Building Physical Intuition - Acceleration

It may come as a surprise, but when people are asked to speak about acceleration carefully they often make mistakes. Does a large acceleration mean you are going fast? Careful! The confusion between velocity and acceleration is one that we will begin to address in this worksheet. The utility of what we do here is by no means limited to the topic of kinematics; in fact, it will come up time and time again in physics.

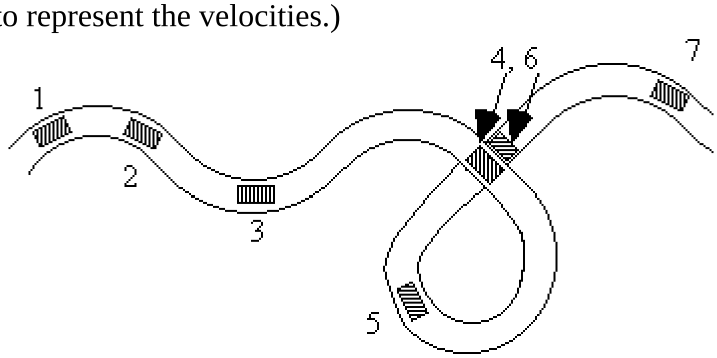
Vectors

Any physical quantity that includes spatial direction is a vector. Spatial directions include vertical (up or down), horizontal (north, south, east, west, and so on), down along an inclined surface, toward the big tree, and so on. Examples of vector concepts are: displacement (from an earlier position to a later position), velocity (speed in some direction), acceleration (to be seen shortly), and force (a push or pull in some direction). Any vector may be represented pictorially ("graphically") by an arrow pointing in the corresponding direction.

Instantaneous Velocity

At any **state** (instant) an object has a velocity given by its speed and direction of motion at that instant. As the object moves along any path, the direction of its velocity at any instant is **tangent to the path**. That is, if the object is changing direction, the velocity is in the direction that the object would travel if it stopped turning. Let's have a go at it.

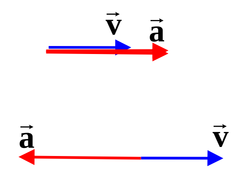
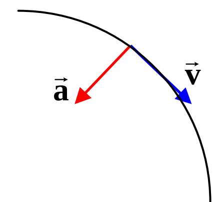
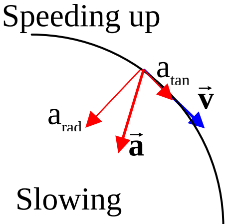
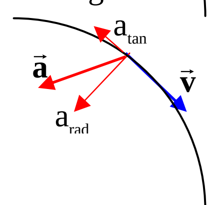
1. *The Direction of the Velocity:* A car travels along a road from state (instant) 1 to state 2 to state 3 and eventually to state 7, as shown below with a top view of the road. Draw in the velocity vector at each state (instant) 1 through 7. (For now, don't worry about the lengths of the arrows used to represent the velocities.)



TOP VIEW OF A CAR MOVING ALONG A HORIZONTAL ROAD

Direction of Acceleration

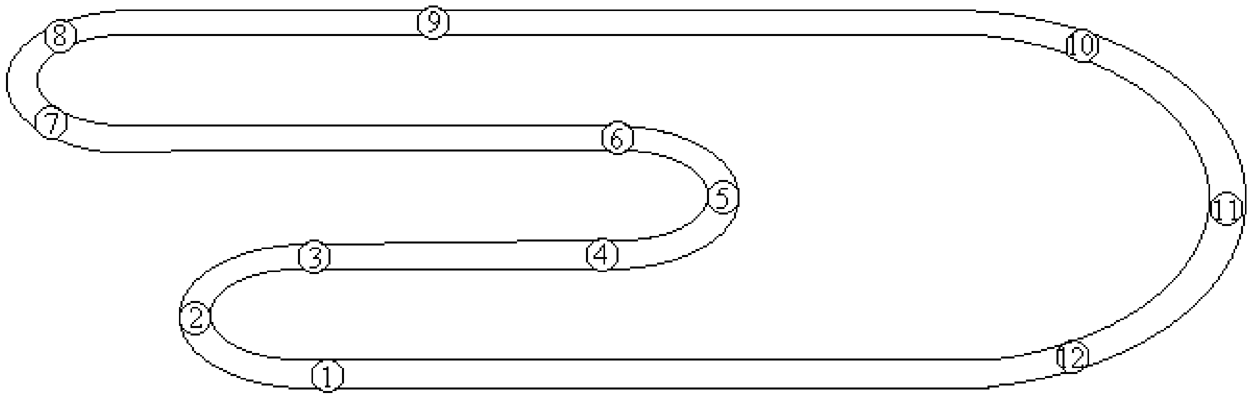
Acceleration is defined to be the rate at which the velocity changes. Since velocity is a vector, acceleration is also a vector. Therefore, it has both a magnitude and a direction. There are three general ways that an object can be accelerating. They are listed below along with the direction of the acceleration relative to the direction of the velocity.

	TYPES OF ACCELERATION	DIRECTION OF ACCELERATION	PICTURE
1.	Changes **speed**: * Speeds up * Slows down	Acceleration is * In direction of velocity * Opposite direction of velocity	
2.	Changes **direction** (but not speed)	Acceleration is ⊥ to velocity (*into* the turn)	
3.	Changes **both** speed and direction	Acceleration has two components First component is tangential acceleration * In direction of velocity (If speeding up) or… * Opposite direction of velocity (If slowing down) Second component is radial acceleration * ⊥ to velocity(*into* the turn)	Speeding up  Slowing 

2. *The Direction of the Velocity and Acceleration:* A car is driven along the track shown as shown in the following figure. Draw in the velocity and acceleration vectors at each state (instant) shown given the situation described below. Use different colors for velocity and acceleration vectors and indicate which color corresponds to each.

   •Car travels from earlier state (state 1) to later states (2, 3, 4, and so on).

   •See next page for description of what's happening to the speed at each instant.



State	What's Happening to the Speed
1	Speeding up
2	Not changing speed
3	Speeding up
4	Slowing down
5	Not changing speed
6	Speeding up
7	Slowing down
8	Speeding up
9	Not changing speed
10	Slowing down
11	Speeding up
12	Speeding up

1-D Vectors: designating direction with a +/– sign

1-dimensional motion is motion along a straight line. Examples of this are walking up and down an aisle in a grocery store, a sprinter running a 100-meter race, an object on the end of a spring going back and forth, and so on. In these cases, the only change in direction is going from forward to backward or backward to forward. We can conveniently distinguish the two possible directions by designating either direction (your choice) to be the positive (+) direction and the other direction to be the negative (–) direction. For example: if east is the + direction, west is the – direction, but if west is the + direction, east is the – direction; if up (vertical) is the + direction, down (vertical) is the – direction, but if down is the + direction, up is the – direction. [NOTE: "north" should never be used to refer to the vertical direction!!]

It is *very* important to note that the *direction* of the acceleration is entirely dependent upon the direction of the velocity and how the velocity is changing—as illustrated in the previous exercise. It is IN NO WAY dependent on which direction is chosen to be +. Thus we can make the following statement that is contrary to most people's preconception…but it is correct to say that:

"**Deceleration**" means "slowing down," but it does NOT necessarily mean that the acceleration is negative. To determine the sign of the acceleration, one must first determine the direction of the acceleration based on the direction of the velocity and what is happening to the velocity and then see if the acceleration is in the direction referred to as + or –.

Please answer 3, 4, and 5 on a separate piece of paper.

3. *+/– For Velocity and Acceleration of 1-D Motion:* Let's choose north to be the positive (horizontal) direction. For parts b through e, make a **sketch** of each, show **both** the velocity and acceleration vectors, and determine the **sign** (±) of the velocity and the acceleration.

a) What is the negative direction?
b) You are running north and speeding up.
c) You are running north and slowing down.
d) You are running south and speeding up.
e) You are running south and slowing down.
f) Does just the sign of the acceleration tell you if you are speeding up or slowing down? Is "deceleration" synonymous with negative acceleration?
g) What *does* the sign of the velocity tell you? What *does* the sign of the acceleration tell you?

1-D Acceleration: at what rate is the velocity changing?

The average acceleration for 1-D motion is:

$$a_{ave} \overset{is}{\equiv} \frac{\Delta v}{\Delta t} = \frac{v_{\text{earlier state}} - v_{\text{later state}}}{\text{elapsed time between states}}$$

<u>Critical Points To Be Aware Of</u>:

- the units of acceleration are the units of velocity divided by the units of time:

$$\text{units of acceleration are units of } \frac{speed}{time}$$

$$\text{for example: } \frac{m/s}{s} \text{ which can be written as } \frac{m}{s^2} \text{ or, } \frac{mi/h}{s} \text{ and so on.}$$

- The average acceleration may be either positive or negative.
- Knowing the magnitude of the acceleration at an instant
  - does NOT tell you the velocity!!
  - does NOT even tell you the change in velocity!!
  - only tells you the rate at which the velocity is changing! (see exercises below)
- Graphically, the acceleration is the slope on a velocity vs. time (v vs. t) graph.

4. *Keep 'em Straight!*
    a) Give an example of a case where the acceleration is large and the speed is small.
    b) Give an example of a case where the acceleration is small and the speed is large.
    c) Give an example of a case where the acceleration is zero but the speed is not zero.
    d) Give an example of a case where the acceleration is not zero but the speed is zero.

5. *Water Flow Analogy*
    a) If I say that water was coming out of a faucet at a high rate, can you tell me if a lot of water came out or not? Why not? What else would you need to know?
    b) If I said that the water was slowly dripping out of a faucet, can you give me a situation where the amount of water is quite large?
    c) How does this analogy apply to the distinction between acceleration and velocity?