8.2: An Automobile Factory

When making anything, whether it is is at home or in a factory, it is important to make sure there are enough raw materials on hand. Likewise, if one is working with a limited supply of raw materials, it would be helpful to know how much of a particular product may be made. At home, this could very well apply to making cookies or sandwiches or knowing how many doses of medication may be left.

Figure 8.2.1: A classic '57 Chevy. (Doug Watanabe via Unsplash)

How Much Product Can We Make?

For our introduction, let's assume we are working in an automobile factory. The objective in an automobile factory, of course, is to make cars. There are many, many parts that go into making an automobile. For simplicity, let's look at the number of frames, bumpers, and wheels that go into making one car. In order to make one car, we need one frame, two bumpers, and four wheels. In equation form, this could be written as :

$$1 \text{ frame} + 2 \text{ bumpers} + 4 \text{ wheels} \rightarrow 1 \text{ car}$$

Next, let's consider a scenario where there were 50 frames, 80 bumpers, and 100 wheels available. A reasonable question might be, what is the maximum number of cars that could be made from the available supply?

Looking at the equation, we should be able to identify the following relationships and possible conversions:

Relationship	Possible Conversions	
1 frame: 1 car	$\frac{1 \text{ frame}}{1 \text{ car}}$	$\frac{1 \text{ car}}{1 \text{ frame}}$
2 bumpers: 1 car	$\frac{2 \text{ bumpers}}{1 \text{ car}}$	$\frac{1 \text{ car}}{2 \text{ bumpers}}$
4 wheels: 1 car	$\frac{4 \text{ wheels}}{1 \text{ car}}$	$\frac{1 \text{ car}}{4 \text{ wheels}}$

The appropriate conversion factor is used in such a manner that units cancel when calculating the number of cars.

$$50 \ \cancel{\text{frames}} \times \frac{1 \text{ car}}{1 \ \cancel{\text{frame}}} = \cancel{50 \text{ cars}}$$

$$80 \ \cancel{\text{bumpers}} \times \frac{1 \text{ car}}{2 \ \cancel{\text{bumpers}}} = \cancel{40 \text{ cars}}$$

$$100 \ \cancel{\text{wheels}} \times \frac{1 \text{ car}}{4 \ \cancel{\text{wheels}}} = \boxed{25 \text{ cars}}$$

These calculations show that 25 cars is the maximum number that may be made from a supply of 50 frames, 80 bumpers, and 100 wheels. Even though there are enough frames to make 50 cars and enough bumpers to make 40 cars, we run out of wheels once 25 cars are made. It is impossible to make any more than 25 cars due to the limited supply of wheels.

This analogy allows the introduction of several terms that will be used throughout this chapter and remainder of this text:

⚡ Terms Associated with Stoichiometry

- The **limiting reactant** is the reactant that limits the amount of product that can be made.
- An **excess reactant** is one that is not entirely consumed.
- The **theoretical yield** is the maximum amount of product that may be made when all of the limiting reactant is converted to product.
- The **actual yield** is the actual amount of product that is made. The actual yield may never exceed the theoretical yield.
- The **percent yield** is the percentage of the theoretical yield that is actually obtained. The percent yield may never exceed 100%.

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

In the example above, *wheels are the limiting reactant* since they limited the number of cars that could be made. *Frames and bumpers are both excess reactants* since more cars could have been made from the frames and bumpers had there been more wheels available. *The theoretical yield is 25 cars*, since this is the maximum number of cars that could be made from the available supply of frames, bumpers, and wheels.

Let's go one step further. Let's say that some of the wheels were found to be defective. As a result, only 23 cars were made. In this case, *there was a 92% yield of cars*. To calculate the percent yield:

$$\%\ \text{yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{23\ \cancel{\text{cars}}}{25\ \cancel{\text{cars}}} \times 100 = \boxed{92\%\ \text{yield}}$$

How Much Raw Materials Are Needed?

What if we wanted to go the other direction? In other words, how could we find out how much raw materials are needed when a specific amount of product is needed. Using the automobile factory and simplified example and equation once again:

$$1\ \text{frame} + 2\ \text{bumpers} + 4\ \text{wheels} \rightarrow 1\ \text{car}$$

How many frames, bumpers, and wheels would be needed to make 126 cars? The same relationships previously used still apply and each relationship may be used as a conversion factor in such a manner that units cancel.

$$126\ \cancel{\text{cars}} \times \frac{1\ \text{frame}}{1\ \cancel{\text{car}}} = \boxed{126\ \text{frames}}$$

$$126\ \cancel{\text{cars}} \times \frac{2\ \text{bumpers}}{1\ \cancel{\text{car}}} = \boxed{252\ \text{bumpers}}$$

$$126\ \cancel{\text{cars}} \times \frac{4\ \text{wheels}}{1\ \cancel{\text{car}}} = \boxed{504\ \text{wheels}}$$

As we can see, it would take 126 frames, 252 bumpers, and 504 wheels to make 126 cars.

✅ Example 8.2.1

If 30 bumpers were available, how many frames and wheels would be needed to make complete cars?

Solution

The equation is:

$$1\ \text{frame} + 2\ \text{bumpers} + 4\ \text{wheels} \rightarrow 1\ \text{car}$$

The relevant relationships from the equation are:

1 frame: 2 bumpers

2 bumpers: 4 wheels

Each relationship may be used as a conversion factor in such a manner that units cancel.

$$30 \ \cancel{\text{bumpers}} \times \frac{1 \text{ frame}}{2 \ \cancel{\text{bumpers}}} = \boxed{15 \text{ frames}}$$

$$30 \ \cancel{\text{bumpers}} \times \frac{4 \text{ wheels}}{2 \ \cancel{\text{bumpers}}} = \boxed{60 \text{ wheels}}$$

These answers make sense, since the number of frames should be half of the number of bumpers and the number of wheels should be twice the number of bumpers.

✏️ Exercise 8.2.1

How many cars could be made using 300 wheels, assuming there were excess frames and bumpers available?

Answer

75 cars

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