SCIENTIFIC MEASUREMENTS

Textbook References:

- *Textbook 4^{th}, Appendix A-1 & C-1*
- *Textbook 5^{th}, Appendix B*

Lesson Objectives:

By Studying this chapter, you will learn

1. What the fundamental quantities of mechanics are, and the units used by scientists to measure them
2. The difference between scalars and vectors, and how to add and subtract vectors graphically
3. How to find the component of a vector graphically

I. Units:

Physical experiments involve the measurement of a variety of quantities, and a great deal of effort goes into making these measurement as accurate and reproducible as possible. the first step toward ensuring accuracy and reproducibility is defining the units in which the measurements are made.

In this course, we emphasize the system of units known as **SI units**, which stands for the French phrase "le system international d'unites". By international agrement, this system employs the **meter (m)** as the unit of length, the **kilogram (kg)** as the unit of mass, and the **second (s)** as the unit of time. Two other system of units are also used, however. The CGS system utilizes the centimeter (cm), the gram (g), and the second for length, mass, and time respectively, and the BE or British engineering system that uses the foot (ft), the slug (sl),, and the second. The table below summarizes the units used for length, mass, and time in the three systems.

	SI	CGS	BE
Length	Meter (m)	Centimeter (cm)	Foot (ft)
Mass	Kilogram (kg}	Gram (g)	Slug (sl)
Time	Second (s)	Second (s)	Second (s)

Figure 1: Units of measuremnts

The units for length, mass and time, along with few others that will arise later in this course, are regarded as **base units**. The word "base" refers to the fact that these units are used along with various laws to define additional units for other important physical quantities, such as force and energy area and so on. The units for such other physical quantities are referred to as **derived** units, since they are combinations of base units.

Example

Here the derived property is the area which can be calculated from the direct measurement of the length and the width of the rectangle. The unit of the derived property can also be found from the units of the individual measurements, here for example:

$$\boxed{unit(area) = unit(length) \times unit(width) = m \times m = m^2}$$

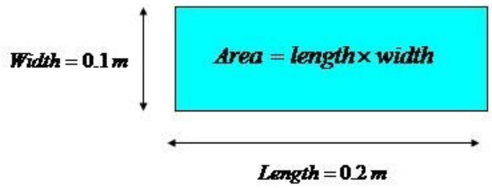


Figure 2: Unit of area

II. Standard prefixes:

When a measurement is either very large or very small the unit used to define its size can be modified using prefixes. The prefixes depend on the system of unit used. In the (SI) the prefixes are multiples of power of 10. The table below lists some of these prefixes with their associated power of 10.

Prefixes	Power of 10	Abbreviation
Giga	10^{9}	G
Mega	10^{6}	M
kilo	10^{3}	k
centi	10^{-2}	c
milli	10^{-3}	m
micro	10^{-6}	μ

Figure 3: Standard pefixes

Example

$\boxed{0.000001\ m = 10^{-6}\ m = 1\ \mu m}$ where μm stands for "micrometer"

Note:

Sometimes it is helpful to keep the same unit and express the measurement in scientific notation, in which the measurement is written as a product of a number between 1 and 9 multiplied by a power of 10.

Example

$$\boxed{1025\ m = 1.025 \times 10^{3}\ m}$$

III. Conversion factors:

Since any quantity, such as length, can be measured in several different units it is important to know how to convert from one unit to another. This conversion is made possible using **conversion factors**.

Example

$$1\ in = 2.54\ cm$$

Tables of conversion factors can be found in all scientific text books, in the first or last few pages.

Example: convert 25 *in* into centimeters

$$\boxed{25\ in = 25 \times (2.54\ cm) = 63.5\ cm}$$

IV. Scalars and Vectors:

IV-1. Scalars:

A scalar is any quantity that can only be described with a single number (including any units) giving its size or magnitude.

Example

$$\boxed{mass = 5\ kg}$$

IV-2. Vectors:

A vector is a quantity that can be described by a value-called magnitude and always positive- and a direction.

Example

A car moving **north** with a speed of $\underline{60\ mph}$. Here the magnitude is 60 *mph*, and the direction is **north**.

Note:

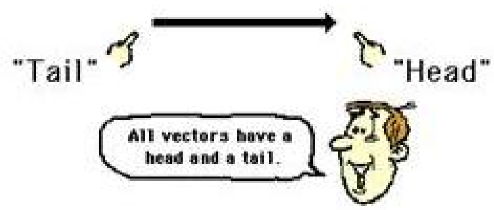
Often for the sake of convenience, quantities such as volume, time, displacement and others are represented by symbols. Here we write vectors as symbols (usually letters) with arrows above them.

Example

$$\boxed{\vec{V}\ :\ 60\ mph,\ north}$$

IV-3. Graphical representation of vectors:

Graphically a vector is represented by an arrow: The direction of the arrow is the direction of the vector. The length is the magnitude and may be drawn to scale.

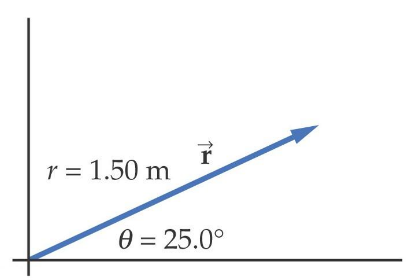


Vectors can be directed due East, due West, due South, and due North. But some vectors are directed northeast (at a 45 degree angle); and some vectors are even directed northeast, yet more north than east. Thus, there is a clear need for some form of a convention for identifying the direction of a vector which is not due East, due West, due South, or due North. There are a variety of conventions for describing the direction of any vector. In this course we will adopt the convention described below:

The direction of a vector is often expressed as an angle of rotation of the vector about its "tail" from either east, west, north, or south. For example, a vector can be said to have a direction of 40 degrees North of West (meaning a vector pointing West has been rotated 40 degrees towards the northerly direction); of 65 degrees East of South (meaning a vector pointing South has been rotated 65 degrees towards the easterly direction).

Another Example

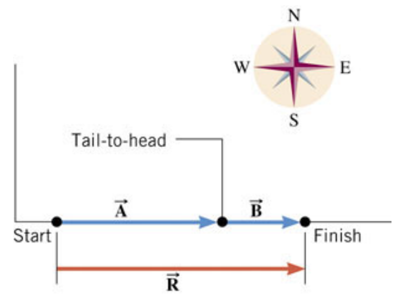
$$\boxed{\vec{r}\ :\ 1.50\ m\ ,\ 25.0^o\ North\ of\ east}$$



Here the magnitude is ($1.5\ m$), and the angle of rotation from the east direction and toward the north is (25^o).

IV-4. Adding two vectors graphically:

Often it is necessary to add one vector to another, and the process of addition must take into account both the magnitude and direction of the vectors. the simplest situation is when the vectors point along the same direction as in the figure below. here a car first move along a straight line, with a displacement vector ($\vec{A}\ :\ 275\ m\ ,\ east$). Then the car moves again in the same direction, with a displacement vector ($\vec{B}\ :\ 125\ m\ ,\ east$). These two vectors add to give the total displacement vector $\vec{R}$ which would apply if the car had moved from start to finish in one step. The symbol $\vec{R}$ is used because the total vector is often called the **resultant vector**. With the tail of the second arrow located at the head of the first arrow, the two lengths simply add to give the length of the total displacement. In such cases we add the individual magnitudes to get the magnitude of the total, knowing in advance what the direction must be.

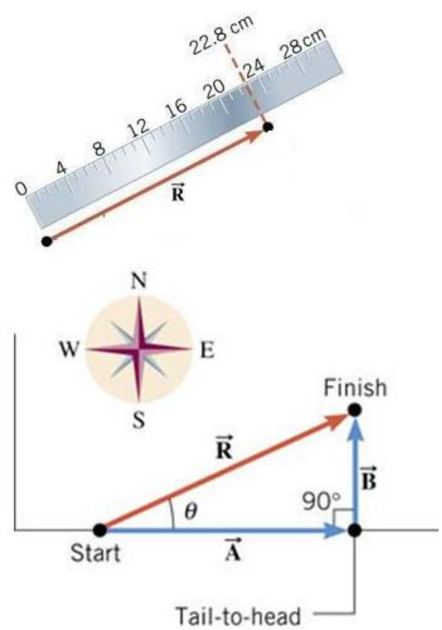


Formally, the addition is written as follow:

$$\vec{R} = \vec{A} + \vec{B}$$

$$\vec{R} = 275\ m\ ,\ east + 125\ m\ ,\ east = 400\ m\ ,\ east$$

Perpendicular vectors are often encountered, and the figure below indicate how they can be added.



This figure applies to a car that first travels with a displacement vector ($\vec{A}\ :\ 275\ m\ ,\ east$), and then with a displacement vector ($\vec{B}\ :\ 125\ m\ ,\ north$). The two vectors add to give a resultant vector $\vec{R}$. Once again, the vectors to be added are arranged in tail-to-head fashion, and the resultant vector points from the tail of the first to the head of the last vector. The resultant displacement is given by the vector equation.

$$\vec{R} = \vec{A} + \vec{B}$$

Here the magnitude of $\vec{R}$ can be measured using a ruler. Its direction can also be measured this time using a protractor.

IV-6. Subtracting two vectors graphically:

The subtraction of one vector from another is carried out in a way that depends on the following fact. when a vector is multiplied by -1, the magnitude of the vector remains the same, but the direction of the vector is reversed. The figure below illustrates the meaning of this statement.

A women climbs 1.2 m ladder as in part (a) of the figure below, so that her displacement vector $\vec{D}$ is 1.2 m, upward along the ladder

(a) (b)

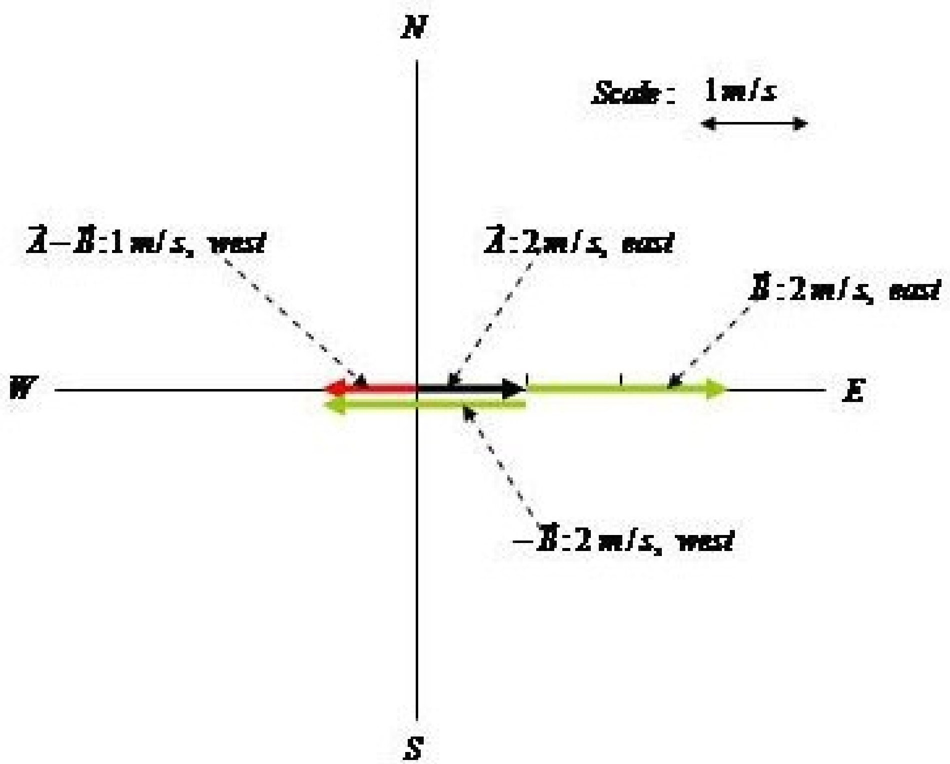
A displacement vector $-\vec{D}$ is (-1)$\vec{D}$ and has the same magnitude as the vector $\vec{D}$, but opposite in direction. Thus (-1)$\vec{D}$ would represent the displacement of a woman climbing 1.2 m down the ladder as in part of the same figure.

In practice, vector subtraction is carried out exactly like vector addition, except that one of the vectors added is multiplied by a scalar factor of -1.

$$\vec{A} - \vec{B} = \vec{A} + (-\vec{B}) = \vec{A} + (opposite\ of\ \vec{B})$$

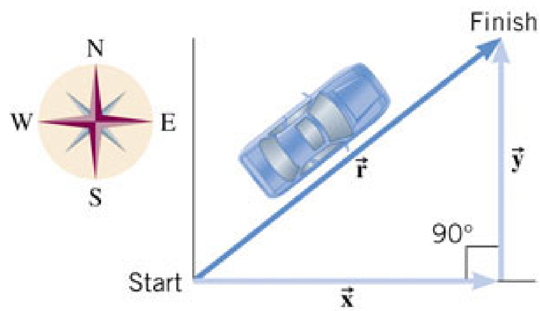
$\Rightarrow$ Subtracting $\vec{B}$ from $\vec{A}$ is similar to adding $\vec{A}$ and $-\vec{B}$

<u>*Example:*</u> Subtracting ($\vec{B} : 2\ m/s,\ east$) from ($\vec{A} : 1\ m/s,\ east$)



IV-7. Components of a vector:

Suppose a car moves along a straight line from start to finish in the figure below, the corresponding displacement vector being $\vec{r}$. The magnitude and direction of the vector $\vec{r}$ give the distance and the direction traveled along the straight line. However the car could also arrive at the finish point by first moving due east, turning through 90^o, and then moving due north. This alternative path is shown in the drawing and is associated with the two displacement vectors $\vec{x}$ and $\vec{y}$. the vectors $\vec{x}$ and $\vec{y}$ are called the x vector component and the y vector component of $\vec{r}$.



The components add together to equal the original vector

$$\boxed{\vec{r} = \vec{x} + \vec{y}}$$