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Units and Measurement

Module Overview

Acknowledgments

This presentation is based on and includes content derived from the following OER resource:

University Physics Volume 1

An OpenStax book used for this course may be downloaded for free at:
https://openstax.org/details/books/university-physics-volume-1

The Scope of Physics

Physics, which comes from the Greek *physis*, meaning nature, is concerned with describing the interactions of energy, matter, space, and time to uncover the fundamental mechanisms that underlie every phenomenon. The forces that govern galaxies are the same ones that we experience on Earth, and they are described by the same physical laws.

Physics describes everything from atoms to the whole universe. It has applications in chemistry, biology, electronics, and many other fields.

The Scale of Physics

The **order of magnitude** of a number is the power of 10 that most closely approximates it.

length in meters (m)	mass in kilograms (kg)	time in seconds (s)
10^{-5} m = diameter of a red blood cell	10^{-30} kg = mass of an electron	10^{-3} s = duration of a nerve impulse
10^{0} m = 3 feet or 1 yard	10^{2} kg = mass of a person	10^{5} s = one day
10^{2} m = height of the Eiffel Tower	10^{25} kg = mass of the Earth	10^{11} s = recorded human history

Building Models

A **model** is a representation of something that is often too difficult (or impossible) to display directly. Models help us think about complicated systems but are limited in what they describe correctly.

A **theory** is a testable explanation for patterns in nature supported by scientific evidence and verified multiple times by various groups of researchers.

A **law** uses concise language to describe a generalized pattern in nature supported by scientific evidence and repeated experiments.

Units and Standards

A **physical quantity** is defined either by how it is measured or how it is calculated from other measurements. Measurements are specified in standardized **units**, such as miles, meters, or parsecs.

The two major systems of units in use today are **SI units** and **English units**. Most of the world (with the notable exception of the United States) uses SI units, which include the meter, second, and kilogram.

Base and Derived Units

Quantities defined by a measurement are called **base quantities** and the units that describe them are **base units**. Every other quantity and unit, called **derived quantities** and **derived units**, is expressed as an algebraic combination of base quantities and units.

In the SI system, the base quantities include length, time, and mass, and the base units corresponding to them are meters, seconds, and kilograms, respectively. Area (m^2), speed (m/s), and mass density (kg/m^3) are all examples of derived quantities.

Units of Time, Length, and Mass

Over time, units have been defined in increasingly precise ways to make communication about units unambiguous. The **second** is defined as the time needed for a cesium atom to vibrate 9,192,631,770 times. The **meter** is defined as the distance light travels in a vacuum in 1/299,792,458 of a second. The **kilogram** is currently defined by the weight of a platinum-iridium cylinder stored at the International Bureau of Weights and Measures near Paris, though ways to redefine the kilogram more precisely are underway.

Metric Prefixes

prefix	symbol	meaning
giga-	G	10^9
mega-	M	10^6
kilo-	k	10^3
centi-	c	10^{-2}
milli-	m	10^{-3}
micro-	µ	10^{-6}
nano-	n	10^{-9}

Unit Conversion

A **conversion factor** is a ratio that expresses how many of one unit are equal to another unit. Conversion factors can be used to convert between unit systems or to convert to different between units in the same unit system.

$$20\ \text{ft} = 20\ \text{ft} \times \frac{1\ \text{yd}}{3\ \text{ft}} = 6.7\ \text{yd}$$

$$50\ \text{mph} = \frac{50\ \text{mi}}{1\ \text{hr}} \times \frac{1\ \text{hr}}{3600\ \text{s}} \times \frac{1609\ \text{m}}{1\ \text{mi}} = 22.3\ \text{m/s}$$

$$1\,\frac{\text{g}}{\text{cm}^3} = \frac{1\ \text{g}}{1\text{cm}^3} \times \frac{1\ \text{kg}}{1000\ \text{g}} \times \left(\frac{100\ \text{cm}}{1\ \text{m}}\right)^3 = 1000\ \text{kg/m}^3$$

Dimensional Analysis

The **dimension** of any physical quantity expresses its dependence on the base quantities in the form $\mathrm{M}^a\mathrm{L}^b\mathrm{T}^c$, where M represents mass, L represents length, and T represents time. Quantities with no dependence on base quantities are called **dimensionless**. For example, velocity has dimension $\mathrm{M}^1\mathrm{T}^{-1}$, but angles are dimensionless.

Each term in an algebraic equation relating physical quantities must have the same dimension in order to be **dimensionally consistent**. Arguments to standard mathematical functions like sine and cosine must be dimensionless.

Estimates and Fermi Calculations, Part 1

strategy	example
Make big things from small things.	A ream of paper has 200 sheets and is 2 in. tall, so one piece is 0.01 in. thick.
Get areas and volumes from lengths.	An object looks cubic with side length 2 m, so its volume is roughly 8 m^3.
Get masses from volumes and densities.	Water's density is 1 g/cm^3, so 1000 cm^3 of water has a mass of 1 kg.

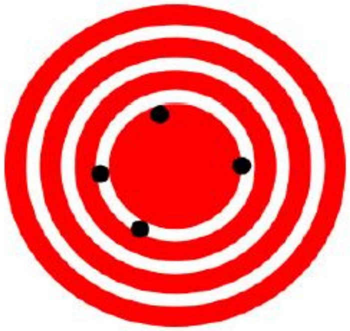
Estimates and Fermi Calculations, Part 2

strategy	example
Bound the solution.	A small dog's mass is somewhere between that of a person (10^2 kg) and a mouse (10^{-2} kg).
Keep the arithmetic simple.	Estimate π as equal to 3.
Ask if the answer makes sense.	You calculate that a balloon weighs 50 kg. Does this agree with your experience?

Accuracy and Precision of a Measurement

Accuracy is how close a measured value is to its accepted reference value.

Precision is how close repeated independent measurements are to one another. A set of measurements can be precise, accurate, neither, or both.



(a) High accuracy, low precision

(b) Low accuracy, high precision

(University Physics Volume 1. OpenStax. Fig. 1.12)

Accuracy, Precision, Uncertainty, and Discrepancy

Uncertainty is a quantitative measure of the precision of a set of measurements. Measuring a quantity several times and getting slightly different answer results in uncertainty in the best measured value.

Discrepancy is a quantitative measure of the accuracy of a set of measurements. If the best guess for a quantity is different from the accepted or true value, this results in a discrepancy. For example, if a stack of paper is 11.0 inches tall, and your best guess is 11.1 inches, there is a discrepancy of 0.1 inches.

Percent Uncertainty and Adding Uncertainties

If the measured value of a quantity is A and the uncertainty in the measurement is δA, the **percent uncertainty** is $\frac{\delta A}{A}$ x 100%. Uncertainties in calculated values can be determined by the **method of adding percents** if the measured uncertainties are small. If multiplying two numbers together, their percent uncertainties can be added together to get the new percent uncertainty. If dividing two numbers, their percent uncertainties can be subtracted to get the new percent uncertainty.

Significant Figures

The number of **significant figures** in a measured quantity is equal to the number of non-zero digits plus the number of zeros not at the beginning of the quantity. For example, 1.300 has four significant figures and 1.05 has three significant figures, but 0.053 has only two significant figures.

When adding or subtracting, keep only the number of decimal places of the number with the least precision. When multiplying or dividing, keep only the number of significant figures of the number with the fewest significant figures.

Solving Problems in Physics

The strategy of solving a physics problem is typically to first understand and sketch the problem, identify the known and unknown quantities, then identify the physical principles and mathematical equations that relate the knowns and unknowns. Finding the solution to a problem is a process of plugging known values and units into mathematical equations to determine unknown values. Finally, check whether units are consistent throughout the calculation, check that the solution is reasonable, and think about what phenomena the solution describes.

How to Study this Module

- Read the syllabus or schedule of assignments regularly.
- Understand key terms; look up and define all unfamiliar words and terms.
- Take notes on your readings, assigned media, and lectures.
- As appropriate, work all questions and/or problems assigned and as many additional questions and/or problems as possible.
- Discuss topics with classmates.
- Frequently review your notes. Make flow charts and outlines from your notes to help you study for assessments.
- Complete all course assessments.

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