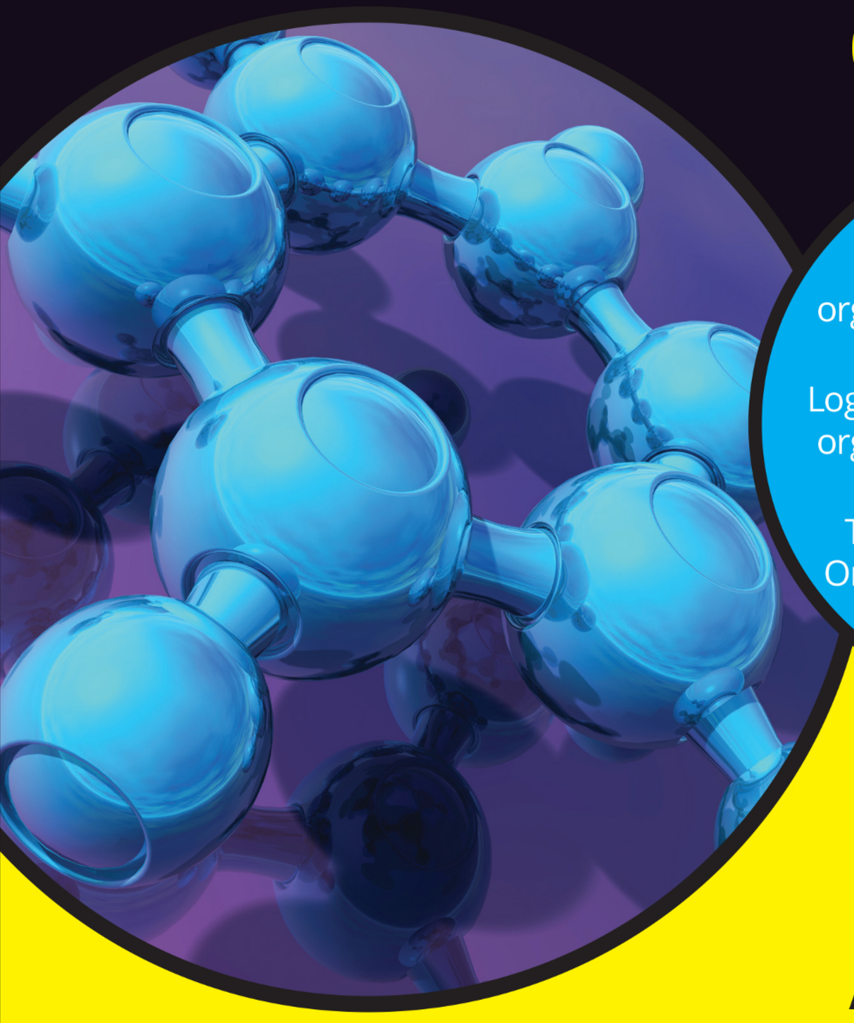
LEARNING MADE EASY

2nd Edition

Organic Chemistry I for dummies

A Wiley Brand



Clear explanations of organic chemistry principles

Logical approaches to solving organic chemistry problems

Tips to helpyou ace your Organic Chemistry I course

Arthur Winter, PhD

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Contents at a Glance

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Introduction

Regrettably, when many people think of chemicals, the first things that usually pop into their minds are substances of a disagreeable nature — harmful pesticides and chemical pollutants, nerve agents and chemical weapons, or carcinogens and toxins.

But most chemicals play roles of a more positive nature. For example, both water and sugar are chemicals. Why are these chemicals important? Well, for one thing, both are components of beer. The enzymes in yeasts are also important chemicals used in fermentation, a process that involves the breakdown of sugars into beer. Ethyl alcohol is the all-important chemical responsible for beer's effect on the body. In my view, these three representative examples of chemicals thoroughly rebut the notion that all chemicals are bad.

In fact, those who have a bad opinion of all chemicals must suffer from the psychological condition of self-loathing, because human bodies are essentially large vats of chemicals. Your skin is made up of chemicals — along with your heart, lungs, kidneys, and all your other favorite organs and appendages. And most of the chemicals in your body — in addition to the chemicals in all other living things — are not just any kinds of chemicals, but organic chemicals. So, anyone who has any interest at all in the machinery of living things (or in the chemistry of beer and wine) will have to deal at some point and at some level with organic chemistry.

Of course, the natures of these dealings have historically not always been so pleasant. Pre-med students and bio majors (and even chemistry majors) have butted heads with organic chemistry for decades, and, regrettably, the winner of this duel has not always been the human.

Part of the problem, I think, comes from students' preconceptions of organic chemistry. I admit that, like many students, I had the worst preconceptions going into organic chemistry. When I thought of organic class, I thought of wearying trivia about the chemical elements, coma-inducing lectures delivered in a monotone, complex mathematical equations sprawling across mile-long chalkboards, and a cannon fire of structures and chemical reactions vomited one after the other in succession. The only successful students, I thought, would be those wearing thick spectacles, periodic-table ties, and imitation leather shoes with Velcro straps.

But if my preconceptions of organic lecture were bad, my preconceptions of organic labs were worse. I feared the organic laboratory course, certain the instant I would step into the lab, all the chemicals would instantly vaporize, condense on my unclothed extremities, and permeate my hair, pores, follicles, and nails. As a result, my skin would erupt in a rash. I would bald. My nails would yellow. The love of my life would take one look at my scarred physiognomy, sicken of men, and leave me sitting alone, Job-like, amongst the ashes of my existence, scratching my weeping sores with a broken potsherd.

Turns out I was wrong on that one. I was surprised to find that I actually *liked* organic chemistry. I really liked doing it — it was fun! And working in the laboratory making new substances was less toxic than I thought it would be and was instead interesting and even entertaining. I was wrong about the math, too: If you can count to 11 without taking off your shoes, you can do the math in organic chemistry. The turning point, really, was when I stopped fighting organic chemistry, stopped feeding my preconceptions, and changed my attitude. That was when I really started enjoying the subject.

I hope you choose not to fight organic chemistry from the beginning (as I did) and instead decide to just get along and become friends with organic chemistry. In that case, this book will help you get to know organic chemistry as quickly as possible (and as well as possible), so that when your professor decides to test you on how well you know your newfound comrade, you'll do just fine.

About This Book

With *Organic Chemistry I For Dummies,* I've written the book that I would've wanted when I was taking the first semester of organic chemistry. That means that this book is very practical. It doesn't try to mimic a textbook, or try to replace it. Instead, it's designed as a complement to a text, highlighting the most important concepts in your textbook. Whereas a textbook gives you mostly a "just-the-facts-ma'am" style of coverage of the material — and provides you with lots of problems at the ends of chapters to see if you can apply those facts — this book acts as an interpreter, translator, and guide to the fundamental concepts in the subject. This book also gets to the nuts and bolts of how to actually go about tackling certain problems in organic chemistry.

Tackling the problems is where the majority of students have the most trouble, in part because so many aspects of a problem must be considered. Where's the best place to start a problem? What should you be on the lookout for? What interesting features (that is, sneaky tricks) do professors like to slip into problems, and what's the best strategy for tackling a particular problem type? I answer some of these questions in this book. Although this book cannot possibly show you how to solve every kind of problem that you encounter in organic chemistry, it does provide guides for areas that, in my experience, students typically have trouble with.

Beyond the problem types covered, these guides should give you insight into how to logically go about solving problems in organic chemistry. They show you how to rationally organize your thoughts and illustrate the kind of thinking you need to perform when approaching new problems in organic chemistry. In this way, you see how to swim instead of just panicking after being shoved abruptly into the deep end of the pool.

Additionally, I make clear the most important underlying principles in organic chemistry. I use familiar and easy-to-understand language, along with a great many clarifying analogies, to make palatable the hard concepts and technical jargon that comes with the territory. While this book is designed for students taking a first-semester course in introductory organic chemistry, it should also be a solid primer for those who want to understand the subject independently of a course.

Foolish Assumptions

In this book, I assume that you've had at least some chemistry in the past, and that you're familiar with the basic principles of chemistry. For example, I assume that you're familiar with the periodic table, that you understand what atoms are and what they're made up of (neutrons, protons, and electrons), and that you have some knowledge of bonding and chemical reactions. You should also know about kinetics (like rate equations and rate constants) and chemical equilibria. If you've had a two-semester course in general chemistry, that's perfect. (If you feel that your general chemistry is a bit rusty, turn to Chapter 2 — there, I review the most important concepts that you need to know for organic chemistry.)

Icons Used in This Book

Icons are the helpful little pictures in the margins. I use them to give you a heads-up about the material. I use the following icons in this book:

TIP

I use this icon when giving timesaving pointers.

REMEMBER

I double dip with this icon. I use it not only to jog your memory about something that you should have learned previously, but also for really important concepts that you should remember.

WARNING

I use this icon to warn you of common traps that students can fall into when tackling certain problems.

TECHNICAL STUFF

I try to avoid getting too technical, so you won't see this icon very much. When I use it, I do so to mark a discussion of a concept that's a little more in depth (which you can skip if you want to).

Beyond the Book

In addition to the material in the print or e-book you're reading right now, this product also comes with some access-anywhere material on the web. For the common functional groups in organic chemistry and the periodic table of elements. To view this book's Cheat Sheet, simply go to `www.dummies.com` and search for Organic Chemistry I For Dummies Cheat Sheet in the search box.

You can find some articles online that tie together and offer new insights to the material you find in this book. To view this book's Extras, simply go to `www.dummies.com` and search for Organic Chemistry I For Dummies Extras in the search box.

Where to Go from Here

In short, from here you can go anywhere you want. All of the chapters in this book are designed to be modular, so you can hop-scotch around, reading the chapters in any order you find most suitable. Perhaps you're having trouble with a particular concept, like drawing resonance structures or solving for structures using NMR spectroscopy. In that case, skip straight to the chapter that deals with that particular topic. Or, if you want, you can read the book straight through, using it as a kind of interpreter and guide to the textbook.

If you get the gist of what organic is all about, and have a solid background in the critical concepts in general chemistry — like electron configuration, orbitals, and bonding — you may want to skip the first two chapters and dive right into Chapter 3, which explains how organic structures are drawn. Or you may want to just skim the first couple chapters as a quick introduction and memory refresher (summer vacations have a strange way of wiping your memory slate sparkly clean, particularly in the area of chemistry).

This book is yours, so use it in any way you think will help you the most.

1

Getting Started with Organic Chemistry

IN THIS PART . . .

Get an introduction to organic chemistry.

Speak organic chemistry using Lewis structures.

See acids and bases and functional groups.

Look at organic molecules in three dimensions.

IN THIS CHAPTER

- Coping with pre-organic anxiety
- Defining organic chemistry
- Breaking down the mysteries of carbon
- Seeing what organic chemists do

Chapter 1

The Wonderful World of Organic Chemistry

Organic chemistry is a tyrant you've heard about a lot. You've heard your acquaintances whisper about it in secret. It's mean, they say; it's brutish and impossibly difficult; it's unpleasant to be around (and smells sort of funny). This is the chapter where I introduce you to organic chemistry, and where, I hope, you decide to forget about the negative comments you've heard about the subject.

In this chapter, I show you that the nasty rumors about organic chemistry are (mostly) untrue. I also talk about what organic chemistry is, and why you should spend precious hours of your life studying it. I show you that discovering organic chemistry really is a worthwhile and enjoyable expedition. And the journey is not all uphill, either.

Shaking Hands with Organic Chemistry

Although organic is a very important and valuable subject, and for some it's even a highly enjoyable subject, I realize that organic chemistry is intimidating, especially when you first approach it. Perhaps you've already had what many old-timers refer to simply as The Experience, the one where you picked up the textbook for the first time. This is the time when you heaved the book off the shelf in the bookstore. When you strained your back trying to hold it aloft. When you felt The Dread creep down your spine as you scanned through the book's seemingly infinite number of pages and feared that, not only would you have to read all of it, but that reading it wouldn't be exactly like breezing through a Hardy Boys adventure or a Nancy Drew mystery.

No doubt, the material appeared strange. Opening to a page halfway through the book you saw bizarre chemical structures littering the page, curved arrows swooshing here and there like flocks of starlings, and data tables bulging with an inordinate number of values — values that you suspect you might be required to memorize. I admit that organic chemistry is a little frightening.

I think most students feel this way before they take this class, and probably even your professor did, as did her professor before her. *So you're not alone.* But you can take comfort in knowing that organic chemistry is not as hard as it looks. Those who put in the required amount of work — which, admittedly, is a lot — and don't fall behind, almost always do well. More than almost any other subject, organic chemistry rewards the hard workers (like you), and relentlessly punishes the slothful (the others in your class). I think understanding organic chemistry is not so much hard as it is hard work.

REMEMBER

I hope all this talk about how intimidating the course is hasn't put a damper on your enthusiasm, because the subject of organic chemistry really is a doozy. To learn about organic chemistry is to learn about life itself, because living organisms are composed of organic molecules and use organic molecules to function. Swarms of organic molecules are at work in your body — fueling your brain, helping your neurons fire, and getting the muscles in your mouth to clench open and shut — and that's just a small sampling of the organic molecules needed in order for you to complain about your school's chemistry requirements.

Humans, in fact, are composed almost entirely of organic molecules (all the soft parts anyway), from our muscles, hair, and organs, to the fats that cushion our bellies and keep us toasty warm during sweltering summer nights (some people are more richly blessed in this regard than others). Organic molecules can also range in size from the very tiny, like the carbon dioxide you exhale that consists of only three atoms, to the staggeringly large, like DNA, which acts as your molecular instruction manual and is made up of millions of atoms.

THE SOAP OPERA OF ORGANIC MOLECULES

Organic molecules govern our life processes like metabolism, genetic coding, and energy storage. In nature, organic molecules also play out a crazy soap opera, acting as the medium for many twists and turns, deceptions, betrayals, strategic alliances, romances, and even warfare.

Take plants, for example. They seem so defenseless. When a predator comes to lunch on a plant's leaves, the plant can't just pack up its bags and take off. It's stuck where it is, so there's nothing it can do, right? But although plants may seem defenseless, they're not. Many plants produce *antifeedants*, nasty organic compounds that are unpleasant tasting or even toxic to those who would dare eat them. (As a kid, I always *knew* Brussels sprouts contained something like this.) Predators that have feasted on a plant rich in these unpleasant compounds make sure to refrain from eating them in the future.

To produce antifeedants to discourage being eaten is bad enough, but sometimes plants have defenses that seem evil. Certain species of plants, for example, can detect when a caterpillar has decided to munch on its leaves (by detecting organic molecules present in the caterpillar's spit!). When the plant detects that a caterpillar has decided to make supper on its leaves, the plant emits volatile organic molecules into the air, chemicals designed to attract wasps. When the wasps buzz by to check out what's up, they see the caterpillars eating the plant and killing it. The wasps couldn't care less about the misfortunes of the plant, but the female wasps do need a comfortable spot to hatch their eggs. And what's a snugger nursery than the innards of a fat, juicy caterpillar?

When a wasp spots a caterpillar, it swoops down, makes a crash landing on the caterpillar's back, stings the caterpillar into paralysis, and lays its eggs *inside* of it! When the wasp larvae hatch shortly thereafter, they make the caterpillar their first meal, munching on it contentedly from the inside out. The wasp has now reproduced and has had its little offspring fed, and the plant is rid of its pest — a strange alliance between wasp and plant, all thanks to communication by organic molecules. And that's just one episode in this never-ending soap opera, produced, funded, and sponsored by organic molecules.

What Are Organic Molecules, Exactly?

But what ties all of these molecules together? *What exactly makes a molecule organic?* The answer lies in a single, precious atom: carbon. All organic molecules contain carbon, and to study organic chemistry is to study molecules made of carbon and to see what kinds of reactions they undergo and how they're put together. When these principles are known, that knowledge can be put to good use, to make better drugs, stronger plastics, better materials to make smaller and faster computer chips, better paints, dyes, coatings, explosives, and polymers, and a million other things that help to improve our quality of life.

That said, I should also point out that the field of organic chemistry is essentially an arbitrary one, that the same fundamental laws of chemistry and physics that apply to inorganic molecules apply just as well to organic ones. This connectivity of the branches of chemistry is actually a relatively new idea, as organic molecules were once falsely thought to have a "vital life force" that other molecules didn't possess. Despite the destruction of this theory of *vitalism,* chemists still keep the old divisions of chemistry, divisions that define the branches of physical chemistry, inorganic chemistry, and biochemistry. But these barriers are slowly beginning to dissolve, and they're kept mainly to help students focus on the material taught in a given course.

Given the many elements present in the universe, it is fascinating that living things selected carbon as their building block. So, what makes carbon so special? What makes it better as the foundation for life than any of the other elements? What makes this atom so important that an entire subject focuses around this single atom, while the chemistries of all the other elements are tossed into a big mushy pile known as *inorganic chemistry?* Is carbon really, in fact, all that special compared to the many other elements that could have been selected?

In short, yes. Carbon is very special, and its usefulness lies in its versatility. Carbon has the capability of forming four bonds, so molecules that contain carbon can be of varied and intricate designs. Also, carbon bonds represent the perfect trade-off between stability and reactivity — carbon bonds are neither too strong nor too weak. Instead, they epitomize what chemists refer to affectionately as the *Goldilocks principle* — carbon bonds are neither "too hot" nor "too cold," but are "just right." If these bonds were too strong, carbon would be unreactive and useless to organisms; if they were too weak, they would be unstable and would be just as worthless. Instead, carbon bonds straddle the two extremes, being neither too strong nor too weak, making them fit for being the backbone of life.

Also, carbon is one of the very few elements that can form strong bonds to itself, in addition to being able to form bonds to a wide variety of other elements. Carbon bonds can even double back to form rings. Because of this ability to bond with itself and other elements, carbon can form an incredibly vast array of molecules. Millions of organic compounds have already been made and characterized, and undoubtedly many millions more will be discovered (perhaps, dear reader, by you!).

An Organic Chemist by Any Other Name . . .

Just as the field of chemistry can be broken down into different branches, so, too, can the field of organic chemistry be broken down into specialized areas of research. Those who work in these different areas — these specialized "organic chemists" — illustrate the diversity of the field of organic chemistry and its connection to other branches in chemistry, branches like physical chemistry, biochemistry, and inorganic chemistry.

Synthetic organic chemists

Synthetic organic chemists concern themselves with making organic molecules. In particular, synthetic chemists are interested in taking cheap and available starting materials and converting them into valuable products. Some synthetic chemists devote themselves to developing procedures that can be used by others in constructing complex molecules. These chemists want to develop general procedures that are flexible and can be used in synthesizing as many different kinds of molecules as possible. Others devote themselves to developing reactions that make certain kinds of bonds, such as carbon-carbon bonds.

Others use known procedures to tackle multistep syntheses — the making of complex compounds using many individual, known reactions. Performing these multistep syntheses tests the limits of known procedures. These multistep syntheses force innovation and creativity on the part of the chemist, in addition to encouraging endurance and flexibility when a step in the synthesis goes wrong (things inevitably go wrong during the synthesis of complex molecules). Such innovation contributes to the body of knowledge of organic chemistry.

Synthetic organic chemists often flock to the pharmaceutical industry, mapping out efficient reaction pathways to make drugs and optimizing reactions to make complicated organic molecules as cheaply and efficiently as possible for use as pharmaceuticals. (Sometimes improving the yield of the reaction of a big-name drug by a few percentage points can save millions of dollars for a pharmaceutical company each year.) If you take a laboratory course in organic chemistry, you'll be doing a lot of organic synthesis.

Bioorganic chemists

Bioorganic chemists are particularly interested in the enzymes of living organisms. Enzymes are very large organic molecules, and are the worker bees of cells, catalyzing (speeding up) all the reactions in the cell. These enzymes range from the moderately important ones, such as the ones that keep us alive by breaking down food and storing energy, to the really important ones, like the ones in yeasts that are responsible for fermentation, or the breaking down of sugars into alcohol.

These catalysts work with an efficiency and selectivity that synthetic organic chemists can only envy (see the previous section). Bioorganic chemists are particularly interested in looking at these marvels of nature, these enzymes, and determining how they operate. When chemists understand the mechanisms of how these enzymes catalyze particular reactions in the cell, this knowledge can be used to design enzyme *inhibitors*, molecules that block the action of these enzymes.

Such inhibitors make up a great deal of the drugs on the market today. Aspirin, for example, is an inhibitor of the *cyclooxegenase* (COX) enzymes. These COX enzymes are responsible for making the pain transmitters in the body (called the *prostaglandins*). These transmitters are the messengers that tell your brain to feel pain in the thumb that you just smashed with a slip of your hammer. When the aspirin drug inhibits these COX enzymes from operating, the enzymes in your body can no longer make these pain-signaling molecules. In this way, the feeling of pain in the body is reduced. Many other examples of these kinds of inhibitor drugs exist today, and the process of designing these drugs is aided by bioorganic chemists.

Natural products chemists

Natural products chemists isolate compounds from living things. Organic compounds isolated from living organisms are called *natural products.* Throughout history, drugs have come from natural products. In fact, only recently have drugs been made synthetically in the lab. Penicillin, for example, is a natural product produced by a fungus, and this famous drug has saved millions of lives by killing harmful bacteria. The healing properties of herbs and teas and other "witches' brews" are usually the result of the natural products contained in the plants. Some Native American groups chewed willow bark to relieve pain, as the bark contained the active form of aspirin; other Native American groups engaged in the smoking of peyote, which contains a natural product with hallucinogenic properties. Smokers get a buzz from the natural product in tobacco called nicotine; coffee drinkers get their buzz from the natural product found in coffee beans called caffeine.

Even today, a great many of the drugs found on the shelves of pharmacies are derived from natural products. Once extracted from the living organism, natural products are often tested by chemists for biological activity. For example, a natural product might be tested to see if it can kill bacteria or cancer cells, or if it can act as an anti-inflammatory drug. Often when chemists find a "hit" — a compound