Introduction: Syllabus.

Physics:

Perhaps one of the best examples of the '**Scientific Method**' in action is provided by the history of the developments in gravitation. Here it was easy to see the virtue of the process over the alternative, dogmatism. With hindsight the history evolves logically if one keeps in mind the steps in the scientific method:

1) **Observation**
2) **Theory**
3) **Testing predictions of the theory**
4) **Revision if necessary**
5) **Theory acceptance**

From the Copernican assertion that the solar system is sun centered to the data collection of Brahe, the empirical results of Kepler, the decisive theory of Gravity by Newton and its subsequent revision by Einstein, this path of science (physics) and the scientific method was and is distinctly different from the mythology that it went beyond. Even today with recent data indicating an expanding universe that is accelerating it appears that the theory of gravitation will soon require an additional revision.

Physics is the study of fundamental forces and the interaction dynamics of objects subject to these forces.

We are aware of four fundamental forces:

1) **Gravity** mediated by the as yet undetected graviton.
2) **Electromagnetic** forces mediated by the photon.
3) **Weak Nuclear** force mediated by W and Z particles.
4) **Strong Nuclear** force mediated by gluons acting between quark matter.

The first two, gravity and electromagnetism, are most evident in our everyday tasks:

Gravity since we are earth bound by the earth's gravitational pull and electromagnetic interactions in any sundry communications devices, lights, …, and more mundanely in normal forces.

The weak and strong forces are still of course at play but not as observationally evident unless you are at work at Fermilab just up the road in Batavia, IL.

A common feature of all these forces and their accompanying interactions is their reliance on experimental measurements to either validate or negate the theory describing the physics. Without measurements, one is just as well off with a set of dice or the gods of Olympus. Therefore, the text starts, and we will also, with the subject of measurement.

Measurement:

In order to understand physical phenomena a measurement or relative comparison of physical quantities must take place.

A standardized consistent set of units must be used throughout any experiment for example such that the equations used in calculating results are valid.

All physical quantities are defined in terms of 'base quantities' and the standard measures of these base quantities.

The **base quantities** and standards of most interest to us currently are:

Length	Meter	Length traversed by light in 1/(299792458) s
Time	Second	9,192,631,770 periods of Cs transition radiation
Mass	Kilogram	Pt-Ir cylinder in Bureau of Weights and Measure

Note the emphasis on standard invariability in the above.

Some '**derived quantities**' using these base quantities are for example:

Velocity $[v] = m/s$

Acceleration $[a] = m/s/s$

Force $[F] = kg \cdot m/s/s$

The **SI System** of units corresponds to our standardized set of units.

To use the equations of Physics correctly with SI units, all length measurements must be in meters, all time quantities in seconds and all masses specified in kilograms.

Only then will equations relating physical parameters be valid. For example using Newton's Second Law F = Ma, we can see the necessity for consistent units by evaluating the 'dimensions' of both sides of the equation:

LHS $[F] = kg \cdot m/s/s$

RHS $[ma] = [m]*[a] = kg*m/s/s$

There are two other systems of units that we will have some occasion to use and when returning to SI or MKS units will require us to use '**Conversion Factors**'.

These systems and their base units:

CGS -- centimeter, gram, second

British -- foot, slug, second

Converting from one unit to another corresponds to multiplication by one as follows:

If 1 foot = 12 inches, then the conversion factor from inches to feet is:

1 foot / 12 inches = 1.

E.g., 24 inches * $\frac{1\,foot}{12 inches}$ = 2 feet.   See the inside covers of your text for other factors.

Or multiplying twice by 1:

35.0 $\frac{miles}{hour} * \frac{1 hour}{3600 s} * \frac{1609 m}{1 mile}$ = 15.6 m/s

Uncertainty in Measure, Significant Figures, Scientific Notation - Powers of Ten:

Labs 1 and 2 will address the first two of these topics; the following is a summary:

Accuracy: The closeness of a result to its 'true value'. A function of **Systematic Errors**.

Precision: The 'quality' of a measurement or **statistical** spread of repeated measurements.

Table 1.1 Using Significant Figures

Mathematical operation	Significant figures in result
Multiplication or division	No more than in the number with the fewest significant figures *Example:* $(0.745 \times 2.2)/3.885 = 0.42$ *Example:* $(1.32578 \times 10^7) \times (4.11 \times 10^{-3}) = 5.45 \times 10^4$
Addition or subtraction	Determined by the number with the smallest uncertainty (i.e., the fewest digits to the right of the decimal point) *Example:* $27.153 + 138.2 - 11.74 = 153.6$

Note: In this book we will usually give numerical values with three significant figures.

Powers of ten and orders of magnitude are just about one in the same in that order of magnitude calculations are typically only good to within a factor of 10.

Powers of ten and orders of magnitude are one in the same. For example with an eye at table 1 - 1 the distance to Proxima Centauri is 4 orders of magnitude greater than the distance to Pluto and 6 orders of magnitude closer than Andromeda.

An order of magnitude calculation is useful in estimating answers quickly and/or obtaining an approximation without having to do a detailed calculation.

Scientific Notation ➔ Writing results and computed number values as a decimal of proper significant figures followed by a power of ten multiplier.

E.g. $1234.000 = 1.234000 \times 10^{3}$

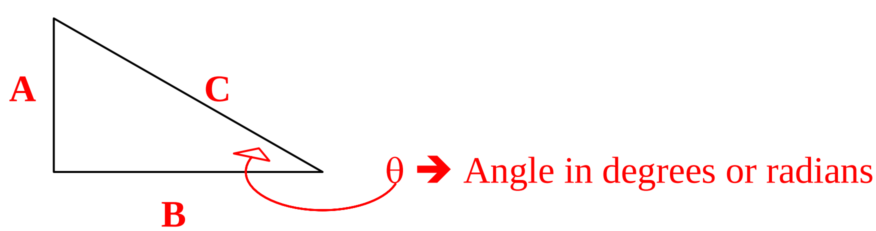
Or $0.00034500 = 3.4500 \times 10^{-4}$

Math Notation and Trigonometry Review:

$$\Delta X = X_{final} - X_{initial} = X_f - X_i$$

$$\sum_{i=1}^{i=5} X_i = X_1 + X_2 + X_3 + X_4 + X_5$$

The trigonometric functions for the right triangle below are:



Sin (θ) = A/C
Cos (θ) = B/C
Tan (θ) = A/B
Cot (θ) = 1/ Tan (θ) = B/A
Sec (θ) = 1/ Cos (θ) = C/B
Csc (θ) = 1/ Sin (θ) = C/A

Pythagorean Theorem $A^2 + B^2 = C^2$

Vectors:

A **scalar** quantity is a quantity represented by a magnitude only as in for example temperatures, energies, masses, and time…

A **vector** quantity requires both a magnitude and a direction for complete specification. Examples are velocities, displacements, and forces…

Given there may be cases where more than one force is acting on an object, then in order to understand the object's dynamics we will have to understand how to perform arithmetic operations on vector combinations such as:

$C = \vec{A} \bullet \vec{B}$ Notice result here is a scalar quantity

$\vec{C} = \vec{A} \pm \vec{B}$

$\vec{C} = \vec{A} \times \vec{B}$

The first and third of the above represent vector multiplication operations which we will investigate in later chapters. Two methods for vector addition and subtraction are:

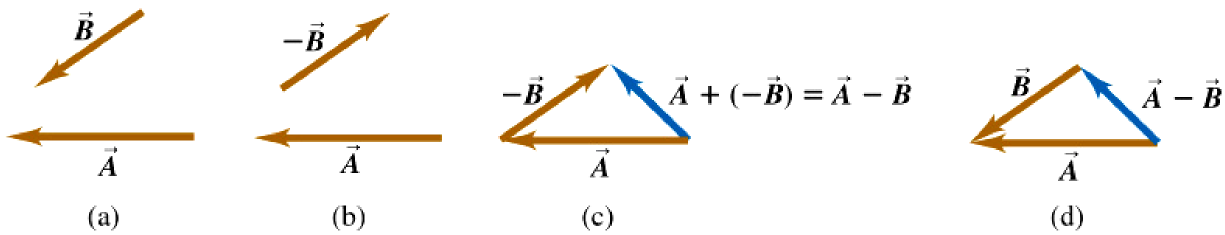
Method 1: Geometric addition and subtraction:

Using graphing paper, a ruler and a protractor, resulting vectors $\vec{C} = \vec{A} + \vec{B}$ is constructed by starting with $\vec{A}$, attaching the '**tail**' of $\vec{B}$ to the '**head**' of $\vec{A}$ and finally connecting the tail of $\vec{A}$ to the head of $\vec{B}$ which is the vector $\vec{C} = \vec{A} + \vec{B}$.

Specification of $\vec{C}$ is made by measuring the length or magnitude of the resulting vector with a ruler and its relative orientation or angle with a protractor.

$\vec{C}$ = {Magnitude, Angle}

Subtracting, $\vec{C} = \vec{A} - \vec{B}$, is done by adding $-\vec{B}$ to $\vec{A}$ where $-\vec{B}$ corresponds to the same magnitude vector as $\vec{B}$, but at 180^0 relative to $\vec{B}$, i.e., the opposite direction.



The following vector arithmetic properties may be verified:

1) **Commutative**: $\vec{A} + \vec{B} = \vec{B} + \vec{A}$

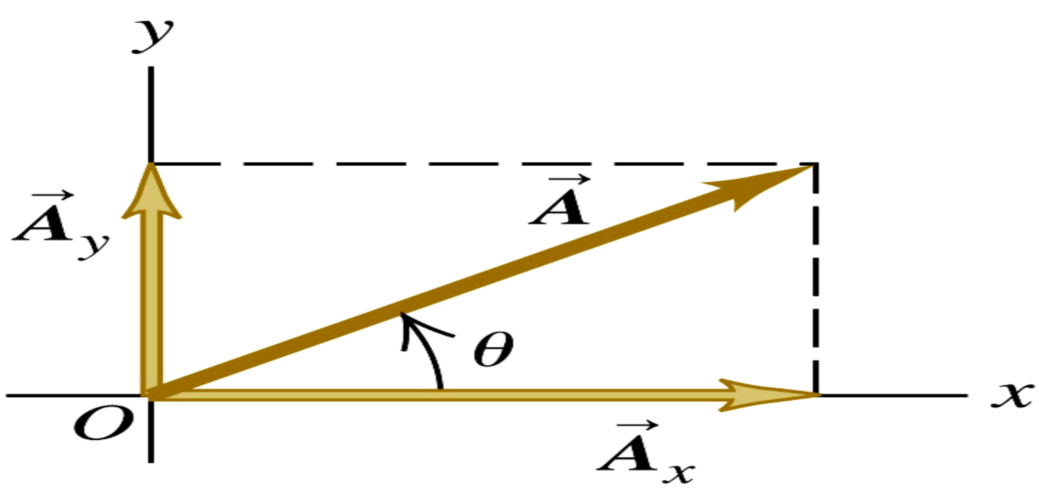
2) **Associative**: $\overrightarrow{(A + B)} + \vec{C} = \vec{A} + (\vec{B} + \vec{C})$

Notice that when using vectors that represent physical quantities, it is only sensible to add/subtract vectors of the same type. For example, reasonable results will obviously not obtain if a force vector is added to velocity vector etc. This is also understood using a dimensions argument.

Method 2: Algebraic addition and subtraction:

The **components** of the vector $\vec{A}$ relate to the magnitude of $\vec{A}$ and the angle θ:

$$A_x = |\vec{A}|\,Cos(\theta) \qquad A_y = |\vec{A}|\,Sin(\theta)$$



If more than one vector is to be added or subtracted, then these additions or subtractions may be carried out in a 'component-wise' fashion by first **resolving** each vector into its components with respect to the coordinate axis and then performing the indicated operations **independently** in each coordinate:

$$\vec{a} = a_x(x\_direction) + a_y(y\_direction)$$

$$\vec{b} = b_x(x\_direction) + b_y(y\_direction)$$

Then for $\vec{c} = \vec{a} + \vec{b} = c_x(x\_direction) + c_y(y\_direction)$

Where $c_x = a_x + b_x$ and $c_y = a_y + b_y$

The magnitude of $\vec{c}$ is from Pythagoras: $|\vec{c}| = \sqrt{c_x{}^2 + c_y{}^2}$

And $\theta_{reference} = Tan^{-1}\left|\frac{c_y}{c_x}\right|$

For Q1 angles (x+, y+) and $\theta_{actual} = \theta_{reference}$

For Q2 angles (x-, y+) and $\theta_{actual} = 180 - \theta_{reference}$

For Q3 angles (x-, y-) and $\theta_{actual} = 180 + \theta_{reference}$

For Q4 angles (x+, y-) and $\theta_{actual} = 360 - \theta_{reference}$

Vector Multiplication:

The two vector multiplication operations we will be using are the **vector dot product** which when operating between two vectors results in a scalar quantity, and the **vector cross product** which when operating between two vectors results in another vector.

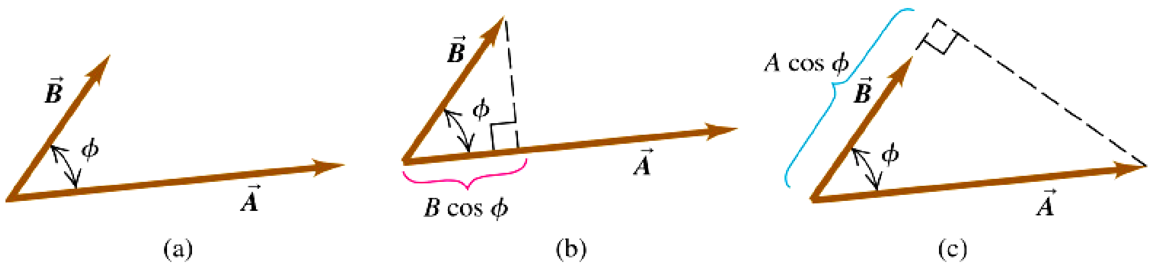
Examples of each are:

Given $\vec{a} = a_x(x\_direction) + a_y(y\_direction) + a_z(z\_direction)$

And $\vec{b} = b_x(x\_direction) + b_y(y\_direction) + b_z(z\_direction)$

Then $\vec{a} \bullet \vec{b} = a_x b_x + a_y b_y + a_z b_z$ is the dot product scalar and

$\vec{a} \bullet \vec{b} = |\vec{a}||\vec{b}| Cos(\phi)$ Where ϕ is the angle between the vectors.



The cross product magnitude is $\vec{a} \times \vec{b} = |\vec{a}||\vec{b}| Sin(\phi)$ where ϕ is the angle between the two vectors, and the direction of $\vec{c}$ is orthogonal to the plane formed by $\vec{a}$ and $\vec{b}$ and given by the **Right-Hand-Rule**.