homogeneous.
- Mathematicians have a system for writing large numbers in a shortened way called standard form.
- Prefixes can be used to reduce the problem of very long numerical measurements.

TEST YOUR KNOWLEDGE

1. The average kinetic energy *E* of a gas molecule is given by the equation:

$$E = 3 / 2\, kT$$

where T is the absolute (Kelvin) temperature. What are the SI base units of k?

- $kg^{-1}\ m^{-1}\ s^{2}\ K$
- $kg^{-1}\ m^{-2}\ s^{2}\ K$
- $kg\ m\ s^{2}\ K^{-1}$
- $kg\ m^{2}\ s^{-2}\ K^{-1}$

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2. The units of all physical quantities can be expressed in terms of SI base units. Which pair contains quantities with the same base units?

- force and momentum
- pressure and Young's modulus
- power and kinetic energy
- mass and weight

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3. Which formula could be correct for the speed *v* of ocean waves in terms of the density ρ of sea-water, the acceleration of free fall *g*, the height *h* of the wave and the wavelength λ?

A $v = \sqrt{\rho g h}$ **B** $v = \sqrt{\frac{g}{h}}$ **C** $v = \sqrt{g\lambda}$ **D** $v = \sqrt{\frac{g}{\rho}}$

- A
- B
- C
- D

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4. An equation $v = u + st$ is given for final velocity. Check the equation for homogeneity

- The equation is inhomogenous

The equation is homogenous

SUBMIT

REFERENCES

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- Crundell M, Goodwin G (2020), Cambridge International AS & A Level Physics Student's Book, https://www.hoddereducation.co.uk/

END OF UNIT