Vectors *vs.* Scalars in Physics

Unit: Mathematics

NGSS Standards/MA Curriculum Frameworks (2016): SP5

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): 1.1.A.1, 1.1.A.3

Mastery Objective(s): (Students will be able to…)

- Identify vector *vs.* scalar quantities in physics.

Success Criteria:

- Quantity is correctly identified as a vector or a scalar.

Language Objectives:

- Explain why some quantities have a direction and others do not.

Tier 2 Vocabulary: magnitude, direction

Notes:

In physics, most numbers represent quantities that can be measured or calculated from measurements. Most of the time, there is no concept of a "deficit" of a measured quantity. For example, quantities like mass, energy, and power can only be nonnegative, because in classical mechanics there is no such thing as "anti-mass," "anti-energy," or "anti-power."

However, vector quantities have a direction as well as a magnitude, and direction can be positive or negative.

A rule of thumb that works *most* of the time in a high school physics class is:

Scalar quantities. These are usually positive, with a few notable exceptions (*e.g.,* work and electric charge).

Vector quantities. Vectors have a direction associated with them. For one-dimensional vectors, the direction is conveyed by defining a direction to be "positive". Vectors in the positive direction are expressed as positive numbers, and vectors in the opposite (negative) direction are expressed as negative numbers.

In some cases, you will need to split a vector into two component vectors, one vector in the x-direction, and a separate vector in the y-direction, in order to solve a problem. In these cases, you will need to choose which direction is positive and which direction is negative for _both_ the x- and y-axes. Once you have done this, every vector quantity must be assigned a positive or negative value, according to the directions you have chosen.

Differences. The difference or change in a variable is indicated by the Greek letter Δ in front of the variable. Any difference can be positive or negative. However, note that a difference can either be a vector, indicating a change relative to the positive direction (*e.g.,* $\boldsymbol{\Delta x}$, which indicates a change in position), or scalar, indicating an increase or decrease (*e.g.,* ΔV, which indicates a change in volume).

Use this space for summary and/or additional notes:

Example:

Suppose you have a problem that involves throwing a ball straight upwards with a velocity of $15\,\frac{\text{m}}{\text{s}}$. Gravity is slowing the ball down with a downward acceleration of $10\,\frac{\text{m}}{\text{s}^2}$. You want to know how far the ball has traveled in 0.5 s.

Displacement, velocity, and acceleration are all vectors. The motion is happening in the y-direction, so we need to choose whether "up" or "down" is the positive direction. Suppose we choose "up" to be the positive direction. This means:

- When the ball is first thrown, it is moving upwards. This means its velocity is in the *positive* direction, so we would represent the initial velocity as $\vec{\mathbf{v}}_o = +15\,\frac{\text{m}}{\text{s}}$.
- Gravity is accelerating the ball downwards, which is the *negative* direction. We would therefore represent the acceleration as $\vec{\boldsymbol{a}} = -10\,\frac{\text{m}}{\text{s}^2}$.
- Time is a scalar quantity, so its value is +0.5 s.

If we had to substitute the numbers into the formula:

$$\vec{\boldsymbol{d}} = \vec{\boldsymbol{v}}_o t + \tfrac{1}{2}\vec{\boldsymbol{a}}t^2$$

we would do so as follows:

$$\vec{\boldsymbol{d}} = (+15)(0.5) + (\tfrac{1}{2})(-10)(0.5)^2$$

and we would find out that $\vec{\boldsymbol{d}} = +6.25\,\text{m}$.

The answer is *positive*. Earlier, we defined positive as "up", so the answer tells us that the displacement is upwards from the starting point.

Use this space for summary and/or additional notes:

What if, instead, we had chosen “down” to be the positive direction?

- When the ball is first thrown, it is moving upwards. This means its velocity is now in the *negative* direction, so we would represent the initial velocity as $\vec{v}_o = -15\,\frac{m}{s}$.
- Gravity is accelerating the ball downwards, which is the *positive* direction. We would therefore represent the acceleration as $\vec{a} = +10\,\frac{m}{s^2}$.
- Time is a scalar quantity, so its value is +0.5 s.

If we had to substitute the numbers into the formula:

$$\vec{d} = \vec{v}_o t + \tfrac{1}{2}\vec{a}t^2$$

we would do so as follows:

$$\vec{d} = (-15)(0.5) + (\tfrac{1}{2})(10)(0.5)^2$$

and we would find out that $\vec{d} = -6.25\,\text{m}$.

The answer is *negative*. However, remember that we defined “down” to be positive, which means “up” is the negative direction. This means the displacement is *upwards* from the starting point, as before.

In any problem you solve, the choice of which direction is positive *vs.* negative is arbitrary. The only requirement is that *every vector quantity in the problem* needs to be consistent with your choice.

Use this space for summary and/or additional notes: