Chapter 7

The Magic of Chemical Reactions

Though enormously important to organic chemists, Grignard reactions really aren't all that interesting to look at.

7.1: A Bunch Of Important Reaction-Related Stuff

As you may recall from one of the chapters that you read a while back, **chemical reactions** occur when one material is turned into another by making and/or breaking chemical bonds. Examples of chemical reactions include the rusting of your crazy neighbor's old car, the old banana in the fridge, and using road flares to set fire to a couch after your team wins the big game.[1]

Who would have ever guessed that college students would be so irresponsible?

What you may *not* remember is stuff about chemical equations. Which isn't surprising, since I never actually talked about them. See what I did there? I'm a sneaky one.

Chemical Equations

Let's say that, for whatever reason, you want to make a fancy meal. If you're anything like me, you'd need to consult a recipe that will tell you whatever you need to make tasty things. In chemistry, we call our recipes **chemical equations**. In these equations, we start off with ingredients (which we call **reagents** or **reactants**[2]), and what we make are called the **products**. We also put an arrow going from the reagents to the products so we don't forget that the reagents form products, and not the other way around:

$$\text{Reagents (i.e. stuff you start with)} \rightarrow \text{Products (i.e. stuff you make)}$$

Example: If you add hydrochloric acid to iron, you get the following reaction:

$$HCl + Fe \rightarrow H_2 + FeCl_2$$

Which, simply means "when HCl and Fe combine, they make H_2 and $FeCl_2$. It may not be an *interesting* recipe, but it's certainly easy to understand.

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1 *Don't do this. Even though it looks cool, it's also dangerous.*

2 *These mean the same thing.*

The Law of Conservation of Mass and Balancing Equations

Unless you're a huge idiot, you already understand the law of conservation of mass. **The law of conservation of mass** simply says that when you do a chemical reaction, the weight of what you make will be the same as the weight of what you started with. In pizza form, this means that if you have 500 grams of crust and 200 grams of cheese, your pizza will end up weighing 700 grams. Likewise, in the reaction with iron and HCl I mentioned above, the weight of the products I form will be the same as the weight of the reagents I started with. No big deal.

Why This Is A Big Deal

It turns out that the law of conservation of mass is less obvious than it would seem. For example, what happens if you really *put 500 grams of crust with 200 grams of cheese? You won't end up with 700 grams of pizza – you'll end up with something like 670 grams of pizza. This is because some of the ingredients (the "missing" 30 grams, to be precise) evaporate or drip to the bottom of the oven. This same sort of experimental error happens in all chemical reactions, which is why the law of conservation of mass is hard to demonstrate.*

This is an example of Lithuanian pizza, showing why nobody ever associates Lithuania with pizza-making.[3]

When performing a chemical reaction, it's important that we do so in a way that shows that the law of conservation of mass is being followed. To do this, we have to **balance** an equation, which a way of ensuring that the same number of atoms of each element are in both the reagent and product side of the equation.

Rather than talk any more about this, I figure I'll just show you how to balance an equation on your own. The equation to balance:

$$H_2 + O_2 \rightarrow H_2O$$

You may think, at first glance, that this equation is perfectly nice. However, if we count the number of atoms of each element on both sides of the equation, they don't add up. Let's make an inventory:

Element	Number of atoms on reagent side of the equation	Number of atoms on the product side of the equation
H	2	2
O	2	1

As you can see, there are two atoms of hydrogen on both the left and right side of the

3 *I was debating in my mind between using this example of pizza and a picture I found of Iranian pizza. I chose this one because it wasn't clear to me that the Iranian one had even been cooked yet. At least, I hope it hadn't.*

equation. However, oxygen has two on the left (from the O_2) and one on the right (from H_2O). We've got to fix this somehow.

How to balance an equation:

Step 1: Make an inventory of every element on both sides of the equation.

- We already did that in the table above, so let's move on.

Step 2: Figure out which elements don't match in each column – if they match, you're done.

- Oxygen has two atoms on the left and one on the right, so it doesn't match.

Step 3: Put a coefficient in front of the compound containing the element in question on whichever side of the reaction has fewer atoms.

- In this reaction, the product side of the equation has one oxygen atom and the reagent side has two. As a result, we need to add a number in front of H_2O on the right side. We'll choose a two, because 2 (the coefficient we added) x 1 (the number of atoms that were already there) = 2, which is the number of oxygen atoms on the other side.

$$H_2 + O_2 \rightarrow 2\ H_2O$$

Step 4: Redo the inventory.

- When we do this, we get the following table:

Element	Number of atoms on reagent side of the equation	Number of atoms on the product side of the equation
H	2	4
O	2	2

Step 5: If the numbers of atoms match for both elements, you're done! If not, go back to step 2 and add some more numbers.

- Because we have 4 hydrogen on the product side and only two on the left, we need to add a 2 in front of the H_2 on the left to get the equation

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

- Doing so gives us the following inventory.

Element	Number of atoms on reagent side of the equation	Number of atoms on the product side of the equation
H	4	4
O	2	2

demonstrating that the equation $2\ H_2 + O_2 \rightarrow 2\ H_2O$ is, indeed, our final answer.

Now For A Word About Our Reaction

Though you may think that the reaction example we've been using would be a relaxing way to make some water, this turns out not to be the case. Though the reaction does, indeed, end up forming water, it also gives off a huge amount of energy, as seen on the right. Which, for those of us who aren't fans of blowing up, is kind of scary.

Moles (non-rodent variety)

Atoms are very small, so any object that you can see contains a whole lot of atoms? How many? As an example, imagine counting every atom in your body at a rate of one per second. At this rate, it would take a really, really long time to count them all. That's because your body has a whole bunch of atoms in it.[4]

4 *A common value I've read for the number of atoms in a 70 kilogram person is 7×10^{27}. At a rate of one per second, it would take 200 quintillion years to count the atoms in your body, by which time all of the stars in the universe would all have run out of nuclear fuel. As a result, you'd need a lamp for the vast majority of the time you spent counting.*

Clearly, counting atoms one by one isn't very handy. Instead, we do it using a special term called the **mole**, which is equal to 6.02×10^{23} things.[5]

This probably doesn't make that much sense, so let's see if we can figure out an easier way to describe what a mole is:

- I have a pair of shoes on right now. You've probably already guessed that if I were to count the shoes on my feet, there would be two of them. After all, the word "pair" equals "two."[6]

- I have a dozen eggs in my refrigerator. If you were to predict how many eggs there are in total, you'd probably guess that there are 12 eggs. This is because the world "dozen" equals "12."

- I have a mole of water molecules in a bottle. How many water molecules is this? It's 6.02×10^{23} molecules. Why? Because the word "mole" equals "6.02×10^{23}."

In other words, the term "mole" is just the shorthand for a number. It's not a chemistry term at all – you could have a mole of moles (the rodent) if you wanted (i.e. 6.02×10^{23} moles), except that they'd take up a lot of space and generate vast quantities of poop.[7] Likewise, you could have a pair of atoms, though they'd be hard to see.

You've already seen this idea, though you didn't know it. For example, when I say that $2\ H_2 + O_2 \rightarrow 2\ H_2O$, what I mean is that "2 molecules of H_2 and 1 molecule of O_2 combine to make 2 molecules of H_2O." However, it also means that "2 moles of H_2 and 1 mole of O_2 combine to make 2 moles of H_2O." By multiplying everything by 6.02×10^{23}, our lives get a lot easier.

Molar Mass

The **molar mass** of a compound is equal to the mass of one mole of the atoms or molecules of that compound. For example, the molar mass of water is 18.0 g/mol because one mole of it weighs 18.0 grams. Not really so hard, is it?[8]

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5 *6.02×10^{23} is called "Avogadro's number", after a chemist named Amedeo Avogadro. He worked with gases and came up with "Avogadro's law", which says "something something something let's be honest you're not reading this footnote anymore." Which is as true today as it was in 1811.*

6 *The word "pair" has some oddball terms that don't seem to fit the "pair = two" rule. From what I've been able to find, "pair" was used in the old days to describe any two similar things that are connected to one another. As a result, a pair of pants has two similar legs, a pair of glasses has two similar pieces of glass, and so on.*

7 *How big would a mole of moles (the rodent) be? There's a good discussion of this over at https://what-if.xkcd.com/4/. The short version: It would be very big.*

8 *No.*

Molar Mass: The Naked Mole Rat

The average molar mass of the naked mole rat is between 30 – 35 grams. Though not actual moles, they are sometimes confused for moles, which is why I have mentioned them here. Actually, that's not true – I didn't mention them because they're confused for moles. I mentioned them because they look like little angry penises with teeth.

I honestly don't have any idea what an appropriate caption for this picture might be.

To calculate the molar mass of a compound, just figure out how many atoms of each element are in the compound and add up their masses from the periodic table. Some examples:

- Water (H_2O): This molecule has two hydrogen atoms and one oxygen atom. The periodic table tells us that each hydrogen atom weighs 1.0 grams, so two of them will equal 2.0 grams. An oxygen atom weighs 16.0 grams. Adding 2.0 grams to 16.0 grams equals 18.0 grams for each mole.[9]
- Calcium hydroxide ($Ca(OH)_2$): There is one calcium atom (mass 40.1 grams), two oxygen atoms (16.0 grams each, for a total of 32.0 grams) and two hydrogen atoms (1.0 grams each, for a total of 2.0 grams). Adding up 40.1 g + 16.0 g + 2.0 g, we get a molar mass of 58.1 g/mol.

Molar Mass: The Star-Nosed Mole

The molar mass of a star-nosed mole is 55 grams/mole. Though the star-nosed mole appears harmless, the star on the front (called the Eimer's organ) can shoot a highly acidic solution that will dissolve a buffalo in a matter of minutes. OK, I made that up, but wouldn't that be cool?[10]

Nose high five!

9 *If you want to round your answers to the nearest hundredth of a gram instead, there's no problem with that. Ask your teacher how far they want you to round when finding molar masses.*

10 *Yes.*

Using this knowledge, we can convert the moles of a compound into grams. This is extraordinarily useful, because it's difficult to count out a mole of particles, but it's no big deal to weigh them on a balance. To do this, use the same basic method that you learned in section 1.3 to convert between metric prefixes. If you don't remember how to do that, head on back to refresh your memory now.[11]

Example: Convert 8.80 grams of water to moles.

Answer: Let's do that t-chart method from section 1.3.

- **Step 1: Make a t**

- **Step 2: Put what the problem gives you in the top left.** In this case, "8.80 grams"

8.80 grams	

- **Step 3: Put these same units in the bottom right.**

8.80 grams	
	grams

- **Step 4: Put the units of what you want in the top right.**

8.80 grams	moles
	grams

11 *I know you're not actually going to go back to section 1.3 because nobody ever refers to earlier sections of the book. However, you really ought to, because this section will be far more comprehensible if you go back and check it out. I know that won't work, but don't say I didn't warn you.*

- **Step 5: Put the unit conversion factor in front of each unit on the right side of the table.** Helpful hint: Always write "1" in front of "moles" and always write a molar mass in front of "grams." Because the molar mass of water is 18.0 g/mol, stick it on the bottom in front of "grams."

8.80 grams	1 mole
	18.0 grams

- **Step 6: Multiply the numbers on the top together and divide by the number on the bottom.**

8.80 grams	1 mole	= 0.489 mol
	18.0 grams	

And there's your answer!

Why Use Moles Instead of Grams?

The unit moles is good for counting numbers of things, and when doing chemical reactions, we have whole numbers of one thing reacting with another. It's not the mass of the things that's important, it's the number of things. If we can convert between the two, all the better.

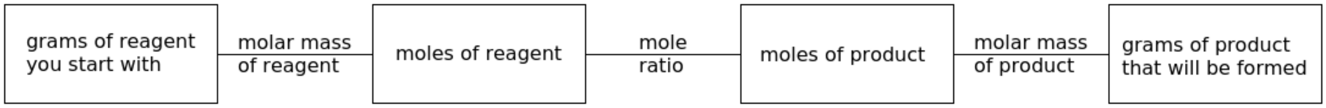
As an example, let's imagine that two celebrities get married. One of them is a chubby dude (120 kilograms) and one of them is an emaciated model (50 kilograms). Now, would it be more right to say that "170 kilograms of celebrities = 1 couple" or "two celebrities = 1 couple"? Given that not all celebrities weigh the same amount, it's best to use numbers rather than weights. it's the same with chemical compounds.

Though you might think that Bea Arthur and Angela Lansbury were a celebrity couple based on the text to the left, this is not the case.

Stoichiometry (pronounced stoy-key-ah-meh-tree)

If you're trying to make some chemical compound or another, you usually want to know how much of it you can make given the reagents you have lying around. The process you use to determine the relationship between quantity of reagents and quantity of products in a reaction is referred to as **stoichiometry**.

In order to do these calculations, you use exactly the same methods you did for mole calculations, except that there are usually three steps to the t-chart. These steps work according to this diagram:

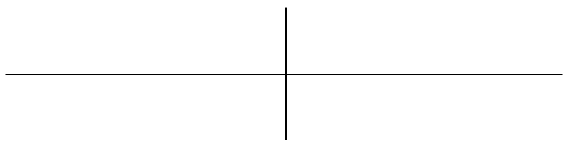


Given the reaction:

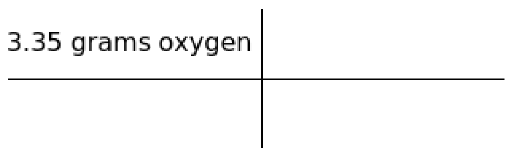
$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

Let's figure out how many grams of water we can make if we combine 3.35 grams of oxygen with an excess of hydrogen.[12]

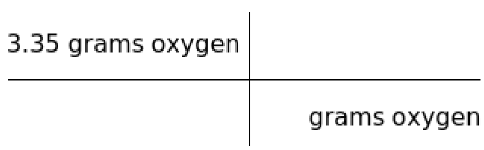
- **Step 1: Make a t**



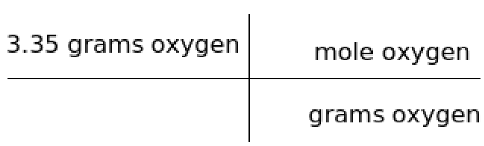
- **Step 2: Put whatever the problem gives you in the top left corner.** We were given "3.35 grams of oxygen" in the problem, so put that up there.



- **Step 3: Put the units of the top left in the bottom right.** In this case, grams of oxygen.



- **Step 4: Put the units of what you're trying to find in the top right.** If you look back at that chart with the four boxes, you can see that the first conversion is from "grams of reagent you start with" to "moles of reagent." Since oxygen is the reagent, put "moles oxygen" in the top right.



12 *The term "excess of hydrogen" means that there's enough hydrogen needed to react with the entire quantity of oxygen given. Put another way, ignore the amount of hydrogen that you'll need for this reaction, because it's not relevant.*

- **Step 5: Put the conversion factors before the units on the right.** As we saw before, write "1" in front of "moles" and the molar mass of water (18.0 g) in front of "grams":

3.35 grams oxygen	1 mole oxygen
	32.0 grams oxygen

- **Step 6: We have to keep going (we still have two steps to go), so add another section to the t.**

3.35 grams oxygen	1 mole oxygen	
	32.0 grams oxygen	

- **Step 7: Go back to step 3 above and put the units of the top left in the bottom right.** In our example, "moles of oxygen" is in the top left, so put "mole oxygen" in the bottom right.

3.35 grams oxygen	1 mole oxygen	
	32.0 grams oxygen	mole oxygen

- **Step 8: Put the units of what you've got in the top right**. Our second calculation converts between moles of reagent and product, so we're trying to find "moles of water."

3.35 grams oxygen	1 mole oxygen	mole water
	32.0 grams oxygen	mole oxygen

Stoichiometry: The Invention of a Word

The word "stoichiometry" comes from the Greek stoicheion *(element) and* metron *(measure). The term was invented by the German chemistry Jeremias Benjamin Richter between 1792-1794. However, nobody really used the term until about ten years later because his writing was so lousy that nobody really read it. Hard to believe that a person who invents a word like "stoichiometry" would be considered a bad writer, isn't it?*

You've got to admit he was a snappy dresser, though.

- **Step 9: Put the conversion factors in front of each value.** Here, the numbers in front of "moles" are the same as the ones in the equation. Since there's an implied "1" in front of oxygen and a "2" in front of water, put a "1" in front of "moles oxygen" and a "2" in front of "moles water." In steps like this where both units involve "moles", the conversion factor is called a **mole ratio**.

3.35 grams oxygen	1 mole oxygen	2 mole water
	32.0 grams oxygen	1 mole oxygen

- **Step 10: Add another step to the t and go through steps 3-5 again.**

3.35 grams oxygen	1 mole oxygen	2 mole water	18.0 grams of water
	32.0 grams oxygen	1 mole oxygen	1 mole water

- **Step 11: Do the math and find your answer.** Here it's 3.77 grams.

I know this sounds like a lot of work, but after you do these problems a few times you'll find that it's really not that challenging. Sure, stoichiometry isn't exactly *fun*, but once you get the hang of it you'll find that it's not that bad, either. Trust me.

7.2: Types of Chemical Reactions

There are a lot of different chemical reactions that can occur when you put stuff together. To make it easier to keep them all straight, we group them into six different categories.[13] There are still just as many reactions as before, but this makes it a little easier for us to figure out what's going on. Let's see what they are.

- **Synthesis**: Synthesis reactions occur when simple chemical compounds combine to make more complex ones. The general formula for these reactions is

  $$A + B \rightarrow C$$

  An example of a synthesis reaction is the one we've been talking about for this whole chapter, the reaction of hydrogen and oxygen to make water:

  $$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

13 *Depending on the book you read, there may be more or fewer different types of reaction. The six I mention here are pretty standard, but if you see somebody add "redox reaction" or "nuclear reaction" to the list, don't be too shocked.*

- **Decomposition:** Decomposition reactions occur when a complex reagent falls apart into smaller products. Put another way, it's a synthesis reaction in reverse:

$$C \rightarrow A + B$$

I could just give you the example of water breaking into hydrogen and oxygen, but since you've seen a lot of that, let's take a look at the decomposition of carbonic acid into water and carbon dioxide:

$$H_2CO_3 \rightarrow H_2O + CO_2$$

The Magic of Carbonation

The bubbles in carbonated drinks are generated by the decomposition of carbonic acid into water and CO_2 bubbles, as shown in the equation above. Carbonic acid isn't terribly stable under normal beverage drinking conditions, which is why soda loses its fizz if you forget to put the cap back on the bottle.

Fanta is a delicious carbonated beverage enjoyed by humans and monkeys alike.

- **Single Displacement:**[14] In a single displacement reaction, one of the elements in a chemical compound is replaced with a pure element.[15] The general formula for this reaction is:

$$A + BC \rightarrow B + AC$$

An example of this reaction can be found with the reaction of sodium bromide and chlorine gas:

$$Cl_2 + 2\ NaBr \rightarrow Br_2 + 2\ NaCl$$

14 *Single and double "displacement" reactions are also referred to as single and double "replacement" reactions. The two terms are interchangeable and have no particular significance.*

15 *Single displacement reactions are usually what people refer to when they mention "redox reactions", in which one element is reduced (gains electrons) and another is oxidized (loses electrons). It should be noted, however, that there are a lot of redox reactions that are not single displacement reactions at all. I'm not sure why single displacement reactions are usually given as an example, but there it is.*

- **Double Displacement:** Double displacement reactions involve the cations of two chemical compounds switching places. The general form for this reaction is:

$$AB + CD \rightarrow CB + AD$$

If you combine silver nitrate with sodium chloride, the following double displacement reaction takes place:

$$AgNO_3 + NaCl \rightarrow NaNO_3 + AgCl$$

- **Acid-base Reactions**: Also called "neutralization reactions", acid-base reactions are double displacement reactions where water is formed:

$$HA + BOH \rightarrow BA + H_2O$$

Neutralizing sodium hydroxide with phosphoric acid yields the following equation:

$$H_3PO_4 + 3\ NaOH \rightarrow Na_3PO_4 + 3\ H_2O$$

- **Combustion Reactions**: Combustion reactions occur when something that contains carbon and hydrogen burn in oxygen to form carbon dioxide and water:

$$(\text{something with C and H}) + O_2 \rightarrow CO_2 + H_2O$$

The propane in a barbecue grill burns in oxygen by the following reaction:

$$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$$

Combustion reactions always give off heat, so if you set something on fire, expect it to get hot.

There was some room at the end of this page, so I added a picture of a propane tank.

7.3: Thermodynamics

My favorite chemical reactions involve explosions and fire.[16] I know that probably means that I'm a psychopath or something, but I've noticed that other people seem to like these things, too. At least, my students request that our labs involve lots of fire.

Thermodynamics is the study of how energy is related to chemical and physical processes. In the case of chemistry, we're primarily interested with energy changes having to do with the making and breaking of chemical bonds.

At the Burning Man festival in Black Rock Desert, Nevada,
hippies burn a bunch of stuff while wearing uncomfortable hemp clothing.

The Law of Conservation of Energy

One of the big concepts we use in thermodynamics is the law of conservation of energy, which states that energy can neither be created nor destroyed. Energy *can*, however, be moved around, which is what we usually see happening.

When something burns, it feels hot. The reason for this is that energy is being given off by the thing that's burning – the rising temperature you observe takes place because the burning thing is busy dumping its energy into its surroundings. Processes that release energy (i.e. get hot) are called **exothermic reactions**.

You've probably seen those ice packs where you break something in a plastic bag and the whole thing gets cold.[17] The reason these things feel cold is that there's a chemical reaction taking place that pulls energy from its surroundings (i.e. you). Reactions that absorb energy (i.e. get cold) are called **endothermic reactions**.

Whether you have an exothermic or endothermic reaction, you'll still have the same amount of energy when you're done as you did when you started. Burning a log may give off energy, but that energy doesn't just disappear. Instead, it adds energy to the surrounding air, the hippies dancing around it, and the marshmallows you use to burn your tongue.

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16 *In this day and age, I need to include the disclaimer that everything involving fire and explosions is officially Very Bad. If you've ever seen a fire, or even anything slightly warm, turn yourself into the local police station for questioning, arrest, and imprisonment. It's for The Good Of Society.*

17 *If you haven't, you really should check it out. They're available as "cold packs" in your local pharmacy.*

All About Marshmallows!

Marshmallows contain only a few healthy ingredients. The main ingredient is healthy sucrose (sugar), along with some water and corn starch. The last ingredient, gelatin, is made by processing various animal by-products, including animal skins, horses, cattle bones, and pigs. Bon appetit!

Oink.

In chemistry, energy takes the form of chemical bonds. When chemical bonds are formed, the bond serves to store energy. When bonds are broken, the energy stored in the bond is released as heat. Either way, though, the amount of energy doesn't change – it just moves from one place to another.

7.4: Chemical Kinetics

Here's a fun reaction you can perform that releases just an insane amount of energy: Go to the gas station and fill up a large container with gasoline. Now, take it home and wait for the fun to begin. No match needed! However, I must warn you that you may be waiting quite a while for the fun to start.

To make more sense of this, let's backtrack and figure out how reactions occur.

How Reactions Occur

In order for a chemical reaction to take place, the following steps must happen in this order:

1. The reagent molecules must come into contact with one another.

2. The reagent molecules must have enough energy that they can collide with the force needed to react.

3. The reagent molecules must collide in such an orientation that the reactive parts come into contact with one another.

The study of reaction rates is referred to as **kinetics**, and it's not as hard as this list may have led you to believe. Back to our story.

Activation Energy

As mentioned above, chemical compounds need to have enough some minimum amount of energy in order to react with one another. This is because simply poking one molecule at another isn't going to cause them to react. They need to be *pushed*. This minimum amount of energy is called the **activation energy**, and without this quantity of energy, the reagent molecules simply won't react, no matter how favorable everything seems.

In the example with the not-flaming gasoline, there's just not enough energy present at room temperature for gasoline and oxygen molecules to react with each other. As a result, you didn't see anything happen.

But Wait! The Reaction Actually Occurred!

It actually turns out that the above statement is almost right. At room temperature, there isn't enough energy for most *of the molecules to react with each other. However,* some *reagent molecules have, just from random chance, enough energy to undergo the combustion reaction we were looking for. As a result, gasoline* will *burn under room temperature conditions. It will just take longer than the lifetime of the universe for it to happen. That's why cars need spark plugs – to add the energy needed to get the reaction going.*

This guy started the gasoline experiment in 1948 and is still waiting for something to happen.

The moral of the story is this: Thermodynamics and kinetics are different things. Thermodynamics tells us whether a process *can* occur under ideal circumstances, whereas kinetics tells us whether it will happen quickly enough to be useful. Which brings us to the magical world of catalysts.

There are a lot of chemical reactions that take place in the body. It turns out that, while very handy for those of us who wish to remain alive, they don't happen very quickly under the conditions of temperature and pressure you find in your body. In other words, the knowledge we've talked about above tells us that, by all rights, you should have a lifespan of about zero seconds.

So, why aren't you dead? It has to do with **catalysts**. Catalysts are chemical compounds that manipulate a chemical system so that the activation energy of the reaction is lower. In biological systems, the main catalysts present are enzymes. Enzymes work in the body by physically grabbing the reagent molecules and cramming them together in the right configuration to undergo a reaction.[18]

18 *This is, of course, a vastly simplified version of what actually happens when enzymes are active in your body. However, it'll do until you take a biochemistry course.*

Because the activation energy of the reactions is made lower by enzymes, there is enough energy in your body for them to occur. Which is nice for those of you who want to survive long enough to read the end of this sentence.

Poison: The Anti-Catalyst

Enzymes are biological catalysts that speed up the reactions we all need to live. If you want something to stop living, then, all you have to do is administer a poison to the thing you're trying to kill. Poisons generally work by neutralizing the enzymes in a biological system so they can't help metabolic processes to happen anymore. And if those reactions stop, things get really dead really fast.

The band Poison release "Every Rose Has It's Thorn" is a song proven to cause metabolic failure in higher-order animals.

Other Ways To Affect Reaction Rates

If you want a chemical reaction to move more quickly, these should help things to move along, too:

- **Increase the concentration of the reagents**: This should make sense – if there are more reagent molecules in a container, they'll smash into each other more often. If they smash into each other more often, they should react more often.
- **Increase the temperature at which you perform the reaction**: This works according to the activation energy idea mentioned above. Adding energy will help the reagents to achieve the needed activation energy, which should speed the reaction.[19]
- **Increase the surface area of the reagents**: This can be something as simple as dissolving a solid reagent to allow the molecules to move around, or it could mean to grind up a compound so more of it will be exposed to the reaction environment.
- **Stir the reagents**: This works in the same way as increasing the surface area, by exposing more of the reagents to the products as the reaction proceeds.

19 *A general rule of thumb says that reaction rates double for every 10° C increase in temperature.*

Let's Blow Stuff Up!

If you light a pool of gasoline on fire, the flames will dance along the top in a beautiful and terrifying fashion. However, if you increase the surface area of the gasoline by blowing it into a fine mist, the reaction rate will increase, causing a huge explosion. This phenomenon is used by the military in thermobaric bombs (also called "fuel-air bombs."

The USS McNulty was decommissioned in 1972 with a little help from a thermobaric bomb.[20]

7.5: Equilibria

Chemical reactions go from reagents → products. We talked about that before, and it's probably not surprising to learn that if you combine some chemicals, they'll react to form new ones. However, what happens when the reaction is **reversible** (i.e. can go both forwards and backwards)?

In the beginning, if you just put the reagents together, you'll form the products. As time goes by, the amount of product will build up and the rate of the reverse reaction will increase as well. Eventually, the forward reaction and the reverse reaction will be the same, a situation referred to as an **equilibrium**.

Let's imagine that you and a friend are playing a game in which you pass pennies back and forth. You start with 100 pennies and she starts with none. Every turn, you have to give her 60% of your pennies and she has to give you 10% of hers. When you're done with the game, how many pennies will each of you have?

It's like Vegas without the buffet tables.

It's completely natural to guess that if you're giving her a larger percent of your pennies than she is that she'll eventually end up with all of them. However, here's what will happen, turn by turn:

20 *Just so you don't feel bad, I thought I'd let you know that the USS McNulty (DE-581) was a target in a planned munitions test, so the ship was empty at the time. This isn't a combat picture or anything.*

Turn	How many pennies each of you transfer to the other[21]	Your pennies at the end of your turn	Her pennies at the end of her turn
0 (start)	n/a	100	0
1	You give 60 She gives none	40	60
2	You give 24 She gives 6	22	78
3	You give 13 She gives 8	17	83
4	You give 10 She gives 8	15	85
5	You give 9 She gives 9	15	85

And after that point, there's no change in the numbers of pennies each of you has.

This example gives us some very important information about how equilibria work:

- **When a system is at equilibrium, the amount of reagent and product will stay the same**. In our example here, at equilibrium you have 15 pennies and she has 85 pennies.

- **When a system is at equilibrium, the process has not stopped**. This idea can be a little hard to get at first because if the amount of reagent and product stays the same, it seems natural to assume that nothing more is happening. As it turns out, this process is still taking place – it's just happening at the same rate in the forward and reverse direction.[22] Such a process is referred to as a "dynamic process."[23]

21 *Rounded when the number transferred is not a whole number.*

22 *As another example, think of this as being like a filled parking lot with 100 spots. When a parking lot is filled, the attendant won't let any people into the parking lot until somebody else leaves. As a result, when cars leave, new ones take their place. The number of cars in the lot will always be 100, but the specific cars will change over time.*

23 *Some books refer to equilibria as being "dynamic equilibria" for some reason or another. Because all equilibria are dynamic, I suspect the term is used to make the book sound more science-y.*

Le Châtelier's Principle

A bit over 100 years ago, a dude named Henry Louis Le Châtelier[24] came up with an important idea in understanding how equilibria work. **Le Châtelier's principle** states the very important idea below:

If you screw around with an equilibrium process, the equilibrium will react in a way that tries to undo whatever you did to it.

This may seem like a stupid thing to say, but it actually makes a lot of sense. For example, let's say that you and your older brother are sitting in a car on a long car trip. You're just sitting there minding your own business in peace, when all of a sudden he starts playing that idiotic "punch buggy" game.[25] What's your response?

Assuming your brother is much bigger than you, your response will be to move out of the way of his arm. Because your brother is no longer able to punch you, you'll both go back to sitting in peace. Put another way, your actions will have served to regain equilibrium by undoing the effects of your brother's actions.

Great Jerks of Science

Henry Louis Le Châtelier was working on a process for making ammonia out of nitrogen and hydrogen gas Unfortunately, this resulted in "a terrific explosion" which "nearly killed an assistant."[26] Le Châtelier was upset by this outcome. Not because he cared about blowing up a lab, but because Fritz Haber successfully performed this reaction five years later and got a Nobel Prize for the discovery.

Lookin' good, Henry.

More Great Jerks of Science

Fritz Haber (mentioned above) did a nice job making ammonia, but the rest of his career was a little less awesome. During the First World War he figured out how to use chlorine gas as a weapon, and in the 1920's his lab developed the Zyklon B poison gas that was eventually used in Nazi gas chambers. His wife, a pacifist, killed herself in 1915, probably because she was so horrified by his work.

Clara Immerwahr preferred death to living with Fritz Haber.

24 *As you might have guessed from the accent, he was French.*

25 *If you've never heard of the punch buggy game, you can read about it here: https://en.wikipedia.org/wiki/Punch_buggy. Don't do it, though, because it's unbelievably annoying.*

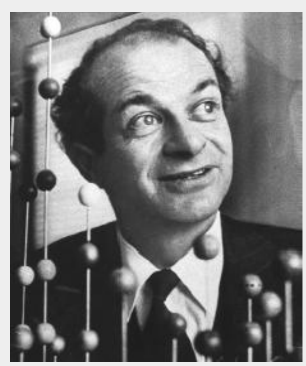
26 *I couldn't find complete reference material, but this account was published in June, 1938. You can read a copy of it here: http://pubs.acs.org/doi/pdf/10.1021/ed015p289.1. It was said that fragments of the steel container in which the reaction was performed were blown through both the floor and the ceiling of the room in which the reaction was performed. No word on whether they were wearing goggles.*

Chemical reactions, on the other hand, have fewer things you can do to them. Let's have a look at some of them:

- **If you add a reagent, the equilibrium will produce more product to get rid of the stuff you added**. As a result, if you're performing a reaction with the equation A + B → C, adding more of compound A will result in a greater production of C to get rid of the A that you added.
- **If you add a product, the equilibrium will go backwards to get rid of the stuff you added.** If, for some reason, you added C to the mixture above, the reaction will actually go backwards and form A + B to get rid of it.[27] Not surprisingly, we're usually not interested in doing this.
- **If you've got a gaseous equilibrium (i.e. A, B, and C are all gases), increasing the pressure by compressing the mixture will result in a shift in the equilibrium toward the side with fewer moles of gas**. In the case of A + B → C, there are two moles of reagents (one of A, one of B) and one of product (C). Because of this, compressing the mixture will result in a greater formation of C to lower the pressures of A and B.[28]
- **Increasing the temperature of a reaction will shift the equilibrium to lower the overall temperature**. Let's say, for example, that A + B → C is an exothermic reaction (i.e. it gets hot). To make the exothermic nature of the reaction clearer, we can write the equation as A + B → C + heat. In this way, increasing the temperature of the reaction will serve the same purpose as adding a product, pushing the formation of more A + B. Likewise, if this were an endothermic reaction, we'd write the equation as A + B + heat → C, so adding heat would result in a greater formation of C.

Nice Guys of Science[29]

Linus Pauling (1909-1994) won the 1954 Nobel Prize for chemistry, based on his work on the nature of chemical bonding and atomic structure. Most guys would have said "Hey, I'm awesome" at this point, but he went on to win the 1962 Nobel Peace Prize for his work against the proliferation of nuclear weapons. As Pauling said in 1961, "I have something that I call my Golden Rule... "Do unto others 25% better than you expect them to do unto you." … The 25% is for error."



Be like this guy when you grow up.

27 *The reason this can happen is that equilibria processes are, by definition, reversible. Any equilibrium process has to, by definition, go both forwards and backwards.*

28 *It turns out that, because of how we measure amounts of stuff, this is really just a restatement of the first two points. However, it's probably just easier to remember it on its own.*

29 *Linus Pauling didn't have anything to do with equilibria, as far as I know. However, the last page's focus on jerks in science was kind of depressing, so I figured I'd lighten things up.*

The Main Ideas In Chapter 7:

- Chemical equations are recipes for doing chemical reactions.
- The law of conservation of mass says that the amount of stuff in the universe will always remain the same.
- It's nice to know about moles because it's a lot easier than individually-counting out 6.02×10^{23} things whenever you want to do a reaction.
- Stoichiometry allows us to figure out how much stuff we'll make in a chemical reaction.
- Thermodynamics is the study of how energy interacts with matter. Exothermic reactions give off energy and get hot, while endothermic reactions absorb energy and get cold.
- The law of conservation of energy says that the amount of energy in the universe will always stay the same. It might get converted from one form to another, but it'll always be hanging around *somewhere*.
- Kinetics is the study of how fast chemical reactions go. It's handy to know about chemical reactions because slow reactions are very boring.
- Equilibria are dynamic processes in which the forward and reverse reactions occur at the same rate.
- Le Châtelier’s Principle states that if you mess with an equilibrium process, it will try to undo whatever you did.
- Some scientists' lives are just a real mess.

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