

Module 1

THE NATURE OF PHYSICS

Introduction - What is physics?

Today we live in a society that is dependent on science and technology – some of us have grown up with these concepts while others find them new and intimidating. However, whatever your experiences, the study of science, and physics in particular, is based on events that occur in our everyday lives. We know from our everyday experiences that if we throw a ball into the air it will not fly off into orbit, it will return to our hands (hopefully); we know that unless you are superman you cannot stop a moving bus; we know that fan-force ovens cook faster than ovens without a fan. We live in a world of matter and motion, forces and energy ... Because we have grown up in this world so many scientific ideas are now second nature. When we drive to work, play sport or cook dinner we instinctively take advantage of a number of simple physical laws. So why then are we not called physicists when we have a lifetime of experience with physical principles? Why, for example, is the expert golfer, Greg Norman, who must know in great detail the physics of hitting a golf ball, called a golfer and not a physicist?

The key to understanding this difference is to recognise that the difference between the golfer and the physicist (or the expert cook and the physicist) is that the physicist looks at situations beyond their personal observation and experiences. They use these experiences to develop a generalisation about the events they have observed. This generalisation or hypothesis is often expressed mathematically and will always be tested by experimentation. Only after such a procedure, which is called the scientific method, will such a hypothesis be accepted as a reproducible law of physics. It should always be noted that even after such rigorous testing every law of nature can be changed if new observations prove it incorrect.

This method of acquisition of knowledge, the scientific method, is what separates science from other branches of knowledge (e.g. philosophy, religion) and it is this method that separates the golfer from the physicist.

In this course we will explore some of your everyday experiences, looking at them through the eyes of a physicist and hence explore some of these laws of nature and how they relate to you.

1.1 How to study physics

There are many things you need to consider as you progress through your study of physics. Many of these things are related to the study of any subject and are outlined in the study skills course within the Tertiary Preparation Program. If you are concerned about your studying skills and not enrolled in the study skills course, discuss your concerns with your physics tutor.

1.1.1 How to use these learning materials

In this course you are provided with a set of study books and have the option to use a video. The introductory book for this course details the particular structure of the course and the relationship between the video and study books.

The study book is divided into four modules of work with modules 2 to 4 further divided into several sections or topics e.g. 1.1 'How to study physics'. When studying this material, students often like to get an overview of the whole course by scanning the module, starting by

reading the list of topics at the beginning of the module. Once you have done that, read through the text. You should also actively summarise this text, making your own copy of the important points, writing down any new words with explanations of their meanings and making a list of all concepts that you don't understand. Remember, however, that physics is an active pursuit. It is not sufficient to simply acquire facts and theories; you must be able to use these to solve unknown problems. It is important that you attempt as many of the activities as you need to master the concepts explored.

When you have finished a section within the module you should check that you have achieved all of the stated objectives for that section and then attempt the post-test. These objectives are placed just before you start the pre-test. If there are concepts and/or problems that you are unable to do, you should seek help.

You should also plan your study using the 'suggested study plan' shown in the introductory book. Set goals for yourself, and try to find a time and place which is suitable for study. Perhaps consider rewarding yourself after you have completed small sections of work. As you study the material use a variety of techniques, such as summarising notes and asking yourself questions. From time to time reflect on the effectiveness of your study techniques; are these techniques allowing you to **fully** understand the material and meet the section objectives?

1.2 How to solve problems

Solving unknown problems is fundamental to the development of your understanding of physics.

A number of investigations have been carried out to determine how people solve problems. Because there are so many different types of problems there are many different approaches to the solution of problems. However, many good problem solvers start by asking the questions: What is unknown? What is known? To help them find the equations that link these quantities they draw a diagram or sketch. This diagram might remind them of a similar problem and hence help with the solution.

To start a problem in your study, one approach you could attempt is:

1. Read the question carefully two or three times and determine what it is that is unknown.
2. List what is known in the question. It might be wise to convert to SI units at this stage (see 1.2.2).
3. Write the problem out in a simpler form. For this you might rewrite the question or draw a sketch or diagram. Sometimes it is useful to make up a new but similar problem which has simpler numbers.
4. Try to make a link between the known and the unknown. The following could help with this stage.
 - Guess a solution – then try to fill the gap between the problem and solution.
 - Break the problem into segments and solve each part.

- Look at similar problems already solved.
 - Modify your problem into a simple problem. This could give you a hint to the more complex solution.
5. Write out your solution carefully and:
- check that your answer is reasonable
 - make sure you understand what the result really means.
6. Check that your solution is correct by:
- checking your mathematics
 - checking your logic
 - using new data and working the problem again
 - trying to redo the question using another method.

1.2.1 How to do home experiments

As you work through each module you will come across a number of home experiments which we would encourage you to perform. These experiments are designed so that you work through the implications of some concepts for yourself and also to give you a taste of things to come in your further studies.

When you come to a home experiment we recommend you complete the following procedure.

1. Read the experiment carefully and understand what the problem is addressing.
2. Think about the problem carefully, write down what you think might happen.
3. Collect all the equipment described, including appropriate materials to record the experiment.
4. Perform the experiment making sure you take notes of the methods **you** used and what happened. This may include making a series of measurements and recording these in a table.
5. When the work is complete write up a report of the experiment.

1.2.2 The home experiment report

In most situations all aspects of an experiment need to be communicated and a written report is required. It contains a record of all aspects of the experiment you have conducted.

Effective reports have a familiar professional appearance. Inside the report there are details of the experiment recorded in a systematic order. The following sections are samples of the headings to use:

(See the appendix for a model report.)

Title:	This should be brief, accurate and informative.
Introduction:	Describes the background and the goals of the experiment.
Materials and methods:	Describes how the experiment is performed and the materials used. All important details including list of materials, diagrams of equipment and procedures need to be included here.
Results:	Details the exact results of the experiment. This may be written observation, tables of measurement or other data or graphs of data.
Discussion:	Deals with the interpretation of the results, shortcomings of the experimental design and relationship of your experiment with the works of others.
Conclusion:	Details the final conclusions that can be made in terms of the original aims of the experiment.
References:	Details of any references to publications that have been referred to in any part of the report. There are standard ways of presenting references, see the referencing style in the Introductory Book for details or in the model report in the appendix.

1.3 Physics and measurement

Physics is often called an exact science and is fundamental to our understanding of other branches of science. Its exact nature means that crucial to our understanding of physics is the understanding of measurement and measurement systems.

1.3.1 System of units

When we measure some quantity it means that we find the size (magnitude) of the quantity relative to some standard. Originally measurements were made by comparing the size of an object to a part of our body e.g. This was how the 'foot' evolved ... but the question is whose foot?

To avoid confusion when measuring things we need to:

- agree on a suitable unit
- agree on a standard of unit
- make sure that this unit is reproducible (able to be copied accurately).

Unfortunately a common unit system is still not in use around the world. There are two main systems and a number of minor systems in use and in the future you might be required to convert from one system to another.

The main system in use is the SI system (International System of Units), which was formalised by international agreement in 1971. Many countries who previously used the British System have changed to the SI system, but the older units are still used in some circumstances.

In this study book we will use the SI system, but have included the conversion from the British to SI units for your information in the appendix.

1.3.2 The SI system

There are seven fundamental units defined in this system.

Quantity	Name	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
temperature	kelvin	K
electric current	ampere	A
number of particles	mole	mol
luminous intensity	candela	cd

The three units that you will encounter most commonly are the metre, kilogram and second, units of length, mass, and time respectively.

Metre

The metre was originally defined as one ten millionth of the distance between the equator and the north pole. This approach was replaced by a use of a metal bar marked with the standard length. Today the metre is defined in terms of one of the wave lengths of light emitted from an isotope of Krypton.

Kilogram

The kilogram is the mass of a certain cylinder of metal kept near Paris, France. This cylinder is used as the reference against which all other standards are regularly compared.

Second

The second was originally defined in terms of a fraction of one solar day. In 1967 a new standard was adopted and was defined in terms of the frequency of a particular radiation emitted/absorbed by atoms of Cesium 133.

All other units are derived from the seven standards mentioned above, so it is not necessary to define other standards for new units. For example, when you study forces, the unit Newton is introduced. In the SI system this unit is equivalent to:

$$\text{kg ms}^{-2} \quad \text{so that} \quad 10 \text{ N} = 10 \text{ kg ms}^{-2}$$

1.3.3 Coping with large and small measurements

In physics, measurements often deal with very large and very small numbers. If written in standard form these numbers can become very awkward. We simplify them by using:

- (a) Standard multiples and submultiples
- (b) Scientific notation

Standard multiples and submultiples

This system uses a series of prefixes to indicate power of ten of a particular unit.

Table 1.1: Prefixes used for powers of 10 in the metric system of measurement

Power	Prefix	Abbreviation
10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
* 10^0	- base unit	–
10^3	kilo	k
10^6	mega	M
10^9	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E

* As can be seen, each of these prefixes corresponds to a power of 10, either positive or negative. Successive prefixes differ from one another by a factor of 10^3 . Prefixes that are commonly used outside this pattern are

centi (c)	10^{-2}
deci (d)	10^{-1}
deka (da)	10^1
hecto (h)	10^2

So it can be seen that using this system:

20 micrometres (μm)	=	$20 \times 10^{-6} \text{ m}$	=	0.000 02 metres
42.195 kilometres (km)	=	$42.195 \times 10^3 \text{ m}$	=	42 195 metres
23 092 megaseconds (Ms)	=	$23\ 092 \times 10^6 \text{ m}$	=	23 092 000 000 seconds

Example:

Convert 1 498 367 200 mm into Mm

Solution:

$$1\text{mm} = 1 \times 10^{-3} \text{ m}$$

$$\text{so } 1\ 498\ 367\ 200 \text{ mm} = 1\ 498\ 367\ 200 \times 10^{-3} \text{ m}$$

$$1\text{Mm} = 1 \times 10^6 \text{ m}$$

$$1\text{m} = 1 \times 10^{-6} \text{ Mm}$$

$$\begin{aligned} \text{so } 1\ 498\ 367\ 200 \times 10^{-3} \text{ m} &= 1\ 498\ 367\ 200 \times 10^{-3} \times 10^{-6} \text{ Mm} \\ &= 1\ 498\ 367\ 200 \times 10^{-9} \text{ Mm} \end{aligned}$$

$$= 1.498\ 307\ 20 \text{ Mm}$$

$$\text{thus } 1498367200\text{mm} = 1.498 \text{ Mm}$$

Activity 1.1

Try these calculations now, and then check your answers against those supplied at the end of this module.

Convert:

Answers:

(a) 7.1m to km

(b) 52nsecs to μ secs

(c) 4.8Mg to mg

(d) 105 sec to psec

(e) 112 g to pg

Scientific notation

It is normal practice in science and engineering to write numbers in scientific notation. This notation is just a transformation on any number which is in standard form to a number with only one digit before the decimal point. The remainder of the digits occur after the decimal point, then the whole number is multiplied by a power of ten. For example:

Standard notation	Scientific notation
3016	3.016×10^3
1 656 000	1.656×10^6
0.000 123	1.23×10^{-4}
0.000 005 5	5.5×10^{-6}
100	1.0×10^2

Activity 1.2

Question 1:

Write the following in scientific notation:

- (a) 70
- (b) 0.003 79
- (c) 58 000
- (d) 0.61
- (e) 0.000 005 1

Answers:

Question 2:

Evaluate, writing your solutions in both scientific notation and standard form.

- (a) $3.62 \times 1.74 \times 10^{-4}$
- (b) $4.775 \times 10^4 + 8.02 \times 10^2$
- (c) $\frac{6.71 \times 10^{-4}}{2.11 \times 10^3}$
- (d) $(7.4 \times 10^2) \div [(6.3 \times 10^2) \times (4.83 \times 10^5)]$
- (e) $3.95 \times 10^4 - (5.17 \times 10^5)$

Answers

1.3.4 Uncertainty in measurement

In any scientific measurement or calculation there is a limit to the accuracy of the result. The degree of accuracy is dependent on the reliability or accuracy of the measuring instrument and the appropriateness of the method used, or the skill of the observer. Any or all of these, together with other possible factors, will affect not only the reliability of the measurement but also any results deduced from these measurements.

Errors

If we measure something, the difference between our measured value and the true (or accepted) value is called the **absolute error**.

$$\text{Absolute error} = \text{measured value} - \text{accepted value}$$

The ratio of the error to the true or accepted value is the relative error. This is usually given as a fraction or a percentage. For example, if you measured the velocity of light to be: $3.167 \times 10^8 \text{ ms}^{-1}$, then knowing that the accepted value of this is $2.998 \times 10^8 \text{ ms}^{-1}$,

$$\begin{aligned}
 \text{relative error} &= \frac{3.167 \times 10^8 - 2.998 \times 10^8}{2.998 \times 10^8} \\
 &= \frac{0.169 \times 10^8}{2.998 \times 10^8} \\
 &= \frac{1}{18} \text{ or } 6\%
 \end{aligned}$$

Significant figures

If we perform a calculation involving a number of measurements we have to consider the level of accuracy of each measurement and understand how this could affect the accuracy of the final answer.

For example, suppose we are asked to find the volume of a container about the size and shape of a shoe box. The measuring instrument is a metre stick, graduated in millimetres, and the measurements we obtain, using the stick as accurately as we can are:

$$8.2 \text{ cm} \times 15.9 \text{ cm} \times 30.1 \text{ cm}$$

Does this mean that the measurements are exact? Not necessarily. What we can say with some certainty is that the dimensions are:

$$15.9 \pm 0.1 \text{ cm}$$

$$8.2 \pm 0.1 \text{ cm}$$

$$30.1 \pm 0.1 \text{ cm}$$

Now we find the volume. Multiplying the three dimensions together gives us 3924.438 cubic centimetres. How accurate is this? Let us consider the two worst cases in our measurement.

Each of the measurements is 1 mm too small i.e. the dimensions should be: $16.0 \times 8.3 \times 30.2$

The volume would then be 4010.56 cm^3

(Remember, the earlier volume was 3924.438 cubic centimetres)

Each of the measurements is 1 mm too large i.e. the dimensions should be: $15.8 \times 8.1 \times 30$

The volume would then be 3839.4 cm^3

It is clear that no more than the first two digits of our first calculation can have any significance and that the best we can say is that the volume is about 3900 cm^3 .

It is here that the use of scientific notation is important. The figure 3900 is still somewhat ambiguous in meaning. Are the zeroes significant? To overcome this we write the actual significant figures as part of an expression in scientific notation. Thus we can say that the volume of the box is $3.9 \times 10^3 \text{ cm}^3$

This example illustrates a general rule used as a guide to determine significant figures in a calculation.

When multiplying several quantities, the number of significant figures in the final result is the same as the number of significant figures in the least accurate of the quantities being multiplied, where 'least accurate' means 'having the lowest number of significant figures'. Note that division involves the same consideration. Since in the example above the 'least accurate' measurement is 8.2, we were entitled to claim only two significant figures in our answer.

When the operation used involves addition or subtraction, the number of significant figures should equal the **smallest number** of decimal places of any term involved.

For example, if the sides of a quadrilateral are 12.4 m, 16.5 m, 8.05 m, and 17 m, then the perimeter is 53.95 by addition. However, because there are no decimals in the fourth measurement, only the whole number digits are significant, so we can say the perimeter is 54 m.

In working problems throughout this course you must keep in mind the rules about significant figures. It is no use giving answers to five decimal places when this is beyond the accuracy of the measuring instrument.

Activity 1.3

Question 1:

Answers:

The value of the speed of light is now known to be $2.997924574 \times 10^8 \text{ ms}^{-1}$.

Express the speed of light to

(a) 1 significant figure

(b) 3 significant figures

(c) 5 significant figures

(d) 7 significant figures

Question 2:

How many significant figures are there in

(a) 3.788×10^5

(b) 2.46×10^{-6}

(c) 0.0032

Question 3:

Carry out the following arithmetical operations, applying the appropriate rules for significant figures:

(a) Find the sum of 756, 37.2, 0.83, 2.5

(b) Find the product of

(i) 3.2 and 3.563

(ii) 5.67 and 11

(c) Subtract 37.2 from 756

(d) Divide 3.2 by 1.4577

Question 4:

Find the area of a circle of radius 4.65 cm

Module review

In this module ideas concerning the nature of physics and how to study the subject were discussed. Information regarding measurement and reporting accuracy were also covered. You should now assess yourself as to whether you have met the module objectives.

You should now be able to:

- provide strategies for studying physics
- state the procedures used for completion of a home experiment
- list the necessary sections in an experimental report
- list the seven fundamental units in the SI system
- write large and small numbers in scientific notation
- calculate with numbers which are written in scientific notation
- convert from one unit of measurement to another
- round numbers to the correct number of significant figures.

Are there concepts and/or problems that you are still unable to do? Have you been able to obtain help for these?

Solutions to activities

Activity 1.1

- (a) $7.1\text{m} = 7.1 \times 10^{-3}\text{ km}$
 $= 0.0071\text{ km}$
- (b) $52\text{ nsecs} = 52\text{ns} \times \frac{10^6\mu\text{s}}{10^9\text{ns}} = 52 \times 10^{-3}\mu\text{s}$
 $= .052\mu\text{s}$
- (c) $4.8\text{ Mg} = 4.8 \times 10^3\text{ kg}$
 $= 4.8 \times 10^3 \times 10^3\text{ g}$
 $= 4.8 \times 10^3 \times 10^3 \times 10^3\text{ mg}$
 $= 4.8 \times 10^9\text{ mg}$
- (d) $105\text{ sec} = 105 \times 10^{12}\text{ps} = 1.05 \times 10^{14}\text{ps}$
- (e) $=112\text{ g} = 112\text{g} \times 10^{12}\text{pg} = 1.12 \times 10^{14}\text{pg}$

Activity 1.2

Question 1:

- (a) $70 = 7 \times 10^1$
- (b) $0.003\ 79 = 3.79 \times 10^{-3}$
- (c) $58000 = 5.8 \times 10^4$
- (d) $0.61 = 6.1 \times 10^{-1}$
- (e) $0.000\ 005\ 1 = 5.1 \times 10^{-6}$

Question 2:

- (a) $3.62 \times 1.74 \times 10^{-4} = 6.2988 \times 10^{-4}$ and $0.000\ 629\ 88$
- (b) $4.775 \times 10^4 + 8.02 \times 10^2$
 $= 48\ 552$
 $= 4.8552 \times 10^4$

$$\begin{aligned} \text{(c)} \quad \frac{6.71 \times 10^{-4}}{2.11 \times 10^3} &= 0.000\,000\,318 \\ &= 3.18 \times 10^{-7} \end{aligned}$$

$$\begin{aligned} \text{(d)} \quad (7.4 \times 10^2) \div (6.3 \times 10^2 \times 4.83 \times 10^5) \\ &= 7.4 \times 10^2 \div 3.8429 \times 10^8 \\ &= 0.000\,002\,432 \\ &= 2.432 \times 10^{-6} \end{aligned}$$

$$\begin{aligned} \text{(e)} \quad 3.95 \times 10^4 - (5.17 \times 10^5) \\ &= -477\,500 \\ &= -4.775 \times 10^5 \end{aligned}$$

Activity 1.3

Question 1:

- (a) 3×10^8
- (b) 3.00×10^8
- (c) 2.9979×10^8
- (d) 2.997925×10^8

Question 2:

- (a) 4
- (b) 3
- (c) 2

Question 3:

- (a) 797
- (b) (i) 11.4
(ii) 62
- (c) 719
- (d) 2.2

Question 4:

67.9 cm²