Chapter 2 Putting in Some Numbers

Section 2.1 Motion (with constant speed)

Figure 2.1 An air-powered rocket launch, with three video frames taken 1/30 s apart. The rocket is moving much faster than the boy in the red shirt can react! Can you use these images to determine how fast the rocket is moving?

Imagine you are in a car going along the road. What is your speed? Maybe your speedometer reads 30 miles per hour. What does this mean? This is a rate... your position is changing at a rate of 30 miles every hour. So, in two hours you would travel 60 miles and in 10 minutes (a sixth of an hour) your position would change by 5 miles (a sixth of 30 miles). In this class, we'll normally use meters and seconds, so you should express speed in meters per second (m/s).

Exercise 2.1 **Guess off the top of your head, how many miles per hour is 1 m/s? Then, use your knowledge that a mile is about 1.6 km, and there are 3600 s in an hour to find the speed of 1 m/s in miles per hour. Be sure to show your work and cancel units.**

Exercise 2.2 **Can you walk at one meter per second? Try it. Is this a reasonable walking speed?**

Exercise 2.3 **The fastest humans can run at a rate of 10 meters per second. At this rate, how long would it take someone to run the length of a soccer field, about 100 meters? Close your eyes and imagine seeing that happen. Does this seem reasonable?**

Since we know that speed is the change in position over a change in time, we can express it in a formula that defines speed. Physicists try to be consistent in using the same symbols (usually letters) to mean the same thing in many different equations, to avoid confusion. So for speed:

$$\boldsymbol{v} = \frac{\Delta \boldsymbol{x}}{\Delta \boldsymbol{t}} \qquad \text{Equation 2.1}$$

where $\boldsymbol{v}$ is the symbol for speed (or velocity), $\boldsymbol{x}$ is the symbol for position (or displacement), and $\boldsymbol{t}$ is the symbol for time. In this text, the uppercase Greek letter $\boldsymbol{\Delta}$ (Delta) always means "change in…"; thus, $\boldsymbol{\Delta x}$ means "change in position."

Exercise 2.4 **In Figure 1.9, the rocket changes position in each frame of the video. We can use those three frames to estimate the speed of the rocket. Do this by creating a graph of the motion:**

1) **Find something in the figure that allows you to estimate the scale of the image.**
2) **Set up a graph with time on the horizontal axis and rocket height on the vertical axis. Be sure to include the units for each axis.**
3) **On the graph, make three points, one for each video frame, showing the position and time. Hopefully your graph shows that the position of the rocket changes over time.**
4) **Try to fit a line through your three points (if you do this in a spreadsheet program, it should have an automatic curve fit function).**
5) **The slope of the line (often called "rise over run") tells you how much the measurement on the vertical axis changes compared to the measurement on the horizontal axis. Find the slope for the line on your graph.**
6) **That slope measures a change in height divided by a change in time. So it is distance / time. The slope is the speed of the rocket! What is that speed? Remember to include units!**

Does your answer seem reasonable?

Section 2.2 **Momentum**

Figure 2.2 The more momentum player #7 has, the further he will travel before the others stop him. (credit: Ozzzie, Flickr)

Momentum is about velocity (speed) and mass. Mass, a measure of how much matter is in an object, is represented by $\boldsymbol{m}$, and it is measured in kilograms [kg], though most Americans usually think in pounds [lb][iii]. The symbol for momentum is $\boldsymbol{p}$, and it is defined as follows:

$$\boldsymbol{p} = \boldsymbol{mv} \qquad \text{Equation 2.2}$$

Thus, we could make an ordering of increasing momentum: a child walking, an adult walking, a bicyclist at high speed, a speeding car, a speeding truck, a speeding train, a full cargo ship, another planet.

Exercise 2.5 The unit for mass is kg; the unit for speed is m/s. Use Equation 2.2 to convince yourself that the unit for momentum is kg·m/s.

Momentum is important because it is conserved: the total momentum of an isolated system (a system is a single object or group of objects) doesn't change. Only a few physical quantities are conserved in nature, and momentum is one of them; mass is another that should be familiar to you.

Momentum can be transferred from one object to another by a force between the two objects. This usually happens through a collision or some other force including springs, magnets, or friction.

Consider what happens when a car bumps into a truck, as shown in Figure 2.3. There is a repulsive force between the two vehicles, pushing the car backwards and the truck forwards. The momentum that the car

[iii] In fact, a pound is not a unit of mass; it is a unit of force. The correct US Customary unit for mass is the slug!

loses in the collision is equal to the momentum that the truck gains in the collision. So, the total change in momentum of the system is zero; momentum is conserved.

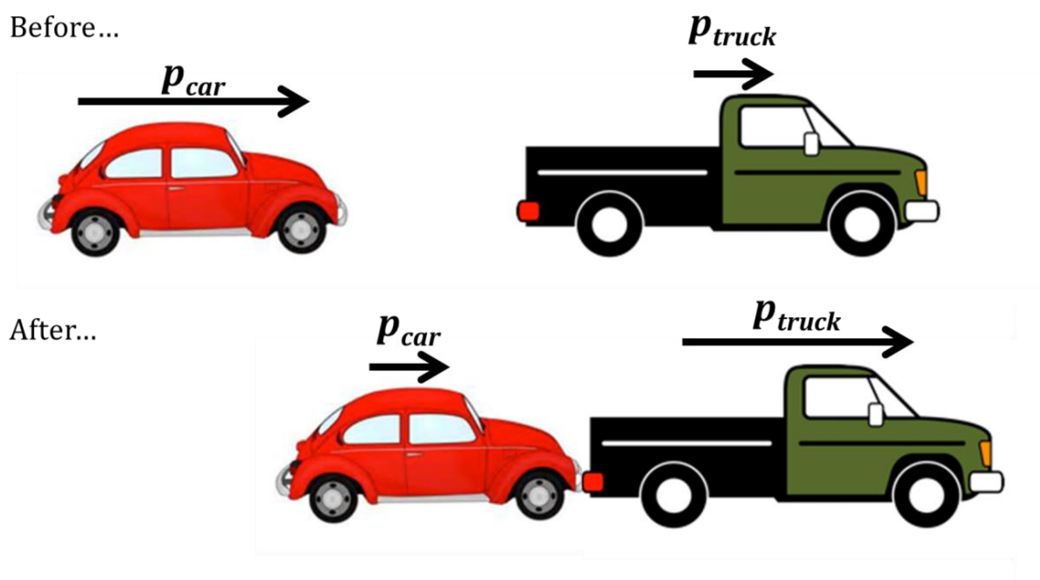

Figure 2.3 **The faster car hits the slower truck. The lengths of the arrows represent the magnitude (size) of the momentum. During the collision, the repulsive force between the two increases the momentum of the truck, and reduces the momentum of the car by the same amount. Thus, the total momentum of the car/truck system remains constant.**

We can say that the total momentum of the system (the two vehicles) is conserved if there is no outside force. In reality, there are outside forces such as wind friction, which would reduce the total momentum of the system. However, it is reasonable to neglect these outside forces because in the moment of the collision, the forces provided by the engines and friction are small compared to the forces of the impact between the vehicles.

Exercise 2.6 **A fly smashes into your windshield as you are driving.**

a. **Draw momentum blocks of the fly and the car before and after the collision.**
b. **Which has the greater change in momentum, the fly or the car, or are they the same?**
c. **Which has the greater change in velocity, the fly or the car, or are they the same?**
d. **Are your answers to part b and part c the same? If not, how can that be?**

Exercise 2.7 **What is the momentum of each of the following…**

a. **A 70 kg adult running at 8 m/s? Is 8 m/s a reasonable running speed for an adult? It may help to convert 8 m/s into units that you more familiar with.**

b. **A 10 kg child who is standing still? How fast would this child need to run in order to have the same momentum as the adult in part a of this question? Is the speed that you find a reasonable running speed for a child?**

c. **The 7×10^{22} kg moon orbiting the earth at 1000 m/s?** [iv]

[iv] Not sure how to use scientific notation (like 7×10^{22}) ? There are some great tutorials on Khan Academy, https://www.khanacademy.org/math/pre-algebra/pre-algebra-exponents-radicals/pre-algebra-scientific-notation/v/scientific-notation

Section 2.3 **Force**

Figure 2.4 **How many forces can you identify in this photograph? Can you find any "pulling" forces? (Credit: U.S. Navy photo [Public domain], via Wikimedia Commons)**

Force and Momentum

In Section 1.4 we noted that one object can give momentum to another object through a force. The momentum of an object does not change unless there is a force applied to it. Think of a meteor moving through space. If there's no force on it, the momentum stays the same. If you want to change its momentum, you have to push on it – applying a force. The change in momentum of an object is equal to the total force $\boldsymbol{F}$ on it multiplied by the length of time the force is applied:

$$\Delta \boldsymbol{p} = \boldsymbol{F} \Delta \boldsymbol{t} \qquad \textbf{Equation 2.3}$$

where $\boldsymbol{p}$ is momentum and $\boldsymbol{t}$ is the length of time that the force is applied. The SI unit of force is the Newton [N]. To get an idea about what a Newton feels like, pick up a deck of playing cards. The force that you need to use to lift the deck of cards is approximately one Newton.

Exercise 2.8 **The unit for momentum is kg·m/s; the unit for time is s. Use Equation 2.3 to convince yourself that we could use kg·m/s^2 as a unit for force. In fact, 1 N = 1 kg·m/s^2.**

Exercise 2.9 **In the cannonball example at the beginning of this section, imagine that the cannon gives the cannonball an initial upward momentum of 200 kg·m/s. If the force from the cannon lasted for 0.01 seconds, how large was the force?**

Force and Energy

A force also results in work being done on an object as it moves over a distance. Think of an egg falling to the floor and breaking. If it falls only a short distance, the shell may not break, but the amount of work available to break the shell increases with the distance the egg falls. Since energy is the ability to do work, that means that as the distance increases, so does the amount of energy. The change in the energy of an object (which is also the same as the work done on the object) is equal to the force exerted on it (in this case gravity) multiplied by the distance traveled in the direction of the force:

$$\boldsymbol{W} = \Delta \boldsymbol{E} = \boldsymbol{F}\Delta \boldsymbol{x} \qquad \text{Equation 2.4}$$

Where $\boldsymbol{W}$ is the work done, $\boldsymbol{\Delta E}$ is the change in energy, $\boldsymbol{F}$ is the force, and $\boldsymbol{\Delta x}$ is the change in position, which is normally the way we would measure the distance something moves. The SI unit of both work and energy is the Joule [J].[v]

Exercise 2.10 **Use Equation 2.4 to convince yourself that we could use kg·m^2/s^2 as a unit for work and energy. In fact, 1 J = 1 kg·m^2/s^2.**

Exercise 2.11 **If a sled dog pulls with a force of 200 N, how much work does the dog do in moving the sled 5 m? Draw a picture, and consider whether your answer makes sense—would the dog be doing work if it were pulling a sled? Trace the energy transformations starting with the work the dog is doing.**

Force and Acceleration

The relationship between force and acceleration is usually referred to as "Newton's Second Law." (What happened to the First Law? We'll get to that later!) This is one of the most famous equations in physics,

$$\boldsymbol{F} = \boldsymbol{ma} \qquad \text{Equation 2.5}$$

where $\boldsymbol{F}$ is the external force on an object, $\boldsymbol{m}$ is the object's mass, and $\boldsymbol{a}$ is the object's acceleration. Acceleration is a change of speed, which we will learn about in Chapter 4. Note that Equation 2.5 is not a definition of force; it is a description of how a force affects the acceleration of an object.

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[v] In the US we use a variety of different units for energy, depending on the context. Some of these units include the foot-pound, the British Thermal Unit (BTU), the kilocalorie (also known as the Calorie with a capital C), and the kilowatt-hour (kWh). We will stick with Joules!