# INTRODUCTION (CH. 1 & 3.1 – 3.2)

## Units

The seven fundamental units of the SI system are defined in the lecture notes below. For more information, refer to Appendix A in your textbook.

## Equations

(3.1) $\sin\theta = \frac{opp}{hyp} = \frac{a}{c};\ \cos\theta = \frac{adj}{hyp} = \frac{b}{c};\ \tan\theta = \frac{opp}{adj} = \frac{a}{b}$

**trigonometric functions: sine** (opposite / hypotenuse), **cosine** (adjacent / hypotenuse), and **tangent** (opposite / adjacent)

(3.2) $\theta = \sin^{-1}\left(\frac{opp}{hyp}\right) = \cos^{-1}\left(\frac{adj}{hyp}\right) = \tan^{-1}\left(\frac{opp}{adj}\right)$

**inverse trigonometric functions** used to find the angle

(3.3) $a^2 + b^2 = c^2$ — **Pythagorean theorem**; used to find the missing side of right triangle, or the missing component of a vector

(3.4) $\vec{r} = x\hat{\imath} + y\hat{\jmath}$ — general **position vector** ($\vec{\boldsymbol{r}}$) in a 2D coordinate system, where $\hat{\imath}$ and $\hat{\jmath}$ are unit vectors, and $x$ and $y$ are scalars

(3.6) $\vec{r}_1 + \vec{r}_2 = (x_1 + x_2)\hat{\imath} + (y_1 + y_2)\hat{\jmath}$ — vector sum (addition)

(3.7) $\vec{r}_2 - \vec{r}_1 = (x_2 - x_1)\hat{\imath} + (y_2 - y_1)\hat{\jmath}$ — vector difference (subtraction)

(3.8) $r = \sqrt{x^2 + y^2},\ \theta = \tan^{-1}\left(\frac{y}{x}\right)$ — vector magnitude and direction, given vector components

(3.9) $x = r\cos\theta$ and $y = r\sin\theta$ — vector components, given magnitude and direction

(3.10) $a\vec{r} = ax\hat{\imath} + ay\hat{\jmath}$ — multiplication of a vector by a scalar

## What is Physics? (Introduction)

- **Physics** answers the question of how things work, from the very small to the very large. In this class, we will focus on **mechanics**, a branch of physics that is concerned primarily with the **motion** of objects and the **forces** that affect that motion.

## Measurements in Physics (1.1 – 1.4)

- If we are to describe anything in physics, we must be able to measure it in some way. **Math** is the language of physics, allowing us to quantify the properties of objects and interactions around us, and enabling us to make connections between different these objects and interactions. For this class, a basic understanding of algebra and/or pre-calculus is required. We will review the necessary concepts in the first few lectures, expanding when necessary to complete problems in later chapters.

- Without a common reference point, no one would be able to agree on a given measurement, which could lead to all kinds of problems. The **Système Internationale** of measurements (**or SI system**) was developed to define common units for each of the fundamental quantities of nature based on rationale (uses powers of 10 for conversions, which makes sense, since we count using our 10 fingers) and universality (instruments and the quantities they measure can be calibrated by measuring universal phenomena). The seven fundamental units of nature and their abbreviations are listed here (for more information, see Appendix B in your textbook):
    - The fundamental unit of **length** (or **distance**) is the **meter (m)**.
    - The fundamental unit of **mass** is the **kilogram (kg)**. Note that the kilogram is the only unit that has an SI prefix in front of it (kilo); gram is the base unit.
    - The fundamental unit of **time** is the **second (s)**.
    - The fundamental unit of **electric current** is the **ampere (A)**.
    - The fundamental unit of **temperature** is the **kelvin (K)**.
    - The fundamental unit of an **amount of substance** is the **mole (mol)**.
    - The fundamental unit of **luminous intensity** is the **candela (cd)**.
- Other units are defined by combining the fundamental units in different ways. For example, the unit of **momentum** is $\frac{\mathrm{kg \cdot m}}{\mathrm{s}}$. Some units are used so much that they have their own special names. For example, the unit of **force** is the **Newton (N)**, which is equal to $\frac{\mathrm{kg \cdot m}}{\mathrm{s^2}}$.
- When measurements become very small or very large, they can become difficult to write. **Scientific notation** is most helpful when describing numbers that are much larger or much smaller than the standard units of measurements, such as the mass of a planet or an atom. Another way to express larger and smaller values is to use **SI prefixes**, which change the magnitude of a number by some power of 10. To do this by hand, just move the decimal place to the right (for larger numbers) or to the left (for smaller numbers) by the correct number of spaces. Normal, everyday human experiences tend to fall in the middle of the range, where scientific notation isn't necessary, as long as you're using the right prefix. For a list of SI prefixes, see Appendix B in your textbook. For a better perspective of the scale (or size) of things, see the video on Blackboard called "Scales of the Universe".
- Other common measurement systems include the **cgs system** (short for centimeter-gram-second) and the **English system** (primarily only used in the US for non-scientific measurements). Units in one system can be converted to units in another that measure the same kind of thing (for example, a distance measured in feet can be converted into meters but not kilograms). For a list of common unit conversions, see Appendix C in your textbook.
- **Dimensional analysis** and **order-of-magnitude estimates** can often be used to either start a problem or check your work. Sometimes, just knowing the proper units for your answer can help you to decide which variables need to be combined, and in which order (dimensional analysis). It is also a good idea to always ask if your answer makes sense. If an answer seems way too big or small, you may have missed a unit conversion or used the wrong approach entirely (order-of-magnitude estimates).

- The **accuracy** of a measurement tells you how close you are to the real-world answer (either the true or accepted value). If you think of a target, good accuracy would mean hitting close to the bullseye. Many scientific instruments use a calibration standard to adjust for a loss of accuracy over time. **Precision**, on the other hand, refers to the repeatability of a measurement. Thinking of the target again, good precision would mean hitting in the same spot multiple times, regardless of how close you are to the bullseye.
- **Significant figures** are used to record a measurement within the precision of a given measurement. All digits in a number, except for zero, contribute to the number of significant figures. Zeros can only be counted as significant if they appear *between* two non-zero numbers, or *after* another number *and after* the decimal place. For example, the number 0.003 has only 1 significant figure, 0.0030 has 2 significant figures, 3.00 has 3 significant figures, and 303 has 3 significant figures. Zeros before the decimal place only count *if* the decimal place is included in the number. For example, the number 2700. has 4 significant figures, but the number 2700 only has 2. If it is unclear how many significant figures a number has, the number should be written using scientific notation or SI prefixes. Significant figures should be including when making calculations using the following rules:
    - For multiplication and division, the answer should have the same number of significant figures as the number with the least significant figures.
    - For addition and subtraction, the answer should have the same number of decimal places as the number with the least number of significant decimal places.
    - Numbers or constants with exact values do not contribute to the significant figures.
    - Wait to round answers until all steps have been calculated. Keep as many significant figures or decimal places as possible until the end to avoid rounding error.

## Trigonometry Review (3.1)

- In this class, we will be describing the motion of objects in two dimensions (2D). Before starting a problem or taking any measurements, we must agree on a reference point. Physicists commonly use a **Cartesian coordinate system**, which consists of two perpendicular axes (for 2D motion), x and y, that intersect at the origin. It is important to note that the origin and orientation of a coordinate system is arbitrary. Sometimes, creative placement and orientation of your coordinate system will make a problem easier to solve.
- Many of the problems that we will do in this class require the use of algebra and trigonometry. Some of the more common **trigonometric functions** are summarized in Equations 3.1 – 3.2, along with the **Pythagorean theorem** (Eq. 3.3). These functions are based on the relationships among the sides of a right triangle, and their associated angles. It is also important to note that the values of the trig functions change if you change angles. For a list of trig functions and their values for common angles, see Appendix A in your textbook. Table 3.1 on pg. 42 also gives decimal values to three significant figures.

## Scalars & Vectors (3.2)

- A **scalar** can be thought of as a single number that can be used to quantify something; it may or may not have units associated with it. A **vector**, on the other hand, consists of 2 or more numbers, or scalars, and is often described graphically using arrows.
- The first physical quantity that we will talk about is **position**. A **position vector** ($\vec{\boldsymbol{r}}$) gives the location of an object in any coordinate system, with the tail of the vector at the origin, and the head of the vector at the location of the object. The arrow above the variable tells you that it is a vector and not a scalar. The **components** of the position vector gives the x- and y-coordinates of its location, such as

$$\vec{r} = \langle 200 \text{ m}, 100 \text{ m} \rangle \quad \text{or} \quad \vec{r} = \langle 200, 100 \rangle \text{ m}$$

  These individual components are in turn scalars.
- In physics, vectors are often written out using **unit vector notation**, such as

$$\vec{r} = 200 \text{ m}\,\hat{\imath} + 100 \text{ m}\,\hat{\jmath} \quad \text{or} \quad \vec{r} = (200\,\hat{\imath} + 100\,\hat{\jmath}) \text{ m}$$

  In this notation, $\hat{\imath}$ and $\hat{\jmath}$ refer to the positive x- and y-directions, respectively. The general position vector (in 2D) is given in Equation 3.4.
- When adding or subtracting vectors, we can use the unit vector notation to add or subtract just like we would with algebra. Just like with scalar math, both vectors and the answer (which is also a vector) have the same units. Note: with subtraction, make sure to keep the same order.

  If $\vec{r}_1 = x_1\,\hat{\imath} + y_1\,\hat{\jmath}$

  And $\vec{r}_2 = x_2\,\hat{\imath} + y_2\,\hat{\jmath}$

  Then $\vec{r}_3 = \vec{r}_1 + \vec{r}_2 = (x_1 + x_2)\,\hat{\imath} + (y_1 + y_2)\,\hat{\jmath}$ (Eq. 3.6)

  And $\vec{r}_4 = \vec{r}_2 - \vec{r}_1 = (x_2 - x_1)\,\hat{\imath} + (y_2 + y_1)\,\hat{\jmath}$ (Eq. 3.7)
- Graphically, you can add two vectors by placing the tail of $\vec{r}_2$ at the head of $\vec{r}_1$. It is important to note that the direction of each vector be <u>exactly the same</u> as before. For example, the vector $\vec{r}_3$ will be the vector from the tail of $\vec{r}_1$ to the head of $\vec{r}_2$. For subtraction, you place the tails of both vectors together, and the answer, $\vec{r}_4$, will be the vector from the head of $\vec{r}_1$ to the head of $\vec{r}_2$.
- You can also multiply a vector by a scalar (Eq. 3.10). In this case, every component of the vector gets multiplied by the same scalar. Multiplying by a scalar changes the magnitude of the vector, but not its direction.
- Instead of using the x and y components to describe a vector, you could also use its **magnitude** and **direction angle**. The magnitude is another way of interpreting the physical length of the vector (a scalar) and is found using the Pythagorean theorem (Eq. 3.3), where the x and y components give the sides of the triangle, and the magnitude is the hypotenuse.

$$a^2 + b^2 = c^2 \quad \text{becomes} \quad y^2 + x^2 = r^2$$

$$\text{which gives} \quad r = \sqrt{x^2 + y^2}$$

The direction can then be described as the angle between the +x axis (or the unit vector $\hat{\imath}$) and the vector itself. This angle can be found by using the inverse tangent function (Eq. 3.2), where x is the adjacent side and y is the opposite side.

$$\theta = \tan^{-1}\left(\frac{opp}{adj}\right) = \tan^{-1}\left(\frac{y}{x}\right)$$

Conversely, you can use a vector's magnitude, direction angle and the corresponding trig functions to find its components (Eq. 3.9).

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|---|---|---|---|
| Start with | $\cos\theta = \frac{adj}{hyp}$ | and | $\sin\theta = \frac{opp}{hyp}$ |
| Replace adj, opp, and hyp with x, y, and r | $\cos\theta = \frac{x}{r}$ | and | $\sin\theta = \frac{y}{r}$ |
| Multiply both sides by the magnitude to get | $x = r\cos\theta$ | and | $y = r\sin\theta$ |