Lesson #1 – Extended Notes

1A Units
1B Scientific Notation
1C Significant Digits

Introduction:

Physics requires from you an appreciation and understanding of
conceptual ideas
measurable quantities
observational techniques
mathematical sophistication
You will work to develop and improve your skills in all these areas.

Understanding physics means developing a mental view and a visual view of the physical world, including the need to:
Develop and refine your understanding of key concepts
Develop mental (visual) models to match physical events
Develop simple and then more complete mathematical models

Developing an experimental view of the physical world requires:
Making careful and reproducible observations
Designing experiments for making more accurate measurements
Analyzing data and comparing results to mathematical models and challenging the models with carefully planned test cases.

These varied aspects of Physics interact with each other and enable us to refine the concepts, construct more accurate models, generate more accurate estimates, and design more penetrating experiments. This is a process that takes time to develop. You will learn by doing and by practicing. This includes doing homework, performing laboratory experiments, and interpreting the results of those experiments in light of the mathematical models we will be developing in class.

The experimental and conceptual aspects of physics constantly interact with each other even in the most sophisticated experiments performed by professional physicists. It is viewed as a sort of combat in which the experimenters challenge the mathematical modelers with actual experimental results. When the results from the mathematical models and the experiments disagree the scientific community has identified another aspect of the physical world where the modelers (also called “theorists”) and the experimentalists need to focus more of their attention.

Your first step on the road to understanding Physics and the physical world begins with understanding the language of Physics. This will be a recurring theme in this course; learning the language (especially the mathematical language) of Physics.

Units:

Measure something; anything at all. The thing measured is not (usually) effected by the measurement. The result of the measurement must be reported in multiples or fractions of some <u>reference standard</u> or no one will understand what you're talking about.

Units are things like: gallons, inches, hours, pounds, etc. You will learn about even more unusual ones like the newton, tesla, ampere, and coulomb, among others.

Quantities are measured and expressed as multiples or fractions of an accepted standard unit. In this course, as in all of modern science, we will use the SI system of units. It is based on the somewhat earlier metric system of units. We will not be using, except for some early practice in converting them to SI units, the U.S. Customary System of units.

The result of any measurement is then a number with its associated unit. A numerical result without its units is meaningless. The two are inextricably linked.

TIP: In this course numbers without their units will not be accepted anywhere at any time - not on homework, quizzes, tests, lab write ups, work at the board, etc.

Unit Names: The fundamental units are given here. Other units are multiples, fractions, or combinations of these basic units.

The base SI unit of **mass** is the kilogram - kg.

The base SI unit of **distance** is the meter - m.

The base SI unit of **time** is the second - s.

The base SI unit of **temperature** is the kelvin - K.

The base SI unit of **rotation** is the radian - rad.

The base SI unit of **electric charge** is the coulomb - C

The base SI unit of **electric current** is the ampere - A.

The base SI unit for "**quantity of material**" is the mole - mol.

Many other quantities have units that are merely combinations of the base units. For example, the unit of velocity is the meter per second; m/s or m s^{-1}. The unit of area is meters squared or m^2, while volume is meters cubed or m^3.

Some of these combination units are considered so important that they have been given their own special names. These names usually honor an important physicist from history. For example, the unit of force, which you will soon learn, is created by the combination kilogram times meters divided by seconds squared; kg m/s^2. The kilogram meter per second squared has been named the newton (N), in honor of Sir Isaac Newton. The newton is a so-called derived unit. There are many of these derived units and you will learn a dozen or so of them in this course.

In the SI system, the names of units which are powers of ten larger or smaller than the standard unit are easily constructed with the use of prefixes which indicate how many powers of ten larger or smaller than the standard unit.

(*See the table of SI multipliers inside the back cover of the textbook*)

Changing the size of the unit by adding prefixes makes the naming more convenient in ordinary speech, but using scientific notation and sticking with the base units is the only way to work problems on homework, labs, quizzes, and tests.

Scientific Notation:

The best and most accurate way to deal with quantities that are much larger or much smaller than the standard unit of measurement is to write the results in standard scientific notation. This consists of a pre-exponential number between 1 and 10 that contains all the significant digits appropriate to the reported number and an exponential part that shows how many powers of ten larger or smaller that the base unit.

This approach keeps the space occupied on the page to a minimum size, and also makes the very large and very small numbers much easier to read without mistakes.

For example: 4.489×10^{15} N = 4.489E15 N = 4,489,000,000,000,000 N

8.671×10^{-11} s = 8.671E-11 s = 0.000 000 000 086 71 s

1.602×10^{-19} C = 1.602E-19 C = 0.000 000 000 000 000 000 160 2 C

6.02×10^{23} mol^{-1} = 6.02E23 mol^{-1} = 602,000,000,000,000,000,000,000 mol^{-1}

TIP: Convert all numbers to standard SI units first (that means either base units or one of the derived units), then write the numerical part in standard scientific notation before you begin working on any problem where this has not been done for you. Convert your final answer to some prefixed version of the standard SI units only if requested to do so. Otherwise, leave the answer in the standard SI units in standard scientific notation.

Examples:

1. ***Converting to standard units in scientific notation***

560 nm	=	560×10^{-9} m	=	5.60×10^{-7} m
1,348 Gs	=	$1{,}348 \times 10^{9}$ s	=	1.348×10^{12} s
0.00272 g	=	0.00272×10^{-3} kg	=	2.72×10^{-6} kg
2.551 yrs	=	2.551 yrs x 365.25 day/yr x 24 hr/day x 60 min/hr x 60 s/min		
	=	80,503,437.6 s	=	8.050×10^{7} s (4 SF)
35.0°C	=	273.15 K + 35.0 K	=	308.2 K (4 SF)
167°	=	2π {167°/360°} rad	=	2.91469985 rad
			=	2.91 rad (3 SF)

2. ***Adding two numbers together*** (note that units and exponents must agree before you can start adding or subtracting pairs or groups of numbers).

$$\begin{array}{r} 10{,}200 \text{ nm} \\ \underline{+ \quad 477\ \mu\text{m}} \end{array} \rightarrow \begin{array}{r} 10{,}200 \times 10^{-9} \text{ m} \\ \underline{+ \quad 477 \times 10^{-6} \text{ m}} \end{array} \rightarrow \begin{array}{r} 10.2 \times 10^{-6} \text{ m} \\ \underline{+477 \quad \times 10^{-6} \text{ m}} \\ 487.2 \times 10^{-6} \text{ m} \end{array}$$

$\downarrow$

$\rightarrow 487.2 \times 10^{-6}$ m = 487×10^{-6} m (3 SF)

If this is only an intermediate value to be used in further calculations, use the unrounded version, 487.2×10^{-6} m, when making additional calculations. This is why it is essential that you write down both the unrounded and the rounded version of every answer. Make sure the unrounded version has at least one or two more digits than the rounded version. Mark the rounded versions with the SF designation.

3. When multiplying two numbers together or dividing two numbers. Units and exponents need not agree, and in fact they seldom do. Almost all the interesting physics involves putting compound units together in this way.

Multiplication		Division
$(4.74 \times 10^4\ m)\ \times\ (3.1 \times 10^{-5}\ s^{-1})$	$\equiv$	$(4.74 \times 10^4\ m)\ \div\ (3.2258 \times 10^4\ s)$
$\downarrow$		$\downarrow$
$(4.74 \times 3.1)\ \times\ (10^4 \times 10^{-5})\ m\ s^{-1}$		$(4.74 \div 3.2258)\ \times\ (10^4 \div 10^4)\ m/s$
$\downarrow$		$\downarrow$
$14.694 \times 10^{4-5}\ \ m\ s^{-1}$		$1.469 \times (\ 1\ )\ m/s$
$\downarrow$		
$1.4694 \times 10^{4-5+1}\ m\ s^{-1}$		$\downarrow$
$\downarrow$		
$1.4694 \times 10^0\ m\ s^{-1} = 1.5\ m\ s^{-1}$ (2 SF)		1.47 m/s (3 SF)

(See significant figures examples)

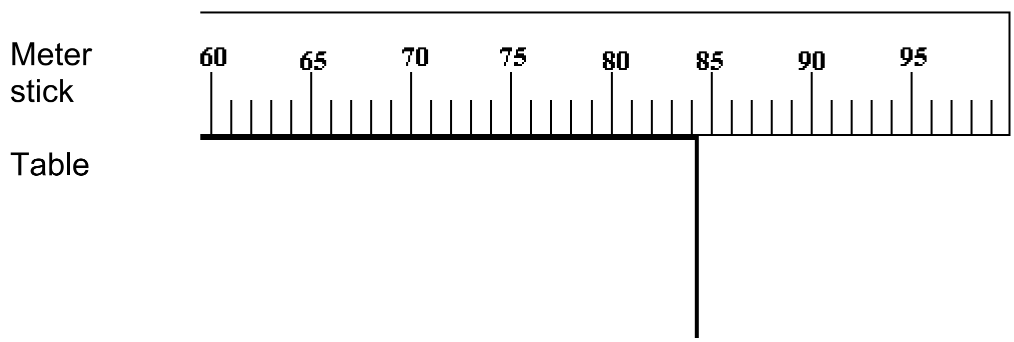
Significant Figures (Significant Digits - SF):

Almost all quantities in Physics are measured quantities, and all measured quantities have some error. Exceptions are the “defined” relationships among the standard units of measurement (eg. 1 ft is exactly 12.0000… inches, 1 in is exactly 2.5400… cm, 1 kg is exactly 1,000.000… grams, pi = π = 3.14159265..., e = 2.71828182..., 1/2 = 0.500..., etc. These defined numbers and relationships have no error and therefore they have more significant digits than any measured number in your calculations. Therefore, they do not limit the number of significant figures in your answers.

It is the <u>measured numbers</u> put into the calculation that limit the number of significant digits in your answer.

By long standing agreement among scientists, when you report a measured number you are allowed to add one extra digit, and only one, that contains any error from reading the scale or meter of the measuring instrument. When you make a measurement it is up to you to conform your measurements to this standard.

Here is an example of a length measurement:



The first two digits are easily read directly from the meter stick's scale, while the third digit is estimated between the smallest tick marks and therefore it is somewhat uncertain.

84.	cm	(exact)
0.3	cm	(only an estimate, not exact, but still a SF)
84.3	cm	(3 SF in this measurement)

On a standard meter stick each centimeter is further divided by 10 smaller lines. Thus, four significant figures is the standard of measurement expected from a standard meter stick. On a standard meter stick the smallest tick marks are only 1 mm apart. Therefore, you should be able to estimate to the nearest 0.1 mm, or 0.0001 m.

You might imagine that we could improve the readability of the scale by using a magnifying glass to make a more accurate estimate of where the table length sits between the tick marks on the scale. Simply looking at the scale more carefully does not increase the number of significant figures you get in the answer. The scale itself determines the limit on the readability of the scale, not how carefully you look at it. Careless measurement on your part might increase the error but it cannot decrease the error.

84	cm	(still exact)
0.3	cm	(only an estimate, not exact, but still a SF)
84.3	cm	(3 SF in this measurement)

Even with the magnifying glass we are still not allowed to estimate more than one digit between the finest divisions on the scale. To get more precision we will need a meter stick with 10 divisions between the finest ones on the meter stick shown in the figure. With such a meter stick we would be allowed to estimate one digit between those finer tick marks. The scale on any measuring tool sets the limit on the number of significant digits we must report with any measurement using that tool.

The number of significant figures reflects the smallest readable scale division on the instrument plus one extra digit "estimated" or "guessed" between the finest (smallest) marks on that scale. We are not allowed under any circumstances to estimate two digits between the finest scale marks. That would imply that we could distinguish among 100 small unmarked divisions using our eyes alone. That is not possible.

The number of significant digits in a measured number reflects how accurately a reasonable person would be able to read the instruments used for the measurement. The only honest answer is the one that conveys the correct number of significant digits. It is up to each of you to make sure that your own reports are accurate in this sense.

When someone else makes a measurement you are dependent on that person or group to report the proper number of SFs in their report. You would certainly consider it a breach of your trust if they lied to you about the data. No self-respecting scientist or student would let that happen, so you must be able to rely on their honesty and they must be able to rely on yours.

Given that there is going to be uncertainty in the data, the number of significant figures in a reported result obtained by using that data must also reflect the level of uncertainty introduced in that result by the known error in the input values. Your adherence to the following rules will insure that your results are in agreement with the level of uncertainty contained in your starting data.

This matter of significant figures must not be taken lightly. Misrepresentation of the data or the results is a fraud just as surely as lying to the IRS or a judge in court. Do not overstate or understate the level of precision in your calculations. Once we get past this introduction and practice phase, the consequences of misrepresentation become more dire.

On the other hand, it is essential that you not round off digits during a long and complex calculation until the very end. For the intermediate steps in a calculation you must keep all the digits your calculator reports. The act of rounding again and again will introduce an additional, unnecessary uncertainty and error. Round results to the correct number of sig figs only after all the intermediate calculations are completed or when writing down interim results. If you do round, however, do not start the next part of the calculation with the rounded number. Continue with the number in the calculator.

Rules for reporting Significant Figures (both when reading numbers reported by others and when reporting the results of your own measurements)**:**

1) All non-zero digits must be significant digits; otherwise don't report them.

2) All interior zeroes are significant; because they are surrounded by SFs.

3) All <u>terminal zeroes</u> to the right of the decimal point must be significant; otherwise they should not be and would not be included.

4) For numbers with absolute values between 0 and 1, zeroes between the decimal point and the first non-zero digit are not significant. They are mere placeholders, e.g.,

$$0.000467 \ \ (3\text{ SF}) = 4.67 \times 10^{-4}$$

One other situation may be encountered. This only happens when numbers are not reported in standard scientific notation. This would usually occur in casual speech, not in any scientific report that you would read or write yourself.

5) For whole numbers greater than one with terminal zeroes and no decimal point, assume that the terminal zeroes are not significant unless you have additional information about which digit is the first one (from the left) to be estimated or uncertain. Then zeroes to the right of that number are not significant.

There are plenty of ways to convey such information; here are some examples:

27,000	2 sig figs
$27{,}000 \pm 10$	4 sig figs
$27{,}\overline{0}00$	3 sig figs
$27{,}0\underline{0}0$	4 sig figs

Use of the over-score and under-score bar is introduced in the textbook, but it is not a standard scientific method of indicating where the last significant figure sits. This is a good technique, however. For ease of editing on quizzes and tests in this course the under-score will be used.

$27{,}000 \pm 1000$	2 sig figs

Note that this example indicates explicitly the same level of error that is only implied in the first example above.