UNCERTAINTY IN MEASUREMENT

There exists a specific set of guidelines governing the presentation of experimental data and theoretical calculations, aimed at rendering the information in a meaningful manner. The objective is to facilitate the ease of numerical interpretation and enhance the coherence of data to the greatest extent possible. Utilizing scientific notations, significant figures, and dimensional analysis proves invaluable in the presentation of both data and theoretical calculations, offering a systematic approach that contributes to clarity and precision.

Measurement In Chemistry

Fundamental An. D Derived Units

Chemistry operates as an experimental science, with experiments involving the observation of a phenomenon under specific conditions. Quantitative scientific observations typically entail measuring one or more physical quantities, such as mass, length, density, volume, pressure, temperature, and more. A physical quantity is conveyed through both a numerical value and a corresponding unit. The numerical value alone lacks significance without the inclusion of its associated unit.

For instance, stating that the distance between two points is "four" holds no meaning unless a specific unit (e.g., inch, centimeter, meter) is specified. The units of physical quantities are based on three fundamental units: mass, length, and time. These fundamental units are considered independent and cannot be derived from others, earning them the label "fundamental units."

Recognizing the limitations of the three fundamental units in describing all physical quantities, seven units—mass, length, time, temperature, electric current, luminous intensity, and amount of substance—have been acknowledged as basic units. All other units, including those for area, volume, force, work, density, velocity, and energy, are derived from these basic units and are consequently termed "derived units."

Conversion Factors

$$1 \text{ angstrom } (\text{Å}) = 10^{-8} \text{ cm} = 10^{-10} \text{ m} = 10^{-1} \text{ nm} = 10^{2} \text{pm}$$

$$1 \text{ inch } = 2.54 \text{ cm} \quad \text{or} \quad 1\text{cm} = 0.394 \text{ inch}$$

$$39.37 \text{ inch } = 1 \text{ metre} \qquad 1\text{km} = 0.621\text{mile}$$

$$1\text{kg} = 2.20 \text{ pounds (lb)} \qquad 1\text{g} = 0.0353 \text{ ounce (o)}$$

$$1 \text{ pound (lb)} = 453.6 \text{ g}$$

$$1 \text{ atomic mass unit (amu) } = 1.6605 \times 10^{-24} \text{ g}$$

$$= 1.6605 \times 10^{-27}\ kg$$

$$= 1.492 \times 10^{-3} \text{erg} = 1.492 \times 10^{-1} \text{ J}$$

$$= 3.564 \times 10^{11} \text{cal} = 9.310 \times 10^{8} \text{eV}$$

$$= 931.48 \text{MeV}$$

$$\text{I atmosphere (atm) } = 760 \text{ torr } - 760 \text{mm Hg} - 76 \text{cm Hg}$$

$$= 1.01325 \times 10^{5} \text{ Pa}$$

$$\text{Icalorie (cal)} = 4.1840 \times 10^{7} \text{erg} = 4.184 \text{ J}$$

$$= 2.613 \times 10^{19} eV$$

$$1 \text{ coulomb (coul) } = 2.9979 \times 10^{9} \text{ esu}$$

$$1\text{curie (Ci)} = 3.7 \times 10^{10} \text{ disintegrations sec}^{-1}$$

$$\text{lelectron volt (eV)} = 1.6021 \times 10^{-12} \text{ erg } = 1.6021 \times 10^{-19} \text{ J}$$

$$= 3.827 \times 10^{-20} \text{cal}$$

$$= 23.06 \text{kcalmol}^{-1}$$

$$1\text{erg} = 10^{-7} \text{ J} = 2.389 \times 10^{-8} \text{cal} = 6.242 \times 10^{11} \text{eV}$$

$$1 \text{ electrostatic unit (esu) } = 3.33564 \times 10^{-10} \text{ coul}$$

$$1 \text{ faraday (F)} = 9.6487 \times 10^4 \text{ coul}$$
$$1 \text{ dyme (dyne)} = 10^{-5} \text{ N coul}$$
$$1 \text{ joule} = 10^7 \text{erg} = 0.2390 \text{cal}$$
$$1 \text{ litre} = 1000 \text{ce} = 1000 \text{ mL} - 1 \text{dm}^3$$
$$= 10^{-3} \text{ m}^3$$

Scientific Notation

- It is well-established that atoms and molecules possess extremely low masses, yet their abundance is significant.
- Chemists routinely work with minute figures, such as 0.00000000000000000000000166 g (the mass of hydrogen atoms), and constants with substantial values, such as Avogadro's number, Planck's constant, the speed of light, and particle charges. The challenge lies in effectively managing these extremely small and large numerical values.
- To facilitate the handling of such numbers, a notation is employed: m × 10n, where m represents a number ranging from .000... to 9.999..., and n is an exponent with positive or negative values.

  For example, the scientific notation for 823.912 is 8.23912×10^2, signifying the decimal being shifted two places to the left. Similarly, 0.00065 can be expressed as 6.5×10^{-4}, indicating the decimal moving four places to the right, hence, -4 as the exponent in the scientific notation.

Uncertainty in Multiplication and Division

Applying the same rule as discussed above we can solve the given problem as:

$$(4.3 \times 10^7) \times (2.7 \text{ x } 10^3) = (4.3 \times 2.7)\ (10^{7+3})$$
$$= (4.3 \times 2.7)\ (10^{10})$$
$$= 11.6 \times 10^{10}$$

Similarly for division,

$$\frac{4.9\times10^{-4}}{3.2\times10^{-6}} = (4.9 \div 3.2)\ (10^{-4-(-6)})$$
$$= 1.531\times10^2$$

Uncertainty in Addition and subtraction

In these procedures, the initial step involves aligning the numbers to ensure they share the same exponents. Consequently, when adding 5.43×10^4 and 3.45×10^3, the exponents are adjusted to be equal, followed by the addition and subtraction of the coefficients.

For example: $5.43 \times 10^4 + 0.345 \times 10^5 = [5.43 + (0.345\times 10)] \times 10^4 = 8.88 \times 10^4$

In the case of subtraction,

$$5.43 \times 10^4 - 0.345 \times 10^5$$
$$= [5.43 - (0.345\times 10)] \times 10^4$$
$$= (5.43 - 3.45) \times 10^4$$
$$= 1.98 \times 10^4$$

Significant Figures

Every scientific measurement, with the exception of counting, inherently involves a level of uncertainty. This uncertainty primarily stems from two factors:

(i) The skill and accuracy of the observer,

(ii) The limitations of the measuring scale.

Scientists employ the term "significant figures" to denote the precision of a measurement. Significant figures in a number encompass all certain digits and one doubtful digit. The count of significant figures conveys that, excluding the digit at the extreme right, all other digits are deemed precise or reproducible.

For instance, consider the mass of an object recorded as 11.24 g. This value signifies that the actual mass falls within the range of 11.23 g to 11.25 g. Consequently, one can confidently assert the accuracy of the first three figures (1, 1, and 2), while the fourth figure remains somewhat imprecise. The total count of significant figures in this number is four.

The following rules are observed in counting the number of significant figures in a given measured quantity:

(i) All non-zero digits are significant.
For example,
42.3 has three significant figures
243.4 has four significant figures.
24.123 has five significant figures.

(ii) A zero becomes significant figure if it appears between two non-zero digits.
For example,
5.03 has three significant figures.
5.604 has four significant figures.
4.004 has four significant figures.

(iii) Leading zeros or the zeros placed to the left of the number are never significant.
For example,
0.543 has three significant figures.
0.045 has two significant figures.
0.006 has one significant figure.

(iv) Trailing zeros or the zeros placed to the right of the number are significant.
For example,
433.0 has four significant figures.
433.00 has five significant figures.
343.000 has six significant figures.

(v) In exponential notation, the numerical portion gives the number of significant figures.
For example,
1.32 x 10-2 has three significant figures.
1.32 x 104 has three significant figures.

(vi) The non-significant figures in the measurements are rounded off.

(a) If the figure following the last number to be retained is less than 5, all the unwanted figures are discarded and the last number is left unchanged,
e.g.,5.6724 is 5.67 to three significant figures.

(b) If the figure following the last number to be retained is greater than 5, the last figure to be retained is increased by I unit and the unwanted figures are discarded,
e.g., 8.6526 is 8.653 to four significant figures.

(c) If the figure following the last number to be retained is 5, the last figure is increased by 1 only in case it happens to be odd. In case of even number, the last figure remains unchanged.
2.3524 is 2.4 to two significant figures.
7.4511 is 7.4 to two significant figures.

Calculations Involving Significant Figures

In many experiments, it is common to mathematically combine observations from various measurements, involving addition, subtraction, multiplication, or division to derive the final result. As not all observations in measurements possess the same precision, it follows that the ultimate result cannot surpass the precision of the least precise measurement. To ensure the appropriate number of significant figures in any calculation, the following two rules should be adhered to.

Rule 1: The result of an addition or subtraction in the numbers having different precisions should be reported to the same number of decimal places as are present in the number having the least number of decimal places.

E.g.:

(a)

33.3 ← (has only one decimal place)
3.11
0.313
Sum 36.723 ← (answer should be reported to one decimal place)
Correct answer = 36.7

(d)

3.1421
0.241
0.09 ← (has 2 decimal places)
Sum 3.4731 ← (answer should be reported to 2 decimal places)
Correct answer = 3.47

(C)

62.831 ← (has 3 decimal places)
- 24.5492
Difference 38.2818 ← (answer should be reported to 3 decimal places after rounding off)
Correct answer = 38.282

Rule 2: The answer to a multiplication or division is rounded off to the same number of significant figures as is possessed by the least precise term used in the calculation.

E.g.:

(a)

142.06
× 000.23 ← (two significant figures)
32.6738 ← (answer should have two significant figures)
Correct answer = 33

(b)

51.028
× 1.31 ← (three significant figures)
66.84668
Correct answer = 66.8

(c)

$$\frac{0.90}{4.26} = 0.2112676$$

Correct answer = 0.21

Representation of Physical Quantities

Physicists characterize a physical quantity as an inherent property of a material or system, measurable and definable by its value. The value, expressed mathematically, represents the physical quantity through the multiplication of a numerical value by an algebraically notated unit of measurement. For instance, "n kg" serves as a mathematical representation of mass, where "n" signifies the numerical value and "kg" denotes the unit of measurement, specifically kilograms.

A key attribute shared by different physical quantities includes both the numerical magnitude and the associated unit of measurement. The numerical value reflects the magnitude of the physical quantity, while the unit provides the standardized scale for measurement.

The term "physical quantity" conventionally pertains to a measurable aspect of matter, such as the frequency of a periodic phenomenon or the resistance of an electric wire. Importantly, it does not assume the existence of an invariant quantity; for instance, in special and general relativity, length qualifies as a physical quantity but undergoes variation based on the influencing coordinate system.

In scientific contexts, the concept of physical quantities is foundational and intuitive, often taken for granted without explicit mention. The understanding prevails that scientists predominantly engage with quantitative data rather than qualitative data in their research pursuits. Explicit discussions of physical quantities are typically absent from standard science programs, with a more fitting placement found within philosophy of science or philosophy programs where foundational concepts are explored.

Characteristic Properties of Physical Quantities

Physical quantities exhibit various distinctive qualities, each linked to specific attributes. Several of these characteristics are outlined below:

- **Non-Negativity:** Physical quantities inherently lack negative values, with the exception of specific cases like electrical charge and temperature. While quantities such as electrical charge or mass can assume a value of 0, others do not, resulting in the object being either electrically neutral (devoid of charge) or massless (as in the case of light).
- **Scalar and Vector Properties:** Physical quantities can be classified as either scalar or vector. Scalar quantities possess only a numerical value and lack a directional component. Examples include volume, mass, and mole. On the other hand, vector quantities necessitate both a value and a direction for complete understanding. Notable examples of vector quantities are velocity and acceleration, where the arrow's direction indicates the specific direction of the physical quantity.

These distinctive properties contribute to the nuanced nature of physical quantities, providing a framework for understanding and categorizing their varied attributes in scientific contexts.

Physical Quantities and Their Measurements

Scientific investigations necessitate quantitative measurements of properties. Many properties of matter, such as length, area, and volume, inherently possess quantitative characteristics. A numerical representation accompanied by specific units is employed for any quantitative observation or measurement.

For instance, the length of a room can be expressed as 6 m, where 6 is the numerical value and "m" denotes meters, the unit of measurement for length.

Historically, two distinct measurement systems, namely the English System and the Metric System, were employed in various parts of the world. The Metric System, originating in France in the late eighteenth century, gained popularity due to its convenience, relying on the decimal system. Eventually, recognizing the need for a unified standard system, the scientific community established such a system in 1960.

Physical quantities are the parameters encountered in our scientific inquiries. Every physical quantity can be evaluated through two components:

(1) The number

(2) The unit: Unit is defined as the reference standard chosen to measure any physical quantity.

The International System of Units (S.I.) of Measurement

(abbreviated as SI, from the French Le System International d'Unités) was established by the eleventh General Conference on Weights and Measures (CGPM, or Conference Générale des Poids et Measures). The CGPM functions as an inter-governmental treaty organization, established through the diplomatic treaty known as the Meter Convention, signed in Paris in 1875. The SI system comprises seven base units, each corresponding to one of the seven fundamental scientific quantities. Other physical quantities, such as speed, volume, and density, can be derived from these fundamental units.

The various fundamental quantities that are expressed by these units along with their symbols are tabulated below:

Base Physical Quantity	Symbol for Quantity	Name of SI Unit	Symbol for SI Unit
Length	ι	Meter	m
Mass	m	Kilogram	Kg
Time	t	Second	s
Electric current	I	Ampere	A
Thermodynamic temperature	T	Kelvin	K
Amount of substance	n	Mole	mol
Luminous intensity	I_v	Candela	cd

Occasionally, submultiples and multiples are employed to either decrease or increase the magnitude of various units. The table below provides the names and symbols of these submultiples and multiples.

The base unit for mass in the SI system is the kilogram, and it already incorporates a prefix. For other units of mass, the names are derived by substituting different prefixes for the "kilo" prefix. It is noteworthy that no other base units in the SI system contain prefixes.

While the utilization of the SI system is gradually expanding, older systems persist. Additionally, the coexistence of older units in scientific literature necessitates familiarity with both the older and newer systems.

Submultiples			Submultiples		
Prefix	Symbol	Sub-multiple	Prefix	Symbol	Sub-multiple
deci	d	10^{-1}	deca	da	10
centi	c	10^{-2}	hecto	h	10^2
milli	m	10^{-3}	kilo	k	10^3
micro	μ	10^{-6}	mega	m	10^6
nano	n	10^{-9}	giga	g	10^9
Pico	p	10^{-12}	tera	t	10^{12}
femto	f	10^{-15}	peta	p	10^{15}
atto	a	10^{-18}	exa	e	10^{18}
zepto	z	10^{-21}	zeta	z	10^{21}
yocto	y	10^{-24}	yotta	y	10^{24}

- **Unit of Time: Second:** The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.

- **Unit of Electric Current: Ampere:** The ampere is defined as that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 meter apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.
- **Unit of Thermodynamic Temperature: Kelvin:** The kelvin, a unit of thermodynamic temperature, is defined as the temperature fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
- **Unit of Amount of Substance: Mole:** The mole is the amount of substance containing as many elementary entities as there are atoms in 0.012 kilograms of carbon-12, represented by the symbol "mol."
- **Unit of Luminous Intensity: Candela:** The candela is the luminous intensity, in a given direction, of a source emitting monochromatic radiation with a frequency of 540×10^{12} hertz and having a radiant intensity of 1,683 watts per steradian.

Note:

The mass standard since 1889 is the kilogram, defined as the mass of a platinum-iridium (Pt-Ir) cylinder stored in an airtight jar at the International Bureau of Weights and Measures in Sevres, France. Pt-Ir was chosen for its high resistance to chemical attack and stability over an extended period.

Before 1960, various unit systems were in use, and among them were the following:

(i) The English or FPS system, utilizing foot, pound, and second for length, mass, and time measurements respectively. However, this system is no longer in contemporary use.

(ii) The MKS system, where M represents meter (length), K represents kilogram (mass), and S represents second (time). It operates on a decimal basis.

(iii) The CGS system, employing centimeter for length, gram for mass, and second for time.

This system is also decimal in nature. The MKS system, commonly referred to as the metric system, gained widespread popularity globally. However, a drawback was the existence of various metric units for the same quantity in different regions. In 1964, the National Bureau of Standards adopted a slightly modified version of the metric system, officially recommended in 1960 by the General Conference of Weights and Measures, resulting in the International System of Units (SI). Scientists worldwide, across all fields of science, engineering, and technology, have since embraced the SI units, which consist of seven fundamental units.

SI Units for Some Common Derived Quantities

(a) Area $=$ length $\times$ breadth

$= m \times m = m^2$ [square metre]

Volume $=$ length $\times$ breadth $\times$ beight

$= m \times m \times m = m^3$ [cubic metre]

(b) Density $= \frac{\text{mass}}{\text{volume}} = \frac{\text{kg}}{\text{m}^3} = \text{kg m}^{-3}$

(c) Speed $= \frac{\text{distance covered}}{\text{time}} = \frac{\text{metre}}{\text{time}} = \text{ms}^{-1}$

(d) Aoceleration $= \frac{\text{change in velocity}}{\text{time taken}} = \frac{\text{ms}^{-1}}{\text{s}} = \text{ms}^{-2}$

(e) Force $=$ mass $\times$ acceleration

$= \text{kg} \times \text{ms}^{-2}$

$= \text{kg ms}^{-2}$ (Newton; abbreviated as N)

(f) Pressure $=$ force per unit area

$= \frac{\text{kg ms}^{-2}}{\text{m}^2} = \text{kg m}^{-1}\ \text{S}^{-2}$ or Nm^{-2} (Pascal Pa)

(g) Energy $=$ force $\times$ distance travelled

$= \text{kg ms}^{-2} \times \text{m}$

$= kg\ m^2S^{-2}$ (joule − J)

Several traditional units are still authorized for use.

For instance, the 'liter,' defined as one cubic decimeter, remains commonly employed by chemists. Additionally, specific units that are not included in the SI system are allowed to persist for a restricted duration. An example is the term 'atmosphere' (atm), a unit of pressure, which falls under this category.

Few of the old units along with conversion factors are given below:

CI²: 1amu= 1.6605 x 10^{-24} g = 1.6605 X10-27 kg

Conversion Factors:

$$1 \text{ angstrom } (\text{Å}) = 10^{-8}\ \text{cm} = 10^{-10}\ \text{m} = 10^{-1}\ \text{nm} = 10^2 \text{pm}$$

$$1 \text{ inch } = 2.54\ \text{cm} \quad \text{or} \quad 1\text{cm} = 0.394 \text{ inch}$$

$$39.37 \text{ inch } = 1 \text{ metre} \qquad 1\text{km} = 0.621\text{mile}$$

$$1\text{kg} = 2.20 \text{ pounds (lb)} \qquad 1\text{g} = 0.0353 \text{ ounce (o)}$$

$$1 \text{ pound (lb)} = 453.6 \text{ g}$$

$$1 \text{ atomic mass unit (amu) } = 1.6605 \times 10^{-2}\ \text{g}$$

$$= 1.6605 \times 10^{-27} \text{ kg}$$

$$= 1.492 \times 10^{-3}\text{erg} = 1.492 \times 10^{-1}\ \text{J}$$

$$= 3.564 \times 10^{11}\text{cal} = 9.310 \times 10^{8}\text{eV}$$

$$= 931.48\text{MeV}$$

$$\text{I atmosphere (atm) } = 760 \text{ torr } - 760\text{mm Hg} - 76\text{cm Hg}$$

$$= 1.01325 \times 10^5 \text{ Pa}$$

$$\text{Icalorie (cal)} = 4.1840 \times 10^7\text{erg} = 4.184 \text{ J}$$

$$= 2.613 \times 10^{19} eV$$

$$1 \text{ coulomb (coul) } = 2.9979 \times 10^9 \text{ esu}$$

$$1\text{curie (Ci)} = 3.7 \times 10^{10} \text{ disintegrations sec}^{-1}$$

$$\text{lelectron volt (eV)} = 1.6021 \times 10^{-12} \text{ erg } = 1.6021 \times 10^{-19} \text{ J}$$

$$= 3.827 \times 10^{-20}\text{cal}$$

$$= 23.06\text{kcalmol}^{-1}$$

$$1\text{erg} = 10^{-7} \text{ J} = 2.389 \times 10^{-8}\text{cal} = 6.242 \times 10^{11}\text{eV}$$

$$1 \text{ electrostatic unit (esu) } = 3.33564 \times 10^{-10}\ \text{col}$$

$$1 \text{ faraday (F)} = 9.6487 \times 10^4\ \text{col}$$

$$1 \text{ dyme (dyne) } = 10^{-5} \text{ N col}$$

$$1 \text{ joule } = 10^7\text{erg} = 0.2390\text{cal}$$

$$1 \text{ litre } = 1000\text{ce} = 1000\ \text{mL} - 1\text{dm}^3$$

$$= 10^{-3}\ \text{m}^3$$

Values of Some Useful Constants

Fundamental constant	Valene in old emits	Value in SI units
"Avogadro"' number (N)	$6.023 \times 10^{23}\ \text{mol}^{-1}$	$6.023 \times 10^{23}\ \text{mol}^{-1}$
Atomies mass unit (amu)	$1.6605 \times 10^{-24}\ \text{g}$	$1.6605 \times 10^{-24}\ \text{g}$
Bohr radius (α_0)	$0.52918 \text{ A} = 0.52918 \times 10^{-8}\text{cm}$	$5.2918 \times 10^{-11}\ \text{m}$
Boltrmame constant (k)	$1.3807 \times 10^{-14}\text{ergdeg}^{-1}$	$1.3807 \times 10^{-23}\text{JK}^{-1}$
Charge on electron (e)	(-)4.8029×10^{-16} eau	$(-)1.6021 \times 10^{-19}$ coul
Change to mass ratio e/ m Of electron	$1.7588 \times 10^8 \text{ coul g}^{-1}$	$1.7588 \times 10^{11}\text{coul kg}^{-1}$.

Electron restmass (m_ϵ)	9.1091×10^{-28}g	9.1091×10^{-31} kg
Gas constant (R)	0.0821 lit atm deg^{-1} mol^{-1} 8.314×10^{7} erg deg^{-1} mol^{-1} 1.987 = 2.0caldeg^{-1} mol^{-1}	8.3.4 $JK^{-1}mal^{-4}$
Molar volume at NTP (V_m)	22.4 L mol^{-1}	22.4×10^{-3} m^3 mol^{-1}
Planek's constant (h)	6.6252×10^{-27} erg see	6.6252×10^{-34} J see
Proton mass (m_p)	1.6726×10^{-24} g	1.6726×10^{-27} kg
Neutron mass (m_e)	1.67495×10^{-24} g	1.67495×10^{-27} kg
Rydberg constant (R_2)	109678 cm^{-1}	1.09678×10^{7} m^{-1}
Velocity of light (c) in vacuum	2.9979×10^{10}cm sec^{-1} or 186281 miles sec^{-1}	2.9979×10^{8} m sec^{-1}
Faraday (F)	9.6487×10^{4}C/ equiv or 96500 Ciequiv	9.6487×10^{4}C/ equiv
$\frac{1}{4\pi\varepsilon_0}$	1	0.8988×10^{30} N m^2C^{-2} or 9×10^{9} N m^2C^{-2}

Derived SI Units

Quantity with Symbol	Unit (SI)	Symbol
Velocity(v)	meter per sec	ms^{-1}
Area (A)	square meter	m^2
Volume (V)	cubie meter	m^3
Density (D)	kilogram m^{-3}	kg m^{-3}
Acceleration (a)	meter per sec	m s^{-2}
Energy (E)	joule (J)	kg m^2 s^{-2}
Force (F)	- newton (N)	kg m s^{-2}
Power (W)	watt (W)	Js^{-1}; kgm^2 s^{-3}
Pressure (P)	pascal (Pa)	Nm^{-2}
Resistance(R)	ohm (Ω)	VA^{-1}
Conduction (C)	ohm^{-1}, mho, siemens	m^{-2} kg^{-1} s^3A^2 or Q^{-1}
Potential difference	volt (V)	kgm^2 $s^{-3}A^{-1}$
Electrical charge	coulomb (C)	A-s (ampere-second)
Frequency (v)	hertz (Hz)	cycle per sec
Magnetic flux × density	tesla (T)	kgs^{-2} A^{-1} = NA^{-1} m^{-1}

Derived SI Units

Popular Units and their SI Equivalents

Physical quantity	Unit with symbol	Equivalent in SI unit
Mass	1amu	1amu = 1.6605×10^{-27}kg
Energy	1 electron volt (eV)	1.602×10^{-19} joule
Length	1Å	10^{-10}m(10^{-1}nm)

Volume	liter	$10^{-3}\ m^3 = dm^3$
Force	dyne	10^{-5} N
Pressure	1 atmosphere	760torr(760 mmHg)
		101325pa or 10^5pa
	1bar	101325pa or 10^5pa
	1 torr	$133.322Nm^{-2}$
Dipole moment	debye, 10^{-18}csu − cm	3.324×10^{-30}cm
Magnetic flux density	gauss (G)	10^{-4} T
Area of nuclear cross section	1 barn	$10^{-24}\ m^2$
Nuclear Diameter	1 fermi (1femto)	10^{-15}m

Precision and Accuracy in Measurement

The process of measurement holds a crucial role in enhancing our understanding of the external world, and throughout the extensive span of our existence, we have refined a highly perceptive ability to measure. Alongside this intrinsic need for measurement, essential instruments have been developed to provide scientists with measurable data. Nevertheless, a significant challenge arises due to the inherent nature of any measurement conducted by these instruments, as it invariably carries a level of uncertainty, commonly referred to as error.

As we navigate the intricate domain of measurement, two fundamental factors take center stage: accuracy and precision. These terms are of utmost importance in evaluating how closely a measurement corresponds to a recognized or accepted value. The proficiency with which we can distinguish between accuracy and precision is essential in ensuring the reliability and validity of the measurements we acquire, ultimately influencing the quality and trustworthiness of scientific data.

Examples of Precision

Example 1:

Consider the scenario where you are engaged in measuring the resistance value with the aid of a digital multimeter. The actual resistance value is determined to be 35 Ohms through reliable means, yet the digital multimeter consistently registers a value of 33 Ohms over the course of 10 measurements. In this context, it becomes evident that the digital multimeter demonstrates precision, as it consistently produces the same result. However, it lacks accuracy, as the recorded values deviate consistently from the true or accepted resistance value of 35 Ohms. This highlights the distinction between precision and accuracy in the context of measurement instruments, emphasizing the importance of both factors for reliable and meaningful measurements.

Example 2:

Consider a situation where the temperature of an object is accurately determined to be 60 degrees Celsius through a reliable method. In this scenario, a thermometer consistently registers a reading of 60 degrees Celsius across multiple measurements. This alignment between the thermometer readings and the actual temperature demonstrates both accuracy and precision.

Accuracy is evident because the recorded values closely match the true temperature of the object, which is 60 degrees Celsius. Precision is observed as the thermometer consistently produces the same reading, indicating a low level of variability in the recorded values.

In summary, this example highlights a case where the thermometer is not only accurate but also precise, showcasing the importance of both aspects in obtaining reliable and consistent measurements.

Difference between Accuracy and Precision

We have often statements like a spot on and bullseye. These statements usually come when one guesses the right answer to a question. Similar to this quiz, the accuracy of data shows how close a measurement is to the ‘true’ value.

Let’s consider the bullseye for example. If one hits the target that one was throwing darts at, and the very center of the target is hit, one would be considered very accurate because that is the ‘true’ value.

However, in case one hits outside the center of the target each time, one would be considered inaccurate because it is not near the ‘true’ value. So, the farther one is from the center, the lesser will be the accuracy.

Accuracy is very important when it comes to data collection. For example, one may wish to measure a certain chemical’s volume in the experiment.

If the actual volume was 60 ml but the measurement was 75 ml, it would not be a very accurate value due to the fact that it is not close to the ‘true’ value of 60 ml. However, if the measurement is of 59 ml, one may consider this as an accurate value because of its immense closeness to the ‘true’ volume.

Now let us go back to the target. This time, when throwing off the darts takes place, the hit is nowhere near the centre. However, one hits the same spot every time.

In this case, the person was not accurate but rather precise. This is because precision refers to the agreement of repeated measures.

Hence, while accuracy shows how close one was to the true value, precision shows how often one would get the same measurement under the same conditions. Experts often call precision as the reproducibility or repeatability.

Significance of Precision and Accuracy in Measurements

The importance of both accuracy and precision cannot be overstated when aiming for the highest quality measurements. Achieving precision in a set of measurements does not necessitate accuracy; the key lies in the grouping of measurements with similar values. The precision of a series of measurements is upheld as long as they exhibit consistency and are closely clustered.

It is important to note that the central value around which the measurements are grouped does not necessarily have to align closely with the true value of the item being measured. Consequently, there are instances where prioritizing accuracy over precision is deemed more practical, especially when determining the required value is of greater utility.

Nevertheless, in the context of maintaining a measurement system, it is imperative to regularly assess both accuracy and precision. Both factors hold equal importance for the success of measurements, ensuring that the system remains reliable and produces results that are both close to the true value and consistently reproducible. Regular checks for accuracy and precision become integral to the overall effectiveness of the measurement process.

Exploration of Dimensional Analysis

Dimensional Analysis serves as a method to quantify both the size and shape of objects, offering a mathematical approach to studying the inherent nature of these entities. This analytical tool encompasses various parameters, including lengths, angles, and geometric properties such as flatness and straightness. By employing the concept of dimension, Dimensional Analysis establishes that mathematical operations such as addition and subtraction can only be carried out between quantities with identical dimensions.

Moreover, the fundamental principle of Dimensional Analysis asserts that two physical quantities can be considered equal only when they share the same dimensions. In essence, this implies that dimensions play a pivotal role in establishing the mathematical relationships and equivalences between different physical quantities. Through Dimensional Analysis, scientists and researchers gain a systematic means of comprehending and expressing the quantitative aspects of the physical world, allowing for more precise and meaningful mathematical descriptions of objects and their properties.

Exploration of Unit Conversion and Dimensional Analysis

Unit conversion, alternatively known as the Factor Label Method or Unit Factor Method, relies on the application of conversion factors to ensure uniformity in units. This method employs specific ratios, or conversion factors, to facilitate the transition between different units. To elucidate this process, consider the scenario where you aim to determine the equivalent length in meters for a given distance in kilometers.

For instance, if you wish to ascertain how many meters are encompassed in 3 kilometers, you can use the conversion factor that establishes the relationship between kilometers and meters. We already know that 1 kilometer is equivalent to 1000 meters. Applying this conversion factor:

$$3 \text{ km} = 3 \times 1000 \text{ meters} = 3000 \text{ meters.}$$

$$3\text{km} = 3 \times 1000 \text{ meters} = 3000 \text{ meters.}$$

In this example, the conversion factor is 1000 meters per kilometer, serving as the bridge to seamlessly convert the quantity from kilometers to meters. The Factor Label or Unit Factor Method, through the systematic use of conversion factors, proves invaluable in simplifying unit conversions and ensuring consistency across different units of measurement.