

CHAPTER 0

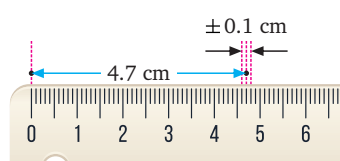
FUNDAMENTALS OF SCIENTIFIC MEASUREMENT



watch video

Significant Figures

Let's discuss what significant figures mean and why we need them.



NOTE: For some numbers, the number of significant figures is not considered.

Let's examine the experimentally obtained values of Earth's mass and density and determine the number of significant figures in these values.

$$m_{\oplus} = (5.9722 \pm 0.0006) \times 10^{24} \text{ kg}$$

$$\rho_{\oplus} = (5.5140 \pm 0.0001) \text{ g/cm}^3$$

EXAMPLE 1: Let's find the number of significant figures in the given values.

	Value	Number of Significant Figures
a.	2.20	
b.	30.20	
c.	0.045	
d.	14.00	
e.	3 200	
f.	16 005	
g.	1.2×10^3	
h.	0.010	

Arithmetic with significant figures

Multiplication and division

Rule: The result should have as many significant figures as the input number with the fewest significant figures.

EXAMPLE 2: The side lengths of a rectangle are 12.7 cm and 4.7 cm. Calculate the area of the rectangle according to the significant figure rules.

EXAMPLE 3: An object has a mass of 0.08250 kg and a volume of 0.0031 m^3 . Calculate the density of the object according to the significant figure rules.

Addition and subtraction

Rule: In addition and subtraction, the precision of the result is determined by the number with the fewest decimal places.

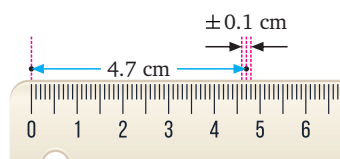
EXAMPLE 4: Perform the following operations according to the significant figure rules:

$$12.11 + 18.0 + 1.013 =$$

$$254 - 8.63 =$$

Uncertainty

Using the first example we discussed, let's examine the concept of uncertainty in measurements.



Uncertainty in arithmetic operations

Addition and subtraction

Rule: In addition and subtraction, the uncertainties are added directly.

Let's express this rule mathematically.

EXAMPLE 5: The lengths of two pieces of a wire are measured as follows:

$$L_1 = (12.4 \pm 0.1) \text{ cm}, \quad L_2 = (8.3 \pm 0.1) \text{ cm}.$$

Find the total length of the wire and its uncertainty.

Multiplication and division

Rule: In multiplication and division, the relative uncertainties are added, and the absolute uncertainty of the result is calculated from this sum. Let's express this rule mathematically.

NOTE: When multiplying by an *exact number*, the uncertainty is multiplied directly by that number.

EXAMPLE 6: The length and width of a metal plate are measured as follows:

$$L = (12.4 \pm 0.2) \text{ cm}, \quad W = (8.2 \pm 0.1) \text{ cm}.$$

Find the area of the plate and its uncertainty.

NOTE: Uncertainty is usually written with one significant figure. The result is then rounded to the same decimal place as the uncertainty.

EXAMPLE 7: The mass and volume of a metal block are measured as follows:

$$m = (24.5 \pm 0.2) \text{ g}, \quad V = (3.2 \pm 0.1) \text{ cm}^3.$$

Find the density of the block and its uncertainty.

EXAMPLE 8: Rewrite the following measurements in the most appropriate form:

- $v = 6.21385 \pm 0.0312 \text{ m/s}$
- $x = 2.6294 \times 10^3 \pm 2 \text{ m}$
- $m = 5.8189 \times 10^{-5} \pm 3 \times 10^{-7} \text{ kg}$

Dimensional Analysis

Let's discuss what the dimension of a quantity means. Let's examine the table below, which gives the dimension symbols of the base quantities.

Quantity	SI Unit	Dimension Symbol
Length	meter (m)	[L]
Mass	kilogram (kg)	[M]
Time	second (s)	[T]
Electric current	ampere (A)	[I]
Temperature	kelvin (K)	[Θ]
Amount of substance	mole (mol)	[N]
Luminous intensity	candela (cd)	[J]

Let's examine the dimensions of some derived quantities.

Quantity	SI Unit	Dimension Symbol
Area	m^2	$[\text{L}^2]$
Volume	m^3	$[\text{L}^3]$
Velocity	m/s	$[\text{L T}^{-1}]$
Force	$\text{N} = \text{kg} \cdot \text{m/s}^2$	$[\text{M L T}^{-2}]$
Energy (Work)	$\text{J} = \text{N} \cdot \text{m}$	$[\text{M L}^2 \text{T}^{-2}]$
Power	$\text{W} = \text{J/s}$	$[\text{M L}^2 \text{T}^{-3}]$
Density	kg/m^3	$[\text{M L}^{-3}]$
Electric charge	$\text{C} = \text{A} \cdot \text{s}$	$[\text{I T}]$
Specific heat	$\text{J/(kg} \cdot \text{K)}$	$[\text{L}^2 \text{T}^{-2} \Theta^{-1}]$
Molar mass	kg/mol	$[\text{M N}^{-1}]$
Illuminance	$\text{lx} = \text{lm/m}^2$	$[\text{J L}^{-2}]$

Let's check the consistency of the following equations using dimensional analysis.

- $v = v_0 + at$
- $\Delta x = v_0 t + \frac{1}{2}at^2$
- $W = \Delta KE$
- $T = 2\pi\sqrt{\frac{L}{g}}$
- $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$
- $v = \sqrt{\frac{T}{\mu}}$
- $Q(t) = Q_0 e^{-t/(RC)}$
- $\frac{d}{dt} \sin(\omega t) = \omega \cos(\omega t)$

Answers

Example questions

- 1 a. 3 b. 4 c. 2 d. 4
e. 2, 3, or 4 f. 5 g. 2 h. 2

2 $A = 6.0 \times 10^1 \text{ cm}^2$

3 $\rho = 27 \text{ kg/m}^3$

4 31.1 245

5 $L = (20.7 \pm 0.2) \text{ cm}$

6 $A = (102 \pm 3) \text{ cm}^2$

7 $\rho = (7.7 \pm 0.3) \text{ g/cm}^3$

- 8 a. $v = (6.21 \pm 0.03) \text{ m/s}$
b. $x = (2629 \pm 2) \text{ m}$
c. $m = (5.82 \pm 0.03) \times 10^{-5} \text{ kg}$