PHYS-2010: General Physics I
Course Lecture Notes
Section I

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Abstract

These class notes are designed for use of the instructor and students of the course PHYS-2010: General Physics I taught by Dr. Donald Luttermoser at East Tennessee State University. These notes make reference to the *College Physics, 11th Edition* (2018) textbook by Serway and Vuille.

I. Introduction

A. The Nature of Physics: Behavior and composition of matter and energy and their *interactions*.

1. 2 main branches:

a) **Classical Physics:**

i) Mechanics (covered in General Physics I).

ii) Thermodynamics (covered in General Physics I).

iii) Fluid Mechanics (covered in General Physics I).

iv) Electromagnetism (covered in General Physics II).

v) Optics (covered in General Physics II).

vi) Wave Mechanics (covered in General Physics II)..

b) **Modern Physics:**

i) Special Relativity and General Relativity.

ii) Quantum Mechanics (also called Atomic Physics).

iii) Nuclear Physics.

iv) Statistical Mechanics (thermodynamics in terms of probabilities).

v) Condensed Matter (once called Solid State Physics).

2. Physics is written in the language of mathematics and is based upon logical thought processes.

a) Physics represents the *foundation* of all of the **physical sciences**, which includes astronomy, geology, chemistry, and their various subfields.

b) The science of astronomy, the oldest of all of the physical sciences, is firmly rooted in physics and both share the same history as mankind attempted to understand the workings of nature.

3. Matter *moves* (*i.e.*, follows trajectories) as a result of a force being applied to it.

a) **Contact forces**: Force exerted through a collision as described by Newton's 2nd law of motion: $F = ma$.

b) **Field** (or natural) **forces**: Force exerted on an object from its location in some natural potential field. There are 4 field forces in nature:

Interaction	Relative Strength	Range
Strong‡	1	10^{-15} m
Electromagnetic† ‡	10^{-2}	∞
Weak† ‡	10^{-6}	10^{-17} m
Gravitational	10^{-43}	∞

† - Under high energies, the electromagnetic and weak forces act as one — the Electroweak force.

‡ - Under even higher energies, all of the natural forces (except gravity) also may act as one, as described by the Grand Unified Theory.

B. The Structure of Physics.

1. There are 6 key definitions that are useful in the description of physics.

a) **Concept:** An idea or physical quantity used to analyze nature (*e.g.*, "**space**," "**length**," "**mass**," and "**time**" are concepts).

b) **Laws:** Mathematical relationships between physical quantities.

c) **Principle:** A very general statement on how nature operates (*e.g.*, the *principle of relativity*, that there is no absolute frames of reference, is the bases behind the *theory of relativity*).

d) **Models:** A representation of a physical system (*e.g.*, the Bohr model atom).

e) **Hypothesis:** The tentative stages of a model that has <u>not</u> been confirmed through experiment and/or observation (*e.g.*, Ptolomy's model solar system).

f) **Theory:** Hypotheses that are confirmed through repeated experiment and/or observation (*e.g.*, Newton's theory of gravity). The word "theory" has different meanings in common English (*i.e.*, it can mean that one is making a guess at something). **However, it has a very <u>precise</u> meaning in science! Something does not become a theory in science unless it has been validated through repeated experiment as described by the scientific method.**

2. Scientific theories are developed through the use of the **scientific method**:

a) A <u>hypothesis</u> is developed from every day experiences or from an instant of insight.

b) Often, a <u>model</u> is constructed from the hypothesis. Note that not all hypotheses have models associated with them.

c) The hypothesis/model is <u>tested</u> via repeated experiment and/or observation.

d) If the hypothesis/model is confirmed from the experiments and/or observations, it becomes a <u>theory</u>.

3. **Theory is <u>not</u> a dirty word!** In science, the word theory does not mean one has no proof (as this word is commonly used). Indeed, in order for a hypothesis to be accepted as a theory, one must present experimental and/or observational verification.

C. Units of Measure.

1. There are three different unit systems that are used in science and engineering. In the list below, the first two are commonly called the **metric system**.

a) **International Standard (SI) units** (once called mks [for meter-kilogram-second] units). This is the unit system used by most scientists.

b) **cgs** (for centimeter-gram-second) **units**. This unit system is still used in some areas of science (*e.g.*, astronomy and thermodynamics).

c) **English units** (foot-slug-second), also called American, British, or Empirical units. This unit system is considered <u>archaic</u> by the scientific community. The United States is the only technologically advanced country that still uses this system (though American scientists do not use it). Strangely, American engineers still use the English system.

2. There are 3 basic units in each unit system that relates to 3 independent concepts in physics: **length**, **mass**, and **time**. For the SI unit system, these 3 concepts are measured in units of:

a) **Length [L]:** meter — [m].

b) **Mass [M]:** kilogram ("kilo" mean 1000, or 1000-grams) — [kg].

c) **Time [T]:** seconds — [s].

3. **Metric Prefixes:** Since physics often deals with very large and very small numbers for the measurement of units, the metric system contain *prefixes* for units as shown in the table below.

Metric Prefix[†]	**Numeric Multiplier**	**Multiplier Name**
yotta- (Y-)	10^{24}	septillion
zetta- (Z-)	10^{21}	sextillion
exa- (E-)	10^{18}	quintillion
peta- (P-)	10^{15}	quadrillion
tera- (T-)	10^{12}	trillion
giga- (G-)	10^{9}	billion
mega- (M-)	10^{6}	million
kilo- (k-)	10^{3}	thousand
hecto- (h-)	10^{2}	hundred
deka- (da-)	10	ten
deci- (d-)	10^{-1}	tenth
centi- (c-)	10^{-2}	hundredth
milli- (m-)	10^{-3}	thousandth
micro- (μ-)	10^{-6}	millionth
nano- (n-)	10^{-9}	billionth
pico- (p-)	10^{-12}	trillionth
femto- (f-)	10^{-15}	quadrillionth
atto- (a-)	10^{-18}	quintillionth
zepto- (z-)	10^{-21}	sextillionth
yocto- (y-)	10^{-24}	septillionth

In the previous table, the prefix name (see the column marked with †), has an abbreviation in parentheses associated with the name that can be associated with the abbreviation for the unit. For instance, centimeter is written in abbreviation form as 'cm' and microjoule is written in abbreviation form as μJ.

4. In order to solve problems in physics, one needs to express all parameters given in the same unit system — this is accomplished with **conversion of units**:

$$v = 5.0\ \frac{\mathrm{mi}}{\mathrm{hr}} = \left(\frac{5.0\ \mathrm{mi}}{\mathrm{hr}}\right)\left(\frac{1.6\ \mathrm{km}}{\mathrm{mi}}\right)\left(\frac{10^3\ \mathrm{m}}{\mathrm{km}}\right)\left(\frac{1\ \mathrm{hr}}{3600\mathrm{s}}\right) = 2.2\ \frac{\mathrm{m}}{\mathrm{s}}\ .$$

Note in the example above that there are 1.6 km in one mile [mi], 10^3 m in one kilometer [km], and 3600 s (seconds) in one hour [hr]. Also note that the conversion fractions have been set up such that the units cancel until we wind up with the units we want (SI units).

D. Scientific Notation.

1. In physics you often find numbers that are both very large and very small. To handle such numbers, scientists express numbers using **scientific notation**:

$$m \times 10^n\ .$$

a) **Rule #1:** m is called the **mantissa** of the number and can be a positive or negative <u>real</u> number, where the absolute value of m ranges anywhere from (and equal to) 1.0 up to (but not including) 10:

$$1.0 \leq |m| < 10.$$

b) **Rule #2:** n is called the **exponent** of the number and must be a positive or negative <u>integer</u> that ranges from $-\infty$ to $+\infty$:

$$-\infty, ..., -3, -2, -1, 0, 1, 2, 3, ..., \infty\,.$$

2. Powers of 10:

$$\begin{array}{rl} 1,000,000 = 10^6 & 0.000001 = 10^{-6} \\ 100,000 = 10^5 & 0.00001 = 10^{-5} \\ 10,000 = 10^4 & 0.0001 = 10^{-4} \\ 1,000 = 10^3 & 0.001 = 10^{-3} \\ 100 = 10^2 & 0.01 = 10^{-2} \\ 10 = 10^1 & 0.1 = 10^{-1} \\ 1 = 10^0 & 1.0 = 10^0 \end{array}$$

3. In terms of scientific notation, the numbers 232 and 0.0232 are expressed as

$$232 = 2.32 \times 10^2 \qquad \text{and} \qquad 0.0232 = 2.32 \times 10^{-2}$$

4. Multiplication:

$$\begin{aligned} (4.6 \times 10^{16})\,(2.0 \times 10^2) &= (4.6 \times 2.0) \times 10^{16+2} = 9.2 \times 10^{18} \\ (-5.0 \times 10^8)\,(6.0 \times 10^{-10}) &= (-5.0 \times 6.0) \times 10^{8+(-10)} = -30. \times 10^{8-10} \\ &= -30. \times 10^{-2} = -3.0 \times 10^{-1} = -0.30 \end{aligned}$$

5. Division:

$$\begin{aligned} \frac{(6.3 \times 10^8)}{(3.0 \times 10^4)} &= \frac{6.3}{3.0} \times 10^{8-4} = 2.1 \times 10^4 \\ \frac{(6.3 \times 10^8)}{(3.0 \times 10^{-4})} &= \frac{6.3}{3.0} \times 10^{8-(-4)} = 2.1 \times 10^{8+4} = 2.1 \times 10^{12} \end{aligned}$$

6. Raising to a power:

$$\begin{aligned} (2\underline{0}0)^2 &= (2.0 \times 10^2)^2 = (2.0)^2 \times 10^{2\times 2} = 4.0 \times 10^4 \\ (1\underline{6}00)^{1/2} &= (16 \times 10^2)^{1/2} = [(4.0)^2]^{1/2} \times (10^2)^{1/2} \\ &= (4.0)^{2\cdot 1/2} \times 10^{2\cdot 1/2} = 4.0 \times 10 = 40. \end{aligned}$$

Note that $\sqrt{x} \equiv x^{1/2}$, $\sqrt[3]{x} \equiv x^{1/3}$, etc. Hence, the square root is the same as raising a number or variable to the one-half power. The "≡" symbol means "defined to be."

7. Note that "as a rule-of-thumb," numbers smaller than 0.01 and larger than 9,999 should be written using scientific notation.

E. Significant Digits.

1. Measurements of data or results of calculations should never be written out as more digits than are significant. The significance of a measurement or calculation is typically limited by the precision of the measuring tool used, by your ability to use that tool, or even by the nature of what you are trying to measure or calculate. *You must learn to express the results of your calculations so that the precision (or lack of precision) is clearly indicated.*

2. The precision of a measurement will be based on the "smallest" marker on your measuring device. For instance, if you are making length measurements with a meter stick whose markings are subdivided into centimeter marks, the precision of your length measurement will be to within 1 cm (*i.e.*, ±0.01 m). If a stop watch is subdivided into one-tenth of a second markers, then your precision is to within ±0.1 s.

3. When carrying out calculations, the result you write down should not exceed the significance of your input numbers, even if your calculator display a lot of digits (*i.e., calculators do not keep track of significant digits – it is up to you to keep track of significant digits*).

4. Multiplication and division have a separate set of rules than addition and subtraction concerning significant digits.

a) In multiplication and division, the number of significant figures (or digits) in the final result should be equal to that factor with the <u>least</u> number of significant digits:

$$\frac{(3.0379624 \times 10^{-24})\,(\underline{2.6} \times 10^{-2})}{(3.14156 \times 10^{-6})} = 2.514261 \times 10^{-20}$$
$$= \underline{2.5} \times 10^{-20}$$

b) In addition and subtraction, the <u>vertical column</u> containing the least significant digit limits the result:

$$\begin{array}{rcll} 37.2697\underline{2} & & & (7 \text{ s.d.}) \\ 25.4\underline{3} & & & (4 \text{ s.d.}) \\ .83\underline{7} & & & (3 \text{ s.d.}) \\ 101.2\underline{2} & & & (5 \text{ s.d.}) \\ 3.\underline{1} & & & (2 \text{ s.d.}) \\ \hline 167.\underline{8}5672 & = & 167.\underline{9} & (4 \text{ s.d.}) \end{array}$$

Here we rounded the least significant digit up by one since the digit just to the right of it is 5 or above.

c) To add or subtract numbers written in scientific notation, one must first re-express the numbers such that they all have the same power of 10. Then the addition or subtraction is carried out following the technique above:

$$\begin{array}{rlcrl} 3.7697 & \times 10^{-4} & = & 376.9\underline{7} & \times 10^{-6} \\ \text{-}2.892 & \times 10^{-6} & = & \text{-}2.89\underline{2} & \times 10^{-6} \\ \cline{4-5} & & & 374.0\underline{7}8 & \times 10^{-6} \quad = \quad 3.740\underline{8} \times 10^{-4} \end{array}$$

d) The significant digits of powers and roots are treated the same as multiplication and division.

e) When an expression has both addition/subtraction and multiplication/division, both rules will have to be used in the order defined by the equation set-up.

5. Often the result of a calculation will have trailing "zeros." One will need to figure out how many of the trailing zeros are significant. One follows the rules described above to determine whether or not a trailing zero is significant.

a) For instance, if a certain length measurement has a precision of 0.1 cm, then one would write that measured length as "38.$\underline{0}$ cm." The underline indicates that the "0" must not be dropped! To drop it would imply a less precise measurement.

b) If a number is written as an integer (*i.e.*, no decimal point shown), trailing zeros after a non-zero integer may or may not be significant. In these cases, **always underline the last zero that is significant**.

c) If a "whole" number is written as a *real* number (*i.e.*, one with a decimal point), then one should assume that all of the trailing zeros after the non-zero number(s) are significant.

d) If one or more are not significant, then one should underline the last significant zero. For instance: 76,000 (2 s.d. – significant digits), 76,0$\underline{0}$0 (4 s.d.), 800. (3 s.d.), 8$\underline{0}$0 (2 s.d.).

e) **Please note that your calculator will drop trailing zeros written after a decimal point (*i.e.*, the right**

side of a decimal point). However if any of those trailing zeros are significant, it is up to <u>you</u> to make sure that you write these significant trailing zeros on your exams and homework.

6. How do we handle "leading" zeros? The answer to this question depends on whether the leading zeros are before or after a decimal point.

a) Leading zeros prior to a non-zero number on the left side of the decimal point are <u>never</u> significant and should not be written out – for instance if we have the following number, 000876.98, we would never write out the leading zeros, instead this number would be written as 876.98, assuming the '.98' is significant.

b) If the zeros follow a decimal point and precede a non-zero integer (*e.g.*, .000789), even though the leading zeros are not significant, they must still be written to properly express the value of the number. However note that in this example, we should express this number in scientific notation (*e.g.*, 7.89×10^{-4}) following the "rule-of-thumb" note at the end of §I.D, Scientific Notation.

7. If one makes unit conversions involving prefixes (millimeters to meters, or kilograms to grams, for example), these will never limit the precision of the results, since the prefixes are defined to be exact.

a) For example, 1 m = 100 cm, exactly.

b) Also, when one has a measurement that must be an integer (6 coins, for example), it is generally assumed that the integer is an exact value. Thus, for example, if one takes the average of 8 measurements, one assumes there were exactly 8 measurements.

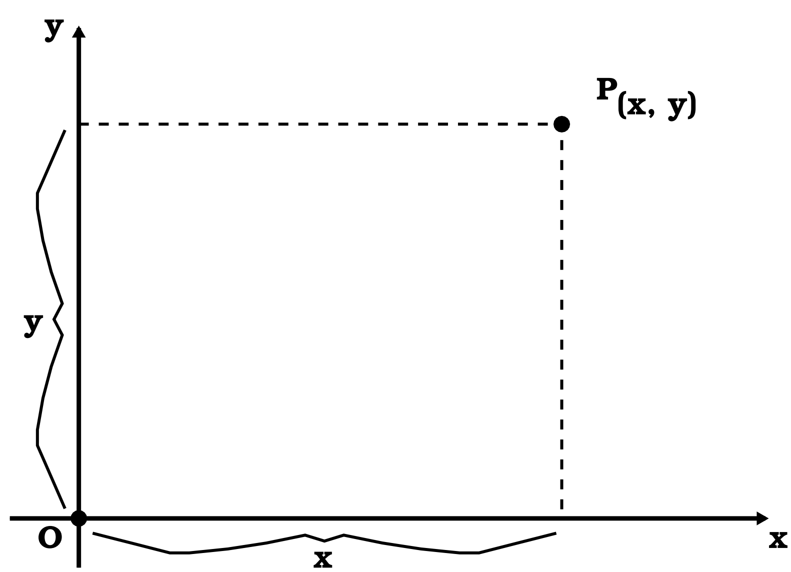
c) These numbers also never limit the precision of results.

d) Also, one sometimes deals with the combination of multiple measurements. In this case, it is sometimes a question whether one should be rounding intermediate results. One way to deal with this is to retain all of the digits in the intermediate results, but then express the final answer with the appropriate number of significant figures, hence avoiding any *round-off* errors. This retention of the digits in intermediate calculations is known as retaining **guard digits**.

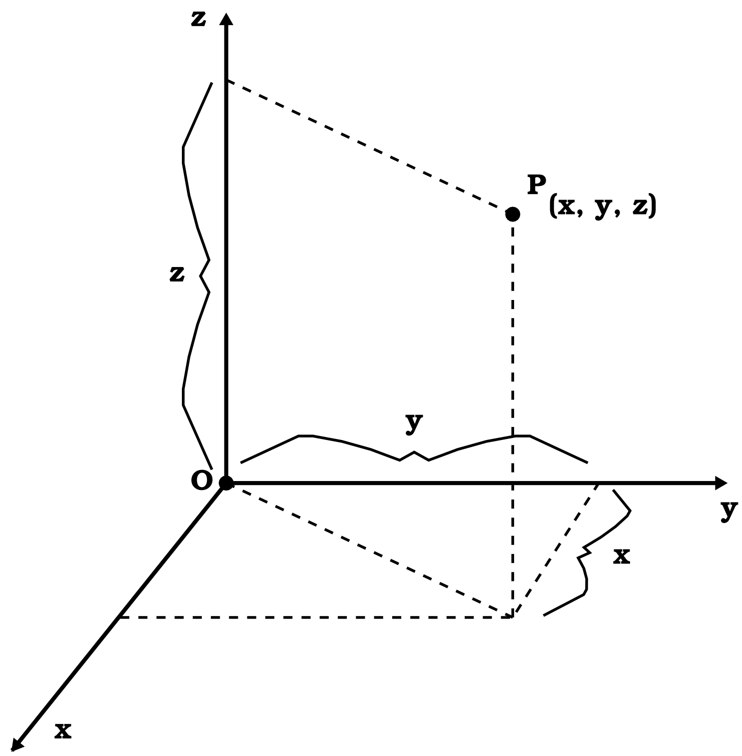
F. Coordinate Systems.

1. **Cartesian** or **orthogonal coordinates** (x, y, z).

a) 2–D (x, y):



b) 3–D $(x,\ y,\ z)$: (Note that the 3 axes in Cartesian 3-D space have a specific orientation that follows the **right-hand rule**: With your right hand thumb extended perpendicularly away from your hand, follow the rotation of the x-axis with your fingers curving towards the y-axis. Then, the direction your thumb points is the direction that the z-axis points.)

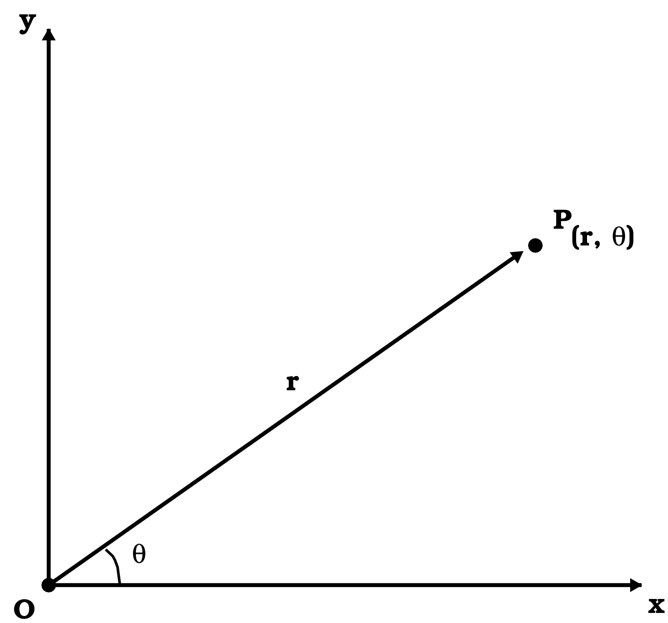


$\Longrightarrow$ Note that the data point $P(x,y,z)$ is x units out of the page from the origin, y units to the right of the origin, and z units above the origin.

2. **Polar coordinates** $(r,\ \theta)$ can also be used in 2–D situations. In 3–D, polar coordinates become either **spherical coordinates** $(r,\ \theta,\ \phi)$ or **cylindrical coordinates** $(r,\ \theta,\ z)$. Here, we will just focus on 2-D polar coordinates.

a) r is called the **radius vector** as is the distance that a point is from the *origin*.

b) θ (Greek letter "theta") is the angle that the radius vector, r, makes with the $+x$-axis (*i.e.*, the **reference axis**). Note that when the radius vector r rotates in the counter-clockwise (CCW) direction with respect to the reference axis, θ is positive ($\theta > 0$), and when r rotates in the clockwise (CW) direction with respect to the reference axis, θ is negative ($\theta < 0$).



3. Coordinate Conversion.

a) To convert from polar coordinates to Cartesian coordinates, use

$$x = r\,\cos\theta \tag{I-1}$$

$$y = r\,\sin\theta \tag{I-2}$$

b) To convert from Cartesian coordinates to polar coordinates, use

$$r = \sqrt{x^2 + y^2} \tag{I-3}$$

$$\tan\theta = y/x \tag{I-4}$$

c) Note that the above '$\tan\theta$' conversion equation (Eq. I-4) is only valid in Quadrant I ($+x$, $+y$) of polar plots. If the radius vector is in Quadrant II or Quadrant III (see the plots below), the calculated θ in the tangent equation above is measured with respect to the <u>negative</u> x-axis (hence $-x$ is the reference axis in these cases). If the radius vector is in Quadrant IV, $+x$ is the reference axis (like Quadrant I), but one gets a negative value for θ since it is rotating clockwise with respect to the reference axis. In this case, since θ is measured with respect to the $+x$ axis rotating in the counterclockwise direction, $\theta = 360° + \theta_{IV}$ as shown below.